– Do not Cite or Quote –
This bibliography does not reflect consensus advice or recommendations, has not been reviewed or approved by the chartered SAB, and does not represent EPA policy

The following is the bibliography that was submitted by the Office of Water for review by the Hypoxia Advisory Panel. The citations were first sorted into groups related to each of the three general areas listed in the charge to the panel, and then each group was sorted into recent citations (≥ 2000) and older citations (< 2000) for the convenience of the panel.

The following Table of Contents is provided to assist the user:

	Pages
Characterization of the Cause(s) of Hypoxia (≥2000)	1 - 65
Characterization of the Cause(s) of Hypoxia – Cont. (<2000)	66 - 117
Characterization of Nutrient Fate, Transport, and Sources (≥2000)	118 - 126
Characterization of Nutrient Fate, Transport, and Sources – Cont. (<2000)	127 - 130
Scientific Basis for Goals and Manaagement Options (≥2000)	131 - 142
Scientific Basis for Goals and Manaagement Options – Cont. (<2000)	143 - 145

Citations Related to:

Characterization of the Cause(s) of Hypoxia
(≥ 2000)

3. Alliance for Coastal Technologies. 2004. ACT Workshop: State of Technology in the Development and Application of Dissolved Oxygen Sensors. UMCES Technical Report Series: TS-444-04-CBL/Ref No. [UMCES]CBL 04-089, Alliance for Coastal Technologies Indexing No. ACT-04-01. N. N. Rabalais served as Facilitator of the Workshop and Drafted the Report.

5. Ammerman, J. W., and W. B. Glover. 2000. Continuous underway measurement of microbial ectoenzyme activities in aquatic ecosystems. Marine Ecology Progress Series 201: 1-12.

Abstract: Microbial ectoenzyme activities in aquatic environments are important agents of polymer hydrolysis and indicators of the state of microbial carbon, nitrogen, or phosphorus nutrition. However, like most other biochemical and molecular measurements, ectoenzyme activities have been Limited to discrete water samples. We have developed a continuous underway method for measuring microbial enzyme activities using high-sensitivity fluorescent substrates. The system we developed consisted of a peristaltic proportioning pump, a temperature-controlled water bath, and a spectrofluorometer interfaced to a portable computer which controlled the fluorometer and logged the data. This method has been applied to alkaline phosphatase and to leucine aminopeptidase measurements in the surface waters of the Mississippi River plume and the Louisiana shelf, and alkaline phosphatase measurements in the surface waters of a Texas lake. This method will enable us to map the surface distributions of microbial enzyme activities on scales comparable to temperature, salinity, in vivo fluorescence, and other parameters which can be continuously mapped from a research ship while underway.

6. Ammerman, J.W., Jason B. Sylvan, Quay Dortch, David M. Nelson, Alisa Maier Brown, and Wendy Morrison (2003), Seasonal Phosphorus Limitation on the Louisiana Shelf: A Result of Anthropogenic Nitrogen Loading From the Mississippi River? EOS Trans. AGU, 84(52), Ocean Sci. Meet. Suppl., Abstract OS21K-08

Abstract: Seasonal phosphorus limitation of primary production during the spring and early summer was demonstrated in the Mississippi River plume and Louisiana continental shelf during a series of cruises in 2001. Mapping of surface water properties over most of the Louisiana shelf and extensive bioassay experiments combined to make a large spatial and temporal dataset. The chlorophyll a response to additions of orthophosphate (Pi) was much greater than the response to either nitrate or silica additions during the spring and early summer. The Pi turnover time was less than 30 minutes during May and July 2001. Elevated nitrogen (N) to phosphorus (P) ratios were seen over much of the shelf during the spring and early summer months. The mean N:P ratio was 64 in March 2001 and was greater than 380 in both May and July 2001 for the entire Louisiana shelf. High alkaline phosphatase activities were seen during March, May and July 2001, including extremely high activities near the mouth of the Mississippi River. By September, however, all the above indicators indicated that much of the Louisiana shelf was N-limited. The observed seasonal P-limitation coincides with both the Mississippi's high flow period during the spring and early summer and the period of high productivity responsible for the annual summer hypoxia. Anthropogenic N loading of the Mississippi River has apparently shifted the Louisiana shelf into spring P-limitation. The Federal-State-Tribal Action plan, recently delivered to the Congress, calling for a 30 percent reduction in N-loading over the next 15 years, will be important in reducing the high N:P ratios which lead to P-limitation. At the same time, P input to the watershed should also be managed to reduce the size of the hypoxic zone.

The abstract of this presentation is available in PDF. The link to the PDF is here: http://www.agu.org/meetings/os04/os04-pdf/os04_OS21K.pdf

7. Ammerman, J.W. and Jason B. Sylvan (2004), Phosphorus Limitation of Phytoplankton Growth in the Mississippi River Plume: A Case for Dual Nutrient Control? EOS Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS11B-07

Abstract: The Action Plan agreed to in 2001 by federal, state and tribal agencies calls for reducing the area of the Mississippi plume hypoxic zone to less than 5,000 square kilometers by 2015, to be achieved by a 30 percent reduction in the dissolved inorganic nitrogen entering the Gulf of Mexico. Evidence collected over that last fifteen years suggests that seasonal phosphorus limitation of phytoplankton growth on the Louisiana shelf coincides with the periods of both highest river flow and maximum primary productivity in the spring. The phosphorus limitation documented here almost certainly results from increased nitrogen input from the Mississippi River over the past fifty years. This phosphorus-limited productivity is most likely responsible for the summer hypoxia, though the detailed mechanism of hypoxia generation is unclear. If the Mississippi River is the major source of phosphorus as well as nitrogen to this system, then it may be time to recommend reductions in phosphorus as well as nitrogen. This would be consistent

with recent recommendations for control of both nitrogen and phosphorus inputs to estuarine systems, as well as with the partial recovery of parts of the Black Sea since the major declines in nitrogen and phosphorus inputs began in the early 1990s. Though unanswered questions about the sources and supply rate of phosphorus to the Mississippi plume system remain, the need for phosphorus reductions should be thoroughly evaluated.
DE: 4834 Hypoxic environments
DE: 4845 Nutrients and nutrient cycling
SC: Ocean Sciences [OS]
MN: 2004 AGU Fall Meeting
http://www.agu.org/cgi-bin/SFgate/SFgate?&listenv=table&multiple=1&range=1&directget=1&application=fm04&database=%2Fdata%2Fepubs%2Fwais%2Findexes%2Ffm04%2Ffm04&maxhits=200&="OS11B-07

8. Ammerman, J.W., Q. Dortch, B. M. Gaas, D. M. Nelson, A. Quigg, J. B. Sylvan, S. Tozzi, Seasonal Phosphorus Limitation on the Louisiana Shelf: A Result of Nitrogen Loading from the Mississippi River? Presented at the EPA Mississippi River Basin Nutrients Science Workshop, St. Louis, Oct. 4-6, 2005.

Abstract: Oxygen-depleted subsurface waters occur on the Louisiana Continental Shelf when the uptake of oxygen by respiration exceeds its resupply. Measurements of shelf water samples demonstrate that geographic extent of oxygen-depleted waters has increased since 1985.

We use the relative abundance of three low-oxygen-tolerant benthic foraminifers (Pseudononion atlanticum, Epistominella vitrea, and Buliminella morgani = PEB index) in sediment cores as a proxy for extending the record of low-oxygen bottom-water conditions on the Louisiana shelf back in time. The PEB index in four sediment cores provides evidence for low-oxygen events that pre-date the start of extensive use of commercial fertilizer in the Mississippi Basin (~1950). Fluctuations in the PEB index between 1817 A.D. and 1910 A.D. may correspond with increased discharge/flooding events in the Mississippi River drainage basin.
Our chronology for one long core from the Louisiana shelf (core PE0305-GC1) indicates low-oxygen events occurred periodically on the Louisiana shelf for at least the last 350 years. High PEB values similar to values found in the last 50 years occur in the early 1700s.

Carbon stable-isotope analyses of sedimentary organic matter have also been completed for core PE0305-GC1. In the upper 100 cm of the core, negative excursions in $\delta^{13}C$ generally correspond to increases in PEB. Below the 100 cm core depth, the correspondence of $\delta^{13}C$ and PEB is more variable. The very negative $\delta^{13}C$ values found in the core most likely represent incorporation of biomass from anerobic microbial recycling communities to the bulk sediment and support the interpretation that high PEB values represent low-oxygen bottom-water conditions.

Fluctuations in the PEB index, supported in part by $\delta^{13}C$, indicate low-oxygen bottom-water events developed periodically on the Louisiana shelf before the extensive use of commercial fertilizer. The PEB proxy indicates that low-oxygen conditions near the Mississippi Delta in the early 1700s were as severe as conditions associated with hypoxia events of the last 50 years. Our results suggest that development of low-oxygen bottom waters on the Louisiana Shelf is a complex natural process that has been altered by human activities.

The abstract and Power Point slides to this presentation are available in PDF. The link to the PDF is here:
http://www.epa.gov/msbasin/taskforce/nutrient_workshop/pdf/session-d_1.pdf

10. Anderson, D. M., P. M. Glibert and J. M. Burkholder. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*, **25**, 704-726.

Abstract: Although algal blooms, including those considered toxic or harmful, can be natural phenomena, the nature of the global problem of harmful algal blooms (HABs) has expanded both in extent and its public perception over the last several decades. Of concern, especially for resource managers, is the potential relationship between HABs and the accelerated eutrophication of coastal waters from human activities. We address current insights into the relationships between HABs and eutrophication, focusing on sources of nutrients, known effects of nutrient loading and reduction, new understanding of pathways of nutrient acquisition among HAB species, and relationships between nutrients and toxic algae. Through specific, regional, and global examples of these various relationships, we offer both an assessment of the state of understanding, and the uncertainties that require future research efforts. The sources of nutrients potentially stimulating algal blooms include sewage, atmospheric deposition, groundwater flow, as well as agricultural and aquaculture runoff and discharge. On a global basis, strong correlations have been demonstrated between total phosphorus inputs and phytoplankton production in freshwaters, and between total nitrogen input and phytoplankton production in estuarine and marine waters. There are also numerous examples in geographic regions ranging from the largest and second largest U.S. mainland estuaries (Chesapeake Bay and the Albemarle-Pamlico Estuarine System), to the Inland Sea of Japan, the Black Sea, and Chinese coastal waters, where increases in nutrient loading have been linked with the development of large biomass blooms, leading to anoxia and even toxic or harmful impacts on fisheries resources, ecosystems, and human health or recreation. Many of these regions have witnessed reductions in phytoplankton biomass (as chlorophyll a) or HAB incidence when nutrient controls were put in place. Shifts in species composition have often been attributed to changes in nutrient supply ratios, primarily N:P or N:Si. Recently this concept has been extended to include organic forms of nutrients, and an elevation in the ratio of dissolved organic carbon to dissolved organic nitrogen (DOC:DON) has been observed during several recent blooms. The physiological strategies by which different groups of species acquire their nutrients have become better understood, and alternate modes of nutrition such as heterotrophy and mixotrophy are

now recognized as common among HAB species. Despite our increased understanding of the pathways by which nutrients are delivered to ecosystems and the pathways by which they are assimilated differentially by different groups of species, the relationships between nutrient delivery and the development of blooms and their potential toxicity or harmfulness remain poorly understood. Many factors such as algal species presence/abundance, degree of flushing or water exchange, weather conditions, and presence and abundance of grazers contribute to the success of a given species at a given point in time. Similar nutrient loads do not have the same impact in different environments or in the same environment at different points in time. Eutrophication is one of several mechanisms by which harmful algae appear to be increasing in extent and duration in many locations. Although important, it is not the only explanation for blooms or toxic outbreaks. Nutrient enrichment has been strongly linked to stimulation of some harmful species, but for others it has not been an apparent contributing factor. The overall effect of nutrient over-enrichment on harmful algal species is clearly species specific.

15. Baustian, M.M. 2005. Benthic Communities in the Northern Gulf of Mexico Hypoxic Area: Potential Prey for Demersal Fish. M.S. Thesis. Louisiana State University. http://etd.lsu.edu/docs/available/etd-07142005-082657/

Abstract: Bottom-water hypoxia (< 2 mg O2 l-1) usually occurs on an annual basis on the Louisiana/Texas continental shelf from mid-May through mid-September over a large area (up to 20,000 km2 in mid-summer). The effects of hypoxia on the benthic infauna (potential prey) for demersal fish were examined, because changes in optimal diet can lead to negative impacts on growth and reproduction. Benthic samples were taken in three areas (inshore and offshore out of hypoxia and in the hypoxic area) during August 2003. Samples were also taken monthly from September 2003 to October 2004 at a fixed station (C6B) where summer hypoxia occurs consistently. The mean abundance of the benthic infauna in the three summer areas were not significantly different indicating similar prey abundances found in the study area. Diverse infaunal communities exist offshore of the hypoxic zone with similar species composition compared to the inshore but different compared to the hypoxic area. An abundance of benthos at the surface was not found at the summer 2003 hypoxic stations; therefore there was not an abundance of available prey at the surface. However, benthos migrated toward the surface at station C6B in June and July 2004 during hypoxia, providing an increase of prey at the surface compared to other months. During the spring months, the infaunal community was more diverse and abundant compared to the post hypoxic months (August, September, and October), which suggests fewer and less diverse potential prey in the fall for demersal predators. The most abundant prey items for demersal fish in the study area were polychaetes and secondarily molluscs. The benthic community abundances during the summer 2003 and 2004 were not expected and may be due to the storm events in summer 2003 and shorter duration of hypoxia in summer 2004.

16. Benner, R., and S. Opsahl (2001), Molecular indicators of the sources and transformations of dissolved organic matter in the Mississippi river plume, Org. Geochem., 32, 597-611.

Abstract: The dynamics of dissolved organic matter (DOM) in the Mississippi river plume were investigated during four cruises to the region in 1990-1993. During each cruise, large-volume water samples were collected from a broad salinity gradient (0-36 psu) for the determination of dissolved organic carbon (DOC) concentrations and the isolation of DOM by tangential-now ultrafiltration. The fraction of DOC recovered by ultrafiltration ranged from 49% in the river to 22% in the Gulf of Mexico. The ultrafiltered DOM (UDOM) was further characterized for the concentrations and compositions of combined neutral sugars and lignin-derived phenols. Concentrations of DOC ranged from 359 muM in the river during the summer to 65 muM in surface waters of the Gulf of Mexico during the winter. Mixing curves indicated minor losses of DOC at low salinities and a major source of DOC at mid salinities. Combined neutral sugars had elevated concentrations at mid salinities where plankton biomass and rates of autotrophic and heterotrophic processes were maximal, indicating that elevated concentrations of sugars and DOC were freshly-derived from plankton. In contrast, concentrations of lignin phenols ill UDOM were depicted at low salinities, indicating losses due to flocculation of terrestrially-derived humic substances. The selective removal of syringyl phenols from dissolved lignin was observed in UDOM from higher salinity (> 25 psu) waters, providing the first molecular evidence of the removal of terrigenous DOM from the coastal ocean due to photooxidation. Together, these molecular biomarkers indicated much greater dynamic behavior of DOM than was apparent from bulk DOC analyses, and they demonstrated that biological as well as physico-chemical processes were important in controlling the concentrations and compositions of DOM in coastal waters.

18. Bianchi, T. S., E. Engelhaupt, P. Westman, T. Andrén, C. Rolf and R. Elmgren. 2000. Cyanobacterial blooms in the Baltic Sea: natural or human-induced? *Limnol. Oceanogr.,* **45**, 716-726.

Abstract: Massive summer blooms of nitrogen-fixing cyanobacteria have been documented in the Baltic Sea since the 19th century, but are reported to have increased in frequency, biomass, and duration in recent decades-presumably in response to the well-documented anthropogenic eutrophication of the Baltic. Here, we present an 8,000-yr record of fossil cyanobacterial pigments, diatom microfossil assemblages, and delta(15)N variations in sediment cores from the Baltic proper. This record indicates that nitrogen-living cyanobacterial blooms are nearly as old as the present brackish water phase of the Baltic Sea, starting as far back as ca. 7000 B.P.-soon after the former freshwater Ancylus Lake turned into the brackish Litorina Sea. Demonstration of cyanobacterial blooms in the Baltic prior to the greatly increased anthropogenic nutrient inputs of the 20th century is important for setting realistic goals when trying to reduce the magnitude of present brooms. Our results suggest that the presently predominating nitrogen (N) limitation of phytoplankton in the Baltic Sea proper is not man-induced, but a natural phenomenon, which has endured for some 7,000 yr. These cyanobacterial blooms were possibly initiated by increased availability of phosphorus (P)-from inflow of P-rich seawater and increased P release from sediments-during periods of deep-water anoxia, caused by the establishment of salinity stratification. Efforts to restore the Baltic proper to a more oligotrophic and natural condition should take into account that nitrogen-fixing cyanobacterial blooms are a characteristic, natural feature of this sea.

20. Bianchi TS, Filley T, Dria K, Hatcher PG. 2004. Temporal variability in sources of dissolved organic carbon in the lower Mississippi River. Geochimica Et Cosmochimica Acta 68 (5): 959-967.

Abstract: Here we report on the temporal changes in the composition of dissolved organic carbon (DOC) collected in the tidal freshwater region of the lower Mississippi River. Lignin-phenols, bulk stable carbon isotopes, compound-specific isotope analyses (CSIA) and C-13 nuclear magnetic resonance (NMR) spectrometry were used to examine the composition of high molecular weight dissolved organic matter (HMW DOM) at one station in the lower river over 6 different flow regimes in 1998 and 1999. It was estimated that the annual input of DOC delivered to the Gulf of Mexico from the Mississippi River was of 3.1 X 10(-3) Pg, which represents 1.2% of the total global input of DOC from rivers to the ocean. Average DOC and HMW DOC were 489 +/- 163 and 115 +/- 47 muM, respectively. C-13-NMR spectra revealed considerably more aliphatic structures than aromatic carbons in HMW DOC. Lignin phenols were significantly C-13-depleted with respect to bulk HMW DOM indicating that C-4 grass inputs to the HMW DOM were not significant. It is speculated that C-4 organic matter in the river is not being converted (via microbial decay) to HMW DOM as readily as C-3 organic matter is, because of the association of C-4 organic matter with finer sediments. The predominantly aliphatic C-13 NMR signature of HMW DOM suggests that autochthonous production in the river may be more important as a source of DOC than previously thought. Increases in nutrient loading and decreases in the suspended load (because of dams) in the Mississippi River, as well as other large rivers around the world, has resulted in significant changes in the sources and overall cycling of riverine DOC.

23. Bierman, V.J., Jr. and H.P. Holmberg. 2000. Case Study - Hypoxia in the Gulf of Mexico. In: Workshop Report, U.S. Environmental Protection Agency, The Ohio State University and Michigan State University, Columbus, Ohio, April 12-13, 2000.

A summary and illustrations for this presentation is available in the following PDF: http://www-agecon.ag.ohio-state.edu/programs/Swank/pdfs/Making%20Environmental%20Policy%20Analysis%20Relevant.pdf

24. Bierman, V.J., Jr., S.C. Hinz, W.J. Wiseman, Jr., N.N. Rabalais and R. Eugene Turner. 2003. Forecasting Hypoxia in the Gulf of Mexico: Responses to Nutrient Loadings from the Mississippi River Basin. In: N.J. Valette-Silver and D. Scavia (eds.), Ecological Forecasting: New Tools for Coastal and Ecosystem Management. NOAA Technical Memorandum NOS NCCOS. pp. 111-115.

Abstract: A zone of hypoxia (<2 mg O2/l) forms each spring and summer on the Louisiana-Texas continental shelf and stresses aquatic life. The principal causes are increased nitrogen loads from the Mississippi River Basin (MRB) combining with the physical stratification of Gulf waters. A mass balance model was developed to address broad, macro-scale questions related to the impacts of nutrient loadings from the MRB on

water quality in the northern Gulf of Mexico. Simulations were conducted for a range of nutrient load reductions to determine how much the bottom water dissolved oxygen concentrations improved. Reducing the nutrient load 20-30 percent led to forecasts of a 15-50 percent increase of bottom water dissolved oxygen concentrations. These results were used to develop a 30 percent nitrogen loading reduction target to meet the long-term Coastal Goal for reducing the areal extent of hypoxia in the northern Gulf of Mexico. A major accomplishment in this study established watershed-scale links between nutrient loads from the MRB and water quality responses in the northern Gulf of Mexico. The study also called attention to some challenging questions facing policy-makers when implementing forecast results developed from research. In view of the complexities of the system, uncertainties in the level of knowledge, and the potentially long time period required to observe changes resulting from management action, an adaptive management approach was recommended. This approach includes a comprehensive program of monitoring, modeling, and research to facilitate continual improvement in scientific knowledge and gradual adaptation of management approaches. Specific recommendations are made for reducing uncertainties and improving forecasting ability for water quality responses. Modeling needs cannot be met independently of monitoring and research needs because models are only tools for synthesizing environmental data, not substitutes for these data. In the end, there must be compatibility among management questions, model capabilities and available data.

34. Boynton, W. R. and W. M. Kemp. 2000. Influence of river flow and nutrient loads on selected ecosystem processes. A synthesis of Chesapeake Bay data. Pp. 269-298 in *Estuarine Science: A Synthesis Approach to Research and Practice,* Hobbie, J. E. (ed.), Island Press, Washington, D.C.

Abstract: In this chapter we assembled and analyzed two data sets, one a discontinuous 22-year time series (1972-1977, 1985-1993) of observations from a single mesohaline site in Chesapeake Bay, and the other, a much shorter time series from that site plus similar sites in four bay tributaries. For all locations, the data set includes measurements of river flow, nutrient-loading rate, phytoplankton primary production rates and biomass, water-column nutrient concentrations, and sediment-water exchanges of ammonium. In addition, data on sedimentation rates of chlorophyll *a* and bottom-water dissolved oxygen concentrations were analyzed at one site.

We examined a series of hypotheses concerning the influence of river flow and nutrient loading on these variables toward the goal of understanding underlying mechanisms. Significant relationships to flow and associated nutrient loads were found for all variables, some being stronger than others. In most cases, the influence of flow was found to extend over relatively short time periods (months to 2 years) and there were temporal lags between flow events and ecosystem responses on time scales of weeks to months. Results of analyses based on the time series from one location and on comparative analyses of data from five different sites were qualitatively similar; in this system it was not necessary to invoke comparative analyses to capture a large enough signal in forcing and response to observe interpretable patterns. Analyses generally

indicated that relationships proximal to flow or nutrient loading rate were stronger (for example, nutrient load versus water-column nutrient mass) than those more removed from the direct influence of flow or nutrient load (for example, flow versus sediment nutrient releases). These analysis indicate the importance of freshwater flow and associated nutrients in shaping chemical and biological responses in this estuary. Analyses are continuing and the next step will be to examine the effects of flow and nutrient loads on submersed vascular plant distributions and zooplankton and benthic communities.

35. Breed GA, Jackson GA, Richardson TL. 2004. Sedimentation, carbon export and food web structure in the Mississippi River plume described by inverse analysis. Marine Ecology-Progress Series 278: 35-51.

Abstract: The Mississippi River stimulates the coastal marine ecosystem directly with dissolved organic matter and indirectly with inorganic nutrients that enhance primary production. To understand the river's effect, we need to track the fate of both sources of organic matter. Using readily available data, we investigated the planktonic ecosystem of the buoyant Mississippi River plume using an inverse analysis technique to describe the carbon flow for the complete planktonic system. For each season we divided the marine waters receiving Mississippi River discharge into 4 dilution regions connected by movement of river water. Our results show that during 3 seasons (spring, summer, and fall) mid-salinity waters (15 to 29 psu) exported organic matter (strongly net autotrophic), whereas the other regions imported it (net heterotrophic). More than 20% of total plume primary productivity was exported from the entire modeled region, as continued water movement carried organic carbon into surrounding waters. In contrast, the winter plume was net-heterotrophic everywhere, as high bacterial respiration overwhelmed relatively low primary production, and riverine dissolved organic carbon (DOC) and organic carbon from resuspended sediments were required to balance a carbon deficit. From the spring through fall, sedimentation of organic carbon was linked to primary production, with strongest sedimentation in mid-salinity regions. Sedimentation was enhanced beneath less productive, higher-salinity regions, by import of organic carbon moving out of mid-salinity regions. In contrast, winter organic carbon sedimentation rates were calculated to be zero in all model regions. The analysis showed a dynamic relationship between primary production and sedimentation and provides a good starting point for future development of mechanistic models that directly address the relationships between nutrient input, primary production, sedimentation and hypoxia on the Louisiana Shelf.

37. Brush, G. S. and W. B. Hilgartner. 2000. Paleoecology of submerged macrophytes in the Upper Chesapeake Bay. *Ecol. Monogr.,* **70**, 645-667.

Abstract: Fossil seed distributions of submerged aquatic vegetation (SAV) from dated sediment cores in tributaries of the upper Chesapeake Bay show prehistoric changes in species composition and abundance and reflect the response of SAV species to human disturbance since European settlement. The interval of time spanned by the cores includes several centuries prior to, and three centuries following, European settlement. Species diversity is greatest in the low-salinity northern and upper tributaries, while areas

of higher salinity and extensive salt marshes are characterized by low diversity or absence of SAV. Mapped distributions of seed abundances show the migration from upstream to downstream in some tributaries of the brackish species Potamogeton perfoliatus, Zannichellia palustris, and Ruppia maritima following deforestation. The largest increase in SAV, represented by the highest abundance of fossilized seeds, occurred during the 1700s after Europeans first cleared the land for farms, and the largest and most widespread decline took place in the 1960s and 1970s after most of the watershed had been at one time or another cleared and heavily fertilized for agriculture. Distributions of SAV are highly variable both temporally and spatially, reflecting the dynamic nature of estuarine habitats. Despite high environmental variability, local and regional extinctions occurred only in the most recent decades, indicating a threshold response to land use changes and nutrient loading which had begun at least two centuries earlier and intensified in the mid- to late 19th century.

38. Brush, G. S. 2001. Natural and anthropogenic changes in Chesapeake Bay during the last 1000 years. *Hum. Ecol. Risk Assess.,* **7**, 1283-1296.

Abstract: Sediment cores from tributaries, marshes and the main stem of Chesapeake Bay were analyzed for paleoecological indicators of climate change and land use. Indicators include pollen and seeds of terrestrial and aquatic plants, diatoms, charcoal, nutrients, and trace metals. Two major events, one climatic and the other anthropogenic, occur-red within the last millennium. The Medieval Climatic Anomaly and the Little Ice Age are recorded in Chesapeake sediments by terrestrial indicators of dry conditions for 200 years, beginning about 1000 years ago, followed by increases in wet indicators from about 800 to 400 years ago. There were no corresponding shifts in estuarine diatoms and seeds of submerged macrophytes. During the last few centuries following European settlement, deforestation and agriculture have resulted in the transport of large sediment and nutrient loads to estuarine waters. The terrestrial flora shifted from arboreal to herbaceous, and much of the estuarine benthic biota was replaced by pelagic species. These changes had a profound effect on the Chesapeake fishery. In assessing risks associated with climate change, it must be recognized that changes wrought by human activity are likely to influence effects of future climate change, in ways not evident from the fossil record.

40. Burnett, L. E. and W. B. Stickle. 2001. Physiological responses to hypoxia. Pp. 101-114 in Rabalais, N. N. and R. E. Turner (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems.* Coastal and Estuarine Studies **58**, American Geophysical Union, Washington, D.C.

Abstract: Hypoxia can have profound effects on individual organisms. This chapter focuses on the mechanisms different kinds of animal possess to avoid, tolerate, and adapt to low levels of oxygen in water; selected examples illustrate these mechanisms. While some organisms can detect and avoid hypoxic water, avoidance is not always possible, especially in the sense of sessile organisms. When an organism cannot avoid hypoxia, its response may depend on the intensity and duration of the bout of low oxygen. Examples of responses to hypoxia include a depression in feeding as well as a decrease in molting

and growth rates. During acute exposures to hypoxia some organisms can maintain aerobic metabolism by making effective use of a respiratory pigment, or increasing ventilation rates, or increasing the flow of blood past the respiratory surfaces or combinations of all three. Responses to chronic hypoxia are different and include the production of greater quantities of respiratory pigment and changing the structure of the pigment to one with an adaptive higher oxygen affinity. Many organisms respond to hypoxia by switching from aerobic to anaerobic metabolism and some simply reduce their overall metabolism. Hypoxia is often accompanied by hypercapnia (an elevation in water CO_2), which produces an acidification of the body tissues, including blood, and has physiological implications that can also be profound and separate from the effects of low oxygen. Finally, there is evidence that hypoxia can inhibit immune responses, causing greater mortality than would otherwise occur when organisms are challenged with a pathogen.

41. Cai, W. J., and S. E. Lohrenz (2005), Carbon, Nitrogen, and Phosphorus Fluxes from the Mississippi River and the Transformation and Fate of Biological Elements in the River Plume and the Adjacent Margin, in Carbon and nutrient fluxes in continental margins: a global synthesis, edited by K. K. Liu, et al., Springer-Verlag, NY.

47. Chen, N., T. S. Bianchi, B. A. McKee and J. M. Bland. 2001. Historical trends of hypoxia on the Louisiana shelf: application of pigments as biomarkers. Organic Geochem., **32**, 543-561.

Abstract: Increases in the deposition of phytoplankton-derived organic carbon resulting from increases in nutrient inputs through the Mississippi-Atchafalaya system since the early 1950s has been speculated as the primary reason for the occurrence of hypoxic events in this region (Rabalais, N.N., Wiseman, W.J., Turner, R.E., Sen Gupta, B.K., Dortch, Q., 1996. Nutrient changes in the Mississippi river and system responses on the adjacent continental shelf. Estuaries 19(2B), 386-407). However, due to the lack of long-term measurements of oxygen in this region it is unclear if hypoxia events occurred prior to anthropogenic inputs of nutrients from the Mississippi river. In this study, we used naturally occurring radionuclides and plant pigment biomarkers to document changes in hypoxia events over the past 100 years. Specifically, we used pigments derived from the anoxygenic phototrophic brown-pigmented green sulfur bacteria Chlorobium phaeovibroides and C. phacobacteroides. In sediments, at a hypoxic site west of the Mississippi plume, we observed high concentrations (52 nmol/g OC) of bacteriochlorophyll-e along with the specific decay product homologues of bacteriopheophytin-e (15 nmol/g OC). The down-core distribution of bacteriochlorophyll-c and bacteriopheophytin-e homologues (in particular the more stable bacteriopheohytin-e) indicated that the highest concentrations occurred between 1960 and the present, coinciding with increased nutrient loading from the Mississippi river. These bacteriopigments were not detected prior to the early 1900s. These results are consistent with the view that increases in riverine nutrient loadings is likely the major cause of increasing trends in hypoxic events along the Louisiana coast over the past 50 years.

48. Chen, X., S. E. Lohrenz, and D. A. Wiesenburg (2000), Distribution and controlling mechanisms of primary production over the Louisiana-Texas continental shelf, Journal of Marine Systems, 25, 179-207.

Abstract: The northwest (NW) Gulf of Mexico is marked by strong seasonal patterns in regional and mesoscale circulation and variable effects of riverine/estuarine discharge, which influence distributions of nutrients, phytoplankton biomass and primary production. During a series of five cruises in the NW Gulf of Mexico in 1993 and 1994, an extensive data set was collected including nutrients, phytoplankton biomass (chlorophyll a), and photosynthesis-irradiance (P-E) parameters. Primary production was estimated using P-E parameters in conjunction with profiles of biomass and irradiance. Relatively high biomass and primary production were observed in inner shelf waters during spring conditions of high river discharge. This was attributed to the retention of biomass and nutrients on the shelf by the combination of high river outflow and a westward flow along the inner shelf with consequent onshore Ekman component. During summer, when surface currents shifted towards the north and east, values of nutrients, biomass and primary production were relatively high east of Galveston Bay and decreased outward from the coast. This pattern was apparently a consequence of nutrient inputs from riverine, upwelling and benthic sources. Nutrients, biomass and productivity in the western portion of the study area in summer were generally lower as a result of the upcoast Row of oligotrophic offshore water. Inter-annual variability was observed between November 1993 and 1994 with higher biomass and productivity occurring in November 1993. This was partially attributed to higher river discharge prior to November 1993, retention of biomass and nutrients by the downcoast flow along the inner shelf, and possibly, injection of nutrients onto the shelf at the shelf break. Our findings demonstrate that the interaction of circulation and availability of Light and nutrients are largely responsible for variations in primary production. Nitrogen appeared to be the primary limiting nutrient, however, a potential for phosphate limitation was also observed particularly during periods of higher river discharge. Light availability was a critical variable during the fall and winter months, when higher primary production was restricted to shallow waters where vertical mixing was constrained by bottom topography. In deep waters, counteractive changes in nutrient and light availability apparently resulted in minor temporal variation between seasons. The annual carbon production in the Louisiana-Texas (LATEX) continental shelf region was estimated to be 159 g C m(-2) year(-1), which is within the range of prior estimates for this region. Given that the area of the study region was approximately 140,000 km(2), this would be equivalent to an areal carbon production of about 22.2 million metric tons.

49. Chesney, E. J., D. M. Baltz, and R. G. Thomas (2000), Louisiana estuarine and coastal fisheries and habitats: Perspectives from a fish's eye view, Ecological Applications, 10, 350-366.

Abstract: Stimulated by nutrients from the Mississippi River, the vast coastal wetlands of the river's past and present deltas interface with the Gulf of Mexico to form a complex and prolific marine ecosystem. This highly productive system has yielded annual fishery landings of >453.6 x 10(6) kg (1 billion pounds) since 1969. The Louisiana ecosystem has been heavily exploited and significantly altered over the years to meet the demands

for coastal development, seafood production, navigation, oil exploration, flood control, and other social, economic, and industrial activities. While not all impacts can be viewed as detrimental to fisheries or their habitat, some of these habitat impacts have contributed to significant ecological problems such as saltwater intrusion, loss of coastal wetlands, and development of vast area of hypoxia along the coast. Management strategies to deal with some of these problems propose directed manipulations of the coastal environments to stop or reduce rates of degradation. Over the past 46 years, fisheries yields from Louisiana waters have remained strong. Although quantitative data are lacking to examine more than a few decades of environmental changes, an analysis of fishery-independent trends for selected inshore species of nekton over a recent 21-yr period suggests that many species have been remarkably resilient to significant changes in their habitats and pressures from exploitation. Over a longer period (60 yr), more significant changes to inshore demersal trawl assemblages are apparent, but data are lacking to conclusively identify their causes or quantitatively document the magnitude of change. We review some of the major changes that have occurred in habitat believed to be essential to fishes and review other factors likely to be significant in structuring fish populations. Given the significant number of environmental impacts affecting the system, we also discuss potential reasons why more dramatic changes in nearshore and estuarine fish populations of coastal Louisiana are not apparent.

50. Chesney, E. J. and D. M. Baltz. 2001. The effects of hypoxia on the northern Gulf of Mexico coastal ecosystem: A fisheries perspective. Pp. 321-354 in Rabalais, N.N. and R.E. Turner, (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems.* Coastal and Estuarine Studies **58**, American Geophysical Union, Washington, D.C.

51a.Childs, C. R., N. N. Rabalais, R. E. Turner, and L. M. Proctor (2002), Sediment denitrification in the Gulf of Mexico zone of hypoxia, Marine Ecology-Progress Series, 240, 285-290.

Abstract: The largest zone of anthropogenic bottom water hypoxia in the Western Hemisphere occurs seasonally in the northern Gulf of Mexico between the Mississippi River delta and the coast of eastern Texas. This zone of hypoxia reaches its greatest extent in the summer months and is a consequence of seasonal stratification of the water column combined with the decomposition of organic matter derived from accelerated rates of primary production. This enhanced productivity is driven primarily by the input of inorganic nitrogen from the Mississippi River. There are 3 likely sinks for fixed nitrogen within this zone of hypoxia: sequestration in the sediment, dispersion and dilution into the Gulf of Mexico, and denitrification. We assessed potential denitrification rates at 7 stations in the zone of hypoxia during the summer of 1999. Those data are compared with bottom water nitrate, ammonium and dissolved oxygen (DO) concentrations. No denitrification was observed in the water column. Denitrification potential rates in the surface sediments were unexpectedly low and ranged between 39.8 and 108.1 mumol m(-1) h(-1). The highest rates were observed at stations with bottom water DO concentrations between 1 and 3 mg l(-1). Denitrification activity was significantly lower at stations where DO was lower than 1 mg l(-1) or higher than 3 mg l(-1). Nutrient data for these stations demonstrate that as anoxia is approached, the

dominant species of nitrogen shifts from nitrate to ammonium. The shift in nitrogen species suggests competition between microbial populations in the sediment community. The lower denitrification rates at stations with bottom water DO <1 mg l(-1) may be due to nitrate limitation or an increase in the competitive advantage of microorganisms capable of dissimilatory nitrate reduction to ammonium (DNRA). Suppression of denitrification at low DO by any mechanism will increase the residence time of bioavailable nitrogen. This trend could act as a positive feedback mechanism in the formation of hypoxic bottom waters.

52. Cloern, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology and Progress Series 210:223-253.

Abstract: A primary focus of coastal science during the past 3 decades has been the question: How does anthropogenic nutrient enrichment cause change in the structure or function of nearshore coastal ecosystems? This theme of environmental science is recent, so our conceptual model of the coastal eutrophication problem continues to change rapidly. In this review, I suggest that the early (Phase I) conceptual model was strongly influenced by Limnologists, who began intense study of lake eutrophication by the 1960s. The Phase I model emphasized changing nutrient input as a signal. and responses to that signal as increased phytoplankton biomass and primary production, decomposition of phytoplankton-derived organic matter, and enhanced depletion of oxygen from bottom waters. Coastal research in recent decades has identified key differences in the responses of lakes and coastal-estuarine ecosystems to nutrient enrichment, The contemporary (Phase II) conceptual model reflects those differences and includes explicit recognition of (1) system-specific attributes that act as a filter to modulate the responses to enrichment (leading to large differences among estuarine-coastal systems in their sensitivity to nutrient enrichment); and (2) a complex suite of direct and indirect responses including linked changes in: water transparency, distribution of vascular plants and biomass of macroalgae, sediment biogeochemistry and nutrient cycling, nutrient ratios and their regulation of phytoplankton community composition, frequency of toxic/harmful algal blooms, habitat quality for metazoans, reproduction/growth/survival of pelagic and benthic invertebrates, and subtle changes such as shifts in the seasonality of ecosystem functions. Each aspect of the Phase II model is illustrated here with examples from coastal ecosystems around the world. In the last section of this review I present one vision of the next (Phase III) stage in the evolution of our conceptual model, organized around 5 questions that will guide coastal science in the early 21st century: (1) How do system-specific attributes constrain or amplify the responses of coastal ecosystems to nutrient enrichment? (2) How does nutrient enrichment interact with other stressors (toxic contaminants, fishing harvest, aquaculture, nonindigenous species, habitat loss, climate change, hydrologic manipulations) to change coastal ecosystems? (3) How are responses to multiple stressors linked? (4) How does human-induced change in the coastal zone impact the Earth system as habitat for humanity and other species? (5) How can a deeper scientific understanding of the coastal eutrophication problem be applied to develop tools for building strategies at ecosystem restoration or rehabilitation?

54. Colman, S. M. and J. F. Bratton. 2003. Anthropogenically induced changes in sediment and biogenic silica fluxes in Chesapeake Bay. *Geology,* **31**, 71-74.

Abstract: Sediment cores as long as 20 m, dated by C-14, Pb-210, and Cs-137 methods and pollen stratigraphy, provide a history of diatom productivity and sediment-accumulation rates in Chesapeake Bay. We calculated the flux of biogenic silica and total sediment for the past 1500 yr for two high-sedimentation-rate sites in the mesohaline section of the bay. The data show that biogenic silica flux to sediments, an index of diatom productivity in the bay, as well as its variability, were relatively low before European settlement of the Chesapeake Bay watershed. In the succeeding 300400 yr, the flux of biogenic silica has increased by a factor of 4 to 5. Biogenic silica fluxes still appear to be increasing, despite recent nutrient-reduction efforts. The increase in diatom-produced biogenic silica has been partly masked (in concentration terms) by a similar increase in total sediment flux. This history suggests the magnitude of anthropogenic disturbance of the estuary and indicates that significant changes had occurred long before the twentieth century.

55. Conmy RN, Coble PG, Chen RF, Gardner GB. 2004. Optical properties of colored dissolved organic matter in the Northern Gulf of Mexico. MARINE CHEMISTRY 89 (1-4): 127-144.

Abstract: Variations in the concentration and inherent optical properties of colored dissolved organic matter (CDOM) in river-dominated margins provide information on the cycling of carbon and its chemical composition. Large-scale temporal and spatial variability in CDOM concentration and optical properties were observed in the Northern Gulf of Mexico in June of 2000 and April of 2001. Terrestrial CDOM from the Mississippi and Atchafalaya Rivers dominates the region. Although the primary factor controlling CDOM in this region is the quantity of fresh water runoff, strong regional variability in fresh water sources also plays a major role. Physical complexity due to changes in circulation patterns, volume of river flow and multiple river sources makes observation of biological and photochemical effects challenging in this region. We have used two approaches to distinguish between source and transformation effects: mixing models, which include the concentration and inherent optical properties,of CDOM from discrete samples, and high-resolution three-dimensional mapping of multi-spectral fluorescence.

67. Dagg, M. J., and G. A. Breed (2003), Biological effects of Mississippi River nitrogen on the northern gulf of Mexico - a review and synthesis, Journal of Marine Systems, 43, 133-152.

Abstract: The Mississippi River currently delivers approximately 1.82 Tg N year(-1) (1.3 x 10(11) mol N year(-1)) to the northern Gulf of Mexico. This large input dominates the biological processes of the region. The "new" nitrogen from the river stimulates high levels of phytoplankton production which in turn support high rates of bacterial production, protozoan and metazoan grazing, and fisheries production. A portion of the particulate organic matter produced in the pelagic food web sinks out of the euphoric zone where it contributes to high rates of oxygen consumption in the bottom waters of the

inner shelf, resulting in the development of an extensive zone of hypoxia each summer. In spite of the significance of this river system to the coastal ocean of the northern gulf, we do not have an adequate understanding of the inputs, processing and ultimate fates of river nitrogen. Here we review available literature on this important system and propose a conceptual model showing how biological processes evolve in the river plume between the point of discharge and the point where plume waters are fully diluted by mixing with oceanic water.

68. Dagg M, Benner R, Lohrenz S, Lawrence D. 2004. Transformation of dissolved and particulate materials on continental shelves influenced by large rivers: plume processes. CONTINENTAL SHELF RESEARCH 24 (7-8): 833-858.

Abstract: The world's ten largest rivers transport approximately 40% of the fresh water and particulate materials entering the ocean. The impact of large rivers is important on a regional/continental scale (e.g. the Mississippi drains similar to40% of the conterminous US and carries approximately 65% of all the suspended solids and dissolved solutes that enter the ocean from the US) and on a global scale (e.g. the Amazon River annually supplies approximately 20% of all the freshwater that enters the ocean; e.g. approximately 85% of all sedimenting organic carbon in the ocean accumulates in coastal margin regions). River plume processes are affected by a suite of complex factors that are not fully understood. It is clear however, that the composition, concentration and delivery of terrestrial materials by large rivers cannot be understood by simply scaling Lip the magnitudes and impacts of dominant processes in smaller rivers. Because of high rates of particulate and water discharge, the estuarine processes associated with major rivers usually take place on the adjacent continental shelf instead of in a physically confined estuary. This influences the magnitude and selectivity of processes that transform, retain or export terrestrial materials. Buoyancy is a key mediating factor in transformation processes in the coastal margin. In this paper we review and synthesize Current understanding of the transformation processes of dissolved and particulate organic and inorganic materials associated with large river (buoyant) plumes. Chemical and biological activities are greatly enhanced by the changed physical and optical environment within buoyant plumes. Time and space scales over which these transformation processes occur vary greatly, depending on factors such as scales of discharge, suspended sediment loads. light and temperature. An adequate understanding of transformation processes in these highly dynamic, buoyancy-driven systems is lacking. In this paper, we review the biogeochemical processes that occur in large river plumes.

74. Diaz, R.J. and R. Rosenberg. 2001. Overview of anthropogenically induced hypoxic effects on marine benthic fauna. P. 129-145. In: N. Rabalias and G. Turner (eds.) Hypoxia and the Gulf of Mexico, AGU Press.

75. Diaz, R. J., J. Nestlerode, and M. L. Diaz. 2004. A global perspective on the effects of eutrophication and hypoxia on aquatic biota. In: Proceedings of the 7th International Symposium on Fish Physiology, Toxicology, and Water Quality, Tallinn, Estonia, May 12-15, 2003, G. L. Rupp and M. D. White (eds). U.S. Environmental Protection Agency, Ecosystems Research Division, Athens, Georgia, USA. EPA 600/R-04/049, pp 1-33.

The complete proceedings of this symposium are available as a PDF: http://water.montana.edu/symposium/proceedings/default.htm

79. Dortch, Q., N. N. Rabalais, R. E. Turner and N. A. Qureshi. 2001. Impacts of changing Si/N ratios and phytoplankton species composition. Pp 37-48 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: While nitrogen (N) and phosphorus (P) inputs from the Mississippi River have increased since the 1950s concomitantly with increasing productivity and hypoxia, silicate (Si) inputs have decreased. As a result, nutrient ratios have changed so that Si can now be limiting, especially in the spring. Si limitation controls size and species compostion of the diatom bloom by selecting species lower Si requirements. Evidence from the Louisiana shelf indicates that phytoplankton sinking, especially of diatoms in the spring, contributes to the vertical carbon flux that causes hypoxia. Most of the sinking phytoplankton are diatoms that are moderately to heavily silicified. Similar results have been obtained in other eutrophic areas. Consequently, the Si/N input ratio may influence the environmental impacts of increasing nutrient inputs through control of phytoplankton species composition. Nutrient control strategies to reduce hypoxia need to consider the consequences of changing nutrient ratios as well as changing nutrient concentrations.

81. Eadie BJ, Mckee BA, B, A, Metz S, H. Records of nutrient-enhanced coastal ocean productivity in sediments from the Louisiana continental-shelf. ESTUARIES 17 (4): 754-765.

Abstract: Shelf sediments from near the mouth of the Mississippi River were collected and analyzed to examine whether records of the consequences of anthropogenic nutrient loading are preserved. Cores representing approximately 100 yr of accumulation have increasing concentrations of organic matter over this period, indicating increased accumulation of organic carbon, rapid early diagenesis, or a combination of these processes. Stable carbon isotopes and organic tracers show that virtually all of this increase is of marine origin. Evidence from two cores near the river mouth, one within the region of chronic seasonal hypoxia and one nearby but outside the hypoxic region, indicate that changes consistent with increased productivity began by approximately the mid-1950s when the inorganic carbon in benthic forams rapidly became isotopically lighter at both stations. Beginning in the mid-1960s, the accumulation of organic matter, organic delta(13)C and delta(15)N all show large changes in a direction consistent with increased productivity. This last period coincides with a doubling of the load of nutrients from the Mississippi River, which levelled off in the mid-1980s. These data support the hypothesis that anthropogenic nutrient loading has had a significant impact on the Louisiana shelf.

85. First M (2002) Microbial food web structure and dynamics along the Texas coast and the Gulf of Mexico. M. Sc. Thesis. University of Akron

100. GLOBEC (2000) GLOBEC in the Gulf of Mexico: Large Rivers and Marine Populations. Rep No 19, Chesapeake Biol Lab, Solomons, MD

108. Gordon, E. S., M. A. Goni, Q. N. Roberts, G. C. Kineke, and M. A. Allison (2001), Organic matter distribution and accumulation on the inner Louisiana shelf west of the Atchafalaya River, Cont. Shelf Res., 21, 1691-1721.

Abstract: Surficial sediment samples from seven shallow cross-shelf transects west of the Atchafalaya River in the northern Gulf of Mexico were analyzed during three sampling periods to determine the distribution of organic matter along the shelf and to evaluate the temporal variability of its deposition. Downcore sediment profiles from four sites, which represent 50-200yr of deposition, were also examined to assess long-term changes in organic matter accumulation in this region. The Atchafalaya "mud stream," which transports fine sediment westward parallel to the coastline, appears to play an important role in the transport of river-derived organic matter. In general, sedimentary organic carbon (%OC) and total nitrogen (%TN) decrease seaward within each transect and westward along the shelf. Atomic organic carbon: nitrogen (C/N) ratios indicative of a terrestrial source (> 20) are observed near the mouth of the river during each sampling period, but values along the remainder of the shelf fall within a narrow range (9-11) with no apparent offshore trends. Depleted stable carbon isotope (delta C-13) values typical of C3 plant debris (-27 parts per thousand) are found near the river mouth and become more enriched (-22 to -21 parts per thousand) offshore. Organic matter distribution throughout much of the study area is similar during each sampling period, with significant seasonal differences close to the river mouth. Sediment, particulate organic carbon (POC), and particulate organic nitrogen (PON) budgets constructed for the study area reveal that 31 % of the sediment exported by the Atchafalaya River is presently deposited within the study area annually, while the organic matter burial rates in the same region represent only 21% and 22% of the riverine POC and PON inputs, respectively. The POC and PON budgets also suggest that the organic matter remineralized in the water column is of algal origin (C/ N = 7.2), whereas riverine organic matter (C/N = 10) appears to be respired within the sediments. The 22.7 g POC m(-2) yr(-1) and 2.7 g PON m(-2) yr(-1) buried in the study area account for similar to 5 % of the combined riverine and autochthonous OC and ON inputs to this region of the Louisiana shelf.

109. Gordon ES, Goni MA. 2003. Sources and distribution of terrigenous organic matter delivered by the Atchafalaya River to sediments in the northern Gulf of Mexico. GEOCHIMICA ET COSMOCHIMICA ACTA 67 (13): 2359-2375.

Abstract: Suspended sediments (SS) from the Atchafalaya River (AR) and the Mississippi River and surficial sediment samples from seven shallow cross-shelf transects west of the AR in the northern Gulf of Mexico were examined using elemental (%OC, C/N), isotopic (delta(13)C, Delta(14)C), and terrigenous biomarker analyses. The organic matter (OM) delivered by the AR is isotopically enriched (similar to-24.5%) and relatively degraded, suggesting that soil-derived OM with a C4 signature is the predominant OM source for these SS. The shelf sediments display OC values that generally decrease seaward within each transect and westward, parallel to the coastline. A

strong terrigenous C/N (29) signal is observed in sediments deposited close to the mouth of the river, but values along the remainder of the shelf fall within a narrow range (8-13), with no apparent offshore trends. Depleted stable carbon isotope (delta(13)C) values typical of C3 plant debris (-27parts per thousand) are found near the river mouth and become more enriched (-22 to -21parts per thousand) offshore. The spatial distribution of lignin in shelf sediments mirrors that of OC, with high ligpin yields found inshore relative to that found offshore (water depth > 10 m). The isotopic and biomarker data indicate that at least two types of terrigenous OM are deposited within the study area. Relatively undegraded, C3 plant debris is deposited close to the mouth of the AR, whereas more degraded, isotopically enriched, soil-derived OM appears to be deposited along the remainder of the shelf. An important input from marine carbon is found at the stations offshore from the 10-m isobath. Quantification of the terrigenous component of sedimentary OM is complicated by the heterogeneous composition of the terrigenous end-member. A three-end-member mixing model is therefore required to more accurately evaluate the sources of OM deposited in the study area. The results of the mixing calculation indicate that terrigenous OM (soil-derived OM and vascular plant debris) accounts for similar to79% of the OM deposited as inshore sediments and 66% of OM deposited as offshore sediments. Importantly, the abundance of terrigenous OM is 40% higher in inshore sediments and nearly 85% higher in offshore sediments than indicated by a two-end-member mixing model. Such a result highlights the need to reevaluate the inputs and cycling of soil-derived OM in the coastal ocean.

110. Graham, W. M. (2001), Numerical increases and distributional shifts of Chrysaora quinquecirrha (Desor) and Aurelia aurita (Linne) (Cnidaria : Scyphozoa) in the northern Gulf of Mexico, Hydrobiologia, 451, 97-111.

Abstract: Fisheries resource trawl survey data from the National Marine Fisheries Service from a 11-13-year period to 1997 were examined to quantify numerical and distributional changes of two species of northern Gulf of Mexico scyphomedusae: the Atlantic sea nettle, Chrysaora quinquecirrha (Desor), and the moon jelly, Aurelia aurita (Linne). Trawl surveys were grouped into 10 statistical regions from Mobile Bay, Alabama to the southern extent of Texas, and extended seaward to the shelf break. Records of summertime C. quinquecirrha medusa populations show both an overall numerical increase and a distributional expansion away from shore in the down-stream productivity field of two major river system outflows: Mobile Bay and the Mississippi-Atchafalaya Rivers. In addition, there is a significant overlap between summer C. quinquecirrha and lower water column hypoxia on the Louisiana shelf. In trawl surveys from the fall, A. aurita medusae showed significant trends of numerical increase in over half of the regions analyzed. For both species, there were statistical regions of no significant change, but there were no regions that showed significant decrease in number or distribution. The relationships between natural and human-induced (e.g. coastal eutrophication, fishing activity and hard substrate supplementation) ecosystem modifications are very complex in the Gulf of Mexico, and the potential impact of increased jellyfish populations in one of North America's most valuable fishing grounds is a most critical issue. Several hypotheses are developed and discussed to guide future research efforts in the Gulf of Mexico.

111. Gray, J. S., R. S.-s. Wu and Y. Y. Or. 2002. Review. Effects of hypoxia and organic enrichment on the coastal marine environment. *Mar. Ecol. Progr. Ser.*, **238**, 249-279.

Abstract: Eutrophication is one of the most severe and widespread forms of disturbance affecting coastal marine systems. Whilst there are general models of effects on benthos, such as the Pearson-Rosenberg (P-R) model, the models are descriptive rather than predictive. Here we first review the process of increased organic matter production and the ensuing sedimentation to the seafloor. It is shown that there is no simple relationship between nutrient inputs and the vertical flux of particulate organic matter (POM). In particular, episodic hydrographic events are thought to be the key factor leading to high rates of sedimentation and accompanying hypoxia. We extend an earlier review of effects of hypoxia to include organisms living in the water column. In general, fishes are more sensitive to hypoxia than crustaceans and echinoderms, which in turn are more sensitive than annelids, whilst molluscs are the least sensitive. Growth is affected at oxygen concentrations between 6.0 and 4.5 mg O-2 1(-1), other aspects of metabolism are affected at between 4 and 2 mg O-2 1(-1) and mortality occurs where concentrations are below 2.0 to 0.5 mg O-2 1(-1). Field studies, however, show that complex behavioural changes also occur as hypoxia increases, and these are described herein. The areas where hypoxia occurs are frequently areas that are stagnant or with poor water exchange. Thus again, hydrographic factors are key processes determining whether or not hypoxia and eutrophication occur. Tolerance to ammonia and hydrogen sulphide is also reviewed, as these substances are found at near zero concentrations of oxygen and are highly toxic to most organisms. However, the effects of interactions between oxygen, ammonia and hydrogen sulphide only occur below oxygen concentrations of ca. 0.5 mg O-2 1(-1), since only below this concentration are hydrogen sulphide and oxygen released into the water. Models of eutrophication and the generation of hypoxia are discussed, and in particular the P-R model is analysed. Although agreement with the model is widely reported the actual predictions of the model have rarely been tested. Our review suggests that the major effects on benthic fauna result from hypoxia rather than organic enrichment per se and suggests that the P-R model is descriptive rather than predictive. Finally, a managerial tool is proposed, based on the stages of effects of hypoxia and organic enrichment suggested by the P-R model and on an earlier study. The proposed strategy involves rapid assessment tools and indicates where more detailed surveys are needed. Managers are advised that remedial action will not produce rapid results and that recovery from eutrophication will probably take decades. Thus it is essential to detect potential hypoxia and eutrophication effects at early stages of development.

114. Grimvall, A. and Stålnacke, P. 2001. Riverine inputs of nutrients to the Baltic Sea. Pp. 113-131 in Wulff, F. V., L. A. Rahm and P. Larsson (eds.), *A Systems Analysis of the Baltic Sea,* Ecological Studies Analysis and Synthesis **148**, Springer, Berlin.

130. Jochem FJ (2001) Morphology and DNA content of bacterioplankton in the northern Gulf of Mexico – analyses by epifluorescence microscopy and flow cytometry. Aquat Microb Ecol 25:179-194

Abstract: The distribution of pelagic bacteria was assessed along 2 offshore - onshore transects in the northwestern Gulf of Mexico in July and October 1999 and along a salinity gradient (0.2 to 34.4 parts per thousand) in the Mississippi River plume in May 2000. Cell abundance was estimated by epifluorescence microscopy after DAPI staining and by flow cytometry after DNA staining with SYBR Green I. Total bacterial counts by both techniques corresponded well. Bacterial abundance ranged from 0.9 x 10(6) to 1.35 x 10(6) cells ml(-1) in the upper 200 m of the water column in the northwestern Gulf and from 0. 1 x 10(6) to 2.05 x 10(6) cells ml(-1) in the Mississippi River plume. Bacteria exhibited surface maxima in July 1999 but subsurface maxima in the upper half of the chlorophyll maximum in October 1999 and off the Louisiana shelf break in May 2000, Stations with a thin layer of low-salinity plume water exhibited an additional bacterial maximum at the surface. Within the Mississippi River plume, bacterial abundance decreased with increasing salinity, and their maximum abundance preceded the chlorophyll maximum along the salinity gradient. Three morphotypes of bacteria were distinguished by epifluorescence microscopy: cocci, rod-shaped bacteria, and curved bacteria. Cocci (40 to 60 % of total bacteria; counts corrected for Prochlorococcus spp.) were the most common morphotype, Rods and curved bacteria had similar shares (18 to 25%) and presented multi-species consortia as indicated by the variability in size and shape of cells within each group. Flow cytometry revealed 4 bacterial subpopulations distinguished by their DNA content, none of which seem to reflect a specific morphotype. Whereas regional differences in the contribution of the distinguished DNA types to total bacterial abundance were low in the open Gulf, a switch in predominance from low-DNA to high-DNA cells below the subsurface chlorophyll maximum was obvious in all profiles. The ecological significance of bacterial DNA types as revealed by flow cytometry is discussed in the context of published results.

131. Jochem FJ (2003) Photo- and heterotrophic pico- and nanoplankton in the Mississippi River Plume: Distribution and Grazing Activity. J Plankton Res 25:1201-1214

Abstract: The abundance of pico- and nanophytoplankton, bacteria and heterotrophic nanoflagellates, and grazing rates on phototrophic pico- and nanoplankton and bacterioplankton were assessed along a salinity gradient (0.2-34.4) in the Mississippi River plume in May 2000. Grazing rates were established by serial dilution experiments, and analysis by flow cytometry allowed differentiation of grazing rates for different phytoplankton subpopulations (eukaryotes, Synechococcus spp., Prochlorococcus spp.). Grazing rates on phytoplankton tended to increase along the salinity gradient and often approached or exceeded 1 day(-1). Phytoplankton net growth rates (growth-grazing) were mostly negative, except for positive values for eukaryotic nanoplankton in the low-salinity, high-chlorophyll region. Grazing pressure on bacteria was moderate (similar to0.5 day(-1)) and bacteria gained positive net growth rates of similar to0.3 day(-1). Eukaryotic nanophytoplankton were the major phototrophic biomass and protozoan food source, contributing 30-80% of the total consumed carbon. Bacteria were the second most important food source at 9-48% of the total consumed carbon. Synechococcus spp. and Prochlorococcus spp. remained an insignificant Portion of protozoan carbon consumption, probably due to their low contribution to the total pico- and nanoplankton biomass. Group-specific grazing losses relative to standing stocks suggest protozoan prey

preference for eukaryotes over bacteria. Protozoan grazers exerted a major grazing pressure on pico- and nanophytoplankton, but less so on bacteria.

132. Jochem FJ, Lavrentyev PJ, First, MR (2004a) Growth and grazing rates of bacteria sub-populations with different apparent DNA content in the Gulf of Mexico. Mar Biol 145:1213-122.

Abstract: Growth rates and grazing losses of bacterioplankton were assessed by serial dilution experiments in surface waters in the Mississippi River plume, the northern Gulf of Mexico, a Texas coastal lagoon (Laguna Madre), southeast Gulf of Mexico surface water, and the chlorophyll subsurface maximum layer in the southeast Gulf of Mexico. Bacteria were quantified by flow cytometry after DNA staining with SYBR Green, which allowed for discrimination of growth and grazing rates of four bacteria subpopulations distinguished by their apparent DNA content and cell size (light scatter signal). Total bacteria growth rates (0.2 - 0.9 day(-1)) were mostly balanced by grazing losses, resulting in net growth rates of - 0.18 to 0.45 day(-1). Growth rates of DNA subpopulations varied within experiments, sometimes substantially. In most, but not all, experiments, the largest bacteria with highest DNA content exhibited the highest growth rates, but a relationship between DNA content and growth rates or grazing losses was absent. Small bacteria with the lowest DNA content showed positive growth rates in most experiments, sometimes higher than growth rates of bacteria containing more DNA, and were grazed upon actively. Low- DNA bacteria were not inactive and were an integral part of the microbial food web.

133. Jochem FJ, McCarthy MJ, Gardner WS (2004b) Microbial ammonium recycling in the Mississippi River plume during the drought spring of 2000. J Plankton Res 26:1265-1275

Abstract: Microbial potential uptake and regeneration rates of ammonium (NH4+) were studied along a salinity gradient (salinities 0.2-34.4) in the Mississippi River plume during an extreme drought in spring 2000. Chlorophyll concentrations up to 30 mug L-1 were highest in the low- and mid-salinity regions (salinities 8.5-28.2) and comparable to records of other years but extended over smaller areas than during periods of normal river flow. Bacterial biomass (5.1-28.3 mug C L-1) was at the low end of the range observed in normal flow years, decreased with distance from the river mouth and did not peak with chlorophyll. Heterotrophic nanoflagellate abundance (1.4-4.0 mug C L-1) did not reflect phytoplankton and bacterial spatial distribution but peaked at 9.2 mug C L-1 at salinity 8.5. Microbial NH4+ regeneration rates were estimated by (NH4+)-N-15 isotope dilution experiments for the whole microbial community, under light and dark conditions, and for the <2 mum bacterium-dominated size fraction. Microbial NH4+ regeneration rates (0.018-0.124 mumol N L-1 h(-1)) were low relative to previous reports and peaked at salinity 28. Total NH4+ regeneration rates were higher than those in the <2 mum size fraction at only four stations, suggesting that bacterial mineralization was a significant component of NH4+ recycling in some parts of the river plume. Higher NH4+ regeneration in whole-water samples versus <2 mum fractions provided evidence for microbial grazing in regions where chlorophyll and regeneration rates peaked and at two full-salinity stations.

143. Justić, D., N. N. Rabalais and R. E. Turner. 2001. Future perspectives for hypoxia in the northern Gulf of Mexico. Pp 435-449 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: General circulation models predict that Mississippi River runoff would increase 20% if the concentration of atmospheric CO_2 doubles. This hydrologic change would be accompanied by an increase in winter and summer temperatures over the Gulf of Mexico coastal region of a 4.2^{o}C and 2.2^{o}C, respectively. Using a coupled physical-biological model, we examined the potential effects of climate variability on the Gulf of Mexico hypoxic zone. Model simulations suggest that increased freshwater inflow and surface oxygen cycling in the coastal waters of the northern Gulf of Mexico. In simulation experiments, a 20% increase in annual runoff of the Mississippi River, relative to a 1985-1992 average, resulted in a 50% increase in net primary productivity of the upper water column (0-10 m) and a 30 to 60% decrease in summertime subpycnoclincal oxygen content within the present day hypoxix zone. These model projections are in agreement with the observed increase in severity and areal extent of hypoxia during the Great Mississippi River Flood of 1993.

144. Justić, D., N. N. Rabalais and R. E. Turner. 2002. Modeling the impacts of decadal changes in riverine nutrient fluxes on coastal eutrophication near the Mississippi River Delta. Ecological Modeling 152: 33-46.

Abstract: A mathematical model was used to link decadal changes in the Mississippi River nutrient flux to coastal eutrophication near the Mississippi River Delta. Model simulations suggest that bottom water hypoxia intensified about 30 years ago, as a probable consequence of increased net productivity and increased sedimentation of the organic material produced in situ in the upper water column. Model simulations also suggest that long-term increase in riverine nutrient fluxes has been responsible for this historical decrease in bottom layer oxygen concentrations. Importantly, model simulations are in good agreement with the available historical data from the northern Gulf of Mexico, and are additionally supported by the retrospective analyses of sedimentary records. Conclusively, this modeling study supports the hypothesis that riverine nutrient fluxes, via their influence on net productivity of the upper water column, play a major role in controlling the development of bottom water hypoxia and accumulation of organic carbon in coastal sediments.

145. Justić, D., N. N. Rabalais, and R. E. Turner (2003), Simulated responses of the Gulf of Mexico hypoxia to variations in climate and anthropogenic nutrient loading, Journal of Marine Systems, 42, 115-126.

Abstract: A mathematical model was used to simulate monthly responses of the Gulf of Mexico hypoxia to variations in climate and anthropogenic nutrient loading over a 45-year period. We examined six hypothetical future scenarios that are based on observed and projected changes in the Mississippi River discharge, Mississippi River nitrate concentrations, and ambient water temperatures. In particular, we investigated the

implications of a 30% decrease in the Mississippi River nitrogen flux, which was recently proposed by the Mississippi River Watershed/Gulf of Mexico Hypoxia Task Force as a measure to reduce the size of the hypoxic zone. Model simulations suggest that the frequency of hypoxia in the northern Gulf of Mexico is highly sensitive to variations in riverine nitrate flux, but also to variations in freshwater discharge and ambient water temperatures. A 30% decrease in the Mississippi River nitrate flux, for example, would reduce the frequency of hypoxia by 37%. Nevertheless, a 20% increase the Mississippi River discharge, which may occur under some climate change scenarios, would produce an increase in the frequency of hypoxia of the same magnitude. Thus, if the potential climatic variations are taken into account, a 30% decrease in the nitrogen flux of the Mississippi River may not be sufficient to accomplish the proposed hypoxia management goal.

146. Justić, D., N. N. Rabalais, R. E. Turner. 2003. Climate, hypoxia and fisheries: Implications of global climate change for the Gulf of Mexico hypoxic zone. In R. F. Kazmierczak, Jr. and L. J. Thibodeaux (eds.) Proceedings of the 2000 Louisiana Environmental State of the State Conference, available on line at the Department of Agricultural Economics & Agribusiness, Louisiana State University, http:www.agecon.lsu.edu/ESOS-V Proceedings/index.htm

Abstract: A large-scale hypoxic zone (< 2 mg O2 l-1) in the coastal waters of the northern Gulf of Mexico, recently approaching 20,000 km2, overlaps with habitat and fishing grounds of commercial fish and shrimp species. Projections of general circulation models have indicated that the Mississippi River runoff would increase if atmospheric CO2 concentration doubles. A higher freshwater runoff would be accompanied by an increase in temperatures over the Gulf Coast region of 2 to 4°C. These two results are likely to affect water column stability, surface productivity and global oxygen cycling in the northern Gulf of Mexico, leading perhaps to an expanded hypoxic zone.

This presentation is available in its entirety as a PDF. The link to the PDF is here: http://www.agecon.lsu.edu/ESOS-V%20Proceedings/pdf/JusticESOS-VProceedings.pdf

147. Justić, D., R. E. Turner and N. N. Rabalais. 2003. Climatic influences on riverine nitrate flux: Implications for coastal marine eutrophication and hypoxia. Estuaries 26: 1-11.

Abstract: The average nitrate flux of the lower Mississippi River increased 3.3-fold between 1954-1967 and 1983-2000. During the same time period, the average nitrate concentration increased 2.3-fold while the average discharge increased 40%. Partitioning of the observed trend in nitrate flux among the two flux components, nitrate concentration and discharge, revealed that about 80% of the observed increase in flux could be explained by the increase in nitrate concentration. This indicates that a historical increase in the anthropogenic nutrient inputs has had a far greater impact on the lower Mississippi River nitrate flux than a change in climate. The influence of climatic factors on nitrate flux has been significant and may further increase as a result of global climate change. This argument is supported by two tines of evidence. The residual component of nitrate flux, obtained by removing a trend from the time series, is controlled primarily by

the variability in discharge, i.e., climatic factors. Also, there is a highly significant relationship between discharge and nitrate concentration at the low end of the discharge spectrum (< 13,000 m(3) s(-1)). The differences in nitrate flux between flood and drought years are significantly larger than the variations in discharge. This makes the Mississippi River nitrate flux potentially sensitive to future changes in the frequency of extreme climatic events. Because of the importance of nitrate for the productivity of coastal phytoplankton, future climate change would likely have important implications for coastal marine eutrophication and hypoxia.

148. Justić, D., R. E. Turner and N. N. Rabalais. 2004. Perspectives for coastal marine hypoxia in a warmer world. Pp. 57-72 in G. L. Rupp and M. D. White (eds.), Proceedings of the 7th International Symposium on Fish Physiology, Toxicology and Water Quality, Tallinn, Estonia, May 12-15, 2003. EPA 600/R-04/049, U.S. Environmental Protection Agency, Ecosystems Research Division, Athens, Georgia.

The complete proceedings of this symposium are available as a PDF:
http://water.montana.edu/symposium/proceedings/default.htm

149. Justić, D., N. N. Rabalais and R. E. Turner. 2005. Coupling between climate variability and marine coastal eutrophication: historical evidence and future outlook. Journal of Sea Research 54: 25-35.

Abstract: It is generally believed that coastal eutrophication is primarily controlled by the magnitude of anthropogenic nutrient loading and this cause-effect relationship is often used as a common explanation for the widespread eutrophication observed during the second half of the 20th century. This paper examines the coupling between climate variability and coastal cutrophication, and discusses how future changes in climate may affect nutrient fluxes to the coastal zone, nutrient ratios, phytoplankton production and the severity of hypoxia. We focus on the northern Gulf of Mexico, a coastal ecosystem dominated by inflow of the Mississippi River, where recorded decadal and interannual variations in the size of a large hypoxic zone (> 2 x 10(4) km(2)) provide examples of anthropogenic and climatic controls on eutrophication. Using a mathematical model, four hypothetical future climate scenarios were examined. The scenarios were based on projected changes in the Mississippi River discharge, nitrate flux, and ambient water temperatures, and the simulation results were compared to the standard model. The forcing functions in the standard model included the observed time-series of temperature, riverine freshwater discharge and nitrate flux over the 45-y period 1955-2000. In all four model scenarios, simulated frequency of hypoxia differed significantly from the standard model, ranging from a 58% decrease to a 63% increase. The Gulf of Mexico responses to climate-driven variations in freshwater inflow may not be representative for other coastal ecosystems. A comparison of the northern Gulf of Mexico and the Hudson River estuary revealed that the increased riverine freshwater inflow, which causes cutrophication in the northern Gulf of Mexico, improves trophic conditions in the Hudson River estuary. Hence, the degree to which coastal eutrophication will be affected by future climate variability will vary from one system to another, depending on the characteristics of the physical environment and the current eutrophication status.

150. Justić, D., N. N. Rabalais, and R. Eugene Turner. In press. Implications of Global Climate Change for Coastal and Estuarine Hypoxia: Hypotheses, Observations and Models for the Northern Gulf of Mexico. In Proceedings, 6th International Symposium, Fish Physiology, Toxicology and Water Quality, Hypoxia in the Aquatic Environment, La Paz, Baja California, Mexico, January 2001, EPA Rpt. No. EPA/600/R-02/097, Environmental Protection Agency, Ecosystems Research Division, Athens, Georgia.

Abstract: Scientists from fifteen countries presented papers at the Sixth International Symposium on Fish Physiology, Toxicology, and Water Quality held in La Paz, Baja, Mexico, January 22-26, 2001. These Proceedings include 25 papers presented in sessions convened over four days. Papers addressed the effects of hypoxia and anoxia on the physiology of fishes and aquatic invertebrates as a global phenomenon, the role of adenosine as a universal promoter of fish survival under hypoxia, the effects of hypoxia on fish species, and the specific effects of hypoxia and anoxia in: temperate estuaries, the continental shelf, the deep sea environment, shallow eutrophic lakes, and the subtropical environment. Water quality papers included: general discussions on hypoxia, effects of anoxia on the marine sulfur cycle, effects of hypoxia/anoxia on major ion and redox chemistry, physical effects of anoxia on sediment biota morphology, hypoxia in the Gulf of California, effect of hypoxia on the ecological conditions of coastal estuaries, nonpoint source pollution effects on coastal hypoxia, modeling effects of climate change on hypoxia, and the use of euthrophication modeling to assess water quality and ecological endpoints.

These proceedings are available in their entirety as a PDF:
http://www.epa.gov/ATHENS/publications/reports/EPA_600_R02_097.pdf

151. Karlsen, A. W., T. M. Cronin, S. E. Ishman, D. A. Willard, R. Kerhin, C.W. Holmes and M. Marot. 2000. Historical trends in Chesapeake Bay dissolved oxygen based on benthic foraminifera from sediment cores. *Estuaries*, **23**, 488-508.

Abstract: Environmentally sensitive benthic foraminifera (protists) from Chesapeake Bay were used as bioindicators to estimate the timing and degree of changes in dissolved oxygen (DO) over the past five centuries. Living foraminifers from 19 surface samples and fossil assemblages from 11 sediment cores dated by Pb-210, Cs-131, C-14, and pollen stratigraphy were analyzed from the tidal portions of the Patuxent, Potomac, and Choptank Rivers and the main channel of the Chesapeake Bay. Ammonia parkinsoniana, a facultative anaerobe tolerant of periodic anoxic conditions, comprises an average of 74% of modern Chesapeake foraminiferal assemblages (DO = 0.47 and 1.72 ml l(-1)) compared to 0% to 15% of assemblages collected in the 1960s. Paleoecological analyses show that A. parkinsoniana was absent prior to the late 17th century increased to 10-25% relative frequency between approximately 1670-1720 and 1810-1900, and became the dominant (60-90%) benthic foraminiferal species in channel environments beginning in the early 1970s. Since the 1970s, deformed tests of A. parkinsoniana occur in all cores (10-20% of Ammonia), suggesting unprecedented stressful benthic conditions. These cores indicate that prior to the late 17th century, there was limited oxygen depletion.

During the past 200 years, decadal scale variability in oxygen depletion has occurred, as dysoxic (DO = 0.1-1.0 mi l(-1)), perhaps short-term anoxic (DO < 0.1 mi l(-1)) conditions developed. The most extensive (spatially and temporally) anoxic conditions were reached during the 1970s. Over decadal timescales, DO variability scents to be Linked closely to climatological: factors influencing river discharge; the unprecedented anoxia since the early 1970s is attributed mainly to high freshwater now and to an increase in nutrient concentrations From the watershed.

152. Karlson, K., R. Rosenberg and E. Bonsdorff. 2002. Temporal and spatial large-scale effects of eutrophication and oxygen deficiency on benthic fauna in Scandinavian and Baltic waters – a review. *Oceanogr. Mar. Biol. Ann. Rev.*, **40**, 427-489.

Abstract: Eutrophication has been an increasing ecological threat during the past 50 yr in many Scandinavian and Baltic marine waters. Large sedimentary areas are seasonally, or more or less permanently, affected by hypoxia and/or anoxia with devastating effects on the benthic macrofauna in, for example, the Baltic Sea, the Belt Seas and Oresund between Denmark and Sweden, the Kattegat and the Skagerrak coast towards the North Sea. In this review figures for the input of nitrogen and phosphorus to different sea areas are presented, and in several cases also changes of nitrogen and phosphorus concentrations in the water. The nutrient input is related to production levels, and related to macrobenthic infauna. Changes of dominant benthic species, abundance and biomass are presented in relation to both changes in organic enrichment and hypoxia and/or anoxia in time and space. Since the 1950s-60s, the benthic faunal biomass has increased in the Gulf of Bothnia as a result of increased organic enrichment. In the Aland Archipelago, the number of benthic species decreased since the 1970s but abundance and biomass increased. Drifting algae at the sediment surface has also been an increasing problem. The changes were caused by increasing eutrophication. In the Finnish Archipelago Sea, large-scale eutrophication has resulted in periodic bottom water hypoxia and drifting algal mats with negative effects on benthic fauna. In the Gulf of Finland, the benthic fauna has been negatively affected by hypoxic bottom water below 70 in depth since the 1960s, but with a period of improved oxygen conditions during 1987-94. In the Baltic Proper, large sea-bed areas of 70 000-100 000 km(2) below 70-80 in water depth have been more or less hypoxic and/or anoxic since the 1960s with no or reduced sediment-dwelling fauna. This process was a result of increased eutrophication and lack of larger inflows of oxygenated water from the Kattegat. Several coastal areas and larger basins in the southern Baltic (e.g. the Bornholm Basin, the Arkona Basin and the Kiel Bay), have, on occasions, been similarly negatively affected by hypoxic bottom water. Many sedimentary areas below similar to 17 in in the Danish Belt Seas have been affected by seasonal hypoxia since the 1970s with negative consequences for the bottom fauna. On the Danish Kattegat coast, the benthic fauna in the Limfjord, the Mariager fjord and the Roskilde fjord have been particularly negatively affected. In the southeast, open Kattegat, increased input of nutrients in combination with stratification have resulted in seasonal hypoxia since 1980 with negative effects on benthic animals and commercial fish species in most years. Several fjords on the Swedish and Norwegian Skagerrak coast have shown negative temporal trends in bottom water oxygen concentrations, and some of them lack benthic fauna in the deeper parts for several

months or more. In this review the temporal development of bottom water hypoxia and/or anoxia is discussed and consequent possible losses of sediment-dwelling faunal biomass are roughly calculated. In total for the areas investigated, the worst years of hypoxia and/or anoxia combined may have reduced the benthic macrofaunal biomass by 3 million t. This loss is partly compensated by the biomass increase that has occurred in well-flushed organically enriched coastal areas. Tolerance of some Baltic species to hypoxia and/or anoxia is discussed and also their different strategies to cope with hypoxia and/or anoxia and H2S.

156. Lane RR, Day JW, Justić D, Reyes E, Marx B, Day JN, Hyfield E. 2004. Changes in stoichiometric Si, N and P ratios of Mississippi River water diverted through coastal wetlands to the Gulf of Mexico. ESTUARINE COASTAL AND SHELF SCIENCE 60 (1): 1-10.

Abstract: During the spring of 2001, we monitored nutrient concentrations and stoichiometry of diverted Mississippi River water as it flowed through the Breton Sound estuary, Louisiana, USA. River water was discharged through a diversion structure at Caernarvon as a two-week pulse that peaked at 220 m(3) s(-1). There were reductions in observed concentrations of TN, TP, DIN, DIP and DSi, of up to 44%. 62%, 57%. 23%, and 38%, respectively, as water flowed through the estuary. TN, TP, DIN, DIP and DSi concentrations in the river were 137-140, 5.0-5.1, 104-153, 1.1-1.3 and 114-121 muM, respectively, and 36-122, 1.8-3.6, 13-119, 0.3-1.8 and 29-110 muM, respectively, at the Gulfward end member stations. The DSi:DIN ratio rose from 0.9 at the Caernarvon diversion to 2.6 at the Gulf end member station, while the DIN:DIP ratio fell from 107 to 26. This study shows that freshwater diversions can significantly alter riverine nutrient concentrations and ratios and reduce the overall amount of exported nitrogen.

157. Lawrence, G.B., Goolsby, D.A., Battaglin, W.A., and Stensland, G.J., 2000. Atmospheric nitrogen in the Mississippi River Basin - emissions, deposition and transport. Science of the Total Environment 248 (2-3): 101-113.

Abstract: Atmospheric deposition of nitrogen has been cited as a major factor in the nitrogen saturation of forests in the north-eastern United States and as a contributor to the eutrophication of coastal waters, including the Gulf of Mexico near the mouth of the Mississippi River. Sources of nitrogen emissions and the resulting spatial patterns of nitrogen deposition within the Mississippi River Basin, however, have not been fully documented. An assessment of atmospheric nitrogen in the Mississippi River Basin was therefore conducted in 1998-1999 to: (1) evaluate the forms in which nitrogen is deposited from the atmosphere; (2) quantify the spatial distribution of atmospheric nitrogen deposition throughout the basin; and (3) relate locations of emission sources to spatial deposition patterns to evaluate atmospheric transport. Deposition data collected through the NADP/NTN (National Atmospheric Deposition Program/National Trends Network) and CASTNet (Clean Air Status and Trends Network) were used for this analysis. NOx Tier 1 emission data by county was obtained for 1992 from the US Environmental Protection Agency (Emissions Trends Viewer CD, 1985-1995, version 1.0, September 1996) and NH3 emissions data was derived from the 1992 Census of Agriculture (US Department of Commerce. Census of Agriculture, US Summary and

County Level Data, US Department of Commerce, Bureau of the Census. Geographic Area series, 1995:1b) or the National Agricultural Statistics Service (US Department of Agriculture. National Agricultural Statistics Service Historical Data. Accessed 7/98 at URL, 1998. http://www.usda.gov/nass/pubs/hisdata++ +.htm). The highest rates of wet deposition of NO3- were in the north-eastern part of the basin, downwind of electric utility plants and urban areas, whereas the highest rates of wet deposition of NH4+ were in Iowa, near the center of intensive agricultural activities in the Midwest. The lowest rates of atmospheric nitrogen deposition were on the western (windward) side of the basin, which suggests that most of the nitrogen deposited within the basin is derived from internal sources. Atmospheric transport eastward across the basin boundary is greater for NO3- than NH4+, but a significant amount of NH4+ is likely to be transported out of the basin through the formation of (NH4)2SO4 and NH4NO3 particles--a process that greatly increases the atmospheric residence time of NH4+. This process is also a likely factor in the atmospheric transport of nitrogen from the Midwest to upland forest regions in the North-East, such as the western Adirondack region of New York, where NH4+ constitutes 38% of the total wet deposition of N.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=10805230&dopt=Abstract

160. Levin, L. A., J. D. Gage, C. Martin and P. A. Lamont. 2000. Macrobenthic community structure within and beneath the oxygen minimum zone, northwest Arabian Sea. *Deep-Sea Res. II,* **47**, 189-226.

Abstract: Investigations of macrobenthos were carried out within and beneath the oxygen minimum zone (OMZ, < 0.5 ml l(-1)) during Fall 1994 on the Oman margin, NW Arabian Sea. Six stations (400, 700, 850, 1000, 1250 and 3400m) were characterized with respect to macrofaunal abundance, biomass, body size, taxonomic composition, diversity and lifestyles, and the relation of these parameters to environmental conditions. The OMZ (400-1000 m) was dominated by a dense (5818-19,183 ind m(-2)), soft-bodied assemblage consisting largely (86-99%) of surface-feeding polychaetes, Spionids and cirratulids dominated at the 400- and 700-m stations, paraonids and ampharetids at the 850- and 1000-m stations. Molluscs and most crustaceans were common only below the OMZ (greater than or equal to 1250 m); a species of the amphipod Ampelisca was abundant within the OMZ, however. Both density and biomass were elevated within the OMZ relative to stations below but body size did not differ significantly among stations. The lower OMZ boundary (0.5 ml l(-1)) was not a zone of enhanced macrofaunal standing stock, as originally hypothesized. However, abundance maxima at 700-850m may reflect an oxygen threshold (0.15-0.20 ml l(-1)) above which macrofauna take advantage of organically enriched sediments. Incidence of burrowing and subsurface-deposit feeding increased below the OMZ, Species richness (E[S-100]), diversity (H') and evenness (J') were lower and dominance (R1D) was higher within than beneath the OMZ. Within-station (between-boxcore) faunal heterogeneity increased markedly below the OMZ. Surface sediment pigment concentrations and oxygen together explained 96-99% of the variance in measures of E[S-100], H' and J' across the transect; grain size and % TOC did not yield significant regressions. Pigments, assumed to reflect food availability

and possibly oxygen effects on organic matter preservation, were negatively correlated with species richness and evenness, and positively correlated with dominance. The reverse was true for water depth. Macrobenthic patterns of calcification and lifestyle within the Oman margin OMZ (0.13-0.3 mi l(-1)) match the dysaerobic biofacies of paleo-environmental reconstruction models.

162. Liu, S. M., J. Zhang, H. T. Chen, Y. Wu, H. Xiong and Z. F. Zhang. 2003. Nutrients in the Changjiang and its tributaries. *Biogeochem.*, **62**, 1-18.

Abstract: Dissolved and particulate, organic and inorganic N, P and Si were measured in the main stream and 15 major tributaries of the Changjiang (Yangtze River) in April-May 1997. The nutrient concentrations are related to water discharge, suspended particulate matter, anthropogenic activities etc. The nutrient levels were quite low in the upper reaches, and significantly increased in the main stream in a region of 2000-3000 km inland from the river mouth. The northern tributaries contribute more nutrients to the Changjiang than the southern tributaries. Based on atomic ratios of N, P and Si, the limiting nutrient in the Changjiang drainage basin was P. The nutrient yields in the Changjiang and its major tributaries indicated high rates of transport of nutrients within the watersheds. Concentrations of nitrate in the Changjiang have increased, but there have been no systematic trends for phosphate and silicic acid since 1980. The DIN/P ratios and DIN/Si ratios increased. The DIN/P and DIN/Si ratios may be expected to continue to increase after construction of the "Three Gorges Dam", which will exercise a great deal of influence on the ecological environment of the Changjiang estuary and its adjacent sea.

163. Liu H, Dagg JM (2003) Interactions between nutrients, phytoplankton, growth, and micro- and mesozooplankton grazing in the plume of the Mississippi River. Mar Ecol Prog Ser 258:31-42.

Abstract: In March 2002, we conducted 6 shipboard grazing experiments spanning locations from near the largest discharge point of the Mississippi River to a far-field, high salinity location approximately 60 km to the SW. Waters were characterized by salinity, nitrate and size-fractionated chlorophyll a (chl a), None of our stations were in truly oligotrophic conditions typical of the open Gulf of Mexico. Experiments measured growth of 3 phytoplankton size categories (<5, 5 to 20 and >20 mum) and associated microzooplankton and mesozoplankton grazing. Rates of phytoplankton growth in all size categories were high in the near- and intermediate-fields, but declined dramatically in the far-field due to nutrient limitation. Microzooplankton grazing rates were low in the near-field, highest in intermediate stations and then declined in the far-field. The mesozooplankton grazing rate was generally low compared to the microzooplankton grazing rate. The mesozooplankton grazing rate was highest at the far-field station where more than 86% of daily growth of >20 mum phytoplankton was consumed by mesozooplankton. As the plume dispersed and mixed with higher salinity shelf water, inorganic nutrients became exhausted and phytoplankton growth (especially the large diatoms) became nutrient-limited. During this transition, the microzooplankton grazing rate surpassed the phytoplankton growth rate, causing a decline in phytoplankton

biomass. Mesozooplankton grazing enhanced this decline by adding an additional grazing mortality, especially to the large phytoplankton cells. The dynamics between growth and grazing mortality in the different size fractions of the phytoplankton community, combined with varying growth rates associated with declining nutrient concentrations, and superimposed on a background of dilution derived from mixing of plume waters with oligotrophic oceanic water, makes interface regions between large rivers and the ocean exceptionally complex.

164. Liu HB, Dagg M, Campbell L, Urban-Rich J. 2004. Picophytoplankton and bacterioplankton in the Mississippi River plume and its adjacent waters. ESTUARIES 27 (1): 147-156.

Abstract: Picoplankton abundance and distribution in the Mississippi River plume and its adjacent waters were studied during two cruises in April (high discharge) and October (low discharge) 2000 using flow cytometry. Concentrations of photosynthetic picoplankton, Synechococcus and picoeukaryotes were low in the turbid plume water but high in the coastal waters-i.e., the green waters resulting from mixing of river and oceanic waters. In this region, three types of Synechococcus, characterized by their phycoerythrin chromophore composition, were found: Synechococcus cells with a low phycourobilin to phycoerythrobilin ratio (PUB:PEB) occurred throughout the region and dominated the total Synechococcus abundance during both seasons; high PUB:PEB cells, which are the dominant strains in the open or blue ocean, occurred only at the outer shelf stations; and PEB-only Synechococcus were abundant in most of the surveyed area during April, but were not observed during October. Prochlorococcus cyanobacteria only occurred at the oceanic stations, but extended farther inshore in October compared to April. This was a consequence of the reduced discharge and plume size during October. Picophytoplankton were a less important component of total phytoplankton biomass in the turbid river water and more important in the oligotrophic Gulf water. Seasonally, the contribution of picophytoplankton to total phytoplankton biomass in the surveyed area was higher during low discharge in October than during high discharge in April, even though the spring 2000 river discharge was unusually low and might not present a typical high discharge scenario. The abundance of heterotrophic bacteria was weakly correlated to chlorophyll a (chl a) concentration, but better correlated to picophytoplankton biomass. A higher proportion of High DNA bacteria occurred in the river-impacted regions during both seasons, with the ratio of High DNA bacteria to Low DNA bacteria significantly higher in April.

165. Liu HB, Dagg M, Campbell L, Urban-Rich J. 2004. Picophytoplankton and bacterioplankton in the Mississippi River plume and its adjacent waters. Estuaries 27 (1): 147-156.

Abstract: Picoplankton abundance and distribution in the Mississippi River plume and its adjacent waters were studied during two cruises in April (high discharge) and October (low discharge) 2000 using flow cytometry. Concentrations of photosynthetic picoplankton, Synechococcus and picoeukaryotes were low in the turbid plume water but high in the coastal waters-i.e., the green waters resulting from mixing of river and

oceanic waters. In this region, three types of Synechococcus, characterized by their phycoerythrin chromophore composition, were found: Synechococcus cells with a low phycourobilin to phycoerythrobilin ratio (PUB:PEB) occurred throughout the region and dominated the total Synechococcus abundance during both seasons; high PUB:PEB cells, which are the dominant strains in the open or blue ocean, occurred only at the outer shelf stations; and PEB-only Synechococcus were abundant in most of the surveyed area during April, but were not observed during October. Prochlorococcus cyanobacteria only occurred at the oceanic stations, but extended farther inshore in October compared to April. This was a consequence of the reduced discharge and plume size during October. Picophytoplankton were a less important component of total phytoplankton biomass in the turbid river water and more important in the oligotrophic Gulf water. Seasonally, the contribution of picophytoplankton to total phytoplankton biomass in the surveyed area was higher during low discharge in October than during high discharge in April, even though the spring 2000 river discharge was unusually low and might not present a typical high discharge scenario. The abundance of heterotrophic bacteria was weakly correlated to chlorophyll a (chl a) concentration, but better correlated to picophytoplankton biomass. A higher proportion of High DNA bacteria occurred in the river-impacted regions during both seasons, with the ratio of High DNA bacteria to Low DNA bacteria significantly higher in April.

166. Liu H, Dagg MJ, Wu C-J, Chiang K-P (2005) Mesozooplankton consumption of microplankton in the Mississippi River plume with special emphasis on planktonic ciliates. Mar Ecol Prog Ser 286:133-144

Abstract: Grazing of mesozooplankton on phytoplankton, ciliates and other microplankton in the Mississippi River plume was studied by on-deck zooplankton addition incubations during March 2002. Diatoms, numerically predominated by the pennate diatom Pseudonitzschia pseudodelicatissima, were the most abundant microplankton in the plume. We observed that large cells of all types dominated the mesozooplankton diet and that phytoplankton generally comprised the largest dietary component. Microzooplankton contributed between 2 and 60% to the mesozooplankton diet. At the near-field station (nearest the discharge point of the river), P. pseudodelicatissimi concentration was low and consumption of diatoms, ciliates and dinoflagellates by mesozooplankton reflected available concentrations. In the mid-field stations, P. pseudodelicatissimi attained very high concentrations (17 000 cells ml(-1)) but comprised only a small portion of the mesozooplankton diet, which was instead dominated by ciliates and dinoflagellates. At the far-field station (approximately 60 km distance from the discharge point), P. pseudodelicatissimi concentration was intermediate but mesozooplankton clearance rates were still higher on ciliates and dinoflagellates at these stations. This pattern may have been established by changes in the composition of the mesozooplankton grazer community, by the inability of some mesozoopllankton to efficiently ingest the long (>100 mum) and large-sized diatoms, or by the production of toxins by P. pseudodelicatissimi that prevent it from been grazed by mesozooplankton. Our findings are consistent with an earlier published conceptual model in that (1) the abundance of microzooplankton (ciliates) was high in the near- to mid-field and then decreased toward the far-field, in parallel with phytoplankton stock; (2) mesozooplankton

consumed large rather than small prey, thereby affecting the structure of the phytoplankton and microzooplankton community; (3) phytoplankton, dominated by diatoms, were the major food source for mesozooplankton in the plume.

177. Lohrenz, S. E., and P. G. Verity (2004), Chapter 6, Regional Oceanography: Southeastern United States and Gulf of Mexico (2,W), in The Sea, Vol. 14, The Global Coastal Ocean: Interdisciplinary Regional Studies And Syntheses, edited by A. R. Robinson and K. H. Brink, p. in press, Harvard Press, Cambridge.

178. Mahoney, K. L., S. E. Lohrenz, and G. J. Kirkpatrick (in preparation), Mie approximation of light scattering by Karenia brevis and its relationship to in situ total scattering and backscattering during a red tide event, Limnol. Oceanogr.

183. Mee, L. D. 2001. Eutrophication in the Black Sea and a basin-wide approach to its control. Pp. 71-91 in von Bodungen, B. and R. K. Turner (eds.), *Science and Integrated Coastal Management,* Dahlem University Press, Berlin.

184. Meyer-Reil, L.-A. and M. Köster. 2000. Eutrophication of marine waters: effects on benthic microbial communities. *Mar. Pollut. Bull.,* **41**, 255-263.

Abstract: During the last century organic pollution in coastal areas of the sea has become a serious world problem. One of the major stresses comes from the input of excessive macronutrients (nitrogen, phosphorus) resulting in a change of the trophic status of a given body of water, which leads to eutrophication. Although the effects of eutrophication are well-known, the mechanisms governing its effects are poorly understood. In particular, effects on microbial processes are key to many aspects of the functioning of the ecosystem, and commonly are inadequately addressed. The effects of eutrophication on benthic microbial communities are demonstrated using shallow-water coastal inlets in the southern Baltic Sea as an example. These so-called 'Bodden' are characterized by pronounced gradients of inorganic and organic nutrients. For the hypertrophic innermost parts of the Bodden, critical points can be identified at which the chronic stress caused by eutrophication could no longer be compensated for by the system. Signs of eutrophication of sediments of the Bodden include increases in inorganic and organic carbon, nitrogen and phosphorus, microbial biomass and enzymatic decomposition potential of substrates, nitrification, denitrification, and nutrient fluxes from the sediments, all of which can be measured. Above certain carbon concentrations, further increases in organic carbon are not necessarily paralleled by corresponding increases in biological parameters. This might be taken as an indication of a different status of nutrient enrichment. Eutrophication effects became most obvious from changes in the ratios of pelagic to benthic primary production, oxygen to sulphate respiration, and proteolytic to carbohydrate decomposing enzyme activities. The structure and function of microbial biofilms colonizing stones and sediments also reflected the changed trophic status. With increasing eutrophication, the ratio of autotrophic to heterotrophic microbial processes becomes greatly reduced. Drifting filamentous macroalgae, mats of sulphur oxidizing and anaerobic phototrophic bacteria, represent visible signs of eutrophication. Although the external nutrient loads in the example of the Bodden have been greatly

reduced during the last decade, the internal loads of the sediments remain a serious problem. Remediation concepts can only support the natural self-purification potential of a marine coastal ecosystem.

192. Murrell MC, Stanley RS, Lores EM, DiDonato GT, Flemer DA (2002) Linkage between microzooplankton grazing and phytoplankton growth in a Gulf of Mexico estuary. Estuaries 25: 19-29

Abstract: Microzooplankton dilution grazing experiments were conducted with water collected from Pensacola Bay, Florida (USA) on 12 dates at 2 sites. Statistically significant grazing rates were observed in 22 of 24 experiments. Grazing rates in Upper Bay and Lower Bay were similar averaging 0.54 and 0.51 d(-1), respectively. Phytoplankton growth rates were also similar at the two sites, averaging 1.02 and 1.00 d(-1) at Upper Bay and Lower Bay, respectively. Phytoplankton growth rates usually exceeded grazing rates by about a factor of two, though microzooplankton grazing represented a significant mortality for phytoplankton. The literature suggests a linkage between phytoplankton growth and microzooplankton grazing that spans a wide variety of aquatic environments. While individual growth and grazing rates were variable, growth frequently exceeded grazing by about two-fold. This implies that the role of microzooplankton is similar across a wide variety of aquatic systems.

193. Myint SW, Walker D. 2002. Quantification of surface suspended sediments along a river dominated coast with NOAA AVHRR and SeaWiFS measurements: Louisiana, USA. INTERNATIONAL JOURNAL OF REMOTE SENSING 23 (16): 3229-3249.

Abstract: The ability to quantify suspended sediment concentrations accurately over both time and space using satellite data has been a goal of many environmental researchers over the past few decades. This study utilizes data acquired by the NOAA Advanced Very High Resolution Radiometer (AVHRR) and the Orbview-2 Sea-viewing wide field-of-view (SeaWiFS) ocean colour sensor, coupled with field measurements to develop statistical models for the estimation of near-surface suspended sediments and suspended solids. 'Ground truth' water samples were obtained via helicopter, small boat and automatic water sampler within a few hours of satellite overpasses. The NOAA AVHRR atmospheric correction was modified for the high levels of turbidity along the Louisiana coast. Models were developed based on the field measurements and reflectance/radiance measurements in the visible and near infrared Channels of NOAA-14 and Orbview-2 SeaWiFS. The best models for predicting surface suspended sediment concentrations were obtained with a NOAA AVHRR Channel 1 (580-680 nm) cubic model, Channel 2 (725-1100 nm) linear model and SeaWiFS Channel 6 (660-680 nm) power model. The suspended sediment models developed using SeaWiFS Channel 5 (545-565 nm) were inferior, a result that we attribute mainly to the atmospheric correction technique, the shallow depth of the water samples and absorption effects from non-sediment water constituents.

197. Ning, Z. H., R.E. Turner, T. Doyle, and K. K. Abdollahi 2003. Preparing for a Changing Climate: The Potential Consequences of Climate Change Variability and Change-Gulf Coast

Region ISBN 1-930129-009.
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/gulfcoast/default.htm

198. Ning, Z. H., R.E. Turner, T. Doyle, and K. K.. Abdollahi, 2003. Integrated Assessment of the Potential Consequences of Climate Change Variability and Change for the Gulf Coast Region. ISBN 1-930129-01-7.
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/gulfcoast/default.htm

199. Nixon, S. W. and B. A. Buckley. 2002. "A strikingly rich zone"—nutrient enrichment and secondary production in coastal marine ecosystems. *Estuaries*, **25**, 782-796.

> **Abstract:** Despite a recent review concluding that there is little or no reason to expect that the production of fish and other animals will increase with nutrient enrichment or eutrophication, there is a variety of evidence that anthropogenic nutrients can stimulate secondary production in marine ecosystems. Unique multiple-year fertilization experiments were carried out over fifty years ago in Scottish sea lochs that showed dramatic increases in the abundance of benthic infauna and greatly enhanced growth of fish as a result of inorganic nitrogen (N) and phosphorus (P) additions. These experiments appear to have provided a good qualitative model for the responses of the Baltic Sea to nutrient enrichment and resulting eutrophication. Historical comparisons by others have shown that the weight of benthic animals per unit area above the halocline in the Baltic is now up to 10 or 20 times greater than it was in the early 1920s and that the total fish biomass in the system may have increased 8 fold between the early part of the 1900s and the 1970s. While there are no similar data for the highly enriched central and southern North Sea, there is convincing evidence that the growth rates of plaice, sole, and other species have increased there since the 1960s or 1970s. Cross-system comparisons have also shown that there are strong correlations between primary production and the production and yield of fish and the standing crop and production of benthic macrofauna in phytoplankton-dominated marine ecosystems. Concerns over the growing nutrient (especially N) enrichment of coastal marine waters are clearly valid and deserve the attention of scientists and managers, but the recent demonizing of N ignores the fact that nutrients are a fundamental requirement for producing biomass. Decisions regarding the amount of N or P that will be allowed to enter marine ecosystems should be made with the full knowledge that there may be tradeoffs between increases in water clarity and dissolved oxygen and the abundance of oysters, clams, fish, and other animals we desire.

200. Ortner P, Dagg M (2000) Zooplankton grazing and the fate of phytoplankton in the northern Gulf of Mexico.

201. Osterman LE. 2003. Benthic foraminifers from the continental shelf and slope of the Gulf of Mexico: an indicator of shelf hypoxia. Estuarine Coastal and Shelf Science 58 (1): 17-35.

> **Abstract:** Benthic foraminifers from 74 core-top sediment samples collected primarily from the continental shelf of the Gulf of Mexico were analyzed to determine a microfaunal indicator for shelf hypoxia to be used in future paleoenvironmental studies. Principal component analysis (PCA) and cluster analysis (CA) of 93 species recognized

factors/clusters that were similar to previous investigations of the benthic foraminifers, except that both analyses also identified PCA6/CA6 in the area where hypoxic conditions have been observed. Three low-oxygen-tolerant species, Pseudononion atlanticum, Epistominella vitrea, and Buliminella morgani have high factor loadings in PCA6. The cumulative percentage of three species is defined as the PEB (PEB, Pseudononion, Epistominella, Buliminella) index. The highest PEB values observed in the 74 surface sediment samples occur in the zone of recognized hypoxia on the Louisiana shelf. Values of the PEB index are also elevated along the southern Texas coastline, suggesting that this area may experience periodic hypoxia as well.

202. Osterman, L. E., R. Z. Poore, P. W. Swarzenski, and R. E. Turner 2005. Reconstructing a 180 year record of natural and anthropogenic induced low-oxygen conditions from Louisiana continental shelf sediments. Geology 33: 329-332.

Abstract: Hypoxia on the Louisiana continental shelf is tied to nutrient loading and freshwater stratification from the Mississippi River. Variations in the relative abundance of low-oxygen-tolerant benthic foraminifers in four sediment cores from the Louisiana shelf provide a proxy record of low-oxygen events. Core chronologies are obtained using Pb-201 dating techniques. The foraminiferal data are consistent with previous studies indicating that the intensity of hypoxic events (oxygen < 2 mg/L) has increased over the past 50 yr owing to the higher nutrient loading associated with the use of commercial fertilizer, and also reveal several low-oxygen events between A.D. 1817 and 1910, prior to the widespread use of fertilizer. The pre-1910 low-oxygen events are associated with high Mississippi River discharge rates, indicating that these low-oxygen episodes are related to natural variations in river drainage that enhance transport of nutrients and freshwater to the continental shelf. Our data show that the low-oxygen events of the past few decades were more extreme than any that occurred in the previous similar to 180 yr, and support the interpretation that the increased use of fertilizer has amplified an otherwise naturally occurring process.

203. Paerl, H. W., W. R. Boynton, R. L. Dennis, C. T. Driscoll, H. S. Greening, J. N. Kremer, N. N. Rabalais and S. P. Seitzinger. 2000. Atmospheric deposition of nitrogen in coastal waters: biogeochemical and ecological implications. Pp 11-53 in R. A. Valigura, R. B. Alexander, M. S. Castro, T. P. Meyers, H. W. Paerl, P. E. Stacey and R.E. Turner (eds.), Nitrogen Loading in Coastal Water Bodies. An Atmospheric Perspective. Coastal and Estuarine Studies 57, American Geophysical Union, Washington, D.C.

Abstract: Atmospheric deposition of nitrogen (AD-N, as wet deposition and dry deposition) is a significant and growing source of biologically available nitrogen (NOx, NH3/NH+4, and dissolved organic N (DON) entering nitrogen-limited estuarine and coastal waters (jointly termed coastal). AD-N ranges from 400 to > 1000 mg N m^{-2} yr^{-1}, and represents from <10 to<40% of new N inputs in North American and European coastal waters downwind of emission sources. The relative contribution of AD-N to total external N loading depends on land use, watershed and airshed size, and hydrological and morphological characteristics (i.e., water retention time) of receiving waters. In heavily-impacted, N-sensitive waters, the ecological impacts of AD-N include accelerating

primary production (eutrophication), which may yield a variety of negative impacts including increased algal bloom activity, toxicity, oxygen depletion (hypoxia) events, and food web alterations. Depending on their sources (i.e., agricultural, urban, industrial) certain forms of AD-N are increasing relative to others, leading to qualitative changes in deposition and biogeochemical response in receiving waters. Because phytoplankton and bacteria differentially utilize different forms of N, changes in the ratios of NH4+ to NOx and DON in AD-N may usher in community compositional changes. One example is the intensive animal operations in Western Europe and the U.S. Mid-Atlantic States, which are linked to regionally elevated NH4+ deposition rates. Experimental evidence indicates that increasing levels of AD-NH4+ enhance primary production, while favoring growth of specific phytoplankton functional groups. In addition, AD (as well as other sources of new N) enrichment alters the stoichiometric nutrient ratio (N:P:Si) which may impact phytoplankton community composition and growth potentials. Both quantitative and qualitative changes in AD-N inputs may be linked to eutrophication and algal bloom dynamics.

204. Paerl, H. W., R. L. Dennis and D. R. Whitall. 2001. Atmospheric deposition of nitrogen: implications for nutrient over-enrichment of coastal waters. *Estuaries*, **25**, 677-693.

Abstract: Atmospheric deposition of nitrogen (AD-N) is a significant source of nitrogen enrichment to nitrogen (N)-limited estuarine and coastal waters downwind of anthropogenic emissions. Along the eastern U.S. coast and eastern Gulf of Mexico, AD-N currently accounts for 10% to over 40% of new N loading to estuaries. Extension of the regional acid deposition model (RADM) to coastal shelf waters indicates that 11, 5.6, and 5.6 kg N ha(-1) may be deposited on the continental shelf areas of the northeastern U.S. coast, southeast U.S. coast, and eastern Gulf of Mexico, respectively. AD-N approximates or exceeds riverine N inputs in many coastal regions. From a spatial perspective, AD-N is a unique source of N enrichment to estuarine and coastal waters because, for a receiving water body, the airshed may exceed the watershed by 10-20 fold. AD-N may originate far outside of the currently managed watersheds. AD-N may increase in importance as a new N source by affecting waters downstream of the oligohaline and mesohaline estuarine nutrient filters where large amounts of terrestrially-supplied N are assimilated and denitrified. Regionally and globally, N deposition associated with urbanization (NOx, peroxyacetyl nitrate, or PAN) and agricultural expansion (NH4+ and possibly organic N) has increased in coastal airsheds. Recent growth and intensification of animal (poultry, swine, cattle) operations in the midwest and mid-Atlantic regions have led to increasing amounts of NH4+ emission and deposition, according to a three decadal analysis of the National Acid Deposition Program network. In western Europe, where livestock operations have dominated agricultural production for the better part of this century, NH4+ is the most abundant form of AD-N. AD-N deposition in the U.S. is still dominated by oxides of N (NOx) emitted from fossil fuel combustion; annual NH4+ deposition is increasing, and in some regions is approaching total NO3- deposition. In receiving estuarine and coastal waters, phytoplankton community structural and functional changes, associated water quality, and trophic and biogeochemical alterations (i.e., algal blooms, hypoxia, food web, and fisheries habitat disruption) are frequent consequences of N-driven eutrophication.

Increases in and changing proportions of various new N sources regulate phytoplankton competitive interactions, dominance, and successional patterns. These quantitative and qualitative aspects of AD-N and other atmospheric nutrient sources (e.g., iron) may promote biotic changes now apparent in estuarine and coastal waters, including the proliferation of harmful algal blooms, with cascading impacts on water quality and fisheries.

207. Pakulski JD, Benner R, Whitledge T, Amon R, Eadie B, Cifuentes L, Ammerman J, Stockwell D. 2000. Microbial metabolism and nutrient cycling in the Mississippi and Atchafalaya River plumes. ESTUARINE COASTAL AND SHELF SCIENCE 50 (2): 173-184.

Abstract: Spatial distributions of chlorophyll, bacterial abundances and production, community respiration, and dissolved C, N, P and Si were measured in the Mississippi River (MRP) and Atchafalya River (ARP) plumes during July 1993. Dark bottle incubations were used to estimate net flux rates of inorganic nutrients, community respiration, and changes in chlorophyll concentrations in unfiltered water samples. Concentrations of total dissolved N (TDN) and soluble reactive P (SRP) in the Mississippi River were 55 mu M and 3 mu M higher, respectively, compared with those in the Atchafalaya River. Concentrations of dissolved organic carbon (DOC) and nitrogen (DON) in the Atchafalaya River, however, were 35 and 11 mu M higher, respectively than in the Mississippi River. Elevated chlorophyll concentrations, bacterial abundances and production, and community respiration rates were observed at intermediate (5-25) salinities of both plumes. Property-salinity plots indicated net sinks of dissolved N, P and Si at intermediate salinities consistent with photosynthetic utilization of these substances within the plumes. The distribution of dissolved P, N and chlorophyll suggested phytoplankton-mediated transformation of riverine-NO3- to DON at intermediate salinities of the MRP, and a similar transformation of riverine SRP to dissolved organic P (DOP) at intermediate salinities of the ARP. Net regeneration of dissolved Si and NH4+ was observed in regions of elevated chlorophyll concentrations and net removal rates in both plumes. Nitrification rates in the MRP were c. 10-fold higher than in the ARP. Estimates of C fixation by nitrifying bacteria equalled or exceeded heterotrophic bacterial C production in the low salinity region of the MRP, but were negligible compared to heterotrophic bacterial production in the ARP. Dissolved inorganic N:P, Si:P and DOC:DON:DOP ratios suggested the potential for P limitation in both plume systems during the period investigated.

208. Parsons, M., Q. Dortch and R. E. Turner. 2002. Sedimentological evidence of an increase in *Pseudo-nitzschia* (Bacillariophyceae) abundance in response to coastal eutrophication. *Limnol. Oceanogr.*, **47**, 551-558.

Abstract: Pseudo-nitzschia H. Peragallo, a marine planktonic diatom genus containing some species capable of producing the neurotoxin domoic acid, is often documented in extremely high concentrations in the northern Gulf of Mexico in the plume of the Mississippi River, especially when river flow and nutrient inputs are high. Limited historical data suggest that Pseudo-nitzschia abundance has increased in the northern Gulf of Mexico since the 1950s. Five sediment cores were collected and analyzed to test

whether Pseudo-nitzschia increases coincided with increasing nutrient concentrations in the Mississippi River, thereby suggesting a cause-effect relationship. Pseudo-nitzchia abundance increased in all five cores, correlating significantly with increasing nitrate fluxes and decreasing silicate to nitrate ratios. A diatom dissolution index, based partly on scanning electron microscopic analysis of the fine structure of Pseudo-nitzschia and other lightly silicified diatom valves preserved in the sediment, indicates that the increase in Pseudo-nitzschia abundance appears to reflect a response to eutrophication rather than diagenesis. This study provides evidence for a possible link between coastal eutrophication and harmful algal blooms.

209. Parsons, M. L., Q. Dortch, R. E. Turner and N. N. Rabalais. In press 05. Reconstructing the development of eutrophication in Louisiana salt marshes. Limnology and Oceanography

Abstract: We collected sediment cores from three salt marsh ponds in coastal Louisiana to test the usefulness of proxies of eutrophication. One-centimeter increments of ^{210}Pb- and ^{137}Cs-dated sediment were analyzed for diatoms, pigments (phaeophytin and chlorophyll α), biogenic silica, % organic matter, % carbon, and % nitrogen. Both sediment chlorophyll α and a diatom-based trophic index (TI) were significantly and positively correlated with riverine or local nutrient indices. Two diatom species, *Amphora copulata* Giffen and *Navicula yarrensis* Grunow, were significantly and negatively correlated with riverine and local nutrient indices. These results suggest that these variables can be used as potential indicators of trophic status. Results from a complete-linkage cluster analysis on the diatom assemblage data demonstrated that the sediment cores could be split into three time periods: early 1900s (pre-1930s/1940s), mid-1900s (1930s/40s to 1960s/1970s), and late 1900s (1960s/70s to 1990s). Examination of the sediment chlorophyll α and TI data over these time periods, coupled with an ANOVA of nutrient inputs between the time periods, suggests that nutrient loading increased dramatically from the mid-1960s to the mid-1970s. This study demonstrates that: 1) a retrospective analysis of sediment cores can be conducted in highly variable salt marsh ponds; and 2) these salt marsh environments are already affected by the higher nutrient loads from both riverine and local processes occurring over the last 50 years. Additional nutrient loading, e.g., from river diversion projects for the lower Mississippi River, may exacerbate eutrophication already evident in the marsh environment.

211. Perez BC, Day JW, Justić D, Twilley RR . 2003. Nitrogen and phosphorus transport between Fourleague Bay, LA, and the Gulf of Mexico: the role of winter cold fronts and Atchafalaya River discharge. Estuarine Coastal and Shelf Science 57 (5-6): 1065-1078.

Abstract: Nutrient fluxes were measured between Fourleague Bay, a shallow Louisiana estuary, and the Gulf of Mexico every 3 h between February 1 and April 30, 1994 to determine how high velocity winds associated with cold fronts and peak Atchafalaya River discharge influenced transport. Net water fluxes were ebb-dominated throughout the study because of wind forcing and high volumes of water entering the northern Bay from the Atchafalaya River. Flushing time of the Bay averaged <8 days; however, more rapid flushing occurred in response to northerly winds with approximately 56% of the

volume of the Bay exported to the Gulf in 1 day during the strongest flushing event. Higher nitrate + nitrite (NO2 + NO3), total nitrogen (TN), and total phosphorus (TP) concentrations were indicative of Atchafalaya River input and fluxes were greater when influenced by high velocity northerly winds associated with frontal passage. Net exports of NO2 + NO3, TN, and TP were 43.5, 98.5, and 13.6 g s(-1), respectively, for the 89-day study. An average of 10.6 g s(-1) of ammonium (NH4) was exported to the Gulf over the study; however, concentrations were lower when associated with riverine influence and wind-driven exports suggesting the importance of biological processes. Phosphate (PO4) fluxes were nearly balanced over the study with fairly stable concentrations indicating a well-buffered system. The results indicate that the high energy subsidy provided by natural pulsing events such as atmospheric cold fronts and seasonal river discharge are efficient mechanisms of nutrient delivery to adjacent wetlands and nearshore coastal ecosystems and are important in maintaining coastal sustainability.

213. Platon, E., B. K. Sen Gupta, N. N. Rabalais and R. E. Turner. 2005. Effect of seasonal hypoxia on the benthic foraminiferal community of the Louisiana inner continental shelf: The 20th century record. Marine Micropaleontology 54: 263-283.

Abstract: A species census in sediment core samples reveals significant changes in the composition of the Louisiana-shelf benthic foraminiferal community in the past century; these changes can be explained by an increase in the severity of seasonal hypoxia in bottom waters. Agglutinated and porcelaneous orders living in water depths less than 60 m suffered a noticeable decline during this time. In particular, the genus Quinqueloculina was severely affected by the progression of hypoxia, and nearly disappeared from parts of the study area. In contrast, several hyaline taxa, especially Nonionella basiloba, Buliminella morgani, and Epistominella vitrea, tolerated the progressive oxygen depletion well. Results of cluster and principal components analyses of the foraminiferal assemblage data match the observed species distribution trends and indicate that seasonal hypoxia on the Louisiana shelf, related to eutrophication and water stratification, worsened in the past century, even near the outer edge of the present-day zone of spring and summer oxygen depletion. The temporal trends in the foraminiferal record correspond to that of fertilizer use in the U.S. and nitrogen loading in the Mississippi River, suggesting that the anthropogenic factor has been particularly strong in the development of coastal hypoxia since the early 1940s.

214. Pohlman JW, Campos R, Pohlman AM, Johnson K, Cifuentes LA, Coffin RB (2001) Nitrification induced inhibition of heterotrophic bacterial production in the hypoxic region of the Mississippi River plume. Aquatic Sciences Meeting, ASLO, Feb 12-16, 2001 Albuquerque, NM.

Abstract: The role of nitrification in the carbon cycle and oxygen budget in the hypoxic region of the Mississippi River plume (Nov 97 & Jul 98) was investigated. Nitrification inhibitors (sodium chlorate, allythiourea and methyl fluoride) were used to determine the effect of nitrification on heterotrophic bacterial production, dissolved inorganic carbon production/uptake, oxygen utilization and nutrient cycling. Nitrification was observed at each station sampled in July 1998. The means by which we identified such activity, however, was not expected. Production in nitrification-inhibited samples was twice that

of the uninhibited samples, which indicated nitrification might have inhibited heterotrophic production by as much as 50%. We suggest that nitrification diminished the pool of reduced dissolved inorganic nitrogen (DIN, e.g. ammonia) available to heterotrophic bacteria, thus forcing the heterotrophic community to acquire nitrogen by less energetically favorable nitrate assimilation. An oxygen budget calculated for one of the stations in July suggests that nitrification accounted for 83% of the oxygen demand, but such a demand could not have been sustained by the measured bacterial production rates.
http://aslo.org/albuquerque2001/551.html

217. Powell EN, Parsons-Hubbard KM, Callender WR, Staff GM, Rowe GT, Brett CE, Walker SE, Raymond A, Carlson DD, White S, Heise EA. 2002. Taphonomy on the continental shelf and slope: two-year trends - Gulf of Mexico and Bahamas. Palaeogeography Palaeoclimatology Palaeoecology 184 (1-2): 1-35.

Abstract: The Shelf and Slope Experimental Taphonomy Initiative was established to measure taphonomic rates in a range of continental shelf and slope environments of deposition (EODs) over a multiyear period. We deployed experiments on the forereef slope off Lee Stocking Island, Bahamas, and on the continental shelf and slope of the Gulf of Mexico for 2 yr in 18 distinctive EODs at depths from 15 to 530 m. Overall, most shells deployed at most sites had relatively minor changes in shell condition. Most EODs generated relatively similar taphonomic signatures. A few sites did produce taphonomic signatures clearly distinguishable from the central group and these sites were characterized by one or more of the following: high rates of oxidation of reduced compounds, presence in the photic zone. and significant burial and exhumation events. Thus, unique taphonomic signatures are created by unique combinations of environmental conditions that include variables associated with regional gradients, such as depth and light. and variables associated with edaphic processes. such as the seepage of brine or petroleum or the resuspension and redeposition of sediment. Most sites, however, showed similar taphonomic signatures, despite the variety of EOD characteristics present, suggesting that insufficient time had elapsed over 2 yr to generate a more diverse array of taphonomic signatures. Discoloration and dissolution were by far the dominant processes over the 2-yr deployment period. Periostracum breakdown, loss of shell weight, and chipping and breakage was less noticeable. EODs were chosen based on the expectation that the process of burial and the influence of depth and sediment type should play the greatest roles in determining between-EOD differences in taphonomic signature. EOD-specific edaphic factors often overrode the influence of geographic-scale environmental gradients. Taphonomic alteration was greater on hardgrounds and in brine-exposed sites than on terrigenous muds. Dissolution was less effective at sites where burial was greatest. Discoloration occurred most rapidly at shallower sites and on hardgrounds. Water depth was less influential in determining taphonomic signature than burial state or sediment type. The limited influence of water depth is likely due to the presence of shallow sites that. for one reason or another, were protected from certain taphonomic processes and deeper sites that were characterized by unusually strong taphonomic signals.

218. Powers, S. P., D. E. Harper, Jr. and N. N. Rabalais. 2001. Effect of hypoxia/anoxia on the supply and settlement of benthic invertebrate larvae. Pp 185-210 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: Recovery of benthic animals following large-scale disturbances is primarily a function of larval recruitment. Given the large number of recent studies that have demonstrated the potential importance of larval supply of meroplanktonic larvae is affted by such disturbances is critical in developing a complete understanding of the dynamics of benthic communities. During the summer of 1994 and 1995, we measured the flux of meroplanktonic larvae and holoplankton at three positions in the water column during both stratification and low oxygen events, and during periods when the water column was mixed. We found that benthic polychaete larvae were distributed throughout the water column and that this pattern did not appear to change in response to low oxygen. We found evidence, however, that at least one polychaete species, *Parapriono pinnata*, delayed settlement and remained in the water column until oxygen values returned to a level above 2.0 mg 1^{-1}. Barnacle cyprid larvae and many holoplanktonic species were present in reduced densities below the pycnocline when oxygen concentrations were low. We intpreted the differences in response to plankton to low oxygen conditions to be related to differences in the vertical swimming abilities of these organisms or physiological tolerances to hypoxia and anoxia. Overall, species composition and relative abundance of organisms in the sediment reflected patterns of pelagic larval abundance. These results demonstrate that the supply of meroplanktonic larvae appears to determine the recovery population and that the response of plakton to low oxygen waters varies among taxa.

221. Qureshi, N. A. and N. N. Rabalais. 2001. Distribution of zooplankton on a seasonally hypoxic continental shelf. Pp 61-76 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: The vertical distribution of zooplankton was documented for a station in 20-m water depth through a seasonal decline of bottom-water dissolved oxygen concentration, and across a broad area of hypoxic bottom-water in mid-summer of two years.There was a seasonal progresson of zooplankton abundance with a spring peak and summer decline and a change in the relative proportion of taxa through the year. Copepods (adults and copepedites) were more abundant in the lower water column than in the upper water column (daytime samples) across all monthly samples at the 20-m station that experienced severe hypoxia for extended parts of the summer. Copepods were present at normal or negligible densities for the two sampling dates when the oxygen concentration was below 1 mg 1^{-1}. Copepod nauplii, on the other hand, were reduced in abundance in the bottom water when the oxygen was less than 1 mg 1^{-1}. Across the broad area of hypoxia in the two summer surveys, copepods and copepod nauplii were concentrated below the pycno-oxycline but above the bottom water where they were reduced when the bottom-water oxygen concentration was less than 1 mg 1^{-1}. Meroplankton were concentrated above oxygen-deficient bottom waters in summer and were either delaying

metamorphisis or were unable to recruit to the seabed. Bottom-water oxygen concentrations less than 1 mg 1^{-1} may have disrupted the daytime migration of copepods and copepod nauplii into that layer. The potential for indirect effects of altered zooplankton distributions and behavior on zooplankton food webs, energy transfer, trophic interactions, and secondary production, both pelagic and benthic, exist but are not known.

232. Rabalais, N. N., R. E. Turner, D. Justić, Q. Dortch, W. J. Wiseman, Jr. and B. K. Sen Gupta. 2000. Gulf of Mexico biological system responses to nutrient changes in the Mississippi River. Pp 241-268 in J. E. Hobbie (ed.), Estuarine Science: A Synthetic Approach to Research and Practice, Island Press, Washington, D.C.

233. Rabalais NN (2000) The effects of hypoxia on animal distributions. In: GLOBEC 2000. GLOBEC in the Gulf of Mexico: Large Rivers and Marine Populations. Rep No 19, Chesapeake Biol Lab, Solomons, MD

Abstract: The largest zone of oxygen-depleted coastal waters in the United States is in the northern Gulf of Mexico on the Louisiana-Texas continental shelf. From 1993 to 1997, the size of the hypoxic zone was greater than 16,000 km^2 in mid-summer. Hypoxic waters (< 2 mg l^{-1}) occur near the bottom and extend to as much as 20 m from the bottom over extensive areas. Oxygen depletion begins in the spring, reaches a maximum in mid-summer and disappears in the fall and winter. The operational definition for hypoxia is based upon the lack of fish and shrimp in trawls when oxygen levels fall below the 2 mg l^{-1} level.

Hypoxia affects the behavior and distribution of zooplankton similar to results from the Chesapeake Bay. The dominant zooplankton in the northern Gulf of Mexico, copepods, are normally in low abundance or absent from oxygen depleted waters < 1 mg l^{-1}. Copepod nauplii are more affected than adult copepods. Anoxia disrupts the diel migratory behavior.

A fairly predictable pattern in responses of components of the benthic and demersal communities follows a decrease in oxygen concentrations from 2 mg l^{-1} to anoxia. Motile fish and crustaceans (e.g., crabs, shrimp and mantis shrimp) are generally absent from bottom habitats when the oxygen falls below 1.5-2 mg l^{-1}. Less motile invertebrates die at oxygen levels below 1.5 mg l^{-1}. The organisms that live in the sediments display stress behavior below 1.0 mg l^{-1}. In the community that typically lives in the sediments, the smaller worms, snails, bivalves and crustaceans, there is a fairly linear decrease in benthic diversity and abundance as oxygen concentrations fall from 0.5 mg l^{-1} to anoxia. Oxygen stressed macroinfaunal communities are characterized by limited taxa (none with direct development, e.g., amphipods), characteristic resistant fauna (e.g., a few polychaetes and sipunculans), a reduced species richness, severely reduced abundances (but never azoic), low biomass, and limited recovery following the abatement of oxygen stress. Meiofaunal communities become reduced in abundance and diversity as the oxygen levels approach zero, but selected nematodes maintain populations. The long-

term secondary productivity of the benthos is not known. Differences in benthic foraminiferans demonstrate historic and extant conditons of oxygen stress on the shelf.

Penaeid shrimp avoid hypoxic bottom waters and are concentrated on the inshore and western and eastern margins of the zone. Analysis of long-term data from the northern Gulf of Mexico associated with the by-catch of shrimp trawls indicate that there has been a shift in dominance of the some abundant fishes from those that are associated with the bottom (habitat and food resources) to those that are planktivorous in the upper water column. A bell-shaped curve models a continuum of fishery yield in response to increasing nutrients as ecosystems become eutrophic then dystrophic. In waters with low nutrients, the fishery yield is low. As the quantity of nutrients increases, the fishery yield increases. As the ecosystem becomes increasingly eutrophied, there is a drop in fishery yield but the decreases are variable. The benthos are the first resources to be reduced by increasing frequency of seasonal hypoxia and eventually anoxia; bottom-feeding fishes then decline. Loss of a planktivorous fishery follows as eutrophication increases, with eventually a change in the zooplankton community composition. Where the current Gulf of Mexico fisheries lie along this model of increasing eutrophication is not known. http://www.usglobec.org/reports/rep19/rep19.abs.rabalais.html

234. Rabalais, N. N. 2001. Dead Zone. Pages 242-245 in Vol. 2, R. A Eblen and W. R. Eblen (eds.), Encyclopedia of the Environment. Marshall Cavendish Corporation, Tarrytown, New York.

235. Rabalais, N. N. 2001. Hypoxia in the Gulf of Mexico. NOAA Coastal Services Center, Northern Gulf of Mexico Imagery and Information, http://csc.noaa.gov/products/gulfmex/html/rabalais.htm

236. Rabalais, N. N. and R. E. Turner (eds.). 2001. Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C., 454 p. (Reviewed: Downing, J. A., 2002, Limnology & Oceanography 47(4): 1269)

Abstract: Nutrient over-enrichment in many areas around the world is having pervasive ecological effects on coastal systems. These effects include reduced dissolved oxygen in aquatic systems and subsequent impacts on living resources. The largest zone of oxygen-depleted coastal waters in the United States, and the entire western Atlantic Ocean, is found in the northern Gulf of Mexico on the Louisiana/Texas continental shelf influenced by the freshwater discharge and nutrient load of the Mississippi River system. The mid-summer bottom areal extent of hypoxic waters ($\leq$ 2mg 1^{-1} $O_2)_2$ in 1985-1992 averaged 8,000 to 9,000 km^2 but increased to up to 16,000 to 20,000 km^2 in 1993-2000. Hypoxic waters are most prevalent from late spring through late summer, and hypoxia is more widespread and persistent in some years than in others. Hypoxic waters are distributed from shallow depths near shore (4 to 5m) to as deep as 60m water depth but more typically between 5 and 30m. Hypoxia occurs mostly in the lower water column. The Mississippi River system is the dominant source of fresh water and nutrients to the northern Gulf of Mexico. Mississippi River nutrient concentrations and loading to the

adjacent continental shelf have changed in the last half of the 20th century. The average annual nitrate concentration doubled, and the mean silicate concentration was reduced by 50%. There is no doubt that the average concentration and flux of nitrogen (per unit volume discharge) increased from the 1950s to 1980s, especially in the spring. There is considerable evidence that nutrient enhanced primary production in the northern Gulf of Mexico is causally related to the oxygen depletion in the lower water column. Evidence from long-term data sets and the sedimentary record demonstrate that historic increases in riverine dissolved inorganic nitrogen concentration and loads over the last 50 years are highly correlated with indicators of increased productivity int the overlying water column, i.e., eutrophication of the continental shelf waters, and subsequent worsening of oxygen stress in the bottom waters. Evidence associates increased coastal ocean productivity and worsening oxygen depletion with changes in landscape use and nutrient management that resulted in nutrient enrichment of receiving waters. Thus, nutrient flux to coastal systems has increased over time due to anthropogenic activities and has led to broad-scale degradation of the marine environment.

237. Rabalais, N. N. and R. E. Turner. 2001. Hypoxia in the Northern Gulf of Mexico: Description, causes and change. Pp 1-36 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: Nutrient over-enrichment in many areas around the world is having pervasive ecological effects on coastal systems. These effects include reduced dissolved oxygen in aquatic systems and subsequent impacts on living resources. The largest zone of oxygen-depleted coastal waters in the United States, and the entire western Atlantic Ocean, is found in the northern Gulf of Mexico on the Louisiana/Texas continental shelf influenced by the freshwater discharge and nutrient load of the Mississippi River system. The mid-summer bottom areal extent of hypoxic waters ($\leq$ 2mg 1^{-1} $O_2)_2$ in 1985-1992 averaged 8,000 to 9,000 km^2 but increased to up to 16,000 to 20,000 km^2 in 1993-2000. Hypoxic waters are most prevalent from late spring through late summer, and hypoxia is more widespread and persistent in some years than in others. Hypoxic waters are distributed from shallow depths near shore (4 to 5m) to as deep as 60m water depth but more typically between 5 and 30m. Hypoxia occurs mostly in the lower water column. The Mississippi River system is the dominant source of fresh water and nutrients to the northern Gulf of Mexico. Mississippi River nutrient concentrations and loading to the adjacent continental shelf have changed in the last half of the 20th century. The average annual nitrate concentration doubled, and the mean silicate concentration was reduced by 50%. There is no doubt that the average concentration and flux of nitrogen (per unit volume discharge) increased from the 1950s to 1980s, especially in the spring. There is considerable evidence that nutrient enhanced primary production in the northern Gulf of Mexico is causally related to the oxygen depletion in the lower water column. Evidence from long-term data sets and the sedimentary record demonstrate that historic increases in riverine dissolved inorganic nitrogen concentration and loads over the last 50 years are highly correlated with indicators of increased productivity int the overlying water column, i.e., eutrophication of the continental shelf waters, and subsequent worsening of oxygen stress in the bottom waters. Evidence associates increased coastal ocean

productivity and worsening oxygen depletion with changes in landscape use and nutrient management that resulted in nutrient enrichment of receiving waters. Thus, nutrient flux to coastal systems has increased over time due to anthropogenic activities and has led to broad-scale degradation of the marine environment.

238. Rabalais, N. N., D. E. Harper, Jr. and R. E. Turner. 2001. Responses of nekton and demersal and benthic fauna to decreasing oxygen concentrations. Pp 115-128 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: Researchers assembled 12 years of diver observations and five years of remotely operated vehicle video tapes on the responses of nekton and demersal and benthic fauna to decreasing concentrations of dissolved oxygen on the southeastern Louisiana shelf. Here they outline the variable responses of the fauna, as the concentration of dissolved oxygen decreases from 2mg/L to anoxia.

239. Rabalais, N. N., L. E. Smith, D. E. Harper, Jr. and D. Justić. 2001. Effects of seasonal hypoxia on continental shelf benthos. Pp 211-240 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Abstract: The benthic communities were characterized for two areas of the southeastern Lousiana continental shelf – one near the Mississippi River delta with silty sediments and intermittently affected by hypoxia on times scales of days to weeks and another farther from the Mississippi River delta in sandier sediments but affected by severe seasonal hypoxia lasting several months. The composition of the benthic communities reflected differences in sedimentary regime, seasonal input of organic material and seasonally severe hypoxia/anoxia. Decreases in specific richness, abundance and biomass of organisms were dramatic at the stations affected by severe hypoxia/anoxia, and lower than most literature values for similar habitats. Although there were summer/fall declines in the populations at the intermittently hypoxic site, these were not obviously related to changes in oxygen. Some macroinfauna, the polychaetes *Ampharete* and *Magelona* and the sipunculan *Aspidosiphon*, were capable of surviving extremely low dissolved oxygen concentrations and/or high hydrogen sulfide concentrations. Abundance of macroinfauna, primarly opportunistic polychaetes (similar to the spring), increased in the fall following the dissipation of hypoxia, but the numbers of individuals were only slightly greater than the summer depressed fauna and resulted in no or a negligible increase in biomass. Fewer taxonomic groups characterized the severely affected stations throughout the year. Long-lived, higher biomass and direct-developing species were never members of the severely affected community. Suitable feeding habitat (in terms of severely reduced populations of macroinfauna that may characterize substantial areas of the seabed) is thus removed from the foraging base of demersal organisms, including the commercially important penaeid shrimps.

240. Rabalais, N. N., R. E. Turner, and W. J. Wiseman (2001), Hypoxia in the Gulf of Mexico, Journal of Environmental Quality, 30, 320-329.

Abstract: Seasonally severe and persistent hypoxia, or low dissolved oxygen concentration, occurs on the inner- to mid-Louisiana continental shelf to the west of the Mississippi River and Atchafalaya River deltas. The estimated areal extent of bottom dissolved oxygen concentration less than 2 mg L-1 during mid-summer surveys of 1993-2000 reached as high as 16 000 to 20 000 km(2). The distribution for a similar mapping grid for 1985 to 1992 averaged 8000 to 9000 km(2). Hypoxia occurs below the pycnocline from as early as late February through early October, but is most widespread, persistent, and severe in June, July, and August. Spatial and temporal variability in the distribution of hypoxia exists and is, at least partially, related to the amplitude and phasing of the Mississippi and Atchafalaya discharges and their nutrient flux. Mississippi River nutrient concentrations and loadings to the adjacent continental shelf have changed dramatically this century, with an acceleration of these changes since the 1950s to 1960s. An analysis of diatoms, foraminiferans, and carbon ac accumulation in the sedimentary record provides evidence of increased eutrophication and hypoxia in the Mississippi River delta bight coincident with changes in nitrogen loading.

241. Rabalais, N. N., R. E. Turner and W. J. Wiseman, Jr. 2002. Hypoxia in the Gulf of Mexico, a.k.a. "The Dead Zone." Annual Review of Ecology and Systematics 33: 235-263.

Abstract: The second largest zone of coastal hypoxia (oxygen-depleted waters) in the world is found on the northern Gulf of Mexico continental shelf adjacent to the outflows of the Mississippi and Atchafalaya Rivers. The combination of high freshwater discharge, wind mixing, regional circulation, and summer warming controls the strength of stratification that goes through a well-defined seasonal cycle. The physical structure of the water column and high nutrient loads that enhance primary production lead to an annual formation of the hypoxic water mass that is dominant from spring through late summer. Paleoindicators in dated sediment cores indicate that hypoxic conditions likely began to appear around the turn of the last century and became more severe since the 1950s as the nitrate flux from the Mississippi River to the Gulf of Mexico tripled. Whereas increased nutrients enhance the production of some organisms, others are eliminated from water masses (they either emigrate from the area or die) where the oxygen level falls below 2 mg l(-1) or lower for a prolonged period. A hypoxia-stressed benthos is typified by short-lived, smaller surface deposit-feeding polychaetes and the absence of marine invertebrates such as pericaridean crustaceans, bivalves, gastropods, and ophiuroids. The changes in benthic communities, along with the low dissolved oxygen, result in altered sediment structure and sediment biogeochemical cycles. Important fisheries are variably affected by increased or decreased food supplies, mortality, forced migration, reduction in suitable habitat, increased susceptibility to predation, and disruption of life cycles.

243. Rabalais, N. N., R. E. Turner, Q. Dortch, D. Justić, V. J. Bierman, and W. J. Wiseman (2002), Nutrient-enhanced productivity in the northern Gulf of Mexico: past, present and future, Hydrobiologia, 475, 39-63.

Abstract: Nutrient over-enrichment in many areas around the world is having pervasive ecological effects on coastal ecosystems. These effects include reduced dissolved oxygen in aquatic systems and subsequent impacts on living resources. The largest zone of oxygen-depleted coastal waters in the United States, and the entire western Atlantic Ocean, is found in the northern Gulf of Mexico on the Louisiana/Texas continental shelf influenced by the freshwater discharge and nutrient load of the Mississippi River system. The mid-summer bottom areal extent of hypoxic waters (<2 mgl(-1) O-2) in 1985-1992 averaged 8000 to 9000 km(2) but increased to up to 16 000 to 20 700 km(2) in 1993-2001. The Mississippi River system is the dominant source of fresh water and nutrients to the northern Gulf of Mexico. Mississippi River nutrient concentrations and loading to the adjacent continental shelf have changed in the last half of the 20th century. The average annual nitrate concentration doubled, and the mean silicate concentration was reduced by 50%. There is no doubt that the average concentration and flux of nitrogen (per unit volume discharge) increased from the 1950s to 1980s, especially in the spring. There is considerable evidence that nutrient-enhanced primary production in the northern Gulf of Mexico is causally related to the oxygen depletion in the lower water column. Evidence from long-term data sets and the sedimentary record demonstrate that historic increases in riverine dissolved inorganic nitrogen concentration and loads over the last 50 years are highly correlated with indicators of increased productivity in the overlying water column, i.e. eutrophication of the continental shelf waters, and subsequent worsening of oxygen stress in the bottom waters. Evidence associates increased coastal ocean productivity and worsening oxygen depletion with changes in landscape use and nutrient management that resulted in nutrient enrichment of receiving waters. A steady-state model, calibrated to different observed summer conditions, was used to assess the response of the system to reductions in nutrient inputs. A reduction in surface layer chlorophyll and an increase in lower layer dissolved oxygen resulted from a reduction of either nitrogen or phosphorus loading, with the response being greater for nitrogen reductions.

245. Rabalais, N. N. 2002. Changes in Mississippi River nutrient fluxes and consequences for the northern Gulf of Mexico coastal ecosystem. Pages 134-138 in L. D. de Lacerda, H. H. Kremer, B. Kjerfve, W. Saolmons, J. I. Marshall Crossland, and C. J. Crossland, South American Basins, LOICZ Global Change Assessment and Synthesis of River Catchment-Coastal Sea Interaction and Human Dimensions. LOICZ Reports & Studies No. 21, LOICZ International Project Office, Netherlands Institute for Sea Research, Texel, The Netherlands.

246. Rabalais, N. N. 2002. The Effects of Seasonally Severe Hypoxia on Continental Shelf Fauna. In Proceedings, 6th International Symposium, Fish Physiology, Toxicology and Water Quality, Hypoxia in the Aquatic Environment, La Paz, Baja California, Mexico, January 2001, EPA Rpt. No. EPA/600/R-02/097, Environmental Protection Agency, Ecosystems Research Division, Athens, Georgia.

247. Rabalais, N. N. and S. W. Nixon. 2002. Preface: Nutrient Over-enrichment of the Coastal Zone. Estuaries 25(4b): 497.

248. Rabalais, N. N. 2002. Nitrogen in aquatic ecosystems. Ambio 31(2): 102-112.

Abstract: Aquatic ecosystems respond variably to nutrient enrichment and altered nutrient ratios, along a continuum from fresh water through estuarine, coastal, and marine systems. Although phosphorus is considered the limiting nutrient for phytoplankton production in freshwater systems, the effects of atmospheric nitrogen and its contribution to acidification of fresh waters can be detrimental. Within the estuarine to coastal continuum, multiple nutrient limitations occur among nitrogen, phosphorus, and silicon along the salinity gradient and by season, but nitrogen is generally considered the primary limiting nutrient for phytoplankton biomass accumulation. There are well-established, but nonlinear, positive relationships among nitrogen and phosphorus flux, phytoplankton primary production, and fisheries yield. There are thresholds, however, where the load of nutrients to estuarine, coastal and marine systems exceeds the capacity for assimilation of nutrient-enhanced production, and water-quality degradation occurs. Impacts can include noxious and toxic algal blooms, increased turbidity with a subsequent loss of submerged aquatic vegetation, oxygen deficiency, disruption of ecosystem functioning, loss of habitat, loss of biodiversity, shifts in food webs, and loss of harvestable fisheries.

250. Rabalais, N. N. 2004. Hipoxia en el Golfo de México. Margarito Caso, Irene Pisanty y Exewquiel Excurra (compiladores), Diagnóstico Ambiental del Golfo de México Vol. II, Instituto Nacional de Ecología, Mexico, D.F.

251. Rabalais, N. N. 2004. Eutrophication. Chapter 21, pp 819-865 in A. R. Robinson, J. McCarthy and B. J. Rothschild (eds.), *The Global Coastal Ocean: Multiscale Interdisciplinary Processes*, *The Sea*, Vol. 13, Harvard University Press.

252. Rabalais, N. N., N. Atilla, C. Normandeau and R. E. Turner. 2004. Ecosystem history of Mississippi River-influenced continental shelf revealed through preserved phytoplankton pigments. Marine Pollution Bulletin 49: 537-547.

Abstract: Pigments determined by high performance liquid chromatography (HPLC) provide useful information concerning water column and epibenthic plant and microbial communities in both extant communities and accumulated sediments in lakes, estuaries and the ocean. Chlorophyll and its degradation products provide an estimate of overall biomass, and carotenoid pigments provide taxonomic biomarkers of phytoplankton. We examined the pigments preserved in sediment cores from the Louisiana continental shelf adjacent to the outflow of the Mississippi River system to document changes in phytoplankton community composition, phytoplankton abundance, and conditions of hypoxia over time. Carbon accumulated in sediments from water depths of 20-60 in is primarily derived from marine phytoplankton and represents the history of phytoplankton communities in the overlying water. There is a general increase in chlorophyll a, pheopigments, zeaxanthin, fucoxanthin and most carotenoids over time, with the change gradual from 1955 to 1970, followed by a fairly steady increase to 1997. The highest chloropigment concentrations are in cores from areas more likely to be exposed to seasonal hypoxia. These indicate an increase in eutrophication in the form of greater diatom and cyanobacterial production, or a worsening of hypoxia, or both. This trend expanded westward along the Louisiana shelf in the 1990s.

253. Rabalais, N. N. 2005. Consequences of Mississippi River diversion for Louisiana Coastal Restoration. National Wetlands Newsletter, July-August, 2005: 21-24.

254. Rabalais, N. N. 2005. Relative Contribution of Produced Water Discharge in the Development of Hypoxia. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 2005-044, 56 pp.

255. Rabalais, N. N. 2005. The potential for nutrient overenrichment to diminish marine biodiversity. Pp 109-122 in E. A. Norse and L. B. Crowder (eds.), Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Island Press. Washington, D.C.

256. Rabalais, N. N. 2005. Watershed Alterations and Coastal Ocean Response: the Mississippi River. Contribution to Chapter 5, The Catchment to Coast Continuum in C. J. Crossland et al., eds., Coastal Fluxes in the Anthropocene, Springer.

257. Rabalais, N. N. and R. E. Turner. In press 2005. Oxygen depletion in the Gulf of Mexico adjacent to the Mississippi River. In L. N. Neretin, ed., *Past and Present Marine Water Column Anoxia*. NATO Science Series: IV-Earth and Environmental Sciences, Kluwer.

266. Rowe GT. 2001. Seasonal hypoxia in the bottom water off the Mississippi River delta. JOURNAL OF ENVIRONMENTAL QUALITY 30 (2): 281-290 MAR-APR 2001

> **Abstract:** Hypoxia (oxygen concentration less than 2 mg L-1 or 62.5 mmol m(-3)) occurs on the Louisiana continental shelf during summer when the consumption of oxygen by sediment and water column respiration exceed resupply by photosynthesis and mixing. Biological processes that consume or produce oxygen have been summarized in a budget that can be used to quantify the degree to which consumption in deep water and in the sediments exceeds net production and thus the time it takes to reach hypoxic conditions following the spring onset of stratification. The net consumption rate by the sea floor biota (sediment oxygen consumption, SOC) is inversely related to oxygen concentration and directly related to temperature. Photosynthesis is of potential importance throughout the deep water column and on the sea floor when light is adequate. A non-steady state, time-dependent numerical simulation model is used to compare biological and physical processes with shipboard measurements and continuous near bottom records. The simulations illustrate possible variations in oxygen concentration on time scales of hours to months, and these in general match much of the variability in the direct observations at time stales of days to weeks. The frequently observed unremitting anoxia lasting weeks at some locations is not produced in the present simulations. A possible explanation is the chemical oxidation in the water column of reduced metabolic end-products produced in the sediments by anaerobic metabolism, Direct measurements of biological processes could lead to better understanding of how extrinsic forcing functions can best be managed to improve water quality.

267. Rowe, GT and P Chapman. 2002. Continental shelf hypoxia: some nagging questions. Gulf of Mexico Science 20:155-160.

268. Rowe GT, Kaeqi MEC, Morse JW, Boland GS, Briones EGE (2002) Sediment community metabolism associated with Continental Shelf Hypoxia. Estuaries 25:1097-1106

Abstract: Net fluxes of respiratory metabolites (O-2, dissolved inorganic carbon (DIC), NH4+, NO3-, and NO2-) across the sediment-water interface were measured using in-situ benthic incubation chambers in the area of intermittent seasonal hypoxia associated with the Mississippi River plume. Sulfate reduction was measured in sediments incubated with trace-levels of S-35-labeled sulfate. Heterotrophic remineralization, measured as nutrient regeneration, sediment community oxygen consumption (SOC), sulfate reduction, or DIC production, varied positively as a function of temperature. SOC was inversely related to oxygen concentration of the bottom water. The DIC fluxes were more than 2 times higher than SOC alone, under hypoxic conditions, suggesting that oxygen uptake alone cannot be used to estimate total community remineralization under conditions of low oxygen concentration in the water column. A carbon budget is constructed that compares sources, stocks, transformations, and sinks of carbon in the top meter of sediment. A comparison of remineralization processes within the sediments implicates sulfate reduction as most important, followed by aerobic respiration and denitrification. Bacteria accounted for more than 90% of the total community biomass, compared to the metazoan invertebrates, due presumably to hypoxic stress.

269. Rowe, GT and P Chapman. 2003. A response to "Continental shelf hypoxia: some compelling answers" by DF Boesch. Gulf of Mexico Science 21:206-7.

270. Salisbury, J. E., J. W. Campbell, E. Linder, L. D. Meeker, F. E. Muller-Karger, and C. J. Vorosmarty (2004), On the seasonal correlation of surface particle fields with wind stress and Mississippi discharge in the northern Gulf of Mexico, Deep-Sea Research Part Ii-Topical Studies in Oceanography, 51, 1187-1203.

Abstract: Spatio-temporal correlation analyses were performed on time series of daily freshwater discharge, wind fields, and SeaWiFS-derived surface particle concentrations in the northern Gulf of Mexico. The influences of discharge and winds on surface particle concentrations were investigated by mapping temporal correlation coefficients at each pixel for the whole time series (1997-2000) and for each season during 1999 and 2000. Maps of the correlation between suspended particulate matter concentration (SPM) and river discharge suggest regions that are fluvially influenced. The particulate matter may be sediments carried by the river plume or biogenic particles (e.g., detritus) stimulated by the river discharge. The algorithm used to estimate SPM concentrations does not differentiate between sediment and detritus. Maps of the correlation between wind stress and SPM suggest regions where wind mixing accounts for particulate resuspension and subsequent transport. Regions of significant positive wind-SPM correlation were independent, and often spatially separated, from regions of strong positive discharge-SPM correlation. Thus, the influences of winds and discharge on particle distributions can be investigated independently. Regions of high wind-SPM correlation were associated with shallow shelf areas, as correlation contours generally followed the bathymetric contours, and expanded in size under offshore wind regimes. These areas exhibited less spatial and temporal variability than the regions of high discharge-SPM correlation associated with the Mississippi-Atchafalaya river system. There was no

apparent relationship between the magnitude of Mississippi- Atchafalaya discharge and the spatial extent of the region of high discharge-SPM correlation during seasonal analyses. Instead, the spatial extent and orientation of the discharge-SPM correlation field appeared to be a function of winds (both their direction and speed) and the buoyancy of the plume.

271. Scavia D, Rabalais NN, Turner RE, Justić D, Wiseman WJ Jr (2003) Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. Limnol Oceanogr. 48:951-6.

Abstract: The effects of nutrient loading from the Mississippi River basin on the areal extent of hypoxia in the northern Gulf of Mexico were examined using a novel application of a dissolved oxygen model for a river. The model, driven by river nitrogen load and a simple parameterization of ocean dynamics, reproduced 17 yr of observed hypoxia location and extent, subpycnocline oxygen consumption, and cross-pycnocline oxygen flux. With Monte Carlo analysis, we illustrate through hindcasts back to 1968 that extensive regions of low oxygen were not common before the mid-1970s. The Mississippi River Watershed/Gulf of Mexico Hypoxia Task Force set a goal to reduce the 5-yr running average size of the Gulf's hypoxic zone to less than 5,000 km(2) by 2015 and suggested that a 30% reduction from the 1980-1996 average nitrogen load is needed to reach that goal. Here we show that 30% might not be sufficient to reach that goal when year-to-year variability in ocean dynamics is considered.

272. Scavia D, Justić D, Bierman VJ Jr (2004) Reducing hypoxia in the Gulf of Mexico: Advice from three models. Estuaries 27:419-425

Abstract: Summer hypoxia in the bottom waters of the northern Gulf of Mexico has received considerable scientific and policy attention because of potential ecological and economic impacts from this very large zone of low oxygen and because of the implications for management within the massive Mississippi River watershed. An assessment of its causes and consequences concluded that the almost 3-fold increase in nitrogen load to the Gulf is the primary external driver stimulating the increase in hypoxia since the middle of the last century. Results from three very different models are compared to reach the consensus that large-scale hypoxia likely did not start in the Gulf of Mexico until the mid-1970s and that the 30% nitrogen load reduction called for in an Action Plan to reduce hypoxia, agreed to by a federal, state, and tribal task force, may not be sufficient to reach the plan's goal. Caution is also raised for setting resource management goals without considering the long-term consequences of climate variability and change.

273. See JH, Campbell L, Richardson TL, Pinckney JL, Shen RJ, Guinasso NL. 2005. Combining new technologies for determination of phytoplankton community structure in the northern Gulf of Mexico. Journal of Phycology 41 (2): 305-310

Abstract: In situ analysis of phytoplankton community structure was determined at five stations along the Texas Gulf coast using two instruments, the Fluoroprobe and

FlowCAM. Results were compared with traditional methods to determine community structure (pigment analysis and microscopy). Diatoms and small nanoplankton (most likely haptophytes) dominated the phytoplankton community at all stations. Estimated chl concentrations for diatoms+dinoflagellates obtained via the Fluoroprobe were not significantly different for three of the five stations sampled when compared with HPLC-chemical taxonomy analysis, whereas the concentrations of green algal and cryptophyte chl were overestimated. The FlowCAM estimates of overall nanoplankton and microplankton cell abundance were not significantly different when compared with epifluorescence microscopy, and recorded images of phytoplankton cells provided a representative population of the phytoplankton community at each station. The Fluoroprobe and FlowCAM, when used in tandem, are potentially capable of determining the general characteristics of phytoplankton community structure in situ and could be an important addition to biological observing systems in the coastal ocean.

274. Seitzinger, S. P., C. Kroeze, A. F. Bouwman, N. Caraco, F. Dentener and R. V. Styles. 2002. Global patterns of dissolved inorganic and particulate nitrogen inputs to coastal systems: recent conditions and future projections. *Estuaries*, **25**, 640-655.

Abstract: We examine the global distribution of dissolved inorganic nitrogen (DIN) and particulate nitrogen (PN) export to coastal systems and the effect of human activities and natural processes on that export. The analysis is based on DIN and PN models that were combined with spatially explicit global databases. The model results indicate the widely uneven geographic distribution of human activities and rates of nitrogen input to coastal systems at the watershed, latitudinal, and regional-continental scales. Future projections in a business-as-usual scenario indicate that DIN export rates increase from approximately 21 Tg N yr(-1) in 1990 to 47 Tg N yr(-1) by 2050. Increased DIN inputs to coastal systems in most world regions are predicted by 2050. The largest increases are predicted for Southern and Eastern Asia, associated with predicted large increases in population, increased fertilizer use to grow food to meet the dietary demands of that population, and increased industrialization. Results of an alternative scenario for North America and Europe in 2050 indicate that reductions in the human consumption of animal protein could reduce fertilizer use and result in substantial decreases in DIN export rates by rivers. In another scenario for 2050, future air pollution control in Europe that would reduce atmospheric deposition of nitrogen oxides in watersheds is predicted to decrease DIN export by rivers, particularly from Baltic and North Atlantic watersheds. Results of a newly developed global PN river export model indicate that total global PN and DIN export by rivers in 1990 are similar, even though the global distribution of the two differ considerably.

280. Stow CA, Qian SS, Craig JK. 2005. Declining threshold for hypoxia in the Gulf of Mexico. Environmental Science & Technology 39 (3): 716-723.

Abstract: The northwestern Gulf of Mexico shelf has been nicknamed "The Dead Zone" due to annual summertime (May-September) bottom-water hypoxia (dissolved oxygen less than or equal to2 mg L-1) that can be extensive (>20 000 km(2)) and last for several months. Hypoxia has been attributed to eutrophication caused by increasing nitrogen

loads, although directly linking hypoxia to nitrogen is difficult. While the areal extent of hypoxia has been shown to increase with Mississippi River flow, it is unclear whether this increase results from enhanced vertical water-column stratification or from eutrophication caused by river-borne nutrients. Disentangling the relative contributions of eutrophication versus stratification has important management consequences. Our analysis indicates that the top:bottom salinity difference is an important predictor of hypoxia, exhibiting a threshold, where the probability of hypoxia increases rapidly, at approximately 4.1 ppt. Using a Bayesian change-point model, we show that this stratification threshold decreased from 1982 to 2002, indicating the degree of stratification needed to induce hypoxia has gone down. Although this declining threshold does not link hypoxia and nitrogen, it does implicate a long-term factor transcending yearly flow-induced stratification differences. Concurrently, we show that surface temperature increased, while surface dissolved oxygen decreased, suggesting that factors in addition to nitrogen may be influencing the incidence of hypoxia in the bottom water.

282. Sutula M, Bianchi TS, McKee BA. 2004. Effect of seasonal sediment storage in the lower Mississippi River on the flux of reactive particulate phosphorus to the Gulf of Mexico. LIMNOLOGY AND OCEANOGRAPHY 49 (6): 2223-2235.

Abstract: The annual surface water flux of total reactive (i.e., potentially bioavailable) particulate P from the Mississippi River was estimated by measuring the reactive (including labile, iron, organic, and calcium bound) and nonreactive (detrital) P phases in suspended particulates in the Mississippi River. In addition, the transformation of the major sediment P phases resulting from seasonal channel storage and resuspension was examined. Samples were collected during five cruises over 1 yr at marine and riverine sites. Solid-phase and pore-water nutrients were quantified, and solid-phase P pools were measured using a sequential extraction technique. These results indicate that the Mississippi River exports 134 x 10(6) kg yr(-1) of total reactive P via surface water. Seasonal hydrological forcing controlled the variability in major P phases found in channel sediments through hydrodynamic sorting. Although the 6-9-month time period during which sediments were stored in the river channel was sufficient to see evidence of early diagenesis in the pore waters, no significant net effect was seen on major P phase distribution. The loss of a significant percentage of labile and iron-bound P appears to be occurring only as these riverine sediments are deposited and reworked on the continental shelf.

283. Sylvan, Jason, M.S. Thesis, Institute of Marine and Coastal Sciences,Rutgers University, January, 2004. Thesis title: Mapping evidence of phosphorus limitation in the Mississippi River plume. 65 pages.

284. Thomas, E, T. Gapotchenko, J. C. Varekamp, E. L. Mecray, and M. R. B. ter Brink. 2000. Benthic Foraminifera and environmental changes in Long Island Sound. *J. Coast. Res.*, **16**, 641-645.

Abstract: Benthic foraminiferal faunas in Long Island Sound (LIS) in the 1940s and 1960s were of low diversity, and dominated by species of the genus Elphidium, mainly

Elphidium excavatum clavatum, with common Buccella frigida and Eggerella advena. The distribution of these species was dominantly correlated with depth, but it was not clear which depth-related environmental variable was most important. Differences between faunas collected in 1996 and 1997, and in the 1940s and 1960s include a strong decrease in relative abundance of Eggerella advena over all LIS, an increase in relative abundance of Ammonia beccanii in western LIS, and a decrease in species diversity. The decreased diversity suggests that environmental stress caused the faunal changes. Oxygen isotope data for E. excavatum clavatum indicate that a change in salinity is not a probable cause. Carbon isotope data suggest that the supply of organic matter to the benthos increased since the early 1960s, with a stronger increase in western LIS where algal blooms have occurred since the early 1970s, possibly as a result of nutrient input by waste water treatment plants. These blooms or the resulting episodes of anoxia/hypoxia may have played a role in the increased relative abundance of A. beccarii. There is no clear explanation for the decreased abundance off. advena, but changes in the phytoplankton composition (thus food supply) are a possible cause. Benthic foraminiferal faunal and stable isotope data have excellent potential as indicators of physicochemical environmental changes and their effects on the biota in LIS.

296. Turner, R. E., D. Stanley, D. Brock, J. Pennock and N. N. Rabalais. 2000. A comparison of independent N-loading estimates for U.S. estuaries. Pp 107-118 in R. A. Valigura, R. B. Alexander, M. S. Castro, T. P. Meyers, H. W. Paerl, P. E. Stacey and R.E. Turner (eds.), Nitrogen Loading in Coastal Water Bodies. An Atmospheric Perspective. Coastal and Estuarine Studies 57, American Geophysical Union, Washington, D.C.

Abstract: We assembled 27 recent and independently derived Total Nitrogen (TN) loading estimates for watersheds of east coast and Gulf of Mexico estuaries (watershed size range 27 to 90,672 km^2; yeld range; 44 to 2,722 kg N km^{-2} y^{-1}). These results were compared to those from two other recent studies that used national water quality data bases and computer modeling or statisitical analyses to estimate loadings. The loadings from these other studies average about 50 to 60% of the 27 independently derived TN loading estimates. In many cases the individual estimates are more likely to achieve fuller inclusion of all nitrogen sources to the estuary than these other two efforts, because of the inclusion of groundwater, sewerage, or site-specific point and non-point discharges.

The nitrogen yield from these coastal estuarine watersheds is strongly related to population density, and the per capita yield (kg N $person^{-1}$) is lower thanfor the large watersheds draining into the Northern Atlantic, including the Mississippi River. The variability in TN yield per capita is strongly related to the percentage of the landscape that is harvested cropland, which is generally higher in the larger watersheds. A simple statistical model of population density and % of the watershed that is harvested cropland describes 79% of the variation in TN yield (kg N km^{-2}) for 11 basins, including the Mississippi River basin.

The amount of direct atmospheric deposition to the estuarine surface rises to about 25% of the TN loading to the estuary, when the estuarine surface: watershed area ratio is 0.2.

About 20% of all estuarine surface area in the U.S., distributed in 12 estuaries, has a ratio of 0.2, or higher. The significance of direct atmospheric nitrogen loadings to the estuarine surface is thus responsive to several geomorphic and socio-economic factors that range greatly across U.S. estuaries.

297. Turner, R. E. 2001. Some effects of eutrophication on pelagic and demersal marine food webs. Pages 371-398 in Rabalais, N. N. and R. E. Turner (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems*. Coastal and Estuarine Studies **58**, American Geophysical Union, Washington, D.C.

Abstract: This chapter reviews some of the possible consequences of increased nutrient loading and changing nutrient ratios to marine food webs, especially for larger organisms, and including the northern Gulf of Mexico. Selected results from various ecosystems analyses, and implications from site-specific studies are summarized. Early models and subsequent improvements revealed the sensitivity of the pelagic and demersal consumers to the meager transfer of energy and carbon between trophic levels (upper limit about five or six), and are supported by empirical results documented for many systems. Less than 1% of the phytoplankton production will become fish biomass, which is most often as pelagic, not demersal, consumers. Eutrophication, be definition, increases the amount of primary production available, but the increase is not transferred throughout the food web with linearity or proportionality. Instead, higher nutrient loading may shift carbon flow within and through the 'microbial loop', diminish the percentage flowing into fecal pellet production, and increase flows toward phytoplankton cell aggregations that sink to lower layers. Eutrophication will be accompanied by greater carbon burial rates and export away from hypoxic/anoxic zones which become larger and longer-lasting; higher atomic ratios in water loading into continental shelves falls below 1:1, then there is likely to be a severe disruption in the diatom-copepod-fish food web, and more frequent toxic and noxious phytoplankton blooms.

298. Turner, R. E. and N. N. Rabalais. 2001. Summary: Commonality and the Future. Pp 451-454 in N. N. Rabalais and R. E. Turner (eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

299. Turner, R. E. 2002. Element ratios in aquatic food webs. Estuaries 25: 694-703.

Abstract: Organic matter is the result of concentrating a few non-metals that are relatively rare in the earth's crust. Most of these essential elements are in a rough proportionality within phylogenetic groupings. Life is thus working against a concentration gradient to extract or accumulate these elements, and this metabolic work is accomplished in interrelated and often subtle ways for many other elements. The physiological requirement to sustain these elemental ratios (commonly discussed in terms of the N:P ratios, but also C:N, C:P, and Si:N ratios) constrains organization at the cellular, organism, and community level. Humans, as geochemical engineers, significantly influence the spatial and temporal distribution of elements and, consequently, their ratios. Examples of these influences include the changing dissolved

Si: nitrate and the dissolved nitrate: phosphate atomic ratios of water entering coastal waters in many areas of the world. Human society may find that some desirable or dependent ecosystem interactions are compromised, rather than enhanced, as we alter these elemental ratios. Human-modulated changes in nutrient ratios that cause an apparent increase in harmful algal blooms may compromise the diatom-zooplankton-fish food web. It will be useful to improve our understanding of aquatic ecosystems and for management purposes if the assiduous attention on one element (e.g., N or P) was expanded to include the realities of these mutual interdependencies.

302. Turner, R. E., N. N. Rabalais, D. Justić, and Q. Dortch. 2003. Future aquatic nutrient limitations. Marine Pollution Bulletin 46: 1032-1034.

Abstract: Nutrient limitation of phytoplankton growth in aquatic systems is moving towards a higher incidence of P and Si limitation as a result of increased nitrogen loading, a N:P fertilizer use of 26:1 (molar basis), population growth, and relatively stable silicate loading. This result will likely alter phytoplankton community composition, and may compromise diatom --> zooplankton --> fish food webs.

303. Turner, R. E. 2003. Coastal Ecosystems of the Gulf of Mexico and Climate Change. Pp. 85-103, in Ning, Z. H., R.E. Turner, T. Doyle, and K. K. Abdollahi, 2003. Integrated Assessment of the Potential Consequences of Climate Change Variability and Change for the Gulf Coast Region. ISBN 1-930129-01-7.
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/gulfcoast/default.htm

304. Turner, R.E., Q. Dortch and N. N. Rabalais. 2004. Inorganic nitrogen transformations at high loading rates in an oligohaline estuary. Biogeochemistry 68: 411-422.

Abstract: A well-defined nitrogen retention and turnover budget was estimated for a shallow oligohaline lake (Lake Pontchartrain, Louisiana, USA). In 1997 a month-long diversion of the Mississippi River filled the Lake with highly concentrated river water (80 muM nitrate) and lowered the salinity to 0 psu within 2 weeks. After the spillway was closed the Lake mixed with estuarine tidal waters and came to equilibrium over 4 months with the riverine, atmospheric and offshore water nitrogen sources. A flushing rate of 1.78% d(-1) was estimated by analyzing a plot of In salinity versus time for the first 120 days after the diversion ceased. This flushing rate was similar to the loss rate for total nitrogen (1.75% d(-1)), implying no significant net nitrogen losses or gains were occurring inside the Lake. The percent loss of dissolved inorganic nitrogen was higher than that for TN (4.11% d(-1)), whereas the loss of organic nitrogen was lower (0.94% d(-1)), which suggests a net transfer from inorganic to organic nitrogen. These changes occurred steadily as chlorophyll a concentration ranged from 5 to 200 mug l(-1). The results demonstrate the potential significance of the organic nitrogen and interconversion of nitrogen forms when calculating estuarine nitrogen retention budgets and the necessity of measuring all nitrogen forms when performing mass balance estimates. The significance of denitrification in nitrogen removal is minimal at the high loading rates observed during this study. An implication to estuarine water quality management is that

the relationships between nitrogen loading and retention are not linear and are controlled by factors other than water residence time.

306. Turner, R. E., C. S. Milan and N. N. Rabalais. 2004. A retrospective analysis of trace metals, C, N and diatom remnants in sediments from the Mississippi River delta shelf. Marine Pollution Bulletin 49:548-556.

Abstract: The development of oil and gas recovery offshore of the Mississippi River delta began in shallow water in the 1950s, expanded into deeper waters, and peaked in the 1990s. This area of the outer continental shelf (OCS) is the historical and present location of >90% of all US OCS oil and gas production and reserves. The juxtaposition of its 4000 producing platforms, recovering $10 billion yr(-1) of oil, gas and produced water in the same area where about 28% of the US fisheries catch (by weight) is made and near 40% of the US coastal wetlands, makes this an area worth monitoring for regional pollutant loading. This loading may come from several sources, including sources related to OCS development, but also from the Mississippi River watershed. In this context, any contaminant loading on this shelf may be neither detectable nor significant against a background of climatic or biological variability. We examined the sedimentary record for indicators of industrial by products from OCS oil and gas development and of industrial products entering via the Mississippi River, primarily using vanadium (V) and barium (Ba) concentrations normalized for aluminum (M). Barium is primarily used in drilling muds in the form of barite, whereas V is an important strengthening component of metal alloys, including steel. The fluctuations in the accumulation of Ba, but not V, were coincidental with the presumed use of barite. The fluctuations in V concentration in the sediments were coincidental with the national consumption of V. Copper (Cu), cadmium (Cd) and zinc (Zn) concentrations in sediments fluctuate coincidentally with V, not Ba, thus indicating that the dominant source of these trace metals in offshore sediments were derived from riverine sources, and were not primarily from in situ industrial processes releasing them on the shelf. This is not to suggest that local site-specific contamination is not a significant management or health concern. The low oxygen (hypoxia; less than or equal to2 mg l(-1)) zone that consistently covers much of this continental shelf's bottom layer in summer is attributed to nitrate loading from the Mississippi River. Increased nitrogen loading from river to shelf stimulates diatom production whose loading to the bottom layer and subsequent metabolism results in oxygen being depleted faster than it is replaced. In the last two decades there has been an increased accumulation of organic matter in sediments near the mouth of the Mississippi River. This coupling between river water, surface water and bottom water has recently expanded westward of the Atchafalaya River delta towards the Texas coast. The accumulation of biogenic silica (BSi) and carbon in dated sediments is coincidental with variations in riverine nitrate flux, but not with either V or Ba accumulation rates. These analyses indicate that both OCS development and riverine sources exert strong influences on the sediment constituents offshore, and that these influences may be independent of one another.

307. Turner, R. E., N. N. Rabalais, E. M. Swenson, M. Kasprzak and T. Romaire. 2005. Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. Marine Environmental Research 59: 65-77.

Abstract: An 18-year monitoring record (1978-1995) of dissolved oxygen within a region having hypoxia (dissolved oxygen less than 2 mg l(-1)) in the bottom layer was examined to describe seasonal and annual trends. The monitoring location was near or within a well-described summer hypoxic zone whose size has been up to 20,000 km(2). The monitoring data were used to hindcast the size of the hypoxic zone for before consistent shelfwide surveys started, and to predict it for 1989, when a complete shelfwide survey was not made. The concentration of total Kjeldahl nitrogen (TKN) in surface waters and concentration of bottom water oxygen were directly related, as anticipated if organic loading from surface to bottom was from in situ processes. The TKN data were used to develop a predictive relationship that suggested there was no substantial hypoxia before the 1970s, which was before nitrate flux from the Mississippi River to the Gulf of Mexico began to rise. The peak frequency in monthly hypoxic events is two to three months after both the spring maximum in discharge and nitrate loading of the Mississippi River. These results support the conclusion that persistent, large-sized summer hypoxia is a recently-developed phenomenon that began in the 1970s or early 1980s.

309. Turner, R. E., N. N. Rabalais, B. Fry, N. Atilla, C. S. Milan, J. M. Lee, C. Normandeau, T. A. Oswald, E. M. Swenson, and D. A. Tomasko. 2006. Paleo-indicators and water quality change in the Charlotte Harbor Estuary (Florida). Limnol. Oceanogr. 51: 518-533.

We reconstructed water quality changes for 1800 to 2000 in Charlotte Harbor (Florida), a shallow subtropical estuary, by using a suite of biological and geochemical proxies in dated sediments collected in the region of a present day, midsummer hypoxic zone. The declining freshwater loading into the estuary from 1931 to the 1980s is not the probable causal agent encouraging the appearance or expansion of a hypoxia zone (measuring up to 90 km2 in summer). Rather, the reconstructed trends in nitrogen loading indicate increased phytoplankton production has likely caused a decline in bottom water oxygen concentrations. Sedimentary biogenic silica (BSi), carbon, nitrogen, and phosphorus concentrations increased concurrently with known or inferred changes in nutrient loadings. There were direct relationships between phytoplankton pigments and BSi, heavier $d^{34}S$ with increased carbon loading, and sequestration of P, Al, and Fe as carbon loading increased. The results from the sediment analyses and the results from mixing models using C:N ratios and $d^{13}C$ suggest an estuarine system that is responsive to increased carbon loading from the nitrogen-limited phytoplankton community and whose sediments are becoming increasingly anoxic as a result. The present nitrogen loading is about three times above that prior to the 1800s, suggesting that without management intervention the anticipated doubling of the watershed's population from 1990 to 2020 will greatly increase the nitrogen lo ding to this estuary and will lead to much higher amounts of phytoplankton biomass and accumulation and exacerbate hypoxic conditions.

310. Turner, R. E., N. N. Rabalais and D. Justić. In press. Predicting summer hypoxia in the Northern Gulf of Mexico: Riverine N, P and Si loading. Marine Pollution Bulletin. http://www.sciencedirect.com/science/journal/0025326X

Abstract: We conducted a statistical analysis to discern the relative strengths of the loading of various forms of nitrogen, phosphorus, dissolved silicate and their molar ratios on the variance in the size of the summertime low oxygen zone found off the Mississippi River, northern Gulf of Mexico. A stable statistical model that included Year and riverine nitrate + nitrite loading for the 2 months prior to the measurement of hypoxic zone size described 82% of its variation in size from 1978 to 2004. The usefulness of the term Year is consistent with the documented increase in carbon stored in sediments after the 1970s, which is when the hypoxic zone is predicted to have become a regular feature on the shelf and to have expanded westward. The increased carbon storage is anticipated to cause a sedimentary respiratory demand influencing the size of the zone, and whose temporal influence is cumulative and transcends the annual variations in nitrogen loading. The variable Year is negatively correlated with the TN:TP ratio in a way that suggests N, not P, has become more important as a factor limiting phytoplankton growth in the last 20 years. Nitrogen, in particular nitrate + nitrite, and not phosphorus, dissolved silicate, or their molar ratios, appears to be the major driving factor influencing the size of the hypoxic zone on this shelf. This conclusion is consistent with cross-system analyses that conclude that the TN:TP ratio in the Mississippi River, currently fluctuating around 20:1, is indicative of nitrogen, not phosphorus, limitation of phytoplankton growth. Nutrient management that places stronger emphasis on reducing nitrogen loading as compared to phosphorus loading, is justified.

311. Valigura, R. W., R. B. Alexander, M. S. Castro, T. P. Meyers, H. W. Paerl, P. E. Stacey, R. E. Turner (eds.) 2001. Nitrogen Loading in Coastal Water Bodies: An Atmospheric Perspective. Coastal and Estuarine Studies Volume No. 57. American Geophysical Union, Washington, D.C. 252 pp.

This item is a book chapter. The book is held by the EPA Libraries Network.

314. Walker ND, Hammack AB. 2000. Impacts of winter storms on circulation and sediment transport: Atchafalaya-Vermilion Bay region, Louisiana, USA. JOURNAL OF COASTAL RESEARCH 16 (4): 996-1010.

Abstract: This study investigates the changes in circulation, sediment resuspension, sediment flux and salinity that accompany "winter storms" in the Atchafalaya Bay region, events that occur 20 to 30 times each year between October and April. NOAA-14 satellite reflectance imagery and time-series measurements of winds, water levels, current velocity and turbidity demonstrate that wind direction and speed are the major controlling factors for circulation, sediment transport and suspended sediment concentrations. East winds (occurring 62% of the time) induce westward flow of sediment-laden Atchafalaya river water along the coast. West winds reverse the direction of plume movement and increase the size of the plume, partly as a result of Ekman processes. The strong north winds, characteristic of winter storms, cause rapid flushing from the shallow bays (30-

50% of volume) and water level changes in excess of 1 meter. Seaward of these bays, a large sediment plume (180 km alongshore, 75 km offshore) is produced by the wind-wave resuspension of bottom sediments and the wind-forced seaward transport of bay and inner shelf waters. Water and sediment flux is primarily southeastward, temporarily disrupting the westward flow of river water along the coast. In the Vermilion-Cote Blanche Bay system, northwest winds maximize sediment resuspension and the seaward flux of sediment-laden river and bay water. The storm-related sediment resuspension and transport reduces the rapidity of delta development and deposition in these bays and re-distributes sediment along the inner shelf.

315. Walker ND. 2001. Tropical storm and hurricane wind effects on water level, salinity, and sediment transport in the river-influenced Atchafalaya-Vermilion Bay system, Louisiana, USA. ESTUARIES 24 (4): 498-508.

Abstract: Changes in circulation, water level, salinity, suspended sediments, and sediment flux resulted from Tropical Storm Frances and Hurricane Georges in the Vermilion-Atchafalaya Bay region during September 1998. Tropical Storm Frances made landfall near Port Aransas, Texas, 400 km west of the study area, and yet the strong and long-lived southeasterly winds resulted in the highest water levels and salinity values of the year at one station in West Cote Blanche Bay. Water levels were abnormally high across this coastal bay system, although salinity impacts varied spatially. Over 24 h, salinity increased from 5 to 20 psu at Site 1 on the east side of West Cote Blanche Bay. Abnormally high salinities were recorded in Atchafalaya Bay but not at stations in Vermilion Bay. On September 28, 1998, Hurricane Georges made landfall near Biloxi, Mississippi, 240 km east of the study area. On the west side of the storm, wind stress was from the north and maximum winds locally reached 14 m s(-1). The wind forcing and physical responses of the bay system were analogous to those experienced during a winter cold-front passage. During the strong, north wind stress period, coastal water levels fell, salinity decreased, and sediment-laden bay water was transported onto the inner shelf. As the north wind stress subsided, a pulse of relatively saline water entered Vermilion Bay through Southwest Pass increasing salinity from 5 to 20 psu over a 24-h period. National Oceanic and Atmospheric Administration (NOAA)-14 reflectance imagery revealed the regional impacts of wind-wave resuspension and the bay-shelf exchange of waters. During both storm events, suspended solid concentrations increased by an order of magnitude from 75 to over 750 mg 1 (1). The measurements demonstrated that even remote storm systems can have marked impacts on the physical processes that affect ecological processes in shallow coastal bay systems.

316. Walker ND, Wiseman WJ, Rouse LJ, Babin A. 2005. Effects of river discharge, wind stress, and slope eddies on circulation and the satellite-observed structure of the Mississippi River plume. JOURNAL OF COASTAL RESEARCH 21 (6): 1228-1244 NOV 2005

Abstract: Satellite measurements of suspended sediment, temperature, and chlorophyll a are used in combination with surface current measurements to investigate surface circulation and structure of the Mississippi River plume. River discharge changes affect frontal locations, areal extent, and suspended sediment loads of the plume. During high

river discharge (> 20,000 m(3) s(-1)) in spring, the sediment plume extends 23 km southwestward, covers 2700 km(2), with maximum concentrations of 360 mg L-1. Plume temperatures vary seasonally from 10 degrees to 28 degrees C, with maximum surface fronts of 3.3 degrees C km(-1) in winter. East winds, prevalent in autumn, winter, and spring, drive a westward flow of river waters around the delta, linking two isolated shelf regions and increasing river discharge onto the Louisiana/Texas shelf. During peak river flow, this westward current exhibits velocities of 40-90 cm s(-1), is 20 km wide, and transports 140,000-165,000 m(3) s(-1) of river and shelf water. It usually turns toward the coast between 89.5 degrees W and 90 degrees W, feeding a clockwise gyre in the Louisiana Bight and a westward coastal current. The prevalent east winds trap river water and associated nutrients on the shelf where hypoxia later develops in late spring/summer. During autumn and winter, short-term wind reversals from frontal passages rapidly reverse plume direction, initiate off-shelf transport, and reduce residence times for river waters and associated sediments, nutrients, phytoplankton, and carbon. During summer, persistent southwest and south winds force river water eastward, where cross-margin transport is likely due to the relatively narrow shelf. Slope eddies and the Loop Current control river water after leaving the shelf.

317. Wawrik B, Paul JH, Bronk DA, John D, Gray M (2004) High rates of ammonium recycling drive phytoplankton productivity in the offshore Mississippi River plume Aquat Microb Ecol 35:175-184

Abstract: As part of an integrated study of the regulation of carbon fixation in the offshore Mississippi River plume, we measured the rates of N-15-labeled ammonium and nitrate uptake in the surface plume waters from offshore to nearshore along the plume axis towards the Mississippi Delta. Concentrations of nitrate in the plume ranged from 0.19 to 2.5 muM with the highest concentrations primarily in the shoreward stations, while ammonium ranged from 0.17 to 0.44 muM, showing little spatial variability. Rates of ammonium uptake ranged from 16.5 to 260 nM h(-1), and showed a strong trend of increasing values from offshore towards the Mississippi Delta. In contrast, nitrate uptake rates ranged from 3.2 to 25 nM h(-1). The high rates of ammonium uptake in the presence of low ammonium concentrations and elevated nitrate was made possible by elevated rates of ammonium regeneration that exceeded ammonium uptake by 1.7 to 5.7-fold in the plume. The plume exhibited relatively low f-ratios and also contained elevated levels of Synechococcus as determined by flow cytometry and high levels of form IA (alpha-cyanobacterial) rbcL transcripts. These data suggest that a major portion of the carbon fixation observed in the offshore Mississippi River plume represents recycled production supported by high rates of ammonium regeneration.

318. Wawrik B, Paul JH. 2004. Phytoplankton community structure and productivity along the axis of the Mississippi River plume in oligotrophic Gulf of Mexico waters. AQUATIC MICROBIAL ECOLOGY 35 (2): 185-196.

Abstract: The Mississippi River is the largest freshwater input into the Gulf of Mexico (GOM) and contributes a large nutrient load to northern GOM waters. During the summer, the Mississippi River plume is sometimes found to extend into the eastern

oligotrophic GOM as far as the Dry Tortugas. The objectives of this study were to determine the relative contribution of the Mississippi River plume to the total surface water production in the oligotrophic GOM and the impact of this feature on the composition of phytoplankton found there. Using Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite images, we located and sampled the offshore Mississippi plume along its axis. In situ sampling in combination with remote sensing allowed us to estimate integrated plume primary productivity. Carbon fixation in the northern GOM averaged 0.53 mug C l(-1) h(-1) for non-plume stations, and 9.3 Pg C l(-1) h(-1) in plume stations. We estimated integrated productivity of the plume at ca. 3.28 x 10(9) g C h(-1), which accounted for 41 and 13% of all surface and total water column productivity in the oligotrophic GOM, respectively, at the time of sampling. Analysis of rbcL cDNA clone libraries and HPLC pigment data indicated that our sampling transect traversed several regions with distinctly different phytoplankton assemblages. Non-plume communities were numerically dominated by Prochlorococcus, and contained prymnesiophytes and eustigmatophytes. Diatoms dominated the most productive inshore station, while Synechococcus dominated in the mid-plume just off the Louisiana shelf. The least productive and most offshore portion of the plume was also diatom dominated. Diatoms were the most diverse algal class observed, accounting for over 42% of all unique rbcL genotypes detected in the plume. Collectively, these results indicate that the Mississippi River plume contributes significantly to oligotrophic productivity in the GOM, resulting from localized blooms of both Synechococcus and diatoms.

323. Wiseman, Jr., W. J., N. N. Rabalais, R. E. Turner and D. Justić. 2004. Hypoxia and the Physics of the Louisiana Coastal Current. Pp 359-372 in J.C.J. Nihoul et al., "Dying and Dead Seas," NATO Advanced Research Workshop, Liège, Belgium, NATO ASI Series, Kluwer Academic Publishers, Netherlands.

No abstract or PDF is available for this presentation. Ordering information: http://www.springer.com/sgw/cda/frontpage/0,11855,4-10100-72-33614773-0,00.html

324. Wu, R. S. S., B. S. Zhou, D. J. Randall, N. Y. S. Woo and P. K. S. Lam. 2003. Aquatic hypoxia is an endocrine disruptor and impairs fish reproduction. *Environ. Sci. Technol.*, **37**, 1137-1141.

Abstract: There is increasing concern that certain chemicals in the aquatic environment can disrupt endocrine systems, leading to reproductive impairment and threatening survival of wild populations of invertebrates, fish, bird, reptiles, and wildlife. For the first time, we report that hypoxia is also an endocrine disruptor and poses a significant threat to the reproduction and hence sustainability of fish populations. Serum levels of testosterone, estradiol, and triiodothyronine significantly decreased in carp (Cyprinus carpio) upon chronic exposure to hypoxia. These hormonal changes were associated with retarded gonadal development in both male and female carp, reduced spawning success, sperm motility, fertilization success, hatching rate, and larval survival, indicating that adverse effects of hypoxia on reproductive performance resulted from endocrine disruption. Since aquatic hypoxia commonly occurs over thousands of square kilometers

in aquatic systems worldwide, our results imply that endocrine disruption and reproductive impairment in fish may be a widespread environmental problem.

325. Yin, K., P.-Y. Qian, M. C. S. Wu, J. C. Chen, L. Huang, X. Song and W. Jian. 2001. Shift from P to N limitation of phytoplankton growth across the Pearl River estuarine plume during summer. *Mar. Ecol. Prog. Ser.*, **221**, 17-28.

Abstract: Anthropogenic loading of nutrients in rivers often increases disproportionally among N, P, and Si, and thus may shift the type of phytoplankton nutrient limitation in the coastal receiving waters. The effect of anthropogenic nutrient loading has rarely been addressed in the Pearl River estuary along the southern coast of China, even though it is one of the largest rivers in the world. We conducted a cruise along the Pearl River estuary and adjacent coastal waters south of Hong Kong during July 17 to 18, 1999, Samples were taken for salinity and nutrients (NO3, SiO4, PO4, NH4 and urea) and nutrient addition experiments were conducted on board. Vertical profiles of salinity showed a salt-wedge estuary and the coastal plume covering the waters south of Hong Kong. Concentrations of NO3 were very high (ca 90 muM) upstream of the Pearl River estuary, and much of the riverine NO3 was not utilized in the estuary until depletion at the edge of the coastal plume on the east side of Hong Kong. SiO4 was 120 muM upstream and its utilization was similar to that of NO3. PO4 was low in surface waters (< 0.5 muM) and higher below the halocline in the estuary. NH4 and urea were generally <4 and 1.5 muM, respectively. In the estuary, N:P ratio was 200:1, indicating potential P limitation, while N:Si was below 1 1. Beyond the coastal plume to the east of Hong Kong, N:P and N:Si ratios were <5:1 and 1:0.3, respectively, indicating potential N limitation. Nutrient limitation was shown in nutrient addition experiments and was consistent with the ratios of nutrients, Therefore, nutrient limitation shifted across the coastal plume from P limitation in the estuary to N limitation in the oceanic waters. Potential P limitation was observed in the estuary; P and Si co-limiting occurred at the edge of the coastal plume, and N was limiting in the oceanic side. This spatial shift in nutrient limitation has great implications for nutrient pollution control and coastal management of Hong Kong waters.

326. Yuan JC, Miller RL, Powell RT, Dagg MJ. 2004. Storm-induced injection of the Mississippi River plume into the open Gulf of Mexico. Geophysical Research Letters 31 (9): Art. No. L09312.

Abstract: The direct impact of the Mississippi River on the open Gulf of Mexico is typically considered to be limited due to the predominantly along-shore current pattern. Using satellite imagery, we analyzed chl a distributions in the northern Gulf of Mexico before and after the passage of two storms: Hurricane Lili and Tropical Storm Barry. Our analyses indicate that storm-induced eddies can rapidly inject large volumes of nutrient-rich Mississippi River water to the open gulf, and lead to phytoplankton blooms. Although these events last only a few weeks, they transport significant amounts of fluvial substances to the ocean. These river-ocean interactions are especially significant in tropical and subtropical regions because receiving waters are typically permanently stratified and oligotrophic.

327. Yuan JC, Dagg MJ, Del Castillo CE. 2005. In-pixel variations of chl a fluorescence in the Northern Gulf of Mexico and their implications for calibrating remotely sensed chl a and other products. CONTINENTAL SHELF RESEARCH 25 (15): 1894-1904.

Abstract: Remote sensing instruments such as SeaWiFS and MODIS are often calibrated or tested by comparison with in situ data. These comparisons are based on the premise that there is uniform in-pixel variation of the standard deviation of in situ properties. To evaluate some of the errors resulting from this assumption, we conducted an analysis of in-pixel variation of chl a fluorescence by examining fluorescence data from a flow-through system on an underway vessel mapping surface properties for 10 days on the continental shelf in the vicinity of the Mississippi River delta. Significant variations of in-pixel standard deviation of chl a fluorescence were observed, which indicate that this uniformity assumption is not valid in the Northern Gulf of Mexico. Furthermore, our analysis indicates that a large apparent error by the remote sensor is generated if uniformity of standard deviation is assumed. Our results suggest that one should take into account both in-pixel mean and standard deviation, when comparing remotely sensed ocean color data with in situ measurements. Similar measures should be taken when comparing other remotely sensed products with field determinations.

330. Zimmerman, A. R. and E. A. Canuel. 2002. Sediment geochemical records of eutrophication in the mesohaline Chesapeake Bay. *Limnol. Oceanogr.*, **47**, 1084-1093.

Abstract: An organic geochemical analysis of sediments in three cores fro, the mesohaline Chesapeake Bay was carried out to reconstruct the progression of eutrophication and anoxia/hypoxia over the past five Centuries. Evidence of eutrophication was found in the stable isotopic and lipid biomarker signatures of organic matter in sediments of these cores be-inning in the late 18th and early 19th Centuries and continuing to the present. Enrichments in the carbon and nitrogen isotopic signature of these sediments likely result from enhanced primary productivity and nitro.-en recycling, respectively, and occur, coincidentally, with increased fluxes of total organic carbon (TOC) and episodic enrichments (relative to TOC) of algal and bacterially derived lipid biomarker compounds. More extreme and enduring, chances from the late 19th ceutury to the present are indicated by LIP to fivefold increases in TOC accumulation and 2- to 10-fold enrichments (relative to TOC) in algal and bacterially derived lipid biomarker compounds. Increased dinoflagellate and other nondiatom algae relative to diatom production is indicated by lipid biomarker compound ratios. Increases in the ratio of acid-volatile Sulfur to chromium-reducible sulfur in sediment indicate the first occurrence of anoxia/hypoxia in 1790 at the deepest site (26 m), and in 1915 at a site 15 in deep. The history of Chesapeake Bay productivity is reconstructed using a diagenetic model to estimate the amount Of TOC and biomarker compounds lost to degradation. It is estimated that both TOC delivery and algal and bacterial production have increased by 150% or more relative to pre-Colonial times with a temporal progression similar to anthropogenic alteration of the watershed.

Characterization of the Cause(s) of Hypoxia (Contiued)

(<2000)

2. Allen, J. R., D. J. Slinn, T. M. Shammon, R. G. Hartnoll and S. J. Hawkins. 1998. Evidence for eutrophication of the Irish Sea over four decades. *Limnol. Oceanogr.,* **43**, 1970-1974.

Abstract: The Irish Sea is showing early signs of eutrophication extending offshore, beyond localized inshore effects, according to an unusually long time series of measurements taken in the central Irish Sea. Background levels of dissolved inorganic forms of nitrogen and phosphorus have risen substantially over the last 30 to 40 years. This rise has coincided with a significant rise in phytoplankton biomass, measured as chlorophyll 4 during the late spring bloom. Contrary to trends in other coastal seas, the increase in N and P was not accompanied by a decline in silicate; in fact, a small but significant increase in Si was noted in autumn and winter. This may be related to the well-mixed conditions over much of the Irish Sea. However, the common assumption that there are no anthropogenic sources of dissolved Si may not be valid in this area and requires further consideration.

4. Ammerman JW, Glover WB, Ruvalcaba RHS, MacRae JJD (1995) Continuous underway measurement of microbial enzyme activities in surface waters of the Mississippi River plume and the Louisiana shelf. In Proc 1994 NECOP Workshop, 1–8. Baton Rouge LA

Absract: Microbial ectoenzyme activities in aquatic environments are important agents of polymer hydrolysis and indicators of the state of microbial carbon, nitrogen, or phosphorus nutrition. However, like most other biochemical and molecular measurements, ectoenzyme activities have been limited to discrete water samples. We have developed a continuous underway method for measuring microbial enzyme activities using high-sensitivity fluorescent substrates. The system we developed consisted of a peristaltic proportioning pump, a temperature-controlled water bath, and a spectrofluorometer interfaced to a portable computer which controlled the fluorometer and logged the data. This method has been applied to alkaline phosphatase and to leucine aminopeptidase measurements in the surface waters of the Mississippi River plume and the Louisiana shelf, and alkaline phosphatase measurements in the surface waters of a Texas lake. This method will enable us to map the surface distributions of microbial enzyme activities on scales comparable to temperature, salinity, in vivo fluorescence, and other parameters which can be continuously mapped from a research ship while underway.

Descriptors: Enzymes; Methodology; Aquatic ecosystems; Aquatic microorganisms; Mexico Gulf; USA, Texas; Extracellular enzymes; Measuring techniques; Fluorescence; Fluorometry; Computer applications; Alkaline phosphatase; Leucyl aminopeptidase; Freshwater ecosystems; USA, Louisiana; USA, Mississippi R.; Polymers; Enzymatic activity; Biological surveys; Microbiological analysis; Carbon cycle; Surface water; ASW, USA, Louisiana
http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=4779063

9. Amon RWM, Benner R (1998) Seasonal patterns of bacterial abundance and production in the Mississippi River plume and their importance for the fate of enhanced primary production. Microb Ecol 35:289-300

Abstract: Bacterial abundance and leucine incorporation were measured in the Mississippi/Atchafalaya River plume area during May 1992 and July 1993. Both parameters were highest at intermediate salinities during both season. The peak of bacterial leucine incorporation (similar to 2.5 nM h(-1)) and abundance was located at higher salinities in May 1992 than in July 1993. Leucine incorporation rates in surface waters decreased with increasing westward distance from the plume, whereas rates increased below the pycnocline with increasing westward distance. The high rates of bacterial activity in stratified bottom waters could potentially deplete oxygen within 3 to 50 days. The mean values for depth-integrated bacterial production were higher in May 1992 (787 mg C m(-2) d(-1)) than in July 1993 (644 mg C m(-2) d(-1)). The integrated values for bacterial production indicate that a variable proportion of the primary production is consumed by bacteria during spring and summer. Comparisons to the vertical export of POM and zooplankton grazing suggest that zooplankton grazing determines the amount of organic material available for bacterial mineralization in deeper layers. Depth-integrated gross bacterial production rates were highest in May 1992 when vertical export of particulate organic matter (POM) was also the greatest. The response of heterotrophic bacteria to increased organic matter input in the plume area during spring indicates that the microbes play a crucial role in the development of hypoxic conditions on the Louisiana shelf during early summer.

11. Andersson, L. and L. Rydbert. 1988. Trends in nutrient and oxygen conditions within the Kattegat: effects on local nutrient supply. *Estuar. Coastal Shelf Sci.,* **26**, 559-579.

Abstract: The Kattegat forms the outer part of the Baltic estuary. It is characterized by a stable two-layer stratification maintained by approximately equal supplies of low saline water from the Baltic and high saline oceanic water from the Skagerrak. The nutrient supply to these waters increased rapidly during the past decades and oxygen deficits have been reported from different parts of the estuary. In this paper, we have calculated trends in nutrient and oxygen concentrations within the surface and deep waters of the Kattegat and adjacent waters. This has been done with available data for the past decades, with reference to nutrient supply and phytoplankton production.

Oxygen concentrations within the deep water decreased from 4·58 to 4·08 ml l^{-1} between 1971 and 1982, indicating a 50% increase in oxygen consumption. Concentrations of Tot-N, Tot-P and inorganic nitrogen increased simultaneously, both in the surface water during the winter and in the deep-water during the summer. Changes in Tot-N and Tot-P were dominated by the Baltic water, while local supply to the Kattegat dominated the changes in inorganic nitrogen. Increases in Tot-N and Tot-P suggest a successively increasing biomass.

The importance of local nutrient supply to the Kattegat was studied by comparing expected nutrient concentrations within the surface water (due to exchange with adjacent waters) with actually observed concentrations.

12. Barmawidjaja, D. M., G. J. van der Zwaan, F. J. Jorissen and S. Puskaric. 1995. 150 years of eutrophication in the northern Adriatic Sea: evidence from a benthic foraminiferal record. *Mar. Geol*., **122**, 367-384.

Abstract: The vertical distribution of benthic foraminifera in a sediment core in front of the Po delta has been studied in detail. According to our age model, based on Pb-210 and Cs-137 analyses of another core from exactly the same locality, the studied core spans the past 160 years. The radio-isotope profiles further show that sediment mixing is largely restricted to the top centimeter, suggesting that the core should provide an extremely detailed record of the youngest history of the northern Adriatic Sea. Benthic foraminiferal patterns and grain-size analyses indicate a number of substantial changes in sedimentation rate and food/oxygen availability in the benthic ecosystem. Changes occurring at about 1840 and 1880 can be attributed to man-induced changes in the main outflow canals of the Po river. The first one led to an important reduction of the marine vegetation cover which probably was present up to that date. The second change resulted in the present-day situation in which the Po outflow is passing the studied core locality close by. The local benthic foraminiferal associations indicate a steadily increasing nutrient load from 1900 AD onwards. This trend is interpreted as the effect of anthropogenic eutrophication due to agriculture and waste water disposal, although the faunal record as discussed here only gives a limited impression of the basin-wide development. A marked faunal transition around 1930 indicates intensification of the eutrophication; around 1960 the first signs of an increasing importance of anoxic events can be recognized. The faunal changes in the last decade, which are ascribed to changes in preservation potential, indicate that more intense or more prolonged anoxia started about 10 years ago, and that the ecological health of this part of the northern Adriatic probably is still in decline.

19. Bianchi TS, Lambert CD, Santschi PH, Guo LD. 1997. Sources and transport of land-derived particulate and dissolved organic matter in the Gulf of Mexico (Texas shelf/slope): The use of lignin-phenols and loliolides as biomarkers. Organic Geochemistry 27 (1-2): 65-78.

Abstract: The fate and transport of terrestrial organic matter across the continental margin in the Gulf of Mexico was studied in 1992 and 1993 using chemical biomarkers. Lignin-phenols were utilized as biomarkers for terrestrial inputs and indicated that much of the terrestrial organic matter inputs were deposited on the shelf/break and slope. The lignin-phenol concentrations (normalized to carbon) in POC, HMW DOC, and sediments in slope waters were considerably higher than at other open ocean sites studied previously. The dominant mechanism for transport of terrestrially-derived POC and HMW DOC across the shelf and slope was hypothesized to be advection of riverine and: estuarine discharges through benthic nepheloid layers. Based on loliolide concentrations in the water column, we believe that lateral transport of these materials at the shelf/break

(through extensions of benthic nepheloid layers) may have been an important mechanism for the injection of terrestrially-derived organic matter into deep slope waters.

21. Bierman, VJ Jr, Hinz SC, Zhu D, Wiseman WJ Jr, Rabalais NN, Turner RE (1994) A preliminary mass balance model of primary productivity and dissolved oxygen in the Mississippi River plume/inner Gulf Shelf region. Estuaries 17:886-899

Abstract: A deterministic, mass balance model for phytoplankton, nutrients, and dissolved oxygen was applied to the Mississippi River Plume/Inner Gulf Shelf (MRP/IGS) region. The model was calibrated to a comprehensive set of field data collected during July 1990 at over 200 sampling stations in the northern Gulf of Mexico. The spatial domain of the model is represented by a three-dimensional, 21-segment water-column grid extending from the Mississippi River Delta west to the Louisiana-Texas border, and from the shoreline seaward to the 30-60 m bathymetric contours. Diagnostic analyses and numerical experiments were conducted with the calibrated model to better understand the environmental processes controlling primary productivity and dissolved oxygen dynamics in the MRP/IGS region. Under water light attenuation appears relatively more important than nutrient limitation in controlling rates of primary productivity. Chemical-biological processes appear relatively more important than advective-dispersive transport processes in controlling bottom-water dissolved oxygen dynamics. Oxidation of carbonaceous material in the water column, phytoplankton respiration, and sediment oxygen demand all appear to contribute significantly to total oxygen depletion rates in bottom waters. The estimated contribution of sediment oxygen demand to total oxygen-depletion rates in bottom waters ranges from 22% to 30%. Primary productivity appears to be an important source of dissolved oxygen to bottom waters in the region of the Atchafalaya River discharge and further west along the Louisiana inner Shelf. Dissolved oxygen concentrations appear very sensitive to changes in under water light attenuation due to strong coupling between dissolved oxygen and primary productivity in bottom waters. The Louisiana Inner Shelf in the area of the Atchafalaya River discharge and further west to the Texas border appears to be characterized by significantly different light attenuation-depth-primary productivity relationships than the area immediately west of the Mississippi Delta. Nutrient remineralization in the water column appears to contribute significantly to maintaining chlorophyll concentrations on the Louisiana Inner Shelf.

22. Bierman, Jr., V. J., S. C. Hinz, K. A. Nelson, D. P. Podber, D.-W. Zhu, W. J. Wiseman, Jr., N. N. Rabalais, and R. E. Turner. 1999. Modeling. Chapter 6, pages 103-125 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No. 14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

25. Biggs, DC and LL Sanchez. 1997. Nutrient enhanced primary productivity of the Texas-Louisiana continental shelf. JOURNAL OF MARINE SYSTEMS 11 (3-4): 237-247

Abstract: Light bottle and dark bottle C-14 uptake was measured on deck in 4-6 h shipboard incubations at 12 locations on the NW continental margin of the Gulf of Mexico in July and at 9 locations in October 1990. In July, rates of P-max m(-3) h(-1) were higher than previously reported for the Texas-Louisiana shelf, and daily production calculated from these 4-6 h incubations was 1-1.4 g C m(-2) d(-1) at most inner and middle shelf locations. However, in May-June 1990 freshwater discharge from the nitrate-rich Mississippi-Atchafalaya river system and from the Trinity River had reached highest recorded outflows in many years; near-surface nitrate concentrations over the Texas-Louisiana shelf remained well above the 0.05 mu M l(-1) limit of detection into July. In contrast, near-surface nitrate concentrations were close to or at the limit of detection in October. Reflecting this variation in nitrate inventory, in July the production index (P/B ratio) at stations near riverine and estuarine nutrient sources and over the inner shelf reached 40 mg C fixed m(-3) h(-1).(mg chl m(-3))(-1), whereas in October this index generally was 2- to 3-fold tower. Thus, primary productivity of the Texas-Louisiana continental margin appears to be moderate when not enhanced by the high "new" nitrogen nutrient loads that enter via riverine/estuarine outflows. Since the volume of freshwater discharge varies markedly on seasonal and interannual time scales, we suggest that "discharge driven" is a more appropriate description of the primary productivity of this subtropical continental margin than is its spatial partition into regions of high (250-500), medium (150-250) and low (100-150 mg C m(-2) d(-1)) mean production.

26. Blackwelder P, Hood T, AlvarezZarikian C, Nelsen TA, McKee B. 1996. Benthic foraminifera from the NECOP study area impacted by the Mississippi River plume and seasonal hypoxia. Quaternary International 31: 19-36.

Abstract: Benthic foraminifera influenced by the Mississippi River plume and seasonal hypoxia were assessed from Louisiana inner-continental shelf sediment samples. Surface foraminifera assembla,aes were representative of in-situ populations as established by staining techniques. Community diversity and richness/evenness analyses indicate three regimes: high stress (sediment dominated), intermediate stress (hypoxia dominated), and low stress (low sediment accumulation/high oxygen). Epistominella vitrea and Buliminella morgani are useful tracers of rapid sediment accumulation rate and hypoxia. A bottom-water productivity signal west of the Mississippi River plume is indicated by benthic and planktic foraminifera abundance peaks. Surface benthic foraminifera trends are utilized to interpret changes in historical community structure from hypoxic area sediments deposited since the turn of the century. The hypoxia-tolerant species Buliminella morgani increases markedly upcore, while hypoxia intolerant species decrease or disappear. Diversity and dominance trends temporally correspond to a dramatic increase in U.S. fertilizer application. The results of this study have application to paleoenvironmental research spanning longer geologic timescales. The documented relationships between population structure and stressors in river-dominated marine systems may provide a useful analog for recognition of these conditions in the fossil record.

27. Bode, A and Q Dortch. 1996. Uptake and regeneration of inorganic nitrogen in coastal waters influenced by the Mississippi River: Spatial and seasonal variations. Journal of Plankton Research 18 (12): 2251-2268

Abstract: The Mississippi and Atchafalaya Rivers introduce large amounts of nutrients to surface waters of the northern Gulf of Mexico. This paper reports the most complete data to date on inorganic nitrogen uptake and regeneration in a broad range of coastal environments influenced by the river water, along with information on nutrient concentrations and including pico-, nano-, and microplank ton species composition. Nitrate in surface waters is greatly reduced near the river plume, at salinities between 5 and 25 PSU, where the largest variance in uptake rates was observed, and was coincident with peaks in surface chlorophyll. Despite the depletion of nitrate, nitrogen limitation was a rare event during the study, because of relatively high ammonium concentrations (>1 mu mol NH4+ l(-1)) and regeneration rates. Two contrasting situations characterize the seasonal nitrogen dynamics in surface shelf waters. High nitrate input during the spring caused a large bloom in which the cells were well adapted to use nitrate. The dominant phytoplankton species were chain forming diatoms, also reported in sediment-trap studies in the area. Ammonium regeneration only accounted for a small fraction of the nitrogen requirements during the bloom. In contrast, the low now of river water during summer resulted in low nitrate concentrations in surface water. In this case phytoplankton productivity was highly reduced and may depend greatly on 'in situ' ammonium regeneration.

44. Castillo MLM, Sen Gupta BK, Alcala-Herrera JA. 1998. Late Quaternary change in deep-bathyal and abyssal waters of the Gulf of Mexico: Preservation record of the foraminifer *Biloculinella irregularis.* Journal of Foraminiferal Research 28 (2): 95-101.

Abstract: The stratigraphic distribution of the porcelaneous benthic foraminifer Biloculinella irregularis, whose tests are constructed of high-Mg calcite, indicates major changes in the deep bottom waters of the Gulf of Mexico and the Caribbean Sea during the late Quaternary. The record of B. irregularis in six cores from the southern Gulf of Mexico (960-2,735 m) and the Venezuela Basin (3,925 m) shows that the species, rare or absent in the Holocene, was preserved in significant numbers during the last glacial interval. This distribution is consistent with that found in previous investigations in the Venezuela and Grenada Basins. The occurrence of B. irregularis is associated with an increased abundance of the aragonitic shells of pteropods. This association suggests that the Gulf Basin Water and Caribbean Bottom Water were less corrosive during the last glacial stage than during the Holocene, and permitted the proliferation and/or preservation of dissolution-prone, metastable carbonate shells. The changes in the properties of the deep-bathyal and abyssal waters of the Gulf and the Caribbean at the Pleistocene-Holocene transition are linked with those of an intermediate water (Upper North Atlantic Deep Water) flowing over the Atlantic-Caribbean sills.

45. Cederwall, H. and R. Elmgren. 1990. Biological effects of eutrophication in the Baltic Sea, particularly the coastal zone. *Ambio*, **19**, 109-112.

Abstract: The reported biological effects of the increased nutrient load on the Baltic Sea are summarized, with some comparisons with the Kattegat and Skagerrak. Interest is focused on the coastal zone, where effects are more obvious than in offshore areas, but from which results have not often been published internationally. Reports demonstrate environmental degradation over extensive coastal areas of the Baltic Sea. Recorded effects include increased nutrient levels; increased algal blooms, chlorophyll a concentrations, and primary productivity; decreased water transparency and decreased depth penetration of Fucus vesiculosus ; increased deposition of organic matter on the bottom and increased frequency and severity of oxygen deficiency in bottom waters; and reduction of bottom fauna.

Descriptors: eutrophication; coastal environments; primary production; algal blooms; species composition; algae; pollution effects; marine pollution; phytoplankton; coastal zone; dissolved oxygen; nutrients (mineral); Fucus vesiculosus
http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=2257789

46. Chen CS, Wiesenburg DA, Xie LS. 1997. Influences of river discharge on biological production in the inner shelf: A coupled biological and physical model of the Louisiana-Texas shelf. Journal of Marine Research 55 (2): 293-320.

Abstract: A coupled biological and physical model was applied to study the influence of river discharge on biological variability on the Louisiana-Texas (LATEX) continental shelf. The physical part included a primitive-equation turbulent closure model, and the biological part was a simple phytoplankton (P), zooplankton (Z), and nutrient (N) model. The model was forced by freshwater discharge from the river and ran prognostically under initial conditions of springtime water stratification and a steady-state solution of the P-Z-N model with no horizontal dependence. A nutrient source was included at the mouth of the river. The model predicted a well-defined density frontal zone on the inner shelf. The biological field showed a region of high phytoplankton biomass in the whole water column near the coast and a moderately high biomass patch in the upper 10 m at the outer edge of the frontal zone. A high concentration dome of nutrients was found near the bottom within the frontal zone. New production of nutrients was high throughout the whole water column near the coast and in the upper 10 m at the outer edge of the density front, but lower in the frontal zone. The model results were in reasonable agreement with observational data taken from a May 1993 interdisciplinary survey on the LATEX shelf.

Cross-shelf distribution of biological production varied significantly with direction of wind stress but not with the diurnal tide. The model results suggested that the bottom-rich nutrient distribution within the frontal zone was caused by the interaction of physical and biological processes. Physical processes caused the formation of an area of high nutrient concentration in the weak current region within the frontal zone. Subsequent biological processes limited the increase of nutrients in the upper euphotic zone and hence led to the bottom-rich nutrient pattern.

51b. Chin-Leo G, Benner R (1992) Enhanced bacterioplankton production at intermediate salinities in the Mississippi River plume. Mar Ecol Prog Ser 87:87-103

Abstract: Bacterial abundance and production (thymidine and leucine incorporation) were measured along a salinity gradient from the Mississippi River (0 parts per thousand) to the open waters of the Gulf of Mexico (36 parts per thousand) during July-August 1990 and February 1991. Bacterial production in surface waters was maximal at intermediate salinities (15 to 30 parts per thousand). Nutrient enrichment experiments suggested that bacterial growth near the outflow of the river was C limited whereas bacteria in plume waters of intermediate salinities were P and N limited. Rates of plankton community oxygen demand measured during winter were also maximal at intermediate salinities indicating an area of increased heterotrophic activity. The oxygen demand associated with heterotrophic bacterioplankton activity during summer was an important factor leading to hypoxic conditions in bottom waters of the Louisiana continental shelf. In summer, bacterial abundance and production ranged from 0.25 to 3.34 x 10(9) cells l-1 and from 4 to 90 mug C l-1 d-1, respectively. In winter, the corresponding ranges were 0.36 to 1.09 x 10(9) cells l-1 and 3 to 20 mug C l-1 d-1. Depth-integrated bacterial production on the Louisiana shelf decreased from 443 +/- 144 mg C m-2 d-1 in summer to 226 +/- 124 mg C m-2 d-1 in winter. Using empirically-derived bacterial growth efficiency values of 19 and 29 %, we estimated that bacterial production in summer could be supported by 10 to 58 % of phytoplankton production. In winter, the amount of carbon needed to support bacterial production exceeded phytoplankton production suggesting that bacterial growth during this season was heavily dependent on riverine sources of organic matter.

53. Cochrane JD, Kelly FJ. 1986. Low-Frequency Circulation on the Texas-Louisiana Continental-Shelf. Journal of Geophysical Research-Oceans 91 (C9): 645-659.

Abstract: For the Texas-Louisiana coast west of 92.5°W, long series of data from near Freeport,Texas, together with shorter series from other locations show strong response of coastal current to wind stress in agreement with coastal jet concepts. We infer from coastal winds, scattered current measurements, and distribution of sea-surface salinity and geopotential that a cyclonic gyre elongated along the shelf is the dominant feature of the prevailing shelf circulation. The inshore limb of the gyre is the coastal jet driven by wind with a west or southward (downcoast) component which prevails along much of the coast except in July-August. Because the coast is concave, the shoreward prevailing wind results is a convergence of coastal currents, which marks the downcoast extent of the gyre. Corresponding to the convergence is a seaward flow which forms the southwest limb of the gyre. A prevailing countercurrent (north or eastward flow) along the shelf break includes the outer limb of the gyre. The eastern, shoreward-flowing limb of the gyre corresponds to divergence along the coast centered near 92.5°W. The convergence at the western or southern end of the gyre migrates seasonally with the direction of the prevailing wind, reaching south of the Rio Grande mouth in fall and the Cameron offing in July. The gyre is normally absent in July, but reappears in August-September when a downcoast wind component develops.

56. Conley, D. J., C. L. Schelske and E. F. Stoermer. 1993. Modification of the biogeochemical cycle of silica with eutrophication. *Mar. Ecol. Prog. Ser.*, **101**, 179-192.

Abstract: Nutrient enrichment dnd consequent alteration of nutrient biogeochemical cycles is a serious problem in both freshwater and marine systems. The response of aquatic systems to additions of N and P is generally to increase algal biomass. The partitioning of these nutrients into different functional groups of autotrophic organisms is dependent upon both intrinsic and extrinsic factors. A common response to nutrient loading in northern temperate aquatic ecosystems is an increase in diatom biomass. Because nutrient enrichment generally leads to increases in water column concentrations of total N and total P (and not Si) such nutrient loading can lead to transient nutrient limitation of diatom biomass due to lack of dissolved silicate (DSi). Increased production of diatom biomass can lead to an increased accumulation of biogenic silica in sediments, ultimately resulting in a decline in the water column reservoir of DSi. Such biogeochemical changes in the silica cycle induced by eutrophication were first reported for the North American Laurentian Great Lakes. However, these changes are not a regional problem confined to the Great Lakes, but occur in many freshwater and marine systems throughout the world. Here we summarize the effects of anthropogenic modification of silica biogeochemical cycles for the North American Laurentian Great Lakes, describe some of the biogeochemical changes occurring in other systems, and discuss some of the ecological implications of a reduction in water column DSi concentrations, including changes in species composition, as DSi concentrations become limiting to diatom growth and biomass, changes in food web dynamics, and altered nutrient-recycling processes.

57. Conley, D. J., and A. B. Josefson (1999), Hypoxia, nutrient management and restoration in Danish waters, in Effects of Hypoxia on Living Resources, with Emphasis on the Northern Gulf of Mexico, edited by N. N. Rabalais and R. E. Turner, p. in press.

58. Cooper, S. R. and G. S. Brush. 1991. Long term history of Chesapeake Bay anoxia. *Science*, **254**, 992-996.

Abstract: Stratigraphic records from four sediment cores collected along a transect across the Chesapeake Bay near the mouth of the Choptank River were used to reconstruct a 2000-year history of anoxia and eutrophication in the Chesapeake Bay. Variations in pollen, diatoms, concentration of organic carbon, nitrogen, sulfur, acid-soluble iron, and an estimate of the degree of pyritization of iron indicate that sedimentation rates, anoxic conditions and eutrophication have increased in the Chesapeake Bay since the time of European settlement.

60. Cotner JB, Gardner WS (1993) Heterotrophic bacterial mediation of ammonium and dissolved free amino-acid flux in the Mississippi River plume. Mar Ecol Prog Ser 93:75-87

Abstract: Bacterial nitrogen regeneration processes are an important source of nitrogen in the most productive regions of the Mississippi River plume (Gulf of Mexico). We examined bacterial growth rates, ammonium regeneration rates, and labile dissolved

organic carbon/nitrogen fluxes on 2 cruises in the Mississippi River plume. In summer, surface water bacterial production rates, ammonium regeneration rates, and amino acid turnover rates were higher at intermediate salinities than corresponding rates at the river mouth or in high salinity waters. In winter, surface amino acid turnover rates were highest in the river but growth rates were highest in the plume and ammonium regeneration rates were similar at all sites. Regeneration rates in the plume were an order of magnitude greater in the summer than in the winter. A significant proportion of the bacterial nitrogen demand may be provided by amino acid fluxes in summer, especially in the plume. Measurements of NH4 regeneration after manipulating bacterial abundances suggest that heterotrophic bacteria contributed a variable proportion (7 to 50 %) of total N-regeneration in summer and that dissolved free amino acids could be a major substrate for ammonium regeneration. Depth profiles, spatial distributions, and seasonal differences in ammonium regeneration rates imply that the fastest regeneration rates occur spatially and temporally where primary production is the greatest.

61. Dagg MJ, Ortner PB, Alyamani F. 1988. Winter-time distribution and abundance of copepod nauplii in the Northern Gulf of Mexico. Fishery Bulletin 86 (2): 319-330.

Abstract: Copepod nauplii were collected from continental shelf waters in 3 regions of the northern Gulf of Mexico during winters between 1981 and 1984, off Cape San Blas, Florida, off the Mississippi River delta and off of Galveston, Texas. Some statistically significant ($P < 0.05$) patterns in the abundance and distribution of nauplii were observed: There was significant interannual variability in naupliar concentrations within the region around the Mississippi River delta; naupliar concentrations in the upper 10 m decreased in the onshore-offshore direction 2 of 4 comparisons; naupliar concentrations in the upper 10 m differed regionally in 2 of 3 comparisons; and naupliar concentration was correlated with chlorophyll concentration in nauplii (number per m super(3)) within a water column were 2-10 times greater at stations influenced by the Mississippi River plumes than in the other 2 regions. This condition in attributed to vertical stratification imparted to the water column by the inflowing low salinity water from the Mississippi River. The authors conclude that the physical stratification provides a mechanism for the establishment of high concentrations of nauplii that otherwise would not exist in the winter months on the continental shelf.
http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=1936069

62. Dagg MJ. 1988. Physical and biological responses to the passage of a winter storm in the coastal and inner shelf waters of the Northern Gulf of Mexico. Continental Shelf Research 8 (2): 167-178.

Abstract: Hydrographic and biological properties in coastal and inner shelf waters of the northern Gulf of Mexico were monitored daily over 3 days in February 1984, immediately after the passage of a meteorological front. Strong northerly and westerly components of the wind resulted in upwelling of high salinity inner shelf water containing low nitrate and chlorophyll concentrations. Low salinity coastal water, with associated high concentrations of chlorophyll and nitrate, was transported offshore at the

surface. Isopleths sloping from the surface to the bottom over a distance of approximately 10 km characterized an oceanographic front that separated the two water types of day 1. The frontal boundary became more compact and decreased in slope on day 2, and isopleths were essentially horizontal by day 3, with the coastal water overlying the inner shelf water.

63. Dagg, M., C. Grimes, S. Lohrenz, B. McKee, R. Twilley, and W. J. Wiseman (1991), Continental shelf food chains of the northern Gulf of Mexico, in Food Chains, Yields, Models, and Management of Large Marine Ecosystems, edited by K. Sherman, et al., pp. 67-106, Westview Press, Boulder, CO.

64. Dagg MJ, Whitledge TE. 1991. Concentrations of copepod nauplii associated with the nutrient-rich plume of the Mississippi River. Continental Shelf Research 11 (11): 1409-1423.

Abstract: During spring and summer, discharge plumes of the Mississippi River were located visually by water color. Temperature, salinity, nutrients, chlorophyll a and copepod nauplii were sampled coincidently in a cross-plume direction. Plume waters contained high concentrations of nitrate, silicate and chlorophyll during both spring and summer. Nitrate was depleted before silicate during summer but not during spring. During spring, concentrations of copepod nauplii (50-100 l-1) were similar to those reported in an earlier wintertime study in this region. Summertime concentrations of nauplii were much higher, sometimes > 1000 l-1. Nauplii were associated with plume waters. Strong seasonality in zooplankton production is suggested, with greatest production in summer. Consequently, a larger proportion of plume phytoplankton production should sink directly to the bottom during spring and a larger proportion of the summertime production should be consumed in the water column by grazers.

65. Dagg, M.J. 1995. Copepod grazing and the fate of phytoplankton in the Northern Gulf-of-Mexico. Continental Shelf Research 15 (11-12): 1303-1317.

Abstract: Ingestion of phytoplankton by the copepod community was measured during spring (May 1992) and late summer (September 1991) at two sites in the northern Gulf of Mexico. During both studies, influence of the Mississippi River was more evident at the plume site, located near the mouth of the Mississippi River, than at the mid-shelf site, located farther from river discharge. With the exception of the plume site during spring, the copepod community ingested 14-62% of the daily phytoplankton production. The small transfer (4-5%) of phytoplankton to copepods in spring at the plume site is attributed to high river discharge, which stimulates phytoplankton production to very high rates before the copepod community can numerically respond sufficiently to take advantage of this bloom. This response is also slowed by cooler temperatures in the spring (22 degrees C) compared to the late summer (29 degrees C). In addition to copepods, larvaceans were abundant at all study sites. Indirect estimates of their nutritional demands indicate they were important grazers. The copepod community consumes a significant fraction of the phytoplankton production that is stimulated by riverine nutrient inputs in this region.

66. Dagg M.J., Green EP, McKee BA, Ortner PB. 1996. Biological removal of fine-grained lithogenic particles from a large river plume. JOURNAL OF MARINE RESEARCH 54 (1): 149-160.

Abstract: The pelagic tunicate, Oikopleura dioica, feeds by non-selectively filtering particles in the size range of 0.2-20 mu m. Tn the northern Gulf of Mexico, particulate matter in this size range contains large amounts of fine-grained lithogenic material because of the influence of the Mississippi River. During May 1992, O. dioica populations filtered between 2 and 44% (mean = 20%) of the upper 5 m each day. The filtered lithogenic particles either remain in the oikopleurid house or are defecated in fecal pellets which have high sinking velocities. Either way, the larvacean populations significantly alter the fates of fine-grained lithogenic particles in these waters and thereby enhance light penetration. The widespread occurrence of oikopleurids in coastal regions of temperate and subtropical oceans suggests they could have a significant influence on the fates of fine-grained lithogenic particles in discharge plumes of many of the world's large, sediment-laden rivers.

70. Dauer, D. M., A. J. Rodi, Jr. and J. A. Ranasinghe. 1992. Effects of low dissolved oxygen events on the macrobenthos of the lower Chesapeake Bay. *Estuaries*, **15**, 384-391.

Abstract: The effects of low dissolved oxygen or hypoxia (<2 mg l-1) on macrobenthic infaunal community structure and composition in the lower Chesapeake Bay and its major tributaries, the Rappahannock, York, and james rivers are reported. Macrobenthic communities at hypoxia-affected stations were characterized by lower species diversity, lower biomass, a lower proportion of deep-dwelling biomass (deeper than 5 cm in the sediment), and changes in community composition. Higher dominance in density and biomass of opportunistic species (e.g., euryhaline annelids) and lower dominance of equilibrium species (e.g., long-lived bivalves and maldanid polychaetes) were observed at hypoxia-affected stations. Hypoxia-affected macrobenthic communities were found in the polyhaline deep western channel of the bay mainstem north of the Rappahannock River and in the mesohaline region of the lower Rappahannock River. No hypoxic effects on the infaunal macrobenthos were found in the York River, James River, or other deep-water channels of the lower Chesapeake Bay.

72. de Jonge, V. N. 1990. Response of the Dutch Wadden Sea ecosystem to phosphorus discharges from the Rhine River. *Hydrobiologia,* **195**, 49-62.

Abstract: The primary production in the western part of the Dutch Wadden Sea (Marsdiep tidal basin) has been reported to have increased by a factor of two since the late 1970s. This doubling of the phytoplankton and the microphytobenthos production has been ascribed to the eutrophication of that area: mean annual phosphate concentrations have increased, whereas the nitrogen concentrations have not. Analysis of the available production data indicates a more than tenfold increase of the production of the phytoplankton in the Marsdiep tidal channel since the early 1950s. The increase in the phytoplankton production in the inner area seems to be of the same order of magnitude.

The primary production of the phytobenthos and the secondary production of the macrozoobenthos seems to have increased proportionally to that of the phytoplankton. It is known that the nutrients in the Marsdiep tidal basin originate from the River Rhine. However, there are two possible routes for nutrients to reach that area. One is via the River IJssel and Lake IJssel (varying amounts of fresh water are sluiced out from the latter into the Wadden Sea). The other is along the coast of the North Sea, where the water transport is driven northeastwards by the residual current. Analysis of available data shows that the annual primary production in the Marsdiep tidal basin is mainly determined by the phosphate discharge from Lake IJssel which directly reach that part of the Wadden Sea, rather than from the River Rhine of which the water must run northward along the coast before reaching the western Dutch Wadden Sea. The close relation between fluctations in annual phosphate discharges and fluctations in annual phytoplankton primary production up to more than ten times the 1950 values indicates that primary production in the Marsdiep tidal channel and probably even in the main part of the whole basin, was and is phosphate limited. The mineralization of North Sea particulate organic matter inside the Wadden Sea, previously thought to be the main phosphate source, is questioned. The repercussions of this finding for management are discussed.

http://www.springerlink.com/(ugfne255h2hq2l55ffbq2rmy)/app/home/contribution.asp?referrer=parent&backto=issue,6,18;journal,430,837;linkingpublicationresults,1:100271,1

73. Diaz, R. J. and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. *Ocean. Mar. Biol. Ann. Rev.,* **33**, 245-303.

Abstract: In this review the effects of hypoxia on benthic fauna are summarized and detailed information is given on (1) the impact on community structure and function in fjords, estuaries, coastal and offshore areas (2) behavioural changes (3) recovery processes (4) ecosystem energy flow implications, and (5) tolerance in experimental studies. There is no other environmental variable of such ecological importance to coastal marine ecosystems that has changed so drastically in such a short period as dissolved oxygen. While hypoxic and anoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing, most likely accelerated by human activities. Ecological problems associated with the occurrence of low oxygen are increasing on a global scale. The oxygen budgets of most major estuarine and coastal ecosystems have been adversely affected mainly through the process of eutrophication, which acts as an accelerant or enhancing factor to hypoxia and anoxia, and when coupled with adverse meteorological and hydrodynamic events, hypoxia increases in frequency and severity. The area of hypoxic and anoxic bottom water is even increasing within systems that historically are considered oxygen stressed. Many ecosystems that are now severely stressed by hypoxia appear to be near or at a threshold. Should oxygen concentrations become slightly lower, catastrophic events may overcome the systems and alter the productivity base that leads to fisheries species. Examples of such events are becoming increasingly common. At what point permanent damage will result is difficult to say. To dare there is no large system that has recovered

after development of persistent hypoxia or anoxia. The only exception may be small systems where pollution inputs have ceased and recovery initiated from surrounding non-affected areas. The expanding occurrence of hypoxia and anoxia continues to bring about significant structural changes in benthic communities and to affect benthic-pelagic coupling. Restoring ecosystem balance and reversing the trend of increasing hypoxia and anoxia will require dealing with the global problem of coastal eutrophication and determining how to reduce the production of organic matter in sensitive estuarine and coastal areas.

76. Dortch, Q., D. Milsted, N. N. Rabalais, S. E. Lohrenz, D. G. Redalje, M. J. Dagg, R. E. Turner, and T. E. Whitledge (1992), Role of silicate availability in phytoplankton species composition and the fate of carbon, in Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991, NOAA Coastal Ocean Program, edited by T. S. G. Program, pp. 76-83, Texas Sea Grant Program, College Station, TX.

Ordering information: http://texas-sea-grant.tamu.edu/pubs/pubcat/pubs.php?topic=Urban+Coasts

77. Dortch, Q. and T. E. Whitledge. 1992. Does nitrogen or silicon limit phytoplankton production in the Mississippi River plume and nearby regions? *Cont. Shelf Res.*, **12**, 1293-1309.

Abstract: The Mississippi River carries very high concentrations of nutrients into the otherwise oligotrophic Gulf of Mexico, resulting in high primary production and hypoxia along the Louisiana continental shelf. The hypothesis that nitrogen availability controls and ultimately limits phytoplankton production on the shelf was tested by measuring an indicator of nitrogen deficiency, the ratio of intracellular free amino acids/particulate protein (AA/Pr), in the area of the Mississippi River plume on a spring and a summer cruise. Neither AA/Pr ratios or nutrients in the water showed nitrogen limitation to be widespread. Ammonium concentrations were generally quite high, so the lack of phytoplankton nitrogen deficiency can be explained by rapid regeneration rates. Nitrogen limitation was most likely in the summer at high salinities. However, ratios of dissolved nutrient concentrations suggested that silicate was as likely, or sometimes more likely, to be a limiting nutrient than nitrogen. Although silicate depletion may not cause a decrease in productivity, it could result in major changes in phytoplankton size and species composition, and ultimately influence trophodynamics, regeneration, the fate of carbon, and severity and extent of hypoxia.

78. Dortch Q, Rabalais NN, Turner RE, Rowe GT (1994) Respiration rates and hypoxia on the Louisiana shelf. Estuaries 17:862–872.

Abstract: The spatial and temporal variation in water-column respiration, estimated from enzymatic respiratory electron-transport-system activity, was measured monthly on a cross-shelf transect on the Louisiana shelf from May through October 1991. In July 1991, water-column respiration was also determined on an alongshore transect, and in situ benthic respiration and photosynthesis rates were determined at four stations on the cross-shelf transect. Bottom waters were persistently hypoxic (O-2 < 2 mg l(-1)) at most

stations in July and August and sporadically hypoxic at other times. Water-column respiration rates were in the same range as earlier, less extensive studies and not unusually high for coastal and estuarine waters. They were highest in summer, decreased with distance offshore and depth, and increased with temperature. Their variation with pigment and oxygen concentrations were complex functions of season and depth. Oxygen depletion below the oxycline could occur within days to months, depending on the season and location. In July, benthic respiration rates were also not unusually high in comparison with other shallow sediments, although the ratio of benthic:total (water column + benthic) respiration was high. Combined water-column and benthic respiration could deplete the bottom water oxygen in approximately 1 mo. Because the system rarely goes anoxic (defined as observing sulfide), some mechanism(s) must exist to reaerate bottom waters. Most physical mechanisms are unlikely to provide significant reaeration at this time of year. Measured benthic and conservatively estimated bottom-water photosynthesis could resupply 23% of the oxygen lost daily by respiration. Although this is too limited a dataset from which to draw conclusions about the relative importance of bottom-water and benthic respiration and photosynthesis in determining bottom-water oxygen concentrations, it does suggest that all these processes must be considered.

80. Duce, R. A. 1986. The impact of atmospheric nitrogen, phosphorus, and iron species on marine biological productivity. Pp. 497-529 in P. Baut-Menard (ed.), *The Role of Air-Sea Exchange in Geochemical Cycling.* Reidel.

84. Fahnenstiel, G. L., M. J. McCormick, G. A. Lang, D. G. Redalje, S. E. Lohrenz, M. Markowitz, B. Wagoner, and H. J. Carrick (1995), Taxon-specific growth and loss rates for dominant phytoplankton populations from the northern Gulf of Mexico, Marine Ecology Progress Series, 117, 229-239.

Abstract: Taxon-specific growth and sedimentation rates of dominant phytoplankton were measured during 2 cruises (summer 1990 and spring 1991) in the northern Gulf of Mexico as part of the NOAA Nutrient-Enhanced Coastal Ocean Productivity (NECOP) program. Microzooplankton grazing rates also were measured during the summer cruise. During each of the cruises, a series of stations from the Mississippi River mouth to the hypoxia region (located ca 50 to 100 km west) were sampled to examine variability of growth and loss processes along a strong environmental gradient. Significant taxa- and group-specific differences were noted for both growth and loss rates. Growth rates ranged from <0.1 to 3.0 d(-1) with highest rates in the plume region during the summer cruise, where surface rates were close to or exceeded previous mu(max), values for several taxa. For all taxa, growth rates were lower in the hypoxia region (mean = 0.5 d(-1)) than in the plume region (mean = 1.1 d(-1)); soluble nitrogen concentrations explained over 50 % of the variability in growth rates. Diatom growth rates were similar to non-diatoms in the plume region, but were significantly lower in the hypoxia region, which suggests that silica limitation may exist in this region. The fate of phytoplankton appeared to be controlled by size and by the degree of silicification. Significant microzooplankton grazing loss rates were noted only for small taxa (<20 mu m). For microflagellates, microzooplankton grazing rates averaged 82 % (range 42 to 214%) of the growth rate; sedimentation rates were always <1% of the growth rate. Sedimentation was an important

loss for several diatoms, with significant taxon-specific and seasonal differences noted. Large colonial diatoms, such as Skelelonema costatum and Thalassiosira rotula, exhibited the highest sedimentation rates in the plume region during the spring cruise(0.2 to 1.0 d(-1)), whereas the lowest rates (< 0.01 d(-1)) were noted for Rhizosolenia fragilissima and Cera tulina pelagica in the hypoxia region during the summer cruise. Our results suggest that in the northern Gulf of Mexico, phytoplankton rate processes proceed very rapidly, with growth rates primarily controlled by the supply of nitrogen via the Mississippi River and the fate controlled primarily by size and density (silicification).

87. Gallaway, B. J., J. G. Cole, R. Meyer, and P. Roscigno (1999), Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico, Transactions of the American Fisheries Society, 128, 713-726.

Abstract: Seasonal habitat suitability index models were developed for juvenile red snapper Lutjanus campechanus in the western Gulf of Mexico. Habitat factors considered in the analysis included water temperature, salinity, and dissolved oxygen at the bottom; depth and density of offshore petroleum platforms; and low-relief bottom structures. High-value habitat for juvenile red snapper is characterized by depths between 18 and 64 m, water temperatures of 24-26 degrees C, salinities around 35%, and dissolved oxygen levels of at least 5 mg/L. Density of low-relief structures was not a significant habitat element, and an inverse association was found between juvenile red snapper abundance and the density of offshore platforms. Results of the model analysis suggest that the step-like expansion of the hypoxic area (dissolved oxygen less than or equal to 2 mg/L) offshore of the mouth of the Mississippi River and west to the Louisiana-Texas border, which first occurred in 1993, has reduced habitat carrying capacity for juvenile red snapper in this region by up to 25%, averaging 19%. This environmental change may limit the level to which overfished Golf red snapper stocks can be rebuilt to historical levels.

90. Gardner WS, St John PA (1991) High-performance liquid chromatographic method to determine ammonium ion and primary amines in seawater. Anal Chem 63: 537-540

Abstract: The close interactions of ammonium ion and amino acids with various autotrophic and heterotrophic organisms in aquatic foodwebs *(1-10)* make it desirable to simultaneously measure these two types of dissolved nitrogen in seawater or lake water. Ammonium ion in seawater is now most commonly measured colorimetrically *(I l)* , and dissolved free amino acids (DFAA) are either measured as individual compounds by high-performance liquid chromatography (HPLC) *(12)* or as groups of primary amines after reaction with Fluorescamine (13) or o-phthalaldehyde (OPA) *(14-17).* The advantages and disadvantages of measuring individual amino acids vs. measuring primary amines as a group (i.e., the "global" approach) in aquatic ecosystems have recently been discussed in detail*(14).*

o-Phthalaldehyde, in combination with 2-mercaptoethanol, forms strongly fluorescing derivatives with most amino acids in aqueous solutions *(18)* and has been widely used

for measuring amino acids (and ammonium ion) both as a postcolumn *(19)* and precolumn *(12)* reagent. It is also a useful reagent for measuring primary amines as a group, but if the primary amines are not first isolated from ammonium ion (e.g., refs 16 and 171, the results must be corrected for ammonium ion interference *(14).* Although the fluorescence response is generally much lower for ammonium ion than for most organic primary amines *(17),* this correction is important because concentrations of ammonium ion are commonly higher than those of primary amines in natural waters. For example, in sediment pore waters, ammonium ion concentrations are usually several times higher than those of total free amino acids *(20).*

Ammonium ion can also be measured as a fluorescent derivative(s) of OPA *(21-24),* but likewise, if it is not first separated from amino acids, measurements are subject to interferences from primary amines. This potential interference has recently been substantially reduced, in a flow injection technique, by using sulfite rather than 8-mercaptoethanol in the OPA reagent *(24).* Ammonium ion can also be separated from primary amines by increasing the pH of the water and allowing the ammonia to diffuse into receiving solutions through porous membranes in continuous-flow systems *(22,25).* Alternatively, ammonium ion can be separated from primary amines by ion-exchange chromatography and then reacted with OPA and measured fluorometrically *(21, 26).* This approach not only removes potential interferences but also can provide measurements of both ammonium ion and primary amines in the same sample. Like other OPA techniques, it has the advantages of small sample size and multiday stability of buffers and reagents. The inconveniences of the chromatographic method, as originally described for ammonium ion analysis *(21),* are low fluorometric response for ammonium ion relative to that for primary amines, decreased column efficiency with increasing salinity, and the need to assemble a specialized analytical system driven by gas pressure to make the measurements.

In this paper, we describe an improved HPLC method to analyze small water samples for both ammonium ion and primary amines. A high-efficiency cation-exchange column, combined with modified buffer and reagent solutions, a pulse-damped HPLC pump, and a peristaltic pump-driven postcolumn OPA detection system, provides rapid and complete resolution and sensitive analysis of ammonium ion and primary amines in seawater.

EXPERIMENTAL SECTION

The HPLC system (Figure 1) was assembled from an isocratic HPLC pump (Altex lOOa or Anspec 909), a pulse damper (Scientific Systems Inc., Model LP-2), a sample injection valve (Rheodyne 7125) equipped with a 50-pL sample injection loop, a machined 28-mm **X** 2.4-mm-i.d. Delrin column containing a high-performance strong cation-exchange resin (5-pm beads of sodium-form sulfonic acid cation exchanger with 12% cross-linked **polystyrene/divinylbenzene** polymeric matrix; St. John Assoc.), a postcolumn OPA reaction system held at 47 “C, and a fluorometric detector (Gilson Model 121). Light filters in the fluorometer were a Corning 7-60 (maximum

transmission at 356 nm) for excitation and a Corning 3-71 (sharp cutoff at 482 nm) for emission.

The mobile-phase buffer was prepared by adding 8.0 g of NaCl and 3.0 g of boric acid to about **490** mL of distilled, deionized water (DDW), adjusting the pH to 10.10 with NaOH solution (final volume 500 mL) and passing the solution through a 0.22-pm pore size nylon filter that had been rinsed with DDW. The OPA reagent was prepared as previously described *(21),* except that the pH was adjusted to 7.0 instead of 10.5 to optimize the fluorometric response of OPA-ammonium ion *(23)* relative to that for OPA-amino acid derivatives. Care was exercised to prevent human exposure to caustic NaOH during buffer preparation or to KOH, OPA, or 2-mercaptoethanol during reagent preparation. The 2-mercaptoethanol was handled under a hood to prevent vapor inhalation.

Mobile-phase buffer was pumped through the column at a flow rate of 0.25 mL min-', and reagent solution was pumped into the postcolumn mixing coil at a rate of ca 0.10 mL mi&. For sample injection, at least 0.4 mL of water sample was passed through a 0.22-pm pore size filter directly into the injector sample loop (50 pL). The filter membrane was held in a low-dead-volume filter holder *(27),* modified to include a 22 gauge needle with a blunt end for the Rheodyne injection valve. Four-tenths milliliter of sample was adequate to rinse the filter and sample loop and leave a clean 50-pL sample in the loop for injection and analysis. A solution of EDTA (ethyienediaminetetraacetic acid; ca 1 %) in NaOH (ca 2%) was sometimes pumped through the column between sample runs to remove impurities and maintain column efficiency.

A 1 mM NHICl solution in DDW and a standard amino acid mixture **(AA-S-18,** Sigma Chemical Co.), containing 2.5 nmol ***pL-'***NH4C1 and 17 amino acids, were **stock** solutions for the ammonium ion and primary amine standards. To calculate the primary amine concentrations, **1** pL of the standard mixture was considered to contain 37.5 nmol of primary amines less basic than ammonium ion that eluted in the major primary amine peak and 2.5 nmol each of ammonium ion and arginine that eluted **as** separate ***peaks.***

http://pubs.acs.org/cgi-bin/abstract.cgi/ancham/1991/63/i05/f-pdf/f_ac00005a032.pdf?sessid=6006l3

91. Gardner WS, Cotner JB, Herche LR (1993a) Chromatographic measurement of nitrogen mineralization rates in marine coastal waters with 15N. Mar Ecol Prog Ser 93:65-73

Abstract: Isotope ratios for ammonium were determined directly on seawater filtrates by high performance liquid chromatography (HPLC) for isotope dilution and enrichment experiments in the Mississippi River plume region of the Gulf of Mexico. The 2 isotopic forms could be differentiated by cation exchange chromatography because the ratio of (NH4+)-N-15:(NH3)-N-15 is Slightly greater than the ratio of (NH4+)-N-14:(NH3)-N-14 in aqueous solutions at pH's near the pK for ammonium (ca pH 9). Relatively small (e.g. 60 ml) water samples were fortified in the field with N-15-ammonium or N-15-amino

acids and incubated at simulated in situ temperature and light conditions. At 2 to 13 h intervals, subsamples were filtered (0.2 mum pore size) and frozen for later HPLC analysis in the laboratory. Isotope-dilution experiments conducted on water samples collected from different depths in the plume indicated that maximum ammonium regeneration rates occurred in near-surface waters where phytoplankton and bacterial production rates are relatively high. Amino acid and ammonium concentration changes and N-15-NH4 compositional changes were measured at 4 intervals over 21 h after the addition of an N-15-labeled amino acid mixture (4 muM). Comparison of the amount of N-15 recovered as (NH4)-N-15 to that removed from solution as N-15-labeled amino acids indicated that the potential conversion of 'assimilated' N-15-labeled amino acids to dissolved ammonium ranged from about 50 % in surface water to about 90 % in near-bottom (30 m depth) water. These results demonstrate the usefulness of the HPLC approach for measuring nitrogen regeneration rates or conversion efficiencies in small volumes of marine coastal waters.

92. Gardner WS, Escobar Briones E, Cruz Kaegi E, Rowe, GT (1993b) Ammonium excretion by benthic invertebrates and sediment-water flux in the Gulf of Mexico near the Mississippi River outflow. Estuaries 16:799-808

Abstract: Benthic macroinvertebrate biomass and ammonium excretion rates were measured at four stations in the Gulf of Mexico near the Mississippi River mouth. Calculated areal excretion rates were then compared to sediment-water nitrogen fluxes measured in benthic bottom lander chambers at similar stations to estimate the potential importance of macroinvertebrate excretion to sediment nitrogen mineralization. Excretion rates for individual crustaceans (amphipods and decapods) was 2-21 nmoles NH4+(mg dry weight)-1 h-1. The mean excretion rates for the polychaetes, Paraprionaspio pinnata[6-12 nmoles NH4+(mg dry weight)-1 h-1] and Magelona sp. [27-53 nmoles NH4+ (mg dry weight)-1 h-1], were comparable or higher than previous measurements for similar size benthic or pelagic invertebrates incubated at the same temperature (22 +/-1-degrees-C). Although the relatively high rates of excretion by these selective feeders may have been partially caused by experimental handling effects (e.g., removal from sediment substrates), they probably reflected the availability of nitrogen-rich food supplies in the Mississippi River plume. When the measured weight-specific rates were extrapolated to total areal biomass, areal macroinvertebrate excretion estimates ranged from 7 mumole NH4+ m-2 h-1 at a 40-m deep station near the river mouth to 18 mumole NH4+ m-2 h-1 at a shallower (28-m deep) station further from the river mouth. The net flux of ammonium and nitrate from the sediments to the water measured in bottom lander chambers in the same region were 15-53 mumole NH4+ M-2 h-1 and -25-21 mumole NO3- M-2 h-1. These results suggest that excretion of NH4+ by macroinvertebrates could be a potentially important component of benthic nitrogen regeneration in the Mississippi River plume-Gulf shelf region.

93. Gardner WS, Benner R, Chin-Leo G, Cotner JB, Eadie BJ, Cavaletto JF, Lansing MB (1994) Mineralization of organic material and bacterial dynamics in Mississippi River plume water. Estuaries 17:816–28

Abstract: Net remineralization rates of organic matter and bacterial growth rates were observed in dark-bottle incubation experiments conducted in July-August and February with water samples collected from sites in the Mississippi River plume of the Gulf of Mexico. Our objectives were to measure site-specific degradation rates of labile dissolved and particulate organic matter, quantify the potential importance of bacteria in these processes, and examine the kinetics of degradation over time. Unfiltered samples, and samples treated to remove (or dilute out) particles larger than bacteria, were enclosed in 9-1 bottles and incubated in, the dark for 3-5 d. Respiration rates and inorganic compound accumulation rates were higher in summer than in winter and were highest in unfiltered surface samples at sites of intermediate salinities where phytoplankton were most abundant. The ratio of ammonium accumulation to oxygen removal in summer experiments suggested that the mineralized organic material resembled "Redfield'" stoichiometry. Chemical fluxes were greater in bottles containing large (>1-3 mu m) particles than in the bottles with these particles removed, but bacterial activities were generally similar in both treatments. These results suggest that particle consumers were an important component of total organic matter degradation. However, these experiments may have underestimated natural bacterial degradation rates because the absence of light could affect the production of labile organic substrates by phytoplankton, In agreement, with this hypothesis, bacterial growth rates tended to decrease over time in summer in surface plume waters where phytoplankton were abundant. In conjunction with other data, our results indicate that heterotrophic processes in the water column are spatially and temporally dependent on phytoplankton production.

94. Gardner WS, Bootsma HA, Evans C, St John P (1995) Improved chromatographic analysis of 15N:14N ratios in ammonium or nitrate for isotopic addition experiments. Mar Chem 48:271-282

Abstract: Estimating nitrogen transformation rates in aquatic ecosystems by isotope dilution techniques is simplified by directly measuring nitrogen isotopic ratios for NH4+ in the water using high performance cation exchange liquid chromatography (HPLC). Modifications of HPLC conditions and implementation of a median-area method for retention time determination improved and linearized a previously reported sigmoid relationship between the retention time shift (RT(shift)) of the NH4+ peak and the ratio of [(NH4+)-N-15] : [Total NH4+] in seawater fortified with (NH4+)-N-15. Increasing the temperature of the HPLC column from 47 to 85 degrees C increased mobile phase buffer flow rate relative to column back pressure, decreased the retention time for NH4+, and allowed the buffer pH to be optimized relative to the pK of NH4+. The use of median-area rather than maximum-height to define the retention time of NH4+ further improved the linearity (r > 0.995) of the relationship between the ratio [(NH4+)-N-15] : [Total NH4+] and RT(shift) over the range of isotope ratios. Reduction of NO3- to NH4+ by adding zinc dust to acidified (pH 2) seawater or lakewater samples, followed by pH neutralization, and subsequent analysis of NH4+ isotope ratios by HPLC, extended application of the method to isotope dilution experiments with NO3-. Advantages of this direct-injection method over mass-measurement approaches traditionally used for isotope dilution experiments include small sample size and minimal sample preparation.

95. Gardner WS, Benner R, Amon RMW, Cotner JB, Cavaletto JF, and Johnson JR (1996). Effects of high molecular weight dissolved organic matter and light on heterotrophic nitrogen dynamics in the Mississippi River plume. Mar Ecol Prog Ser 133:287-297

Abstract: The dynamics of N and its interactions with labile dissolved organic C (DOC), bacteria, and phytoplankton were studied to determine potential effects of dissolved organic matter (DOM) and light on N dynamics in surface waters of the Mississippi River (USA) plume in the Gulf of Mexico. Bacterial uptake of added labeled N compounds ((NH4+)-N-15 or N-15-labeled dissolved free amino acids, DFAA) was stimulated more by high-molecular-weight (HMW, >1 kDa) DOM than by low-molecular-weight (LMW, <1 kDa) DOM. An index that inversely indicated the presence of labile DOC was defined as the fraction of assimilated Amino acid-N-15 that was Recovered as N-15-Ammonium (ANRA), following the additions of high-levels (4 mu M) of N-15-DFAA. ANRA ratios were high in the absence of other available carbon sources because heterotrophic bacteria were forced to use the added amino acids as a carbon source for respiration rather than as a nutrient source for biomass formation. In dynamic light/dark experiments, conducted with in situ populations of organisms, uptake rates of added (NH4+)-N-15 were significantly enhanced both by the presence of light and by the addition of HMW DOM. Uptake rates of added N-15-labeled DFAA were increased by the addition of HMW DOM but not by light. ANRA ratios were consistently lower in the presence of added HMW DOM than in controls. Added HMW DOM thus appeared to stimulate the incorporation of assimilated DFAA into bacterial biomass. Bacterial growth rates were relatively high in both light and dark bottles with DFAA additions and in light bottles with HMW DOM plus NH4+ additions, but they remained comparatively low in dark bottles with added NH4+. These results are consistent with the idea that bacterial N dynamics in these euphotic waters may be tightly coupled to photosynthetic activities over short time scales.

96. Gardner WS, Cavaletto JF, Cotner JB, Johnson JR (1997) Effects of natural light on nitrogen cycling rates in the Mississippi River plume. Limnol Oceanogr 42:273-281

Abstract: Isotope-dilution experiments with (NH4+)-N-15 were conducted on near-surface water samples in the Mississippi River plume during May 1992 and July 1993 to quantify community cycling rates for ammonium and determine whether regeneration rates are enhanced by light. Experiments done under natural light in May showed ranges of potential uptake and regeneration rates of 0-0.4 mu M h(-1) and 0-0.18 mu M h(-1). Samples collected offshore from the Atchafalaya River and the Southwest Pass of the Mississippi River in July yielded potential uptake rates of 0.4-1.8 mu M h(-1) under natural light vs. 0-0.45 mu M h(-1) in the dark. Ammonium regeneration rates ranged from 0.08 to 0.75 mu M h(-1) in the light and from 0.02 to 0.3 mu M h(-1) in the dark. The observed light/dark regeneration-rate differences imply a close coupling between phytoplankton production and ammonium regeneration. The ratio of bacterial cell-specific regeneration to uptake rates increased in the outer regions of the plume, indicating a changing contribution of bacterial-sized organisms to nitrogen cycling processes in different regions of the plume.

98. Gaston, G. R. (1985), Effects of hypoxia on macrobenthos of the inner shelf off Cameron, Louisiana, Estuarine, Coastal and Shelf Science, 20, 603-613.

Abstract: The effects of hypoxic bottom water, an annual event, were documented on the inner shelf off Cameron, Louisiana during the summer of 1981. Populations of most species of macrobenthos were dramatically reduced. In an area of fine sediment that was numerically dominated by polychaetous annelids, the most severely affected populations were those of tube-dwelling and surface-feeding species. Burrowing species were less influenced by the hypoxia.

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WDV-4DV0JBT-19&_user=14684&_handle=V-WA-A-W-E-MsSAYZW-UUA-U-AAVCCCEWBE-AAVBAVUUBE-DVAVZVDVD-E-U&_fmt=summary&_coverDate=05%2F31%2F1985&_rdoc=7&_orig=browse&_srch=%23toc%236776%231985%23999799994%23529781!&_cdi=6776&view=c&_acct=C000001678&_version=1&_urlVersion=0&_userid=14684&md5=dd024dc1927b38a9688700b18617880d

99. Giattina, J. D., and D. T. Altsman (1999), Gulf of Mexico Program: Partnership with a purpose, in The Gulf of Mexico Large Marine Ecosystem, edited by H. Kumpf, et al., pp. 3-13, Blackwell Science, Malden, MA.

101. Goni MA, Ruttenberg KC, Eglinton TI. 1997. Source and contribution of terrigenous organic carbon to surface sediments in the Gulf of Mexico. NATURE 389 (6648): 275-278.

Abstract: The sources and burial professes of organic matter in marine sediments are not well understood, yet they are important if we are to have a better understanding of the global carbon cycle(1). In particular, the nature and fraction of the terrestrial organic carbon preserved in marine sediments is poorly constrained. Here we use the chemical and stable carbon isotope signatures of oxidation products from a macromolecular component (lignin)(2) of the terrigenous organic matter preserved in offshore surface sediments in the Gulf of Mexico to complement similar data from an existing onshore transect(3) in this region. The complete onshore-offshore data set, along with radiocarbon dates of the bulk organic material at the same sites, allows the differentiation of material originating from plants that photosynthesize using the C-4 mechanism from those that undergo C-3 photosynthesis. We conclude that the offshore lignins derive from erosion of the extensive grassland (C-4) soils Of the Mississippi River drainage basin, and that the nearshore lignins originate largely from C-3 plant detritus from coastal forests and swamps, This distribution is probably due to the hydrodynamic sorting of the different source materials(4) during their seaward transport, These results suggest that previous studies(3,5) have significantly underestimated the terrigenous fraction of organic matter in offshore sediments by not recognizing the contribution of C-4 vegetation to the carbon-isotope composition. Such an underestimate may force revisions in the assessment of past marine primary productivity and associated organic carbon fluxes(6), and of organic matter preservation/remineralization(7) and nutrient cycling(8) in marine sediments.

102. Goni MA, Ruttenberg KC, Eglinton TI. 1998. A reassessment of the sources and importance of land-derived organic matter in surface sediments from the Gulf of Mexico. Geochimica Et Cosmochimica Acta 62 (18): 3055-3075.

Abstract: Organic matter in surface sediments from two onshore-offshore transects in the northwestern Gulf of Mexico was characterized by a variety of techniques, including elemental, stable carbon, radiocarbon, and molecular-level analyses. In spite of the importance of the Mississippi River as a sediment source, there is little evidence for a significant terrigenous input based on the low carbon:nitrogen ratios (8-5) and the enriched delta(13)C values of bulk sedimentary organic carbon (-19.7 parts per thousand to -21.7 parts per thousand). Radiocarbon analyses, on the other hand, yield depleted Delta(14)C values (-277 parts per thousand to -572 parts per thousand) which indicate that a significant fraction of the sedimentary organic carbon (OC) in all these surface sediments must be relatively old and most likely of allochthonous origin. CuO oxidations yield relatively low quantities of lignin products (0.4-1.4 mg/100 mg OC) along with compounds derived from proteins, polysaccharides, and lipids. Syringyl:vanillyl and cinnamyl:vanillyl ratios (averaging 1.6 and 0.5, respectively) and acid:aldehyde ratios for both vanillyl and syringyl phenols (averaging 0.8 and 1.2, respectively) indicate that the lignin present in sediments originates from nonwoody angiosperm sources and is highly degraded. The delta(13)C values of lignin phenols in shelf sediments are relatively depleted in C-13 (averaging -26.3 parts per thousand) but are increasingly enriched in C-13 at the slope sites (averaging -17.5 parts per thousand for the two deepest stations). We interpret these molecular and isotopic compositions to indicate that a significant fraction (greater than or equal to 50%) of the lignin and, by inference, the land-derived organic carbon in northwestern Gulf of Mexico sediments ultimately originated from C-4 plants. The source of this material is likely to be soil organic matter eroded from the extensive grasslands of the Mississippi River drainage basin. Notably, the mixed C-4 and C-3 source and the highly degraded state of this material hampers its recognition and quantification in shelf and slope sediments. Our data are consistent with higher than previously estimated inputs of land-derived organic carbon to regions of the ocean, such as the Gulf of Mexico, with significant sources of terrigenous C-4-derived organic matter.

112. Green EP, Dagg MJ. 1997. Mesozooplankton associations with medium to large marine snow aggregates in the northern Gulf of Mexico. JOURNAL OF PLANKTON RESEARCH 19 (4): 435-447.

Abstract: Large and diverse mesozooplankton communities were observed on marine snow particles collected in coastal and oceanic waters of the northern Gulf of Mexico. Mesozooplankton were collected from seven phyla, including ostracods, cladocerans, pelecypods and ascidian larvae not previously recorded as being associated with marine snow. Copepod nauplii were the most common, sometimes at concentrations >100 per aggregate. Oncaea spp., Oithona spp. and Microsetella norvegica were the most common copepod species. Total mesozooplankton abundance ranged between 2 and 278 organisms per aggregate. Organisms varied markedly in their distribution across the

aggregate surface and in their behaviour towards the snow matrix. Comparison of snow communities with zooplankton abundance determined from net tows suggests that some species are concentrated on snow particles. Snow particles and their associated microbial communities may be a significant source of nutrition for these mesozooplankton. Mesozooplankton may contribute significantly to the degradation and decomposition of large snow particles as they sink through the upper water column.

115. Guo LD, Coleman CH, Santschi PH. 1994. The distribution of colloidal and dissolved organic-carbon in the Gulf-of-Mexico. MARINE CHEMISTRY 45 (1-2): 105-119.

Abstract: Cross-flow ultrafiltration techniques have been used to extract colloidal organic carbon (COC) from seawater and to investigate different molecular weight fractions of dissolved organic carbon (DOC). Using a high-temperature catalytic oxidation (HTCO) method, DOC and COC of seawater in the Gulf of Mexico were measured during a R/V Gyre cruise in June 1992. DOC concentrations in surface water varied from 131 muM at a near-shore station (water depth approximately 20 m) to 83 muM at an off-shore station (water depth approximately 1550 m). DOC concentrations show statistically significant correlations with apparent oxygen utilization (AOU), as well as with temperature. However, as a upper limit, only 20-30% of the oxygen consumption could be due to dissolved organic carbon oxidation. Furthermore, a good correlation between DOC and AOU existed only in the upper water column across the pycnocline, which we ascribed to lateral exchange processes. Water mixing can be quite important in controlling the distribution of DOC and the relationship between DOC and AOU in the water column. Concentrations of COC > 1000 Dalton ranged from 20 to 69 muM, while COC > 10,000 Dalton ranged from 4 to 16 muM in the study area. On average, COC (> 1000 Dalton) comprised about 45% of the initial DOC, and the mass concentration of colloids was > 1 mg 1-1. This was one order of magnitude higher than the concentration of suspended particulate matter, and indicates that COC may be an important component of the carbon cycle in the ocean. The relative abundance of COC (both > 1000 and > 10,000 Dalton) decreased from surface water to deep water, not only in terms of concentration but also relative to total DOC. The measurement of molecular weight distributions indicated that approximately 35% of the initial DOC was in the 1000-10,000 Dalton fraction, while only about 10% was in the > 10,000 Dalton fraction, leaving approximately 55% in the truly dissolved fraction (i.e. < 1000 Dalton).

116. Hitchcock GL, Wiseman WJ, Boicourt WC, Mariano AJ, Walker N, Nelsen TA, Ryan E. 1997. Property fields in an effluent plume of the Mississippi river. JOURNAL OF MARINE SYSTEMS 12 (1-4): 109-126.

Abstract: Surface property distributions were mapped in the Mississippi River plume during May and August, 1993 while following surface drifters. Prevailing winds were the primary factor controlling the orientation of the plume. In May, under typical southeasterly winds, the plume turned anticyclonically towards the coast, while in August, under anomalous westerly winds, the plume turned east. Remote imagery of sea surface temperature and suspended sediments confirmed the direction of the plume.

Optimally interpolated maps of surface salinity, temperature, chlorophyll a fluorescence, and transmissivity from underway sampling, and periodic nutrient samples, reveal the plume structure. In May concentrations of nitrate, silicate, and phosphate decreased linearly with increasing salinity. Chlorophyll a increased to peak concentrations of 10 mu g l(-1) in the plume, although higher pigment biomass was observed near the coast. In August nitrate and silicate concentrations decreased conservatively near the mouth of SW Pass, except where pigment biomass was enhanced in a convergent surface front. Surface nutrient concentrations in the plume also decreased with increasing salinity. The observations provide the first Lagrangian view of surface property distributions in the Mississippi River plume, and indicate that significant temporal variability exists in physical and biological properties within a day after waters are discharged from the river delta.

117. Howarth, R. W., and R. Marino. 1998. A mechanistic approach to understanding why so many estuaries and brackish waters are nitrogen limited. In: Effects of Nitrogen in the Aquatic Environment (pages 117-136), KVA Report 1998: 1, Kungl. Vetenskapsakademien (Royal Swedish Academy of Sciences), Stockholm.

129. Jansson, B.-O. and K. Dahlberg. 1999. The environmental status of the Baltic Sea in the 1940s, today, and in the future. *Ambio*, **28**, 312-319.

Abstract: In the 1940s, the Baltic Sea was a nutrient-poor sea with low biological production, clear water, and rocky shores with dense growths of the brown seaweed bladderwrack, providing food and shelter for many species, including spawning and nursery grounds for many fish. There was sufficient oxygen in the bottom water for cod to spawn in the deep areas of the Baltic Proper, except for periods of oxygen depletion in the Gotland Deep. Top consumers like seal and sea eagle were common and people living around the Baltic Sea could eat fish without risking their health. The Baltic Sea of today is different. Eutrophication and toxic substances now affect the entire Baltic Sea ecosystem, even the offshore areas. Filamentous green and brown algae shade the bladderwrack and may even totally replace it. Increased plankton blooms and organic particle production has lowered light penetration by 3 m and oxygen depletion and hydrogen sulfide formation sometimes dominate as much as one third of the total bottom area. Seals and sea eagles are slowly recovering emissions of PCB and DDT from the effects of the large during the 1960s and 1970s. To reduce the nutrient load to the levels of the 1940s, a reduction by 65% for phosphorus and 80% for nitrogen is needed. Furthermore, society's massive processing of potentially hazardous chemicals must be substantially reduced, and preferably stopped entirely. We now have adequate knowledge of how the Baltic Sea ecosystem functions, and of what is needed to restore the Baltic environment. This requires large societal changes especially in agriculture, transportation, and industry. The successful elimination of PCB and DDT emissions shows that even large-scale, negative trends can be reversed. Here, an efficient and technologically advanced industry has an important role to play. But success will be delayed, as long as political issues are given higher priority than environmental action.

134. Justić, D., T. Legović and L. Rottini-Sandrini. 1987. Trends in oxygen content 1911-1984 and occurrence of benthic mortality in the northern Adriatic Sea. *Estuar. Coastal Shelf Sci.,* **25**, 435-445.

135. Justić, D. 1988. Trend in the transparency of the northern Adriatic Sea 1911-1982. *Mar. Pollut. Bull*., **19**, 32-35.

Abstract: In the northern Adriatic Sea, the Secchi disk has been used in oceanographic studies since 1911. An analysis of the data collected during summers between 1911 and 1982 demonstrates that, on the average, the Secchi disk depth has decreased in time. It is likely that a decrease in light penetration has reduced the benthic primary production and thus has increased the probability of an occurrence of anoxic events near the bottom. The long-term nutrient enrichment of the freshwaters discharging into the northern Adriatic Sea appears to be the main factor which has caused the above changes.

136. Justić, D. 1991. Hypoxic conditions in the northern Adriatic Sea: historical development and ecological significance. Pp. 95-105 in Tyson, R. V. and T.H. Pearson (eds.), *Modern and Ancient Continental Shelf Anoxia,* Geological Society Special Publication **58**, The Geological Society, London.

137. Justić, D., N. N. Rabalais, R. E. Turner, and W. J. Wiseman, Jr. (1993), Seasonal coupling between riverborne nutrients, net productivity and hypoxia, Marine Pollution Bulletin, 26, 184-189.

Abstract: Seasonal dynamics of net productivity in the northern Adriatic Sea and in the northern Gulf of Mexico is coherent with the dynamics of freshwater discharge from their major rivers, the Po River and the Mississippi River, respectively. Oxygen deficit in the bottom waters also shows significant correlation with the river flow, implying a time-lag of 2 months in the northern Gulf of Mexico, and a time-lag of 4 months in the northern Adriatic Sea. Fluxes of organic matter resulting from 'new' primary production are potentially high, and may be sufficient to induce hypoxia in a highly stratified water column. A large fraction of nutrients in the Po River and the Mississippi River likely originates from synthetic fertilizers and detergents. The above findings, therefore, not only demonstrate close coupling between riverborne nutrients, net productivity and hypoxia, but also show that the anthropogenic nutrient loads can easily overcome the homeostatic potential of a coastal marine ecosystem.

139. Justić, D., N. N. Rabalais, and R. E. Turner (1995), Stoichiometric nutrient balance and origin of coastal eutrophication, Marine Pollution Bulletin, 30, 41-46.

Abstract: We present here an analysis of the stoichiometry of dissolved nutrients in 10 large world rivers, Amazon, Changjiang, Huanghe, Mackenzie, Mississippi, Po, Rhine, Seine, Yukon and Zaire, and in two river-dominated prone to eutrophication, the northern Adriatic Sea and the northern Gulf of Mexico. Our analysis suggests that proportions of dissolved silica (Si), nitrogen (N) and phosphorous (P) in rivers carrying nutrients of

anthropogenic origin, as well as in the coastal waters strongly influenced by those rivers, have changed historically in a way that now closely approximates the Redfield ratio (Si:N:P = 16:16:1). It is likely that coastal phytoplankton productivity has increased under these favourable nutrient conditions and was accompanied by an increasing incidence of noxious phytoplankton blooms and bottom water hypoxia.

140. Justić, D., N. N. Rabalais, R. E. Turner, and Q. Dortch (1995), Changes in nutrient structure of river-dominated coastal waters: Stoichiometric nutrient balance and its consequences, Estuarine, Coastal and Shelf Science, 40, 339-356.

Abstract: We present an analysis of extensive nutrient data sets from two river-dominated coastal ecosystems, the northern Adriatic Sea and the northern Gulf of Mexico, demonstrating significant changes in surface nutrient ratios over a period of 30 years. The silicon:nitrogen ratios have decreased, indicating increased potential for silicon limitation. The nitrogen:phosphorus and the silicon:phosphorus ratios have also changed substantially, and the coastal nutrient structures have become more balanced and potentially less limiting for phytoplankton growth. It is likely that net phytoplankton productivity increased under these conditions and was accompanied by increasing bottom water hypoxia and major changes in community species composition. These findings support the hypothesis that increasing coastal eutrophication to date may be associated with stoichiometric nutrient balance, due to increasing potential for silicon limitation and decreasing potential for nitrogen and phosphorus limitation. On a worldwide basis, coastal ecosystems adjacent to rivers influenced by anthropogenic nutrient loads may experience similar alterations.

141. Justić, D., N. N. Rabalais, and R. E. Turner (1996), Effects of climate change on hypoxia in coastal waters: Doubled CO sub(2) scenario for the northern Gulf of Mexico, Limnol. Oceanogr., 41, 992-1003.

Abstract: Projections of general circulation models suggest that freshwater discharge from the Mississippi River to the coastal ocean will increase 20% if atmospheric CO2 concentration doubles. This result is likely to affect water column stability, surface productivity, and global oxygen cycling in the northern Gulf of Mexico, which is the site of the largest (up to 16,500 km(2)) and most severe hypoxic zone (<2 mg O-2 liter(-1)) in the western Atlantic Ocean. We use a coupled physical-biological two-box model to investigate potential effects of climate change on seasonal oxygen cycling and hypoxia in river-dominated coastal waters. The model was developed and calibrated using comprehensive environmental data sets collected on the Mississippi River and in the northern Gulf of Mexico between 1985 and 1993. The relative magnitude of changes in river runoff and severity of hypoxia during the 1993 Mississippi River flooding provide an excellent data set for model verification. Model simulations for a doubled CO2 climate predict a 30-60% decrease in summertime sub-pycnoclinal oxygen content, relative to a 1985-1992 average. Under those conditions, the hypoxic zone in the northern Gulf of Mexico will expand and encompass an area greater than that of summer 1993.

142. Justić, D., N. N. Rabalais, and R. E. Turner (1997), Impacts of climate change on net productivity of coastal waters: implications for carbon budgets and hypoxia, Climate Research, 8, 225-237.

Abstract: General circulation models predict that freshwater discharge from the Mississippi River (USA) to the coastal ocean would increase 20 % if atmospheric CO2 concentration doubles. Here we use a coupled physical-biological 2-box model to investigate the potential impacts of increased freshwater and nutrient inputs on the production and decay of organic matter in the coastal waters of the northern Gulf of Mexico. Model results for a doubled CO2 climate indicate that the annual net productivity of the upper water column (NP, 0 to 10 m) is likely to increase by 65 g C m(-2) yr(-1), relative to a 1985-1992 average (122 g C m(-2) yr(-1)). Interestingly, this projected increase is of the same magnitude as the one that has occurred since the 1940s due to the introduction of anthropogenic nutrients. An increase in annual NP of 32 g C m(-2) yr(-1) was observed during the Great Mississippi River Flood of 1993, thus indicating the general validity of a doubled CO2 scenario. The total oxygen uptake in the lower water column (10 to 20 m), in contrast, is likely to remain at its present value of about 200 g O-2 m(-2) yr(-1). Thus, carbon export and burial, rather than in situ respiration, are likely to be the dominant processes balancing coastal carbon budgets, leading perhaps to an expanded extent of the hypoxic zone.

153. Kelley CA, Coffin RB, Cifuentes LA (1998) Stable isotope evidence for alternative bacterial carbon sources in the Gulf of Mexico. Limnol Oceanogr 43:1962-1969

Abstract: In temperate coastal waters, it is generally assumed that carbon cycling is primarily supported by phytoplankton production, having $\delta^{13}C$ values ranging from -22 to -18‰. In a transect leading out from the Mississippi River, riverine and seawater $\delta^{13}C$ endmembers of particulate organic matter have previously been measured at -25.5 and -20.0‰, respectively. In addition, $\delta^{13}C$ values of dissolved organic carbon in the northern Gulf of Mexico range from -24.7 to - 19.6‰, with the more ^{13}C-depleted values from fresher waters. Assumptions about coastal transport of dissolved organic matter predict that the bacterial $\delta^{13}C$ values should fall along the conservative salinity mixing line between terrestrial and marine carbon sources. However, in the field survey presented here, $\delta^{13}C$ values of bacteria in coastal regions of the Gulf of Mexico adjacent to the Mississippi River are considerably ^{13}C-depleted, with values as low as -33‰. These isotope values suggest that carbon from sources other than phytoplankton production or terrestrial organic matter are supporting the production of the bacterial assemblage. Possibilities include the incorporation of carbon derived from light hydrocarbons from seep areas and the chemoautotrophic processes of methane oxidation and nitrification. These ^{13}C-depleted stable isotope data are evidence that bacterially assimilated carbon in the northern Gulf of Mexico may be seasonally uncoupled to surface phytoplankton production.

http://aslo.org/lo/toc/vol_43/issue_8/1962.html

158. Levin, L. A. and J. D. Gage. 1998. Relationships between oxygen, organic matter and the diversity of bathyal macrofauna. *Deep-Sea Res. II*, **45**, 129-163.

Abstract: The relationships of environmental factors with measures of macrobenthic community diversity were examined for the total fauna, and for polychaetes only, from 40 bathyal stations in the North Atlantic, eastern Pacific and Indian Oceans (154-3400 m). Stepwise multiple regression revealed that depth, latitude, sediment organic-carbon content and bottom-water oxygen concentration are significant factors that together explained 52-87% of the variation in macrobenthic species richness (E[s(100)]), the Shannon-Wiener index (H'), dominance (D), and evenness (J'). Percent sand and percent clay were not significant factors. After removal of depth and latitudinal effects, oxygen and organic-carbon concentrations combined accounted for 47, 67, 52 and 32% of residual variation in macrobenthic E(s(100)), H', D, and J', respectively. Organic carbon exhibited a stronger relationship than oxygen to measures of community evenness, and appeared to have more explanatory power for polychaetes than total macrobenthos. When only stations with oxygen < 1mll(-1) were considered, oxygen concentration became the dominant parameter after depth. Results suggest existence of an oxygen threshold (< 0.45 mi l(-1)), above which oxygen effects on macrobenthic diversity are minor relative to organic matter influence, but below which oxygen becomes a critical factor. Our regression results lead us to hypothesize that for bathyal faunas, oxygen at low concentrations has more influence on species richness, while organic carbon regulates the distribution of individuals among species (community evenness). Examination of rarefaction curves for Indo-Pacific stations reveals that total macrobenthos, polychaetes, crustaceans and molluscs all exhibit reduced species richness within oxygen minimum zones (OMZs). However, representation under conditions of hypoxia varies among taxa, with polychaetes being most tolerant. Molluscs and crustaceans often (but not always) exhibit few individuals and species in OMZs, and sometimes disappear altogether, contributing to reduced macrobenthic diversity and elevated dominance in these settings. The linear negative relationship observed between bathyal species richness and sediment organic-carbon content (used here as a proxy for food availability) may represent the right side (more productive half) of the hump-shaped, diversity-productivity curve reported in other systems. These analyses suggest then are potentially strong influences of organic matter and oxygen on the diversity and composition of bathyal macrobenthos, especially in the Indo-Pacific Ocean.

159. Levin, L. A., C. L. Huggett, and K. F. Wishner. 1991. Control of deep-sea benthic community structure by oxygen and organic-matter gradients in the eastern Pacific Ocean. *J. Mar. Res.*, **49**, 763-800.

Abstract: At boundaries of oxygen minimum zones (OMZs), bathyal faunas experience steep gradients in oxygen and organic-matter availability. The present study compares changes in microbial, meiofaunal, macrofaunal and megafaunal benthic assemblages along these gradients on Volcano 7, a 2.3-km high seamount in the eastern tropical Pacific. Faunal tolerance to dysaerobic (low oxygen) conditions varies with organism size; microbial and meiofaunal abundances are less affected than macro- and megafaunal abundances. At the exceedingly low concentrations (< 0.1 ml/1) encountered on the upper

summit of Volcano 7, oxygen appears to exert primary control over abundance, composition and diversity of macrofauna, overriding other factors such as food availability and sediment grain size. When oxygen concentration is sufficient, food availability in sediments (indicated by the presence of labile material such as chlorophyll a) is highly correlated with meiofaunal and macrofaunal abundance. Four distinct physical zones were identified on Volcano 7: (1) the coarse-grained upper summit zone (730-770 m) where near-bottom oxygen concentrations were usually lowest (often < 0.1 ml/1) and organic-matter (% organic carbon and chlorophyll a) availability was high, (2) the coarse-grained lower summit (770-1000 m) where near-bottom oxygen concentrations were usually slightly higher (0.11 to 0.16 ml/1) and organic-matter availability remained high, (3) the coarse-grained flank (1000-2000 m) where oxygen concentration was intermediate (0.7-0.9 ml/1) and sediment organic-matter content was very low, and (4) the finer-grained base (2000-3500 m) where oxygen values exceeded 2.5 ml/1, sediment organic carbon was moderate, and chlorophyll a was low. Abundances of larger forms (megafauna and macrofauna) were severely reduced on the upper summit, but attained high values (2.25/m2 and 8,457/m2 respectively) just tens of meters below. The smaller forms (bacteria and meiofauna) attained peak abundances on the low-oxygen upper summit, however, abundances of harpacticoid copepods were greatly reduced on the upper and lower summit, presumably due to oxygen limitation. Macrofaunal abundance and diversity patterns along the Volcano 7 oxygen/enrichment gradient resembled those typically observed along shallow-water gradients of organic pollution. Low densities of a few soft-bodied, low-oxygen tolerant species resided on the upper summit, a high-density, low-diversity assemblage inhabited the lower summit, and low-density, high-diversity assemblages occupied the flank and base sediments. The infaunal communities on Volcano 7 support the idea that OMZ boundaries are regions of enhanced biological activity. Modern faunal distributions and biogenic structures at OMZ boundaries may be useful in reconstructing oxygenation histories of ancient marine basins.

161. Li Y, Nowlin WD, Reid RO. 1997. Mean hydrographic fields and their interannual variability over the Texas-Louisiana continental shelf in spring, summer, and fall. JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS 102 (C1): 1027-1049.

Abstract: New hydrographic data from the Texas-Louisiana continental shelf were combined with data from older cruises covering significant portions of this shelf to produce spatial distributions of surface and bottom temperature and salinity as well as of surface geopotential anomaly relative to 70 dbar. These were used to calculate mean fields with their standard deviations for spring (May), summer (July-August), and fall (November). For each season, histograms were prepared of differences between properties in the individual fields and our seasonal mean values at each grid point in the individual fields. These histograms have highly tuned Gaussian distributions centered on zero differences,, proving that a distribution selected randomly will likely be quite similar to the mean for the season in which the sample was made. The individual fields of salinity for summer and geopotential anomaly for spring are included for comparison with the mean fields. The mean fields, produced by adding a large data set to that used by Cochrane and Kelly [1986], substantiate the bimodal annual patterns of circulation and

property distributions over the inner shelf region described by them. Essentially, there is downcoast (directed from the Mississippi toward Brownsville) nearshore flow except during the summer months. That flow is driven by downcoast along-shelf wind and enhanced by Mississippi-Atchafalaya River discharge. In July and August the average wind has an upcoast component and the nearshore flow is reversed. Patterns and values of the standard deviations are used to infer causes and magnitudes of interannual variability, respectively. Three examples of anomalous property distributions are presented to illustrate the effects of the principal external forcing mechanisms affecting interannual variability on the Texas-Louisiana shelf. These mechanisms are wind stress, Mississippi-Atchafalaya River discharge, and mesoscale eddies in the offshore circulation near the shelf-slope break. For each cruise examined, residuals of geopotential anomaly and surface salinity relative to the seasonal mean are examined in relation to departures of river discharge from the long-term (64 year) average and an index of along-shelf wind component appropriate to the times of the cruises. The residuals of geopotential anomaly were found to be significantly negatively correlated with those of surface salinity, with an intercept of approximately zero indicating that salinity plays the dominant role relative to temperature in year-to-year variability of the geopotential anomaly. Positive river discharge residuals were correlated with negative surface salinity residuals; enhanced downcoast wind resulted in negative surface salinity residuals; and enhanced upcoast wind resulted in positive surface salinity residuals. Most correlations were significant (different from zero) at the 95% confidence level.

167. Lohrenz SE, Dagg ML, Whitledge TE (1990) Enhanced primary production at the plume/oceanic interface of the Mississippi River. Cont Shelf Res 10:639-664

Abstract: Mechanistic and empirical models were used to examine relationships between primary production and environmental variables along the Mississippi River plume/oceanic gradient off Southwest Pass, Louisiana. A large proportion of variation in primary production could be explained on the basis of light and biomass ($r^2 > 0.857$, $N > 25$). However, comparison of observed chlorophyll concentrations with those predicted using a steady-state light limitation model suggested factors in addition to light availability constrained maximum biomass levels in the plume. Factors which may have contributed to low observed biomass included growth limitation or inhibition by substances not measured, losses due to grazing and sinking, and a short residence time for plume waters, which may have prevented populations from reaching steady state. The dissipative effects associated with plume/oceanic mixing may have been enhanced by potential inhibitory effects of large and varying salinity gradients. Nutrient-salinity distributions, in conjunction with approximate calculations of primary consumption of riverine nutrient sources by phytoplankton, led to the conclusion that biomass and production were controlled by nutrient supply at salinities above 30.

168. Lohrenz, S. E., G. L. Fahnenstiel, D. G. Redalje, and G. A. Lang (1992), Regulation and distribution of primary production in the northern Gulf of Mexico, in Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991, edited by N. C. O. Program, pp. 95-104, Texas Sea Grant Publications, College Station, TX.

Ordering information: http://texas-sea-grant.tamu.edu/pubs/pubcat/pubs.php?topic=Urban+Coasts

169. Lohrenz SE, Redalje DG, Fahnenstiel GL, McCormick MJ, Lang GA, Prasad K, Chen X, Atwood DA, Chen B (1994a) Phytoplankton rate processes in coastal waters of the northern Gulf of Mexico and relationships to environmental conditions. Proceed NECOP Workshop, June 26-27, 1994, Baton Rouge, LA

170. Lohrenz, S. E., G. L. Fahnenstiel, and D. G. Redalje (1994), Spatial and temporal variations of photosynthetic parameters in relation to environmental conditions in northern Gulf of Mexico coastal waters, Estuaries, 17, 779-795.

Abstract: On a series of eight cruises conducted in the northern Gulf of Mexico, efforts were made to characterize temporal and spatial variability in parameters of the photosynthesis-irradiance saturation curve (P-max(B), alpha(B), I-k) and to relate the observed variations to environmental conditions. Experiments to examine the importance of diel variation in upper mixed layer populations were conducted in July-August 1990 and March 1991. During July-August 1990, P-max(B) and I-k showed significant increases and alpha(B) decreased during the photoperiod in both river plume and shelf-slope populations. During March 1991, no consistent covariance of P-I parameters with local time was found, although highest values of alpha(B) in the river plume were observed in early morning. Seasonal variation in P-max(B), and alpha(B) were correlated with temperture. Spatial variations of photosynthetic parameters in the upper mixed layer ranged from twofold to threefold within any given cruise. Variations of photosynthetic parameters in the upper mixed layer were related to principal components derived from environmental variables, including temperature, salinity, nutrients, mixed layer depth, attenuation coefficient, and daily photosynthetically available radiation (PAR). Greater than 70% of the variation in the environmental variables could be accounted for by two principal components; the majority of this variation was associated with the first principal component, which was generally strongly correlated with salinity, nutrients, mixed layer depth, and attenuation coefficient. Correlations of P-max(B), alpha(B), and I-k with the first principal component were found to be significant in some cases, an indication that spatial variability in P-I parameters was related to river outflow. Variation of P-I parameters in relation to depth and PAR were evaluated by regressions with principal components derived from depth, temperature, and mean daily PAR. For most cruises, P-max(B), and I-k were negatively correlated with the first principal component, which was strongly positively correlated with depth and negatively correlated with daily PAR. This was consistent with a decrease in both P-max(B), and I-k with depth that could be related to decreasing daily PAR. Positive correlations of alpha(B) with the first principal component for two cruises, March 1991 and April 1992, indicated an increasing trend with depth. In conclusion, relationships between P-I parameters and environmental variables in the region of study were significant in some cases, but variation between cruises made it difficult to generalize. We attributed this variation to the physically dynamic characteristics of the region and the possible effects of variables that were not included in the analysis such as species composition. Our findings do support the view

that a limited set of observations may be adequate to characterize P-I parameter distributions in a given region within a restricted period of time.

171. Lohrenz, S. E. (1995), Relationship of primary production to physical oceanography in the Northeastern Gulf of Mexico, in Northeastern Gulf of Mexico physical oceanography workshop; proceedings of a workshop held in Tallahassee, Florida, April 5-7, 1994, edited by A. J. Clarke, pp. 43-49, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.

These proceedings are available in their entirety as a PDF:
http://www.gomr.mms.gov/homepg/regulate/environ/studies/1994/94-0044.pdf

172. Lohrenz, S. E., D. G. Redalje, and G. L. Fahnenstiel (1995), Optical properties of Mississippi River plume and adjacent shelf waters during March 1991, in Nutrient Enhanced Coastal Ocean Productivity, Proceedings of a Workshop, edited by N. C. O. Program, pp. 67-74, Texas-Louisiana Sea Grant Publications, College Station.

Abstract: Variations in attenuation of irradiance (total photosynthetically active radiation and downwelling spectral irradiance) were related to other optical measurements (beam c, solar-stimulated fluorescence) and to concentrations of particulate and dissolved materials determined from analyses of discrete samples. Four sampling locations were studies representative of conditions ranging from very turbid low salinity plume water to very oligotrophic water over the slope. Highest values of K_{par} (over 2.5 m^{-1}) were observed at the surface in a low salinity plume station, although there was considerable scatter in the values. Lowest values were observed at a slope water station (<0.8 m^{-1}). The utility of measurements of L_u683 as an index of chlorophyll concentrations was found to be limited. Extracted chlorophyll concentrations tended to be overestimated in near surface waters and underestimated at depth. Profiles of beam c revealed high values (>3 m^{-1}) in surface waters of the shelf stations. Spectral attenuation minima at shelf stations were in the vicinity of 540-580 nm. Lowest values of attentuation were observed at the slope water station where the attentuation minimum was around 490 nm. A spectral attentuation model reproduced measured spectra remarkably well considering variations in attenauation spanned over an order of magnitude. It was evident that in shelf waters during this period, absorption and scattering were dominated by dissolved organic carbon and suspended particulate matter.
http://www.glerl.noaa.gov/pubs/abstracts/abs1995.html

173. Lohrenz, S. E., D. G. Redalje, G. L. Fahnenstiel, M. J. McCormick, G. Lang, K. Prasad, X. Chen, D. A. Arwood, and B. Chen (1995), Phytoplankton rate processes in coastal waters of the northern Gulf of Mexico and relationships to environmental conditions, in Nutrient-Enhanced Coastal Ocean Productivity, edited by N. C. O. P. Office, pp. 56-66, Sea Grant Publications, Baton Rouge, LA.

174. Lohrenz, S. E., G. L. Fahnenstiel, D. G. Redalje, G. A. Lang, X. G. Chen, and M. J. Dagg (1997), Variations in primary production of northern Gulf of Mexico continental shelf waters

linked to nutrient inputs from the Mississippi River, Marine Ecology-Progress Series, 155, 45-54.

Abstract: Increases in nutrient concentrations in the Mississippi River over the past 35 yr have led to speculation that primary production of organic carbon has been elevated as a result of increased nutrient fluxes that have occurred in the northern Gulf of Mexico coastal ecosystem. However, studies thus far have not provided direct demonstration of temporal relationships between measured primary production in continental shelf waters and river-borne nutrient fluxes. This investigation compared temporal variations in primary production with associated annual and interannual changes in river-borne nutrient inputs. Primary production in shelf waters near the river delta were found to be significantly correlated with nitrate (NO3-) + nitrite (NO2-) concentrations and fluxes over a 6 yr period from 1988 to 1994. Although light limitation was probably an important factor during winter months, a positive correlation was demonstrated between river inputs of NO3-+NO2- and primary production for data collected from other times of the year. Peak nutrient inputs generally occurred in the spring. The magnitude of the riverborne NO3-+NO2- inputs averaged 106% of estimated nitrogen requirements for phytoplankton in the river-impacted region, considerably greater than in Amazon shelf waters, which have been less subject to anthropogenic nutrient increases. The possibility exists that further increases in anthropogenic nutrients in the Mississippi River could lead to higher and more widespread primary production, and this may intensify and extend the depletion of oxygen that has already been observed in the Louisiana shelf ecosystem. However, such a prediction is difficult because relationships between increasing nutrient inputs and primary production are unlikely to be Linear, and a complete understanding of processes intermediate between primary production of organic matter and oxygen depletion in bottom waters on the Louisiana shelf is still lacking.

175. Lohrenz, S. E., D. A. Wiesenburg, R. A. Arnone, and X. Chen (1999), What controls primary production in the Gulf of Mexico?, in The Gulf of Mexico Large Marine Ecosystem: Assessment, Sustainability and Management, edited by K. Sherman, et al., pp. 151-170, Blackwell Science, Inc., Malden, MA.

176. Lohrenz, S. E., G. L. Fahnenstiel, D. G. Redalje, G. A. Lang, M. J. Dagg, T. E. Whitledge, and Q. Dortch (1999), Nutrients, irradiance, and mixing as factors regulating primary production in coastal waters impacted by the Mississippi River plume, Cont. Shelf Res., 19, 1113-1141.

Abstract: Relationships among primary production, chlorophyll, nutrients, irradiance and mixing processes were examined along the salinity gradient in the Mississippi River outflow region. A series of six cruises were conducted during 1988-1992 at various times of year and stages of river discharge. Maximum values of biomass and primary production were typically observed at intermediate salinities and coincided with non-conservative decreases in nutrients along the salinity gradient. Highest values of productivity (>10 gC m(-2) d(-1)) and biomass (>30 mg chlorophyll a m(-3)) were observed in April 1988, July-August 1990 and April-May 1992; values were lower in March and September 1991. Rates of primary production were apparently constrained by low irradiance and mixing in the more turbid, low salinity regions of the plume, and by

nutrient limitation outside the plume. Highest values of primary production occurred at stations where surface nutrient concentrations exhibited large deviations from conservative mixing relationships, indicating that depletion of nutrients was related to phytoplankton uptake. Mixing and advection were important in determining the location and magnitude of primary production maxima and nutrient depletion. In addition to growth within plume surface waters, enhanced growth and/or retention of biomass may have occurred in longer residence time waters at the plume edge and/or beneath the surface plume. Vertical structure of some plume stations revealed the presence of subsurface biomass maxima in intermediate salinity water that was depleted in nutrients presumably by uptake processes. Exchange between subsurface water and the surface plume apparently contributed to the reduction in nutrients at intermediate salinities in the surface layer. DIN (= nitrate + nitrite + ammonium) : PO4 (= phosphate) ratios in river water varied seasonally, with high values in winter and spring and low values in late summer and fall. Periods of high DIN : PO4 ratios in river nutrients coincided with cruises when surface nutrient concentrations and their ratios indicated a high probability for P limitation. N limitation was more likely to occur at high salinities and during late summer and fall. Evidence for Si limitation was also found, particularly in spring.

179. Malone, T., A. Malej, L. Harding, N. Smodlaka and R. E. Turner (eds.) 1999. Ecosystems at the land-sea margin: Drainage Basin to Coastal Sea. Coastal and Estuarine Studies Series, No. 55. American Geophysical Union. Washington, D.C.

Abstract: Focusing on the northern Adriatic Sea and the Chesapeake Bay, Ecosystems at the Land-Sea Margin: Drainage Basin to Coastal Sea examines the questions of how land-use patterns influence the pathways and rates of nitrogen and phosphorus export from land to water; how physical and ecological characteristics of the coastal ecosystems influence the effects of nutrient enrichment; and to what extent changes in fisheries can be related to changes in water quality.

https://www.agu.org/cgi-bin/agubookstore?memb=agu&topic=CE&book=CECE0552693&cart=24037&search=

180. Mayer, L. M., R. G. Keil, S. A. Macko, S. B. Joye, K. C. Ruttenberg and R. C. Aller. 1998. Importance of suspended particulates in riverine delivery of bioavailable nitrogen to coastal zones. *Global Biogeochemical Cycles*, **12**, 573-579.

Abstract: Total nitrogen (TN) loadings in riverine sediments and their coastal depocenters were compared for Il river systems worldwide to assess the potential impact of riverine particulates on coastal nitrogen budgets. Strong relationships between sediment specific surface area and TN allow these impacts to be estimated without the intense sampling normally required to achieve such budgets. About half of the systems showed higher nitrogen loadings in the riverine sediments than those from the coastal depocenter. In spite of uncertainties, these comparisons indicate that large, turbid rivers, such as the Amazon, Huanghe, and the Mississippi, deliver sediments that in turn release significant or major fractions of the total riverine nitrogen delivery. Riverine particulates must therefore be considered an essential factor in watershed nutrient loading to coastal

ecosystems and may affect delivered nutrient ratios as well as total nutrient loading. The relative importance of particulate versus dissolved delivery has decreased over recent decades in the Mississippi as a result of damming and fertilizer use in the watershed.

186. Miller-Way T, Boland GS, Rowe GT, and Twilley RR (1994) Sediment oxygen consumption and benthic nutrient fluxes on the Louisiana Continental Shelf: A methodological comparison. Estuaries 17:809-815

Abstract: There has been considerable discussion but little experimental evidence regarding the comparability of in-situ and remote (shipboard or laboratory) incubations for the determination of sediment oxygen consumption and benthic nutrient flux rates. This paper presents the results of such a comparison, using in situ chamber and shipboard chemostatic systems, for a shallow station on the Louisiana continental shelf during April 1992. Results indicated no methodological differences between rates of sediment oxygen consumption and nutrient flux (NH4+, NO3-, NO2-, P0(4)(3-), and SiO2/Si(OH)(2)) that could be attributed to the removal of cores from shelf sediments, This conclusion implies that subcoring from box cores is no more destructive of sediment structure and salient environmental characteristics than chamber emplacement. Differences between the methods occurred when ambient oxygen concentrations were low (<2 ml l(-1)), These differences were caused by initial reaeration of bottom water in the shipboard system and reflect the sensitivity of heterotrophic metabolism, dissolution kinetics, and diffusive fluxes to low oxygen concentrations. The differences in exchange rates observed in this study reiterate the importance in maintaining ambient conditions in the experimental apparatus. The results of this study corroborate the small body of data that addresses this issue and extends methodological similarities to include nutrient exchanges. Given the comparability of rates, use of remote chemostatic systems is more advantageous for work in shelf environments than in-situ batch methods due to increased statistical rigor, logistical convenience, and the ability to minimize changes in experimental conditions during incubations.

188. Montagnes DJS, Berges JA, Harrison PJ, Taylor FJR (1994) Estimating carbon, protein, and chlorophyll a from volume in marine phytoplankton. Limnol Oceanogr 39:1044-1060

Abstract: The size of 30 small (2-60 pm) phytoplankton species was examined with a microscope and a Coulter Counter before and after fixation. Acid Lugol's iodine caused cells to shrink immediately. The shrinkage effect was constant for concentrations of l-10% Lugol's iodine (in seawater). For optically measured cells fixed in 2% Lugol's iodine, volume of live cells = 1.33 x (volume of fixed cells). Coulter Counter and optically measured volumes did not agree. For live cells, optical cell volume = 1.24-2.04 x (CoulterCounter determined volume); this difference is likely due to inaccurate volume measurements of nonspherical cells by the Coulter Counter and by inaccurate microscopy resulting from optical distortions (errors of ~0.5 pm in cell dimensions). Cell quota estimates were presented following the relation y = a.x?, where x = optically measured cell volume (pm3), y = any cell constituent (pg cell-'), and a and b are constants. The constants a and b were 0.109 and 0.99 1 for carbon, 0.0172 and 1.023 for nitrogen,0.043 and 1.058 for protein, and 0.00428 and 0.9 17 for Chl a. Our relation of carbon to volume

differs from other literature values, in which there is no consensus. Our data can be used to determine carbon, nitrogen, protein, and Chl a estimates from field material that has been fixed with Lugol's iodine, observed live, optically measured, or Coulter Counter measured; however, the variability in published data suggests that any of these estimates will have a large potential error.

189. Morse JW, Rowe GT (1999) Benthic biogeochemistry beneath the Mississippi River plume. Estuaries 22:206-214

Abstract: Biogeochemical processes occurring near the sediment-water interface of shallow (similar to 20 m) water sediments lying beneath the Mississippi River plume on the Louisiana shelf were studied using benthic chambers and sediment cores. Three sites were chosen with distinctly different characteristics. One was overlain by oxic water where aerobic respiration dominated organic matter remineralization. The second site was overlain by oxic water but organic matter remineralization was dominated by sulfate reduction. The third site was overlain by hypoxic water and aerobic remineralization was of minor significance. Major differences were observed in the fluxes of CO2(17-56 mmol m(-2) d(-1)), O-2(2-56 mmol m(-2) d(-1)) and nutrients (e.g., NH4+, 2.6-4.2 mmol m(-2) d(-1)) across the sediment-water interface, and the relative importance of different electron accepters, even though the sites were in close proximity and at nearly the same water depth. Large variations in the efficiency of organic-C burial (3%-51%) were also calculated based on a simplified model of the relationships between the fraction of organic matter remineralized by sulfate reduction and the fraction of sulfide produced that is buried as pyrite. These observations demonstrate the high degree of spatial heterogeneity of benthic biogeochemistry in this important near-deltaic environment.

190. Mulholland PJ, Best GR, Coutant CC, Hornberger GM, Meyer JL, Robinson PJ, Stenberg JR, Turner RE, VeraHerrera F, Wetzel RG. 1997. Effects of climate change on freshwater ecosystems of the south-eastern United States and the Gulf Coast of Mexico. HYDROLOGICAL PROCESSES 11 (8): 949-970.

Abstract: The south-eastern United States and Gulf Coast of Mexico is physiographically diverse, although dominated by a broad coastal plain. Much of the region has a humid, warm temperate climate with little seasonality in precipitation but strong seasonality in runoff owing to high rates of summer evapotranspiration. The climate of southern Florida and eastern Mexico is subtropical with a distinct summer wet season and winter dry season. Regional climate models suggest that climate change resulting from a doubling of the pre-industrial levels of atmospheric CO2 may increase annual air temperatures by 3-4 degrees C. Changes in precipitation are highly uncertain, but the most probable scenario shows higher levels over all but the northern, interior portions of the region, with increases primarily occurring in summer and occurring as more intense or clustered storms. Despite the increases in precipitation, runoff is likely to decline over much of the region owing to increases in evapotranspiration exceeding increases in precipitation. Only in Florida and the Gulf Coast areas of the US and Mexico are precipitation increases likely to exceed evapotranspiration increases, producing an increase in runoff. However, increases in storm intensity and clustering are likely to

result in more extreme hydrographs, with larger peaks in flow but lower baseflows and longer periods of drought. The ecological effects of climate change on freshwaters of the region include: (1) a general increase in rates of primary production, organic matter decomposition and nutrient cycling as a result of higher temperatures and longer growing seasons: (2) reduction in habitat for cool water species, particularly fish and macroinvertebrates in Appalachian streams; (3) reduction in water quality and in suitable habitat in summer owing to lower baseflows and intensification of the temperature-dissolved oxygen squeeze in many rivers and reservoirs; (4) reduction in organic matter storage and loss of organisms during more intense flushing events in some streams and wetlands; (5) shorter periods of inundation of riparian wetlands and greater drying of wetland soils, particularly in northern and inland areas; (6) expansion of subtropical species northwards, including several non-native nuisance species currently confined to southern Florida; (7) expansion of wetlands in Florida and coastal Mexico, but increase in eutrophication of Florida lakes as a result of greater runoff from urban and agricultural areas; and (8) changes in the flushing rate of estuaries that would alter their salinity regimes, stratification and water quality as well as influence productivity in the Gulf of Mexico. Many of the expected climate change effects will exacerbate current anthropogenic stresses on the region's freshwater systems, including increasing demands for water, increasing waste heat loadings and land use changes that alter the quantity and quality of runoff to streams and reservoirs. Research is needed especially in several critical areas: long-term monitoring of key hydrological, chemical and biological properties (particularly water balances in small, forested catchments and temperature-sensitive species); experimental studies of the effects of warming on organisms and ecosystem processes under realistic conditions (e.g. in situ heating experiments): studies of the effects of natural hydrological variation on biological communities; and assessment of the effects of water management activities on organisms and ecosystem processes, including development and testing of management and restoration strategies designed to counteract changes in climate.

191. Murrell, M.C., JW Fleeger (1989) Meiofauna abundance on the Gulf of Mexico continental-shelf affected by hypoxia. Cont. Shelf Res., 9, 1049-62.

Abstract: Meiofauna were sampled in shallow (8–13 m) continental shelf waters off the coast of Louisiana at three stations on 13 dates from June 1985 to August 1986. Total meiofauna abundances ranged from 525 to 3406 individuals per 10 cm^2 with a mean of 1810 individuals per 10 cm^2. Peak abundances occurred in late spring and early summer while seasonal lows occurred during late summer and winter. The three predominant taxa were Nematoda (91.8%), Copepoda (3.2%) and Kinorhyncha (2.5%). The meiobenthic copepod assemblage displayed low diversity and was dominated by three epibenthic species which together comprised 87% of the copepod fauna. Hypoxic conditions (dissolved oxygen <2 mg l^{-1}) developed seasonally on this shelf as a result of water column density stratification and eutrophication during late spring and summer. Abundances of all taxa declined during the summers of both years apparently in response to hypoxic conditions. Copepods were most dramatically affected, dropping from springtime peak abundances (several hundred per 10 cm^2) to virtually zero in a one-month period of time. Copepod density declines were spatially correlated with the onset

of hypoxia, as inshore stations developed hypoxia later and underwent declines later. Densities remained low after the return of normal oxygen conditions, rising in the spring of the following year. The effect on nematodes and kinorhynchs was not as dramatic. A single collection of meiofauna from July 1983 in nearby normoxic Terrebonne Bay at similar water depths reveals a high density and diversity of copepods, further suggesting the sensitivity of copepods to hypoxia.

195. Nelson DM, Dortch Q. 1996. Silicic acid depletion and silicon limitation in the plume of the Mississippi River: Evidence from kinetic studies in spring and summer. MARINE ECOLOGY-PROGRESS SERIES 136 (1-3): 163-178

Abstract: The surface distributions of dissolved silicic acid, chlorophyll and diatom abundance were measured in the plume of the Mississippi River and adjacent waters during spring (late April and early May 1993) and summer (July 1992). In spring, the time of maximum river now, there was an intense diatom bloom with a mean diatom abundance of 1.5 x 10(7) cells l(-1), more than an order of magnitude higher than in summer. Mixing curves of silicic acid concentration ([Si(OH)(4)]) versus salinity indicate that biological uptake within the river plume removed >99% of the Si(OH)(4) supplied by the river in spring and 80 to 95% in summer. In spring [Si(OH)(4)] was occasionally depleted to <0.2 mu M-among the lowest values ever reported from the ocean-with extensive depletion to <0.5 mu M over the shelf. In summer [Si(OH)(4)] was less severely depleted; the lowest measured was 0.93 mu M and all others were greater than or equal to 2.4 mu M. Si-30 kinetic experiments were performed during both spring and summer to measure the degree to which the rate of Si uptake by the natural diatom assemblages was limited in situ by substrate availability. In spring the dependence of the specific uptake rate (V) on extracellular [Si(OH)(4)] conformed much more closely to the Michaelis-Menten saturation function than has been observed in past studies. Strong dependence of V on [Si(OH)(4)], was observed throughout the most Si(OH)(4)-depleted (<0.5 mu M) region, where V was limited to 12 to 45% of the diatom assemblages' maximum uptake rate (V-max). Half-saturation concentrations for Si uptake (K-s) averaged 0.85 mu M (range = 0.48 to 1.71; n = 7) in spring, with the lowest values equal to the lowest previously reported for natural diatom assemblages. There was only 1 station in summer where V was limited by [Si(OH)(4)], and at that station K-s was 5.3 mu M-quite high in comparison with previous studies. At stations where V was Limited by [Si(OH)(4)], in both spring and summer, Chaetoceros spp, were numerically dominant; where there was no Si limitation other diatoms, usually Skeletonema costatum, dominated. The data thus indicate strong Si limitation in spring, with diatom assemblages well adapted to low [Si(OH)4], but Little or no Si limitation in summer. Historical data suggest that coastal Si(OH)(4) depletion and Si limitation may be recent phenomena in the northern Gulf of Mexico, resulting from increasing [NO3-] and decreasing [Si(OH)(4)] in the Mississippi River during the past 30 to 50 yr.

196. Nelsen TA, Blackwelder P, Hood T, Mckee B, Romer N, Alvarezzarikian C, Metz S. 1994. Time-based correlation of biogenic, lithogenic and authigenic sediment components with anthropogenic inputs in the Gulf-of-Mexico - NECOP study area. ESTUARIES 17 (4): 873-885.

Abstract: Hypotheses related to variability in seasonal hypoxic conditions, coastal nutrient enhancement, and offshelf transport of carbon on the Louisiana continental shelf were tested by characterization of biogenic, lithogenic, and authigenic components from two shelf and one Mississippi Canyon sediment cores. The authigenic-phase glauconite occurs above detection limits only in the core from the hypoxic area. A major increase in glauconite concentration was coincident with the onset (similar to 1940) of the increased use of commercial fertilizers in the United States. In the same hypoxic-area core, benthic foraminifera species diversity decreases upcore from approximately the turn of the century to the present in a manner concurrent with glauconite and fertilizer increases. A subset of opportunistic benthic foraminifera species, known to become more prominent in stressed environments (i.e., hypoxic), increased upcore from similar to 52% of the total population at core bottom to similar to 90% at core top. These benthic foraminifera population and diversity changes were not apparent in a "control" core outside the area of documented hypoxia. Seaward of the shelf, in the Mississippi Canyon, coincident increases in sediment accumulation rate, percentages of coarse fraction and of organc carbon at core top indicate increased offshelf transport of carbon and other components. Quartz percentages indicate that episodic down-canyon transport has been active to core bottom (prior to the mid 1800s).

206. Pakulski JD, Benner R, Amon RWM, Eadie BJ, Whitledge TE (1995) Community metabolism and nutrient cycling in the Mississippi River plume: evidence for intense nitrification at intermediate salinities. Mar Ecol Prog Ser 117:207-218.

Abstract: Community respiration, net nutrient fluxes and heterotrophic bacterial production were investigated in the Mississippi River (USA) plume during May 1992 using dark bottle incubations of unfiltered water. Highest rates of community O-2 consumption and dissolved inorganic carbon regeneration were observed at intermediate (10 to 27 parts per thousand) plume salinities. Plume surface O-2 consumption rates were 2- to 4-fold greater than rates reported previously during the summer and winter. Heterotrophic bacterial production ([H-3]-leucine incorporation) was also highest at intermediate salinities and 2- to 4-fold greater than rates reported from other seasons. Net regeneration of NH4+ was observed in the 0 to 18 parts per thousand region of the plume while low rates of net NH4+ consumption were observed at 27 parts per thousand. Net NO2- regeneration in the Mississippi River suggested the occurrence of nitrification in the fresh waters of the delta. Serendipitous observations of rapid NO3- regeneration at 18 and 27 parts per thousand indicated the development of intense nitrification at intermediate plume salinities. Nitrification accounted for 20 to >50% of the community O-2 demand at 18 and 27 parts per thousand. These data indicated that nitrification was an important component of the plume nitrogen cycle and contributed significantly to oxygen consumption in the plume.

215. Pokryfki L, E. 1987. Nearshore Hypoxia in the Bottom Water of the Northwestern Gulf of Mexico from 1981 to 1984. Marine Environmental Research 22 (1): 75-90.

Abstract: Hypoxia, and occasionally anoxia, occur annually in the northern Gulf of Mexico. Important physical properties preceding and partially causing hypoxia and the

spatial extent of hypoxia are determined. Temporal trends of salinity, temperature, sigma-t, bottom dissolved oxygen, and river dischar ge offshore Cameron, Louisiana, are described and statistically analyzed using four years (1981–1984) of monthly data. A cruise was conducted in July 1984 to measure the spatial extent of hypoxia in coastal waters from Galveston, Texas, to 74 km east of Cameron, Louisina. A 'best-fit' linear model estimating bottom dissolved oxygen concentrations contained the salinity and temperature variables. Time series analysis of the data revealed time lags between low bottom (dissolved oxygen and peak river discharge (2 month lag), and low salinity (1 month lag). The time series model using the river discharge and (density gradient variahles more accurately predicted bottom dissolved oxygen concentrations during hypoxic events.

216. Pomeroy LR, Sheldon JE, Sheldon WM, Peters F (1995) Limits to growth and respiration of bacterioplankton in the Gulf of Mexico. Mar Ecol Prog Ser 117:259-268

Abstract: We compared microbial community respiration and related parameters in the Gulf of Mexico in January and dune 1993. Microbial community respiratory rates in the upper mixed layer varied from <0.03 mu M O-2 h(-1) in the central Gulf in January to 1.4 mu M O-2 h(-1). in the Mississippi River plume in June. Although higher respiratory rates were found in June than in January, no significant differences were found in bacterial numbers or mean cell volume. Dissolved free amino acid concentrations were an order of magnitude higher in June, but there was Little difference in concentrations of phosphate or monosaccharides between January and June. Enrichment experiments in June showed phosphate to be the primary limiting factor for bacterial production and microbial community respiration and organic carbon substrates to be a secondary Limiting factor. Respiratory rate and bacterial secondary production increased when phosphate was added to water samples. Ammonium, iron and other trace metals, vitamins and chelators had no effect. Glucose was utilized only when supplemented with phosphate. Turnover time of bacterial biomass in June, based on counts, sizes, and production data, was 7 to 30 h, with the shortest times at oligotrophic stations. The observed rates of bacterial respiration and production imply the utilization of multiple sources of organic and recycled inorganic nutrients in a complex and inefficient food web.

219. Prasad, K. S., S. E. Lohrenz, and a. D. G. Redalje (1994), Primary production in the Gulf of Mexico coastal waters using "remotely-sensed" trophic category approach, Journal of Mississippi Academy of Sciences, 39, 62.

Abstract: Attempts to derive ocean-color based estimates of pigment and primary production in coastal waters have been complicated by the contributions of signals from non-pigment materials to the water leaving radiance. An ocean-color model to estimate primary production was evaluated for coastal waters of the northern Gulf of Mexico. The model utilizes C_{sat}, (mg m^{-3}) (a variable that accounts for the pigment sensed by the satellite sensor), photosynthetically available radiation (PAR, J m^{-2} day^{-1}) and a parameter. ψ^* m2 (g Chl)$^{-1}$, the water column chlorophyll specific cross-section for

photosynthesis. C_{sat} and PAR were treated as variables while ψ^* was a site-specific parameter in the model. The model uses the approach outlined in Morel and Berthon (1989) Limnology and Oceanography, **34**, 1545–1562, but with site-specific statistical relationships to estimate the integrated pigment in the water column from C_{sat} and site-specific trophic categories (oligotrophic to eutrophic) based on pigment concentration in the water column. The statistical relationships perform extremely well within the ranges of C_{sat} and integral chlorophyll normally encountered in the coastal waters of the northern Gulf of Mexico. ψ^* varies between 0.054 and 0.063 m^2 (g Chl)$^{-1}$ and are comparable to values observed in other regions. The ability of the model to predict production using ψ^* within each of the trophic categories was demonstrated.

The overall performance of the model has been encouraging for two reasons: (a) the possibility of estimating production from future ocean-color sensors, and (b) the fact that the model performs well in a dynamic coastal area.

220. Qureshi, N., N. Rabalais, Q. Dortch, and G. Turner (1995), Fecal pellet carbon flux and bottom water hypoxia on the Louisiana continental shelf.

222. Rabalais, N. N., M. J. Dagg, and D. F. Boesch (1985), Oxygen depletion on the inner continental shelf of the northern Gulf of Mexico, Estuaries, 8, 44A.

223. Rabalais NN, Wiseman WJ, Turner RE (1994) Comparison of continuous records of near-bottom dissolved oxygen from the hypoxia zone of Louisiana. Estuaries 17:850–861

Abstract: Oxygen depletion is a seasonally dominant feature of the lower water column on the highly-stratified, riverine-influenced continental shelf of Louisiana. The areal extent of hypoxia (bottom waters less than or equal to 2 mg l(-1) dissolved oxygen) in mid-summer may encompass up to 9,500 km(2), from the Mississippi River delta to the upper Texas coast, with the spatial configuration of the zone varying interannually. We placed two continuously recording oxygen meters (Endeco 1184) within 1 m of the seabed in 20-m water depth at two locations 77 km apart where we previously documented midsummer bottom water hypoxia. The oxygen meters recorded considerably different oxygen conditions for a 4-mo deployment from mid-June through mid-October. At the station off Terrebonne Bay (C6A), bottom waters were severely depleted in dissolved oxygen and often anoxic for most of the record from mid-June through mid-August, and there were no strong diurnal or diel patterns. At the station 77 km to the east and closer to the Mississippi River delta (WD32E), hypoxia occurred for only 50% of the record, and there was a strong diurnal pattern in the oxygen time-series data. There was no statistically significant coherence between the oxygen time-series at the two stations. Coherence of the oxygen records with wind records was weak. The dominant coherence identified was between the diurnal peaks in the WD32E oxygen record and the bottom pressure record from a gauge located at the mouth of Terrebonne Bay, suggesting that the dissolved oxygen signal at WD32E was due principally to advection by tidal currents. Although the oxygen time-series were considerably different, they were consistent with the physical and biological processes that affect hypoxia on the Louisiana shelf. Differences in the time-series were most intimately tied to the

topographic cross-shelf gradients in the two locations, that is, station C6A off Terrebonne Bay was in the middle of a broad, gradually sloping shelf and station WD32E in the Mississippi River Delta Bight was in an area with a steeper cross-shelf depth gradient and likely situated near the edge of a hypoxic water mass that was tidally advected across the study site.

224. Rabalais, N. N., W. J. Wiseman, Jr., R. E. Turner, D. Justić, B. K. Sen Gupta, and Q. Dortch (1996), Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf, Estuaries, 19, 386-407.

Abstract: The Mississippi River system ranks among the world's top 10 rivers in freshwater and sediment inputs to the coastal ocean. The river contributes 90% of the freshwater loading to the Gulf of Mexico, and terminates amidst one of the United States' most productive fisheries regions and the location of the largest zone of hypoxia in the western Atlantic Ocean. Significant increases in riverine nutrient concentrations and loadings of nib-are and phosphorus and decreases in silicate have occurred this century, and have accelerated since 1950. Consequently, major alterations have occurred in the probable nutrient limitation and overall stoichiometric nutrient balance in the adjacent continental shelf system. Changes in the nutrient balances and reduction in riverine silica loading to the continental shelf appear to have led to phytoplankton species shifts offshore and to an increase in primary production. The phytoplankton community response, as indicated by long-term changes in biological uptake of silicate and accumulation of biologically bound silica in sediments, has shown how the system has responded to changes in riverine nutrient loadings. Indeed, the accumulation of biologically bound silica in sediments beneath the Mississippi River plume increased during the past two decades, presumably in response to increased nitrogen loading. The duration, size, and severity of hypoxia has probably increased as a consequence of the increased primary production. Management alternatives directed at water pollution issues within the Mississippi River watershed may have unintended and contrasting impacts on the coastal waters of the northern Gulf of Mexico.

225. Rabalais NN, Turner RE, Wiseman WJ, Dortch Q. 1998. Consequences of the 1993 Mississippi river flood in the Gulf of Mexico. REGULATED RIVERS-RESEARCH & MANAGEMENT 14 (2): 161-177 Sp. Iss. SI.

Abstract: Seasonally severe hypoxia (less than or equal to 2 mg O-2 1(-1)) occurs in waters below the pycnocline on the northern Gulf of Mexico inner continental shelf in May through September over extensive areas (up to 18000 km(2)). Spatial and temporal variability in the distribution of hypoxic water masses is related, in part, to the amplitude and phasing of freshwater discharge from the Mississippi and Atchafalaya Rivers, circulation patterns, nutrient flux and a close coupling with net productivity. The Mississippi River flood in 1993 and sustained freshwater inputs to the Gulf of Mexico occurred during mid-summer through early autumn when long-term mean flows (1930-1995) are normally lowest. Long-term studies of the Louisiana shelf hypoxic zone provided a natural experiment to examine the effects of extreme high river flow on the adjacent continental shelf. Oxygen levels in bottom waters were severely reduced in July,

August and September compared to long-term averages (1985-1992). Also, the areal extent of the bottom-water hypoxia in mid-summer 1993 was approximately twice as large as the average area mapped in the previous 8 years during mid-summer shelfwide surveys. Contributing to increased severity and areal extent of hypoxia in 1993 were reduced surface water salinities, increased strength of the pycnocline, five to ten times higher nutrient concentrations, greater phytoplankton biomass, an order of magnitude greater abundance of phytoplankton, mostly small, coccoid cyanobacteria, and a shift in diatom community dynamics. An equally extensive hypoxic zone in mid-summer of 1994, when riverine fluxes of freshwater and nutrients were 'normal', suggests some residual effects of the 1993 summer flooding.

226. Rabalais, N. N., R. E. Turner, D. Justić, Q. Dortch, and W. J. Wiseman, Jr (1999), Characterization of Hypoxia: Topic 1 Report for the Integrated Assessment of Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 15., 167 pp, NOAA Coastal Ocean Program, Silver Spring, MD.

227. Rabalais, N. N., R. E. Turner and W. J. Wiseman, Jr. 1999. Hypoxia in the northern Gulf of Mexico: Linkages with the Mississippi River. Pp 297-322 in H. Kumpf, K. Steidinger and K. Sherman (eds.), The Gulf of Mexico Large Marine Ecosystem, Assessment, Sustainability, and Management, Blackwell Science, Malden, Massachusetts, 697 pp.

228. Rabalais, N. N., R. Eugene Turner, W. J. Wiseman, Jr., D. Justić, B. K. Sen Gupta and T. A. Nelsen. 1999. Hypoxia. Chapter 5, pages 79-102 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No. 14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

229. Rabalais, N. N., R. S. Carney and E. G. Escobar-Briones. 1999. Overview of continental shelf benthic communities of the Gulf of Mexico. Pp 171-195 in H. Kumpf, K. Steidinger and K. Sherman (eds.), The Gulf of Mexico Large Marine Ecosystem, Assessment, Sustainability, and Management, Blackwell Science, Malden, Massachusetts, 697 pp.

230. Rabalais, N. N., S. E. Lohrenz, D. G. Redalje, Q. Dortch, D. Justić, R. E. Turner, N. A. Qureshi, M. J. Dagg, B. J. Eadie, and G. L. Fahnenstiel (1999), Nutrient-enhanced coastal productivity and ecosystem responses, in Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico - Understanding the Effects of Nutrients on a Coastal Ecosystem, edited by W. J. Wiseman, Jr., et al., pp. 51-78, NOAA Coastal Ocean Program, Silver Spring, MD.

231. Rabalais, N. N., S. E. Lohrenz, D. G. Redalje, Q. Dortch, D. Justić, R. E. Turner, N. A. Qureshi, M. J. Dagg, B. J. Eadie and G. L. Fahnensteil. 1999. Nutrient-enhanced coastal productivity and ecosystem responses. Chapter 4, pages 51-78 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No.

14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

259. Redalje, D. G., S. E. Lohrenz, and G. L. Fahnenstiel (1992), Phytoplankton dynamics and the vertical flux of organic carbon in the Mississippi River Plume and inner Gulf of Mexico shelf region, in Primary Productivity and Biogeochemical Cycles in the Sea, edited by P. G. Falkowski and A. D. Woodhead, p. 526, Plenum Press, New York.

260. Redalje, D. G., S. E. Lohrenz, and G. L. Fahnenstiel (1992), The relationship between primary production and the export of POM from the photic zone in the Mississippi River plume and inner Gulf of Mexico shelf regions, in Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991, edited by N. C. O. Program, pp. 105-110, Texas Sea Grant Publications, College Station, Texas.

261. Redalje, D. G., S. E. Lohrenz, and a. G. L. Fahnenstiel (1994), The vertical export of particulate and dissolved organic carbon from the surface waters of the northern Gulf of Mexico shelf, Journal of Mississippi Academy of Sciences, 39, 63.

262. Redalje, D. G., S. E. Lohrenz, and G. L. Fahnenstiel (1994), The relationship between primary production and the vertical export of particulate organic matter in a river impacted coastal ecosystem, Estuaries, 17, 829-838.

Abstract: As part of the National Oceanic and Atmospheric Administration's (NOAA) Nutrient Enhanced Coastal Ocean Productivity program, we have conducted four research cruises, July-August 1990, March 1991, September 1991, and May 1992, in the Mississippi River plume and adjacent shelf regions. Over this time period, photic-zone-integrated primary production varied significantly in both the river plume and shelf study regions, with greatest variability observed in the river plume region. In the river plume and the adjacent shelf, highest production occurred during July-August 1990 (8.17 g C m(-2) d(-1) for the plume and 1.89-3.02 g C m(-2) d(-1) for the shelf) and the lowest during March 1991 (0.40-0.69 g C m(-2) d(-1) for the plume and 0.12-0.45 g C m(-2) d(-1) for the shelf). The vertical export of POC from the euphotic zone, determined with free-floating MULTITRAP sediment trap systems, also varied temporally in both study regions, with highest values occurring in May 1992 (1.80 +/- 0.04 g C m(-2) d(-1) for the plume and 0.40 +/- 0.02 g C m(-2) d(-1) for the shelf) and the lowest values occurring during July-August 1990 (0.29 +/- 0.02 g C m(-2) d(-1) for the plume and 0.18 +/- 0.01 g C m(-2) d(-1) for the shelf). The fraction of production exported out of the photic zone was highly variable and was dependent, in part, on phytoplankton species composition and on the grazing activities of microzooplankton and mesozooplankton. The lowest ratio of export to production coincided with the time when production was greatest and the highest ratios occurred when production was the lowest.

275. Sen Gupta BK, Turner RE, Rabalais NN. 1996. Seasonal oxygen depletion in continental-shell waters of Louisiana: Historical record of benthic foraminifers. Geology 24 (3): 227-230.

Abstract: A strong spring and summer oxygen depletion is induced in nearshore bottom waters of the Louisiana continental shelf by density stratification and by the carbon flux from phytoplankton production, which, in turn, is related to the nutrient load of the Mississippi and Atchafalaya rivers. In an attempt to read the historical record of this shelf hypoxia during the past two centuries, we compared the stratigraphic signals of benthic foraminifera (as reflected in a relative-dominance index for two common species of Ammonia and Elphidium) in Pb-210-dated cores, and we found evidence of an overall rise in oxygen stress (in intensity or duration), especially in the past 100 yr. This implies a progressive increase in the influence of river-borne nutrients, particularly anthropogenically influenced nitrates, Judging by our results, foraminiferal indices based on appropriate species ratios should prove useful in testing hypotheses about long-term environmental stresses, including eutrophication and paleohypoxia, on other marine shelves.

276. Shiller, A. M., and L. Mao (1999), Dissolved vanadium on the Louisiana Shelf: effect of oxygen depletion, Cont. Shelf Res., 19, 1007-1020.

Abstract: New measurements of dissolved vanadium in waters of the Louisiana Shelf affected by outflow from the Mississippi/Atchafalaya River system are presented here. These measurements complement previously published estuarine vanadium data and allow a reexamination of prior conclusions. In estuarine and coastal regions it appears that the most significant vanadium depletions occur in association with reducing conditions. These reducing conditions are frequently driven by anthropogenic eutrophication. Sedimentary inputs also appear to be a factor in affecting the flux of vanadium to the ocean in certain environments In contrast to previous results we find no compelling evidence of biological removal of vanadium from estuarine surface waters. Given the uncertainties, it is difficult to accurately estimate the natural flux of dissolved vanadium from the land to the open ocean. Nonetheless, increasing coastal anthropogenic eutrophication could substantially alter the natural fluvial vanadium input as well as possibly shift the primary locus of oceanic vanadium removal.

279. Šolić, M., N. Krustolović, I. Marasović, A. Baranović, T. Pucher-Petković and T. Vučetić. 1997. Analysis of time series of planktonic communities in the Adriatic Sea: distinguishing between natural and man-induced changes. *Oceanol. Acta*, **20**, 131-143.

Abstract: Time series (> 20 years) of bacterioplankton, phytoplankton and zooplankton abundances and of phytoplankton production in the Adriatic Sea were analysed. Multivariate methods were used to extract the main patterns of year-to-year changes in abundances (Principal Component Analysis), and to discriminate between years and sites (Multidimensional Scaling). Increasing long-term trends were established for planktonic abundances and phytoplankton production in both coastal and open sea areas, presumably as a result of eutrophication processes. In the open sea, natural factors (water exchange between the Mediterranean and Adriatic Seas, and temperature) were dominant in controlling year-to-year fluctuations of plankton. On the other hand, long-term fluctuations of plankton in the coastal area were chiefly controlled by man-induced factors. Thus, besides natural factors, the dominant pattern of planktonic fluctuation was

correlated with the fluctuation of nutrients coming from the land as a result of human activities.

281. Strom SL, Strom MW (1996) Microplankton growth, grazing, and community structure in the northern Gulf of Mexico. Mar Ecol Prog Ser 130: 229-240

Abstract: Seawater dilution experiments were conducted during spring and fall in the continental shelf region of the northern Gulf of Mexico. Nutrient-enhanced phytoplankton growth rates of 0.7 to 2.2 d(-1) were measured for the entire phytoplankton community; highest growth rates were associated with >8 mu m cells. Phytoplankton growth was nutrient limited in all May experiments, and >8 mu m phytoplankton, primarily diatoms, showed the strongest response to nutrient addition: their growth rates increased the most and reached the highest values. Rates of microzooplankton grazing on the entire phytoplankton community were moderate (0 to 0.7 d(-1)). During a given experiment, patterns of gracing on 2 phytoplankton size fractions (<8 and >8 mu m) generally differed, and high rates of grazing (>1 d(-1)) on both <8 and >8 mu m cells were sometimes observed. Across all experiments, grazing by microzooplankton averaged 30% of nutrient-enhanced phytoplankton growth. In May, when phytoplankton growth was strongly nutrient limited, grazing averaged 90% of natural (non-nutrient-enhanced) phytoplankton growth. These data indicate that microzooplankton can be a significant source of phytoplankton mortality, even in eutrophic coastal waters. The microzooplankton community, excluding cells <5 mu m, comprised primarily heterotrophic dinoflagellates and aloricate choreotrich ciliates. These organisms exhibited high net growth rates (mean = 0.8 d(-1)) during experiments at higher irradiance levels. Ingestion of chain diatoms by the dinoflagellate Gyrodinium sp. was observed in preserved samples; such grazing pathways, in which relatively large phytoplankton cells are consumed by protozoa, may be quantitatively important in this coastal ecosystem. Due to the variety of taxa and feeding mechanisms within the microzooplankton, their grazing impact was not restricted to the smallest phytoplankton cells, indicating that size-based models of trophic structure could yield misleading predictions about patterns of energy flow in this coastal ecosystem.

285. Toon R, Dagg M (1992a) Nutrient Enhanced Coastal Ocean Productivity (NECOP) Data report: CTD and Hydrographic Data R/V Pelican Cruise, January 1992

286. Toon R, Dagg M (1992b) Nutrient Enhanced Coastal Ocean Productivity (NECOP) Data report: CTD and Hydrographic Data R/V Pelican Cruise, May 5-17, 1992

287. Turner, R. E., R. Kaswadji, N. N. Rabalais, and D. F. Boesch (1987), Long-term changes in the Mississippi River water quality and its relationship to hypoxic continental shelf waters, 261-266 pp.

288. Turner RE, Rabalais NN (1991) Changes in Mississippi River water quality this century: Implications for coastal food webs. BioScience 41:140–148

The link to the first page of this article can be found here:

http://links.jstor.org/sici?sici=0006-3568(199103)41%3A3%3C140%3ACIMRWQ%3E2.0.CO%3B2-L

289. Turner RE, Rabalais NN (1994) Coastal eutrophication near the Mississippi River delta. Nature 368:619-621

Abstract: CHANGES in delivery of river-borne nutrients such as dissolved Phosphate, nitrate and silicate, owing to land-use changes and anthropogenic emissions, are known to result in eutrophication1-enhanced phytoplankton blooms-and more severe hypoxic events2-4 in many enclosed bays and seas, Although similar ecological effects might be expected on continental shelves, the occurrence of such eutrophication has remained unresolved5. Here we present evidence of eutrophication of the continental shelf near the outflow of the Mississippi river, obtained by quantifying biologically bound silica (BSi) in diatom remnants within dated sediment cores. BSi accumulation rates are greatest in water depths of 20 to 50 m within 100 km of the river mouth, and have increased by as much as 100% this century. The increases were substantial by 1980, by which time riverine nitrogen loading had doubled relative to the beginning of the century, even though the silica loading had declined by 50% over the same period. Thus changes in river-borne nutrient loadings can modify coastal food webs and affect the amount and distribution of oxygen in bottom waters on the scale of continental shelves.

290. Turner RE, Boyer ME. 1997. Mississippi River diversions, coastal wetland restoration/creation and an economy of scale. ECOLOGICAL ENGINEERING 8 (2): 117-128.

Abstract: We tested the hypothesis that there is an economy of scale in ecological engineering projects designed to create or restore wetlands by using examples of coastal restoration/creation projects in the Louisiana coastal zone. Land gain and project cost are directly related to the amount of riverflow diverted from the main channel, as expected. However, the $/ha gained was dramatically and directly related to project size. A 1000 fold increase in project size is matched by a 100 fold increase in the cost/ha gained. The smallest river diversion projects ($20,000 each) create land at slow rates (@5 ha/year) and tend to be very cost effective ($20-$500/ha). These low cost/ha gained are in sharp contrast to that of the larger river diversion projects and most other local wetland restoration/creation projects funded by state/federal sponsored programs ($1000 to $100 000/ha) on this coast. There is a 15 fold increase in $/ha gained as project size increases by a factor of 10. This situation of decreasing returns ($/ha gained) with project increasing costs may be called an 'inverse' economy of scale. We propose that there are generic economies of scale inherent to similar environmental management approaches that represent a compromise of at least three attributes: attempts to control ecosystem behavior (predictability and use), ecosystem complexity, and incomplete ecosystem knowledge.

291. Turner RE. 1997. Wetland loss in the northern Gulf of Mexico: Multiple working hypotheses. ESTUARIES 20 (1): 1-13.

Abstract: I examined four hypotheses about causes for the dramatically high coastal wetland losses (0.86% yr(-1)) in the northern Gulf of Mexico: an extensive dredged canal and spoil bank network, a decline in sediments in the Mississippi River during the 1950s, Mississippi River navigation and flood protection levees, and salinity changes. Natural factors contributing to these habitat changes include eustatic sea-level rise and geological compaction, which appear to have remained relatively constant this century, although variation does occur. These four hypotheses were tested using data on land-to-water changes in 15-min quadrangle maps inventoried for four intervals between the 1930s and 1990. Land loss rates were directly proportional to changes in wetland hydrology in time and space. A linear regression of the direct losses due to dredging versus the losses due to all other factors (indirect losses) had a zero intercept and a slope that increased with time. The ratio indirect:direct land loss was highest nearest the estuarine entrance. The coastwide patterns of land loss do not appear to be affected by riverine sediment reductions over the last 60 yr. The effects of changes in wetland hydrology from dredging human-made channels and forming dredged spoil banks appear to be the most efficacious hypothesis explaining these dramatic losses. The effects of extensive human-induced changes on this coast have apparently overwhelmed the causal linkages identified in the historical re-constructionist view of deltaic gain and loss that emphasizes the role of mineral sediments. A paradigm shift is therefore proposed that emphasizes a broad ecological view as contrasted to a mostly physical view emphasizing the role of sediment supply in wetland maintenance. In this view, plants are not an ancillary consequence of strictly geological dynamics such as sediment supply but are dominant agents controlling factors relevant to coastal restoration and management efforts.

292. Turner RE, Qureshi N, Rabalais NN, Dortch Q, Justić D, Shaw RF, Cope J (1998) Fluctuating silicate: Nitrate ratios and coastal plankton food webs. In Proc Nat Acad Sci USA 95:13048-51.

Abstract: Marine diatoms require dissolved silicate to form an external shell. and their growth becomes Si-limited when the atomic ratio of silicate to dissolved inorganic nitrogen (SI:DIN) approaches 1:1, also known as the "Redfield ratio." Fundamental changes in the diatom-to-zooplankton-to-higher trophic level food web should occur when this ratio falls below 1:1. and the proportion of diatoms in the phytoplankton community is reduced. We quantitatively substantiate these predictions by using a variety of data from the Mississippi River continental shelf, a system in which the SI:DIN loading ratio has declined from around 3:1 to 1:1 during this century because of land-use practices in the watershed, We suggest that, on this shelf, when the Si:DIN ratio in the river decreases to less than 1:1, then (i) copepod abundance changes from >75% to <30% of the total mesozooplankton, (ii) zooplankton fecal pellets become a minor component of the in situ primary production consumed, and (iii) bottom-water oxygen consumption rates become less dependent on relatively fast-sinking (diatom-rich) organic matter packaged mostly as zooplankton fecal pellets. This coastal ecosystem appears to be a pelagic food web dynamically poised to be either a food web composed of diatoms and copepods or one with potentially disruptive harmful algal blooms. The system is directed between these two ecosystem states by Mississippi River water quality, which is determined by land-use practices far inland.

293. Turner, R. E. and N. N. Rabalais. 1999. Suspended particulate and dissolved nutrient loadings to Gulf of Mexico estuaries. Pp 89-107 in T. Bianchi, J. Pennock and R. Twilley (eds.), Biogeochemical Dynamics of Estuarine Ecosystems in the Gulf of Mexico. John Wiley & Sons, New York.

295. Turner, R. E. 1999. Inputs and outputs of the Gulf of Mexico. Pp. 64-73, In: H. Kumpf, K. Steidinger, and K. Sherman, eds., The Gulf of Mexico Large Marine Ecosystem. Blackwell Science, Oxford, United Kingdom.

312. Walker ND. 1996. Satellite assessment of Mississippi River plume variability: Causes and predictability. REMOTE SENSING OF ENVIRONMENT 58 (1): 21-35.

Abstract: The Mississippi River is the largest river in North America and 6th largest worldwide in terms of discharge. In this study, 5 years (1989-1993) of NOAA Advanced Very High Resolution Radiometer satellite data were used to investigate the variability of the Mississippi River sediment plume and the environmental forcing factors responsible for its variability. Plume variability was determined by extracting information on plume area and plume length from 112 cloudl-free satellite images. Correlation and multiple regression techniques were used to quantify these relationships for possible predictive applications. River discharge and wind forcing were identifed as the main factors affecting plume variability. Seasonal and interannual variabilities in plume area were similar in magnitude and corresponded closely with large changes in river discharge. However, day-to-day variability in plume size and morphology was more closely associated with changes in the wind field. The plume parameters bst predicted by the multiple regression models were plume area, east and west of the delta. Predictive models were improved by separating the data into summer and winter seasons. The best predictive model for the western area was obtained during summer when 64% of plume variability was explained by river discharge, wind speed, and the east-west wind component. The best model for the eastern plume area was obtained during summer when river discharge, the north-south and east-west wind components explained 70% of plume variability. The best model for the offshore extent of the sediment plume was obtained during summer when 53% of plume variability was explained by the east-west wind component, river discharge, and wind speed. All plume measurements were maximized by eastward winds from slightly different directions. During winter, the area and length of the western plume was additionally enhanced by offshore winds associated with winter storms. Anticyclonic curvature of the plume west of the delta was observed in 42% of the satellite images. This circulation pattern was observed primarily in association with westward winds.

313. Walker ND, Huh OK, Rouse LJ, Murray SP. 1996. Evolution and structure of a coastal squirt off the Mississippi River delta: Northern Gulf of Mexico. JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS 101 (C9): 20643-20655.

Abstract: In early October 1992, satellite-derived sea surface temperature data revealed a 200 km long and 10 to 30-km-wide stream of cool water flowing toward the southwest

from the Mississippi River delta region. Satellite imagery and in situ measurements have enabled a detailed study of the squirt's kinematics and subsurface characteristics over a 2-week period. In its early stages, the squirt appeared as a narrow, high-speed (> 75 cm/s)jet of water which flowed westward over the Mississippi Canyon, forcing a semi-submersible drilling rig to suspend operations from October 2 to 4. After crossing back onto the shelf, the squirt spread laterally, yielding a mushroom-shaped feature, 75 inn wide, which consisted of counter-rotating vortices. Northeasterly wind forcing (averaging 10-15 m/s) and water level setup east of the delta appear to have been the primary mechanisms for evolution of the high-velocity currents. Satellite and in situ measurements demonstrate that the dipole eddy was comprised of a cool low-salinity, low-density water mass at least 26 m deep in the center and 16 m deep along its margins. This event demonstrates that strong northeasterly winds over the northern Gulf of Mexico can initiate along-shelf and off-shelf flows of cooler coastal waters, contributing significantly to seasonal cooling and freshening of the continental shelf and to shelf/slope exchanges of water. During this event, approximately 100 km(3) of inner shelf and river water was transported off the continental shelf, a volume equivalent to 17% of the average annual discharge of the Mississippi and Atchafalaya Rivers.

319. Wiseman, W. J., N. N. Rabalais, R. E. Turner, S. P. Dinnel, and A. MacNaughton (1997), Seasonal and interannual variability within the Louisiana coastal current: stratification and hypoxia, Journal of Marine Systems, 12, 237-248.

Abstract: Ten years of mid-summer survey cruise data mapping the west Louisiana inner shelf, supplemented by data from occasional cruises along a single transect and time series data, is used to characterize the seasonal and interannual variability of stratification in the region. Persistent strong haline stratification is modulated by the intensity and phasing of river discharge from the Mississippi/Atchafalaya River system. This stratification is only destroyed during periods of intense wind mixing. The strong relationship between stratification variability and hypoxia is demonstrated.

320. Wiseman, Jr., W. J. and N. N. Rabalais. 1999. Executive summary. Pages 1-4 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No. 14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

321. Wiseman, Jr., W. J., B. McKee, N. N. Rabalais and S. P. Dinnel. 1999. Physical oceanography and sediment dynamics. Chapter 2, pages 17-36 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No. 322. 14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

328. Zaitsev, Y. P. 1992. Recent changes in the trophic structure of the Black Sea. *Fish. Oceanogr.,* **1**, 180-189.

Abstract: This paper reviews major ecological changes over the past 40 years in the Black Sea. An increase in nutrients has caused eutrophication, with outbursts of phytoplankton blooms and changes in the species composition of these algae. Small-sized zooplankton species and gelatinous zooplankton have become more common, while many of the herbivorous copepods have decreased in abundance or have disappeared. The introduction of the predatory ctenophore Mnemiopsis leidyi in the 1980s has had significant impact on the plankton community and has led to a sharp decline in anchovy stocks. Decreased water transparency has led to a loss of macrophytic algae, except in shallow waters, and to a subsequent decline in the zoobenthos associated with this flora. Eutrophication has also led to decreased oxygen concentrations in the near-bottom water due to large amounts of decomposing phytoplankton, and regions of hypoxia and anoxia now appear on the shelf, with consequent reduction in benthic populations of invertebrates and demersal fish.

329. Zhang, J. 1994. Atmospheric wet depositions of nutrient elements: Correlations with harmful biological blooms in the Northwest Pacific coastal zones. *Ambio*, **23**, 464-468.

Abstract: Eutrophication may occur in northwestern Pacific coastal zones (e.g. in the Yellow Sea) where nutrient concentrations in seawater are quite low (oligotrophic areas). This study provides evidence of a correlation between harmful plankton blooms and episodic atmospheric depositions of nutrients in coastal oligotrophic zones. Time and space coincidences suggest that eutrophication may be induced by the atmospheric supply of nutrients and trace species. In the Yellow Sea, where the influence of waste runoff from land is very limited and/or completely absent, atmospheric deposition may become the major source of nutrient elements to the euphotic zone particularly in regions where upward input (e.g. upwelling) is small. On an average, episodic deposition of nutrient elements accounts for only a small fraction (less than or equal to 10%) of the concentrations in seawater. However, individual rain events may result in temporal eutrophication of surface waters, which may cause harmful blooms to develop in the northwestern Pacific shelf regions.

Citations Related to:

Characterization of Nutrient Fate, Transport, and Sources

(≥ 2000)

1. Alexander, R. B., R. A. Smith, and G. E. Schwarz (2000), Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico, Nature, 403, 758-761.

> **Abstract:** An increase in the flux of nitrogen from the Mississippi river during the latter half of the twentieth century has caused eutrophication and chronic seasonal hypoxia in the shallow waters of the Louisiana shelf in the northern Gulf of Mexico(1-5). This has led to reductions in species diversity, mortality of benthic communities and stress in fishery resources(4). There is evidence for a predominantly anthropogenic origin of the increased nitrogen flux(2,5-7), hut the location of the most significant sources in the Mississippi basin responsible for the delivery of nitrogen to the Gulf of Mexico have not been clearly identified, because the parameters influencing nitrogen-loss rates in rivers are not well known. Here we present an analysis of data from 374 US monitoring stations, including 123 along the six largest tributaries to the Mississippi, that shows a rapid decline in the average first-order rate of nitrogen loss with channel size-from 0.45 day(-1) in small streams to 0.005 day(-1) in the Mississippi river. Using stream depth as an explanatory variable, our estimates of nitrogen-loss rates agreed with values from earlier studies. We conclude that the proximity of sources to large streams and rivers is an important determinant of nitrogen delivery to the estuary in the Mississippi basin, and possibly also in other large river basins.

13. Battaglin, William A., Kendall, Carol, Chang, Cecily C.Y., Silva, Steve R., and Campbell, Donald H., 2001. Isotopic and chemical composition of inorganic and organic water-quality samples from the Mississippi River Basin, 1997-98. U.S. Geological Survey Water-Resources Investigations Report 01-4095, 57 p.

> **Abstract:** Nitrate (NO3) and other nutrients discharged by the Mississippi River combined with seasonal stratification of the water column are known to cause a zone of depleted dissolved oxygen (hypoxic zone) in the Gulf of Mexico each summer. About 120 water and suspended sediment samples collected in 1997 and 1998 from 24 locations in the Mississippi River Basin were analyzed for the isotope ratios δ15N and δ18O of dissolved NO3, and δ15N and δ13C of suspended particulate organic material (POM). Sampling stations include both large rivers (drainage areas more than 30,000 square kilometers)
> that integrate the effects of many land uses, and smaller streams (drainage areas less than 2,500 square kilometers) that have relatively uniform land use within their drainage areas. The data are used to determine sources and transformations of NO3 in the Mississippi River. Results of this study demonstrate that much of the NO3 in the Mississippi River originates in the agriculturally dominated basins of the upper midwestern United States and is transported without significant transformation or other loss to the Gulf of Mexico.

Results from major tributaries that drain into the Mississippi River suggest that NO3 is not significantly altered by denitrification in its journey, ultimately, to the Gulf of Mexico. The spatial variability of isotope ratios among the smaller streams appears to be related to the dominant nitrogen source in the basins. There are some distinct isotope differences among land-use types.

For example, for both NO3 and POM, the majority of δ15N isotope ratio values from basins dominated by urban and undeveloped land are less than +5 per mil, whereas the majority of values from basins dominated by row crops and row crops and/or livestock production are greater than +5 per mil. Also, the median δ18O of NO3 isotope ratio value (+14.0 per mil) from undeveloped basins is more than 6 per mil higher than the median value (+7.3 per mil) from the row crop dominated basins and 5 per mil higher than the median value (+9.0 per mil) from the row crop and/or livestock production dominated basins. The median δ18O of NO3 isotope ratio value (+21.5 per mil) from urban basins is 6.5 per mil higher than the median value (+14.0 per mil) from the undeveloped basins. The majority of NO3 concentrations are greater than 3 milligrams per liter (mg/L) in basins dominated by row crops and row crops and/or livestock production, whereas all NO3 concentrations are less than 2 mg/L in basins dominated by urban and undeveloped land.
http://co.water.usgs.gov/midconherb/pdf/WRIR01-4095.pdf

14. Battaglin, W. A., C. Kendall, C. C. Y. Chang, S. R. Silva, and D. H. Campbell (2001), Chemical and isotopic evidence of nitrogen transformation in the Mississippi River, 1997-98, Hydrological Processes, 15, 1285-1300.

Abstract: Nitrate (NO3) and other nutrients discharged by the Mississippi River are suspected of causing a zone of depleted dissolved oxygen (hypoxic zone) in the Gulf of Mexico each summer. The hypoxic zone may have an adverse affect on aquatic life and commercial fisheries. The amount of NO3 delivered by the Mississippi River to the Gulf of Mexico is well documented, but the relative contributions of different sources of NO3, and the magnitude of subsequent in-stream transformations of NO3, are not well understood. Forty-two water samples collected in 1997 and 1998 at eight stations located either on the Mississippi River or its major tributaries were analysed for NO3, total nitrogen (N), atrazine, chloride concentrations and NO3 stable isotopes (delta N-15, delta O-18). These data are used to assess the magnitude and nature of in-stream N transformation and to determine if the delta N-15 and delta O-18 of NO3 provide information about NO3 sources and transformation processes in a large river system (drainage area similar to2 900 000 km(2)) that would otherwise be unavailable using concentration and discharge data alone. Results from 42 samples indicate that the delta N-15 and delta O-18 ratios between sites on the Mississippi River and its tributaries are somewhat distinctive, and vary with season and discharge rate. Of particular interest are two nearly Lagrangian sample sets, in which samples from the Mississippi River at St Francisville, LA, are compared with samples collected from the Ohio River at Grand Chain, II, and the Mississippi River at Thebes, IL. In both Lagrangian sets, mass-balance calculations indicate only a small amount of in-stream N loss. The stable isotope data from the samples suggest that in-stream N assimilation and not denitrification accounts

for most of the N loss in the lower Mississippi River during the spring and early summer months.

32. Bollinger, J. E., L. J. Steinberg, A. J. Englande, J. P. Crews, J. M. Hughes, C. Velasco, K. H. Watanabe, W. R. Hartley, C. M. Swalm, J. M. Mendler, L. E. White, and W. J. George (2000), Nutrient load characterization from integrated source data for the lower Mississippi River, Journal of the American Water Resources Association, 36, 1375-1390.

Abstract: Nutrient data from all available sources for the lower Mississippi River were examined for potential differences among sampling agencies and geographic locations for the period between 1960 and 1998. Monthly means grouped by parameter, sampling location and agency, were calculated and compared as paired sets, excluding those months where data were not available for both sets. Some significant differences were found between various agencies collecting nutrient data on the river, as well as between various stretches of river, especially in the case of phosphorus nutrient data. Results were used to synthesize data sets from which a history of nutrient loading in the Mississippi River was determined. General trends in nitrate+nitrite, total Kjeldahl nitrogen, orthophosphate, total phosphorus and silica loads, as well as changes in nutrient proportions and the specific limiting nutrient (by month) are reported. This study provides a useful summary of contemporary and historical nutrient data that may assist in the evaluation of Mississippi River water quality and its potential effect on the Gulf of Mexico.

69. Dagg, M. J., T. S. Bianchi, G. A. Breed, W.-J. Cai, S. Duan, H. Liui, B.A. Mckee, R. T. Powell, and C. M. Stewart (2005), Biogeochemical Characteristics of the Lower Mississippi River, USA, During June 2003, Estuaries 28, 664–674.

Abstract: During June 2003, a period of mid level discharge (17,400 m23 s21), a parcel of water in the lower Mississippi River was sampled every 2 h during its 4-d transit from river km 362 near Baton Rouge to km 0 at Head of Passes, Louisiana, United States. Properties measured at the surface during each of the 48 stations were temperature, salinity, dissolved organic carbon (DOC), total dissolved nitrogen, dissolved macronutrients (NO3 + NO2, PO4, Si(OH)4), chlorophyll a (chl a; three size fractions: , 5 mm, 5–20 mm, and . 20 mm), pigment composition by HPLC, total suspended matter (TSM), particulate organic carbon (POC), and particulate nitrogen (PN). Air-water CO2 flux was calculated from surface water dissolved inorganic carbon and pH. During the 4 d transit, large particles appeared to be settling out of the surface water. Concentrations of chl a containing particles . 20 mm declined 37%, TSM declined 43%, POC declined 42% and PN declined 57%. Concentrations of the smaller chl a containing particles did not change suggesting only large particulate materials were settling. There was no measurable loss of dissolved NO3, PO4, or Si(OH)4, consistent with the observation that chl a did not increase during the 4-d transit. DOC declined slightly (3%). These data indicate there was little autotrophic or heterotrophic activity in the lower Mississippi River at this time, but the system was slightly net heterotrophic.

86. Fisher, T. R., D. Correll, R. Costanza, J. T. Hollibaugh, C. S. Hopkinson, Jr., R. W. Howarth, N. N. Rabalais, J. E. Richey, C. Vörösmarty and R. Wiegert. 2000. Synthesizing drainage basin inputs to coastal systems. Pp 81-101 in J. E. Hobbie (ed.), Estuarine Science: A Synthetic Approach to Research and Practice, Island Press, Washington, D.C.

97. Gardner WS, Lavrentyev PJ, Bootsma HA, Caveletto JF, Troncone F, Cotner JB (2000) Effects of natural light on nitrogen dynamics. Verh Internat Verein Limnol 27:64-73

Abstract: Isotope dilution experiments with $^15 NH_4^+$ were conducted in Lake Maracaibo, Venezuela, to examine potential N turnover rates and light effects and to examine the hypothesis that nutrient dynamics are biologically driven in this tropical, hypereutrophic lake. Ammonium and nitrate concentrations were both $<1 \muM$ as compared to particulate N concentrations of 9-29 μM N. Chlorophyll (Chl) levels ranged from 2.5 to 22 $\mug liter^-1$. Numbers and biomass of bacteria ranged from $1.0 to 9.1 \times 10^6 cells ml^-1$ and 45 to 138 $\mug C liter^-1$ and those of heterotrophic nanoflagellates (HNAN) ranged from 0.5 to $3.5 \times 10^3 cells ml^-1 and 2.3 to 17.5 \mug C liter^-1$, respectively. Higest Chl concentration and microbial abundance occurred in a regio affected by sewage discharge from the city of Maracaibo. Potential ammonium uptake rates in near-surface waters ranged from about 1 $\muM h^-1 to 8 \muM h^-1$. Chl-specific uptake rates were highest in central regions that were dominated by chroococcoid cyanobacteria. Ammonium regeneration rates ranged from near detection to 2 $\muM h^-1$ and correlated significantly with the ratio of HNAN to bacterial biomass, likely reflecting the degree of bacterivory. The high ratio of potential turnover rates to ambient ammonium concentrations suggests that internal recycling is a major nutreitn supply process in the lake. Incubation bottle characteristics (e.g., light intensity, spectral quality, or possibly headspqce differences) apparently affected potential uptake rates, which were relatively low in polystyrene bottles and in quartz tubes. Uptake rates were lower in screened polystyrene bottles than in screened polypropylene syringes, with different spectral characteristics, even though total light attenuation was similar (45% vs. 53%).

http://links.jstor.org/sici?sici=0024-3590%28199812%2943%3A8%3C1814%3ANCRALE%3E2.0.CO%3B2-0&size=LARGE

104. Goolsby DA, Battaglin WA, Aulenbach BT, Hooper RP. 2001. Nitrogen input to the Gulf of Mexico. Journal of Environmental Quality 30 (2): 329-336.

Abstract: Historical streamflow and concentration data were used in regression models to estimate the annual flux of nitrogen (N) to the Gulf of Mexico and to determine where the nitrogen originates within the Mississippi Basin. Results show that for 1980-1996 the mean annual total N flux to the Gulf of Mexico was 1568 000 t yr(-1). The flux was about 61% nitrate N, 37% organic N, and 2% ammonium N. The nux of nitrate N to the Gulf has approximately tripled in the last 30 years with most of the increase occurring between 1970 and 1983, The mean annual N flux has changed little since the early 1980s, but large year-to-year variations in N flux occur because of variations in precipitation.

During wet years the N flux can increase by 50% or more due to pushing of nitrate N that has accumulated in the soils and unsaturated zones in the basin. The principal source areas of N are basins in southern Minnesota, Iowa, Illinois, Indiana, and Ohio that drain agricultural land. Basins in this region yield 1500 to more than 3100 kg N km(-2) yr(-1) to streams, several times the N yield of basins outside this region.

105. Goolsby, D.A., Battaglin, W.A., Aulenbach, B.T., and Hooper, R.P., 2000. Nitrogen Flux and sources in the Mississippi River Basin. Science of the Total Environment 248 (2-3): 87-100.

Abstract: Nitrogen from the Mississippi River Basin is believed to be at least partly responsible for the large zone of oxygen-depleted water that develops in the Gulf of Mexico each summer. Historical data show that concentrations of nitrate in the Mississippi River and some of its tributaries have increased by factors of 2 to more than 5 since the early 1900s. We have used the historical streamflow and concentration data in regression models to estimate the annual flux of nitrogen (N) to the Gulf of Mexico and to determine where the nitrogen originates within the Mississippi Basin. Results show that for 1980-96 the mean annual total N flux to the Gulf of Mexico was 1,568,000 metric tons per year (t/yr). The flux was about 61% nitrate as N, 37% organic N, and 2% ammonium as N. The flux of nitrate to the Gulf has approximately tripled in the last 30 years with most of the increase occurring between 1970 and 1983. The mean annual N flux has changed little since the early 1980s, but large year-to-year variations in N flux occur because of variations in precipitation. During wet years the N flux can increase by 50 percent or more due to flushing of nitrate that has accumulated in the soils and unsaturated zones in the basin. The principal source areas of N are basins in southern Minnesota, Iowa, Illinois, Indiana, and Ohio that drain agricultural land. Basins in this region yield 800 to more than 3,100 kilograms total N per square kilometer per year ($kg/km_2/yr$) to streams, several times the N yield of basins outside this region. Assuming conservative transport of N, streams draining Iowa and Illinois contribute on average about 35% of the total N discharged by the Mississippi River to the Gulf of Mexico. In years with high precipitation they can contribute a larger percentage.

http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionC/2401_Goolsby/pdf/2401_Goolsby.pdf

106. Goolsby, D.A., and Battaglin, W.A., 2000, Nitrogen in the Mississippi Basin--Estimating sources and predicting flux to the Gulf of Mexico. U.S. Geological Survey Fact Sheet FS-135-00, 6 p.

107. Goolsby, D. A., and W. A. Battaglin (2001), Long-term changes in concentrations and flux of nitrogen in the Mississippi River Basin, USA, Hydrological Processes, 15, 1209-1226.

Abstract: Current and historical data show that nitrogen concentrations and flux in the Mississippi River Basin have increased significantly during the past 100 years. Most of the increase observed in the lower Mississippi River has occurred since the early 1970s and is due almost entirely to an increase in nitrate. The current (1980-99) average annual nitrogen (N) flux from the Mississippi Basin to the Gulf of Mexico is about 1 555 500 t

year(-1), of which about 62% is nitrate-N. The remaining 38% is organic nitrogen and a small amount of ammonium. The current (1980-99) average nitrate flux to the Gulf is almost three times larger than it was during 1955-70. This increased supply of nitrogen to the Gulf is believed to be partly responsible for the increasing size of a large hypoxic zone that develops along the Louisiana-Texas shelf each summer. This zone of oxygen-depleted water has doubled in areal extent since it was first measured in 1985. The increase in annual nitrate flux to the Gulf can be largely explained by three factors: increased fertilizer use, annual variability in precipitation and increased streamflow, and the year-to-year variability in the amount of nitrogen available in the soil-ground water system for leaching to streams. The predominant source areas for the nitrogen transported to the Gulf of Mexico are basins draining southern Minnesota, Iowa, Illinois, Indiana, and Ohio. Basins in this region yield 1801 to 3050 kg N km(-2) year(-1) to streams, several times the N yield of basins outside this region.

181. McIsaac, G. F., M. B. David, G. Z. Gertner, and D. A. Goolsby (2001), Eutrophication: Nitrate flux in the Mississippi River, Nature, 414, 166-167.

This article is available in its entirely as a PDF:
http://www.nature.com/nature/journal/v414/n6860/pdf/414166a0.pdf

182. McIsaac, G. G., M. B. David, G. Z. Gertner and D. A. Goolsby. 2002. Relating net N input in the Mississippi River basin to nitrate flux in the lower Mississippi River: A comparison of approaches. *J. Environ. Qual.,* **31**, 1610-1622.

Abstract: A quantitative understanding of the relationship between terrestrial N inputs and riverine N flux can help guide conservation, policy, and adaptive management efforts aimed at preserving or restoring water quality. The objective of this study was to compare recently published approaches for relating terrestrial N inputs to the Mississippi River basin (MRB) with measured nitrate flux in the lower Mississippi River. Nitrogen inputs to and outputs from the MRB (1951 to 1996) were estimated from state-level annual agricultural production statistics and NOy (inorganic oxides of N) deposition estimates for 20 states that comprise 90% of the MRB. A model with water yield and gross N inputs accounted for 85% of the variation in observed annual nitrate flux in the lower Mississippi River, from 1960 to 1998, but tended to underestimate high nitrate flux and overestimate low nitrate flux. A model that used water yield and net anthropogenic nitrogen inputs (NANI) accounted for 95% of the variation in riverine N flux. The NANI approach accounted for N harvested in crops and assumed that crop harvest in excess of the nutritional needs of the humans and livestock in the basin would be exported from the basin. The U.S. White House Committee on Natural Resources and Environment (CENR) developed a more comprehensive N budget that included estimates of ammonia volatilization, denitrification, and exchanges with soil organic matter. The residual N in the CENR budget was weakly and negatively correlated with observed riverine nitrate flux. The CENR estimates of soil N mineralization and immobilization suggested that there were large (2000 kg N ha(-1)) net losses of soil organic N between 1951 and 1996. When the CENR N budget was modified by assuming that soil organic N levels have been relatively constant after 1950, and ammonia volatilization losses are redeposited

within the basin, the trend of residual N closely matched temporal variation in NANI and was positively correlated with riverine nitrate flux in the lower Mississippi River. Based on results from applying these three modeling approaches, we conclude that although the NANI approach does not address several processes that influence the N cycle, it appears to focus on the terms that can be estimated with reasonable certainty and that are correlated with riverine N flux.

258. Randall, G. W. and D. J. Mulla. 2001. Nitrate-N in surface waters as influenced by climatic conditions and agricultural practices. Journal of Environmental Quality 30:337-344.

Abstract: Subsurface tile drainage from row-crop agricultural production systems has been identified as a major source of nitrate entering surface waters in the Mississippi River basin. Noncontrollable factors such as precipitation and mineralization of soil organic matter have a tremendous effect on drainage losses, nitrate concentrations, and nitrate loadings in subsurface drainage water. Cropping system and nutrient management inputs are controllable factors that have a varying influence on nitrate losses. Row crops leak substantially greater amounts of nitrate compared with perennial crops; however, satisfactory economic return with many perennials is an obstacle at present. Improving N management by applying the correct rate of N at the optimum time and giving proper credits to previous legume crops and animal manure applications will also lead to reduced nitrate losses. Nitrate losses have been shown to be minimally affected by tillage systems compared with N management practices. Scientists and policymakers must understand these factors as they develop educational materials and environmental guidelines for reducing nitrate losses to surface waters.

277. Smil, V. 2001. *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food.* The MIT Press, Cambridge.

278. Smith, R. A., G. E. Schwarz, and R. B. Alexander (2000), Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico, Nature, 403, 758-761.

Abstract: An increase in the flux of nitrogen from the Mississippi river during the latter half of the twentieth century has caused eutrophication and chronic seasonal hypoxia in the shallow waters of the Louisiana shelf in the northern Gulf of Mexico(1-5). This has led to reductions in species diversity, mortality of benthic communities and stress in fishery resources(4). There is evidence for a predominantly anthropogenic origin of the increased nitrogen flux(2,5-7), hut the location of the most significant sources in the Mississippi basin responsible for the delivery of nitrogen to the Gulf of Mexico have not been clearly identified, because the parameters influencing nitrogen-loss rates in rivers are not well known. Here we present an analysis of data from 374 US monitoring stations, including 123 along the six largest tributaries to the Mississippi, that shows a rapid decline in the average first-order rate of nitrogen loss with channel size-from 0.45 day(-1) in small streams to 0.005 day(-1) in the Mississippi river. Using stream depth as an explanatory variable, our estimates of nitrogen-loss rates agreed with values from earlier studies. We conclude that the proximity of sources to large streams and rivers is an

important determinant of nitrogen delivery to the estuary in the Mississippi basin, and possibly also in other large river basins

305. Turner, R. E. and N. N. Rabalais. 2004. Suspended sediment, C, N, P, and Si yields from the Mississippi River Basin. Hydrobiologia 511: 79-89.

Abstract: The annual loads of C, N, P, silicate, total suspended sediment (mass) and their yields (mass area(-1)) were estimated for six watersheds of the Mississippi River Basin (MRB) using water quality and water discharge records for 1973 to 1994. The highest load of suspended sediments is from the Missouri watershed (58 mt km(2) yr(-1)), which is also the largest among the six major sub-basins. The Ohio watershed delivers the largest load of water (38%). The Upper Mississippi has the largest total nitrogen load (32%) and yield (1120 kg TN km(2) yr(-1)). The loading of organic carbon, total phosphorus and silicate from the Upper Mississippi and Ohio watersheds are similar and relatively high (range 2.1 - 2.5, 0.068 - 0.076, and 0.8 - 1.1 mt km(2) yr(-1), respectively). The yields of suspended sediments, total phosphorus, total nitrogen, and silicate from the Lower Mississippi watershed are disproportionately the highest for its area, which is the smallest of all the watersheds and has the weakest monitoring network. The loading from the Red and Arkansas watersheds are of lesser importance than the others for most parameters investigated. The total nitrogen loading to coastal waters increased an additional 150% since the early 1900s, and is now dominated by loads from the Upper Mississippi watershed, rather than the previously dominant Ohio watershed. An analysis of trends for 1973 - 1994 suggests variability among years, rather than uni-directional change for most variables among 11 key stations. Explanatory relationships were established or confirmed to describe TN and TP loadings in terms of the now largely human-created landscape arising mostly over the last 150 years.

308. Turner, R. E. 2005. Nitrogen and phosphorus concentration and retention in water flowing over freshwater wetlands. pp. 57-66, In: L. Fredrickson, S. L. King and R. M. Kaminski, eds. Ecology and Management of Bottomland Hardwood Systems: The State of Our Understanding. University of Missouri Press, Columbia.

Abstract: We reconstructed water quality changes for 1800 to 2000 in Charlotte Harbor (Florida), a shallow subtropical estuary, by using a suite of biological and geochemical proxies in dated sediments collected in the region of a present day, midsummer hypoxic zone. The declining freshwater loading into the estuary from 1931 to the 1980s is not the probable causal agent encouraging the appearance or expansion of a hypoxia zone (measuring up to 90 km2 in summer). Rather, the reconstructed trends in nitrogen loading indicate increased phytoplankton production has likely caused a decline in bottom water oxygen concentrations. Sedimentary biogenic silica (BSi), carbon, nitrogen, and phosphorus concentrations increased concurrently with known or inferred changes in nutrient loadings. There were direct relationships between phytoplankton pigments and BSi, heavier $\delta^{34}S$ with increased carbon loading, and sequestration of P, Al, and Fe as carbon loading increased. The results from the sediment analyses and the

results from mixing models using C:N ratios and $\delta^{13}C$ suggest an estuarine system that is responsive to increased carbon loading from the nitrogen-limited phytoplankton community and whose sediments are becoming increasingly
anoxic as a result. The present nitrogen loading is about three times above that prior to the 1800s, suggesting that without management intervention the anticipated doubling of the watershed's population from 1990 to 2020 will
greatly increase the nitrogen loading to this estuary and will lead to much higher amounts of phytoplankton biomass and accumulation and exacerbate hypoxic conditions.

This article is available in its entirely as a PDF. The link to the article is here:
http://aslo.org/lo/toc/vol_51/issue_1_part_2/0518.pdf

Characterization of Nutrient Fate, Transport, and Sources (Continued)

< 2000

33. Boynton, W. R., J. H. Garber, R. Summers and W. M. Kemp. 1995. Inputs, transformations, and transport to nitrogen and phosphorus in Chesapeake Bay and selected tributaries. *Estuaries*, **18**, 285-314.

Abstract: In this paper we assemble and analyze quantitative annual input-export budgets for total nitrogen (TN) and total phosphorus (TP) for Chesapeake Bay and three of its tributary estuaries (Potomac, Patuxent, and Choptank rivers). The budgets include estimates of TN and TP sources (point, diffuse, and atmospheric), internal losses (burial in sediments, fisheries yields, and denitrification), storages in the water column and sediments, internal cycling rates (zooplankton excretion and net sediment-water flux), and net downstream exchange. Annual terrestrial and atmospheric inputs (average of 1985 and 1986 data) of TN and TP ranged from 4.3 g TN m(-2) yr(-1) to 29.3 g TN m(-2) yr(-1) and 0.32 g TP m(-2) yr(-1) to 2.42 g TP m-P yr(-1), respectively. These rates of TN and TP input represent 6-fold to and fold and 13-fold to 24-fold increases in loads to these systems since the precolonial period. A recent 11-yr record for the Susquehanna River indicates that annual loads of TN and TP have varied by about 2-fold and 4-fold, respectively. TN inputs increased and TP inputs decreased during the ll-yr period. The relative importance of nutrient sources varied among these estuaries: point sources of nutrients delivered about half the annual TN and TP load to the Patuxent and nearly 60% of TP inputs to the Choptank; diffuse sources contributed 60-70% of the TN and TP inputs to the mainstream Chesapeake and Potomac River. The direct deposition of atmospheric wet-fall to the surface waters of these estuaries represented 12% or less of annual TN and TP loads except in the Choptank River (37% of TN and 20% of TP). We found direct; although damped, relationships between annual rates of nutrient input, water-column and sediment nutrient stocks, and nutrient losses via burial in sediments and denitrification. Our budgets indicate that the annual mass balance of TN and TP is maintained by a net landward exchange of TP and, with one exception (Choptank River), a net seaward transport of TN. The budgets for all systems revealed that inorganic nutrients entering these estuaries from terrestrial and atmospheric sources are rapidly converted to particulate and organic forms. Discrepancies between our budgets and others in the literature were resolved by the inclusion of sediments derived from shoreline erosion. The greatest potential for errors in our budgets can be attributed to the absence of or uncertainties in estimates of atmospheric dry-fall, contributions of nutrients via groundwater, and the sedimentation rates used to calculate nutrient burial rates.

36. Brezonik, P.L., V. J. Bierman, R. Alexander, J. Anderson, J. Barko, M. Dortch, L. Hatch, G. L. Hitchcock, D. Keeney, D. Mulla, V. Smith, C. Walker, T. Whitledge, and W. J. Wiseman, Jr., May 1999. "Effects of Reducing Nutrient Loads to Surface Waters within the Mississippi River Basin and the Gulf of Mexico," Topic 4 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico, NOAA Coastal Ocean Program, Decision Analysis Series No. 18, U.S. Dept of Commerce, Silver Spring, MD.

42. Caraco, N. F. 1995. Influence of human populations on P transfers to aquatic systems: A regional scale study using large rivers. Pp. 235-247 in Tiessen, H. (ed.), *Phosphorus in the Global Environment.* SCOPE **54**. John Wiley & Sons Ltd., New York.

43. Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8: 559-568.

> **Abstract:** Agriculture and urban activities are major sources of phosphorus and nitrogen to aquatic ecosystems. Atmospheric deposition further contributes as a source of N. These nonpoint inputs of nutrients are difficult to measure and regulate because they derive from activities dispersed over wide areas of land and are variable in time due to effects of weather. In aquatic ecosystems, these nutrients cause diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity (including species important for commerce and recreation), loss of aquatic plant beds and coral reefs, and other problems. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture, recreation, and other purposes.
>
> Based on our review of the scientific literature, we are certain that (1) eutrophication is a widespread problem in rivers, lakes, estuaries, and coastal oceans, caused by over-enrichment with P and N; (2) nonpoint pollution, a major source of P and N to surface waters of the United States, results primarily from agriculture and urban activity, including industry; (3) inputs of P and N to agriculture in the form of fertilizers exceed outputs in produce in the United States and many other nations; (4) nutrient flows to aquatic ecosystems are directly related to animal stocking densities, and under high livestock densities, manure production exceeds the needs of crops to which the manure is applied; (5) excess fertilization and manure production cause a P surplus to accumulate in soil, some of which is transported to aquatic ecosystems; and (6) excess fertilization and manure production on agricultural lands create surplus N, which is mobile in many soils and often leaches to downstream aquatic ecosystems, and which can also volatilize to the atmosphere, redepositing elsewhere and eventually reaching aquatic ecosystems. If current practices continue, nonpoint pollution of surface waters is virtually certain to increase in the future. Such an outcome is not inevitable, however, because a number of technologies, land use practices, and conservation measures are capable of decreasing the flow of nonpoint P and N into surface waters. From our review of the available scientific information, we are confident that: (1) nonpoint pollution of surface waters with P and N could be reduced by reducing surplus nutrient flows in agricultural systems and processes, reducing agricultural and urban runoff by diverse methods, and reducing N emissions from fossil fuel burning; and (2) eutrophication can be reversed by decreasing input rates of P and N to aquatic ecosystems, but rates of recovery are highly variable among water bodies. Often, the eutrophic state is persistent, and recovery is slow.

59. Cooper, S. R. 1995. Chesapeake Bay watershed historical land use: impact on water quality and diatom communities. *Ecol. Appln.,* **5**, 703-723.

Abstract: Stratigraphic records preserved in the sediments of the mesohaline Chesapeake Bay were used to reconstruct a 2000-yr history of sedimentation, eutrophication, anoxia, and diatom community structure over time. Diatoms, pollen, total and organic carbon (TOC), total and organic nitrogen, total sulfur, acid-soluble iron, an estimate of the degree of pyritization of iron (DOP), and biogenic silica (BSi) were used as paleoecological indicators in four cores collected from a transect across the Chesapeake Bay from the Choptank River to Plum Point, Maryland. This paper covers results for diatoms, pollen, and BSi. Sediments were dated using radiocarbon and pollen techniques, and sedimentation rates were determined (0.2-5.8 mm/yr) using pollen methods. Geochemical indicators were measured and diatom species identified at subsampled intervals within each core. More than 400 diatom species, primarily marine and estuarine taxa, were identified in the sediments, some for the first time. Analysis of the data indicates that sedimentation rates, eutrophication, turbidity, and anoxia have increased in the Chesapeake Bay since the time of European settlement of the watershed. There is also evidence that freshwater input to the mesohaline Chesapeake Bay has increased. Changes in diatom community structure and geochemical indicators reflect major changes in land use patterns of the watershed and increasing population. Diatom community diversity exhibits a continuing decline, while centric/pennate ratios rise dramatically in most recent sediments.

103. Goolsby, D. A., W. A. Battaglin, G. B. Lawrence, R. S. Artz, B. T. Aulenbach, R. P. Hooper, D. R. Keeney, and G. J. Stensland (1999), Flux and Sources of Nutrients in the Mississippi–Atchafalaya River Basin: Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico, 130 pp, NOAA Coastal Ocean Program, Silver Spring, MD.

185. Miller, J. R. and G. L. Russell. 1992. The impact of global warming on river runoff. *J. Geophys. Res.*, **97**, 2757-2764.

Abstract: River runoff from the world's major rivers is an important part of the hydrologic cycle. Runoff changes in response to global greenhouse-induced warming will have impacts in many areas, including agriculture, water resources, and land use. A global atmospheric model is used to calculate the annual river runoff for 33 of the world's major rivers for the present climate and for a doubled CO2 climate. The model has a horizontal resolution of 4-degrees x 5-degrees, but the runoff from each model grid box is quartered and added to the appropriate river drainage basin on a 2-degrees x 2.5-degrees resolution. The computed runoff depends on the model's precipitation, evapotranspiration, and soil moisture storage. For the doubled CO2 climate, the runoff increased for 25 to the 33 rivers, and in most cases the increases coincided with increased rainfall within the drainage basins. There were runoff increases in all rivers in high northern latitudes, with a maximum increase of 47%. At low latitudes there were both increases and decreases ranging from a 96% increase to a 43% decrease. The effect of the simplified model assumptions of land-atmosphere interactions on the results is discussed.

294. Turner, R. E., N. N. Rabalais and D. Justić. 1999. Long-term watershed and water quality changes in the Mississippi River system. Chapter 3, pages 37-50 in W. J. Wiseman, Jr., N. N. Rabalais, M. J. Dagg and T. E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity

in the Northern Gulf of Mexico. NOAA Coastal Ocean Program, Decision Analysis Series No. 14. U.S. Department of Commerce, National Ocean Service, Center for Sponsored Coastal Research, Silver Spring, Maryland, 156 pp.

Citations Related to:

Scientific Basis for Goals and Management Options
(≥ 2000)

17. Bennett, E. M., S. R. Carpenter and N. F. Caraco. 2001. Human impact on erodable phosphorus and eutrophication: a global perspective. *BioScience,* **51**, 227-234.

This article is available in its entirety as a PDF:
http://www.nrs.mcgill.ca/bennett/GLOBALP.PDF

28. Boesch, D. F., E. Burreson, W. Dennison, E. Houde, M. Kemp, V. Kennedy, R. Newell, K. Paynter, R. Orth and R. Ulanowicz. 2001. Factors in the decline of coastal ecosystems. *Science,* **293**, 1589-1590.

Letter to the Editor: In their review "historical overfishing and the recent collapse of coastal ecosystems," Jeremy B. C. Jackson and colleagues argue for the "primacy" of overfishing in the collapse, in contrast to pollution, species introductions, climate change, diseases, and other human impacts (special issue on Ecology Through Time, 27 Jul., p. 629). They suggest that overfishing had the earliest impacts and was a necessary precondition for the occurrence of other maladies. Although we agree that fishing has contributed to major changes in coastal ecosystems, we believe Jackson and co-authors overstate the case for its primacy. The overfishing and nutrient pollution of coastal seas, for example, have frequently proceeded simultaneously and contributed to degradation synergistically (1).

In Chesapeake Bay, as the authors point out, the process of eutrophication began with land clearing in the 18th century, well before the mechanized harvest of oysters in the late 19th century. Although most of the filtration capacity of oyster populations had been reduced by the 1930s, the dramatic intensification of hypoxia and the extensive loss of seagrasses occurred later, during the last half of the 20th century, associated with a more than doubling of the already elevated nitrogen loading (2).

Recognizing that rebuilding oyster populations could help to mitigate planktonic overproduction due to nutrient pollution (3), the multistate Chesapeake Bay Program has established the ambitious goal of a 10-fold increase in oyster biomass. But restoration of oysters even to precolonial abundances is unlikely to eliminate algal blooms and hypoxia and recover seagrasses without also significantly reducing nutrient loading. Decreasing bottom-up stimulation and increasing top-down controls will be required.

Although the degradation of oyster reefs by overfishing might have made oysters more susceptible to endemic diseases, a particularly virulent pathogen (*Haplosporidum nelsoni*) was introduced from a nonindigenous oyster host in the 1950s (4). This introduced disease now greatly limits the ability to reestablish oyster populations.

Similarly, it is not likely that intact populations of large consumers, such as green turtles and sea cows, would have prevented the deleterious consequences of nutrient pollution, sedimentation, and other human-induced stresses on tropical seagrass ecosystems witnessed in the late 20th century in such regions as Australia (5) and Florida Bay (6). And there were no similar large consumers of temperate seagrasses, which have also undergone decline. Regardless of the historical sequence of human stresses, amelioration of multiple stresses must take a multi-pronged approach to restore coastal ecosystems.

http://www.sciencemag.org/cgi/content/full/293/5535/1589c

29. Boesch, D.F. 2001. Science and integrated drainage basin coastal management. Chesapeake Bay and Mississippi Delta. Pp. 37-50 in *Science and Integrated Coastal Management*, von Bodungen, B., and R. K Turner (eds.), Dahlem University Press, Berlin.

Abstract: Modern precepts of coastal management involve three challenging dimensions: integration, sustainability, and adaptation. The extent to which management addresses these dimensions is examined for two large coastal ecosystems heavily influenced by extensive continental drainage basins: the Chesapeake Bay and the Mississippi delta. The Chesapeake Bay, the largest estuary in the U.S.A., has been affected by eutrophication, habitat loss, and overfishing. Its biggest challenges are the control of diffuse sources of nutrient inputs from agriculture and expanding urban-suburban development and the physical restoration of once plentiful oyster habitats. The Mississippi delta is experiencing rapid loss of coastal wetlands and eutrophication of the adjacent Gulf of Mexico. River controls for navigation and flood protection and the world's most intense industrial agriculture in the upper basin affect this ecosystem greatly. Although assessments and models of nutrient dynamics in the watershed and coastal waters provide a foundation for intermedia and interdisciplinary integration, the management of both systems is not yet well integrated among sectors (e.g., fishing, transportation, and agriculture) and issues (e.g., eutrophication, overfishing, and habitat restoration). While the development of management goals is further advanced in the Chesapeake, even there a scientifically realistic vision of a sustainable future has not been developed. Management of the Chesapeake Bay is adaptive in the long term, but lacks the tight connections between models and outcomes needed for these regions if it included: interdisciplinary and strategic research targeted to the coastal ecosystem and its watershed; more predictive approaches involving historical reconstruction, models, and experiments; more effective integration of modeling, monitoring, and research; and institutional and individual commitment to civic science.

30. Boesch, D. F. 2002. Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. *Estuaries*, **25**, 886-900.

Abstract: Nutrient over-enrichment has resulted in major changes in the coastal ecosystems of developed nations in Europe, North America, Asia, and Oceania, mostly taking place over the narrow period of 1960 to 1980. Many estuaries and embayments are affected, but the effects of this eutrophication have been also felt over large areas of semi-enclosed seas including the Baltic, North, Adriatic, and Black Seas in Europe, the

Gulf of Mexico, and the Seto Inland Sea in Japan. Primary production increased, water clarity decreased, food chains were altered, oxygen depletion of bottom waters developed or expanded, seagrass beds were lost, and harmful algal blooms occurred with increased frequency. This period of dramatic alteration of coastal ecosystems, mostly for the worse from a human perspective, coincided with the more than doubling of additions of fixed nitrogen to the biosphere from human activities, driven particularly by a more than 5-fold increase in use of manufactured fertilizers during that 20-year period. Nutrient over-enrichment often interacted synergistically with other human activities, such as overfishing, habitat destruction, and other forms of chemical pollution, in contributing to the widespread degradation of coastal ecosystems that was observed during the last half of the 20th century. Science was effective in documenting the consequences and root causes of nutrient over-enrichment and has provided the basis for extensive efforts to abate it, ranging from national statutes and regulations to multi-jurisdictional compacts under the Helsinki Commission for the Baltic Sea, the Oslo-Paris Commission for the North Sea, and the Chesapeake Bay Program, for example. These efforts have usually been based on a relatively arbitrary goal of reducing nutrient inputs by a certain percentage, without much understanding of how and when this would affect the coastal ecosystem. While some of these efforts have succeeded in achieving reductions of inputs of phosphorus and nitrogen, principally through treatment of point-source discharges, relatively little progress has been made in reducing diffuse sources of nitrogen. Second-generation management goals tend to be based on desired outcomes for the coastal ecosystem and determination of the load reductions needed to attain them, for example the Total Daily Maximum Load approach in the U.S. and the Water Framework Directive in the European Union. Science and technology are now challenged not just to diagnose the degree of eutrophication and its causes, but to contribute to its prognosis and treatment by determining the relative susceptibility of coastal ecosystems to nutrient over-enrichment, defining desirable and achievable outcomes for rehabilitation efforts, reducing nutrient sources, enhancing nutrient sinks, strategically targeting these efforts within watersheds, and predicting and observing responses in an adaptive management framework.

31. Boesch, DF. 2003. Continental shelf hypoxia: some compelling answers. Gulf of Mexico Science 21: 202-205.

71. David, M. B., McIsaac, G. F., Howarth, R. W., Goodale, C. L., and LE Drinkwater, L. E. 2004. Fertilizer: Complex Issue Calls for Informed Debate. Comment, Nature 427:

This letter is available in its entirety as a PDF:
http://www.nature.com/nature/journal/v427/n6970/pdf/427099b.pdf

82. Elmgren, R. 2001. Understanding human impact on the Baltic ecosystem: changing view in recent decades. *Ambio*, **30**, 222-231.

Abstract: Grave environmental problems, including contamination of biota by organochlorines and heavy metals, and increasing deep-water oxygen deficiency, were discovered in the Baltic Sea in the late 1960s. Toxic pollutants, including the newly

discovered PCB, were initially seen as the main threat to the Baltic ecosystem, and the impaired reproduction found in Baltic seals and white-tailed eagles implied a threat also to human fish eaters. Countermeasures gradually gave results, and today the struggle to limit toxic pollution of the Baltic is an international environmental success story. Calculations showed that Baltic deep-water oxygen consumption must have increased, and that the Baltic nutrient load had grown about fourfold for nitrogen and 8 times for phosphorus. Evidence of increased organic production at all trophic levels in the ecosystem gradually accumulated. Phosphorus was first thought to limit Baltic primary production, but measurements soon showed that nitrogen is generally limiting in the open Baltic proper, except for nitrogen-fixing cyanobacteria. Today, the debate is concerned with whether phosphorus, by limiting nitrogen-fixers, can control open-sea ecosystem production, even where phytoplankton is clearly nitrogen limited. The Baltic lesson teaches us that our views of newly discovered environmental problems undergo repeated changes, and that it may take decades for scientists to agree on their causes. Once society decides on countermeasures, it may take decades for them to become effective, and for nature to recover. Thus, environmental management decisions can hardly wait for scientific certainty. We should therefore view environmental management decisions as experiments, to be monitored, learned from, and then modified as needed.

83. Elmgren, R. and U. Larsson. 2001. Eutrophication in the Baltic Sea area. Integrated coastal management issues. Pp. 15-35 in von Bodungen, B., and Turner, R.K. (eds.), *Science and Integrated Coastal Management*, Dahlem University Press, Berlin.

88. Galloway, J. N. and E. B. Cowling. 2002. Reactive nitrogen and the world: two hundred years of change. *Ambio,* **31**, 64-71.

Abstract: This paper examines the impact of food and energy production on the global N cycle by contrasting N flows in the late-19(th) century with those of the late-20(th) century. We have a good understanding of the amounts of reactive N created by humans, and the primary points of loss to the environment. However, we have a poor understanding of nitrogen's rate of accumulation in environmental reservoirs, which is problematic because of the cascading effects of accumulated N in the environment. The substantial regional variability in reactive nitrogen creation, its degree of distribution, and the likelihood of increased rates of reactive-N formation (especially in Asia) in the future creates a situation that calls for the development of a Total Reactive Nitrogen Approach that will optimize food and energy production and protect environmental systems.

89. Galloway, J. N., J. D. Aber, J. W. Erisman, S. P. Seitzinger, R. W. Howarth, E. B. Cowling and B. J. Cosby. 2003. The nitrogen cascade. *BioScience*, **53**, 341-356.

Abstract: Human production of food and energy is the dominant continental process that breaks the triple bond in molecular nitrogen (N-2) and creates reactive nitrogen (Nr) species. Circulation of anthropogenic Nr in Earth's atmosphere, hydrosphere, and biosphere has a wide variety of consequences, which are magnified with time as Nr moves along its biogeochemical pathway. The same atom of Nr can cause multiple effects in the atmosphere, in terrestrial ecosystems, in freshwater and marine systems,

and on human health. We call this sequence of effects the nitrogen cascade. As the cascade progresses, the origin of Nr becomes unimportant. Reactive nitrogen does not cascade at the same rate through all environmental systems; some systems have the ability to accumulate Nr, which leads to lag times in the continuation of the cascade. These lags slow the cascade and result in Nr accumulation in certain reservoirs, which in turn can enhance the effects of Nr on that environment. The only way to eliminate Nr accumulation and stop the cascade is to convert Nr back to nonreactive N-2.

113. Grimvall, A., P. Stålnacke and A. Tonderski. 2000. Time scales of nutrient losses from land to sea—a European perspective. *Ecol. Engineering,* **14**, 363-371.

Abstract: Empirical data regarding the time scales of nutrient losses from soil to water and land to sea were reviewed. The appearance of strongly elevated concentrations of nitrogen and phosphorus in major European rivers was found to be primarily a post-war phenomenon. However. the relatively rapid water quality response to increased point source emissions and intensified agriculture does not imply that the reaction to decreased emissions will be equally rapid. Long-term fertilisation experiments have shown that important processes in the large-scale turnover of nitrogen operate on a time scale of decades up to at least a century, and in several major Eastern European rivers there is a remarkable lack of response to the dramatic decrease in the use of commercial fertilisers that started in the late 1980s. In Western Europe, studies of decreased phosphorus emissions have shown that riverine loads of this element can be rapidly reduced from high to moderate levels, whereas a further reduction, if achieved at all, may take decades. Together, the reviewed studies showed that the inertia of the systems that control the loss of nutrients from land to sea was underestimated when the present goal of a 50% reduction of the input of nutrients to the Baltic Sea and the North Sea was adopted.

119. Howarth, R. W., D. Anderson, J. Cloern, C. Elfring, C. Hopkinson, B. Lapointe, T. Malone, N. Marcus, K. McGlathery, A. Sharpley, and D. Walker. 2000. Nutrient pollution of coastal rivers, bays, and seas. Issues in Ecology 7: 1-15.

Abstract: Over the past 40 years, antipollution laws have greatly reduced discharges of toxic substances into our coastal waters. This effort, however, has focused largely on point-source pollution of industrial and municipal effluent. No comparable effort has been made to restrict the input of nitrogen (N) from municipal effluent, nor to control the flows of N and phosphorus (P) that enter waterways from dispersed or nonpoint sources such as agricultural and urban runoff or as airborne pollutants. As a result, inputs of nonpoint pollutants, particularly N, have increased dramatically. Nonpoint pollution from N and P now represents the largest pollution problem facing the vital coastal waters of the United States.

Nutrient pollution is the common thread that links an array of problems along the nation's coastline, including eutrophication, harmful algal blooms, dead zones, fish kills, some shellfish poisonings, loss of seagrass and kelp beds, some coral reef destruction, and even some marine mammal and seabird deaths. More than 60 percent of our coastal rivers and bays in every coastal state of the continental United States are moderately to severely

degraded by nutrient pollution. This degradation is particularly severe in the mid Atlantic states, in the southeast, and in the Gulf of Mexico.

A recent report from the National Research Council entitled .Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. concludes that:

- Nutrient over-enrichment of coastal ecosystems generally triggers ecological changes that decrease the biological diversity of bays and estuaries.
- While moderate N enrichment of some coastal waters may increase fish production, over-enrichment generally degrades the marine food web that supports commercially valuable fish.
- The marked increase in nutrient pollution of coastal waters has been accompanied by an increase in harmful algal blooms, and in at least some cases, pollution has triggered these blooms.
- High nutrient levels and the changes they cause in water quality and the makeup of the algal community are detrimental to the health of coral reefs and the diversity of animal life supported by seagrass and kelp communities.
- Research during the past decade confirms that N is the chief culprit in eutrophication and other impacts of nutrient over-enrichment in temperate coastal waters, while P is most problematic in eutrophication of freshwater lakes.
- Human conversion of atmospheric N into biologically useable forms, principally synthetic inorganic fertilizers, now matches the natural rate of biological N fixation from all the land surfaces of the earth.
- Both agriculture and the burning of fossil fuels contribute significantly to nonpoint flows of N to coastal waters, either as direct runoff or airborne pollutants.
- N from animal wastes that leaks directly to surface waters or is volatilized to the atmosphere as ammonia may be the largest single source of N that moves from agricultural operations into coastal waters.

The National Research Council report recommended that, as a minimum goal, the nation should work to reverse nutrient pollution in 10 percent of its degraded coastal systems by 2010 and 25 percent of them by 2020. Also, action should be taken to assure that the 40 percent of coastal areas now ranked as healthy do not develop symptoms of nutrient pollution.

Meeting these goals will require an array of strategies and approaches tailored to specific regions and coastal ecosystems. There is an urgent need for development and testing of techniques that can reliably pinpoint the sources of N pollutants to an estuary. For some coastal systems, N removal during treatment of human sewage may be sufficient to reverse nutrient pollution. For most coastal systems, however, the solutions will be more complex and may involve controls on N compounds emitted during fossil fuel combustion as well as incentives to reduce over-fertilization of agricultural fields and nutrient pollution from animal wastes in livestock feedlot operations.

This article is available in its entirely as a PDF. The link to the article is here; http://www.esa.org/science/Issues/FileEnglish/issue7.pdf

120. Howarth, R. W. 2001. Hypoxia, fertilizer, and the Gulf of Mexico. Science 292: 1485-1486.

Abstract: Human activity has greatly altered the nitrogen cycle on Earth over the past few decades, with major effects on both human health and the ecological functioning of natural ecosystems, particularly coastal marine systems where nitrogen is now the largest pollution problem. Agriculture is the largest driver of this change, with pollution from fossil-fuel combustion being a smaller but still significant driver globally. Much of the nitrogen pollution from agriculture derives from animal-production systems, both as a direct result of nitrogen leakage to the atmosphere and waters from these systems, and from the demand for increased crop production that these animal-production systems demand. Wastewater from urban centers is also a significant component of the nitrogen problem, contributing 12% of the nitrogen pollution in rivers in the US, 25% in Europe, and 33% in China. Wastewater sources dominate the inputs of nitrogen to some coastal ecosystems, but globally and in most regions the non-point sources are larger. Many technical solutions to reducing nitrogen pollution exist, so to some extent the current problem reflects policy and political failures. Nonetheless, further technical solutions can and should be developed. These should recognize the significantly greater mobility of nitrogen than phosphorus in the environment.
http://www.iwaponline.com/wst/04905/wst049050007.htm

121. Howarth, R. W. 2002. Nutrient over-enrichment of coastal waters in the United States: Steps toward a solution. Pew Oceans Commission, Washington, DC.

122. Howarth, R. W., E. W. Boyer, W. J. Pabich, and J. N. Galloway. 2002. Nitrogen use in the United States from 1961-200 and potential future trends. Ambio 31: 88-96.

Abstract: Nitrogen inputs to the US from human activity doubled between 1961 and 1997, with most of the increase in the 1960s and 1970s. The largest increase was in use of inorganic N fertilizer, but emissions of NO,, from fossil-fuel combustion also increased substantially. In 1961, N fixation in agricultural systems was the largest single source of reactive N in the US. By 1997, even though N fixation had increased, fertilizer use and NOx emissions had increased more rapidly and were both larger inputs. In both 1961 and 1997, two thirds of reactive N inputs were denitrified or stored in soils and biota, while one third was exported. The largest export was in riverine flux to coastal oceans, followed by export in food and feeds, and atmospheric advection to the oceans. The consumption of meat protein is a major driver behind N use in agriculture in the US Without change in diet or agricultural practices, fertilizer use will increase over next 30 years, and fluxes to coastal oceans may increase by another 30%. However, substantial reductions are possible.

123. Howarth, R. W., A. Sharpley and D. Walker. 2002. Sources of nutrient pollution to coastal waters in the United States: implications for achieving coastal water quality goals. *Estuaries* **25**, 656-676.

Abstract: Some 60% of coastal rivers and bays in the U.S. have been moderately to severely degraded by nutrient pollution. Both nitrogen (N) and phosphorus (P) contribute to the problem, although for most coastal systems N additions cause more damage. Globally, human activity has increased the flux of N and P from land to the oceans by 2-fold and 3-fold, respectively. For N, much of this increase has occurred over the past 40 years, with the increase varying by region. Human activity has increased the flux of N in the Mississippi River basin by 4-fold, in the rivers of the northeastern U.S. by 8-fold, and in the rivers draining to the North Sea by more than 10-fold. The sources of nutrients to the coast vary. For some estuaries, sewage treatment plants are the largest single input; for most systems nonpoint sources of nutrients are now of relatively greater importance, both because of improved point source treatment and control (particularly for P) and because of increases in the total magnitude of nonpoint sources (particularly for N) over the past three decades. For P, agricultural activities dominate nonpoint source fluxes. Agriculture is also the major source of N in many systems, including the flux of N down the Mississippi River, which has contributed to the large hypoxic zone in the Gulf of Mexico. For both P and N, agriculture contributes to nonpoint source pollution both through losses at the field scale, as soils erode away and fertilizer is leached to surface and ground waters, and from losses from animal feedlot operations. In the U.S. N from animal wastes that leaks directly to surface waters or is volatilized to the atmosphere as ammonia may be the single largest source of N that moves from agricultural operations into coastal waters. In some regions, including the northeastern U.S., atmospheric deposition of oxidized N from fossil-fuel combustion is the major flux from nonpoint sources. This atmospheric component of the N flux into estuaries has often been underestimated, particularly with respect to deposition onto the terrestrial landscape with subsequent export downstream. Because the relative importance of these nutrient sources varies among regions and sites, so too must appropriate and effective mitigation strategies. The regional nature and variability of nutrient sources require that nutrient management efforts address large geographic areas.

124. Howarth, R. W., R. Marino, and D. Scavia. 2003. Priority Topics for Nutrient Pollution in Coastal Waters: An Integrated National Research Program for the United States. National Ocean Service, NOAA, Silver Spring, MD.

125. Howarth, R. W. 2003. Human acceleration of the nitrogen cycle: Drivers, consequences, and steps towards solutions. Pages 3-12 in Choi, E., and Z. Yun (eds.), Proceedings of the Strong N and Agro 2003 IWA Specialty Symposiu, Korea University, Seoul, Korea.

126. Howarth, R. W., K. Ramakrishna, E. Choi, R. Elmgren, L. Martinelli, A. Mendoza, W. Moomaw, C. Palm, R. Boy, M. Scholes, and Zhu Zhao-Liang. 2005. Chapter 9: Nutrient Management, Responses Assessment. The Millenium Assessment, in press.

127. Howarth, R. W., and R. Marino. 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over 3 decades. Limnol. Oceanogr., in press.

Abstract: The first special volume of *Limnology and Oceanography,* published in 1972, focused on whether phosphorus (P) or carbon (C) is the major agent causing

eutrophication in aquatic ecosystems. Only slight mention was made that estuaries may behave differently from lakes and that nitrogen (N) may cause eutrophication in estuaries. In the following decade, an understanding of eutrophication in estuaries proceeded in relative isolation from the community of scientists studying lakes. National water quality policy in the United States was directed almost solely toward P control for both lakes and estuaries, and similarly, European nations tended to focus on P control in lakes. Although bioassay data indicated N control of eutrophication in estuaries as early as the 1970s, this body of knowledge was treated with skepticism by many freshwater scientists and water-quality managers, because bioassay data in lakes often did not properly indicate the importance of P relative to C in those ecosystems. Hence, the bioassay data in estuaries had little influence on water-quality management. Over the past two decades, a strong consensus has evolved among the scientific community that N is the primary cause of eutrophication in many coastal ecosystems. The development of this consensus was based in part on data from whole-ecosystem studies and on a growing body of evidence that presented convincing mechanistic reasons why the controls of eutrophication in lakes and coastal marine ecosystems may differ. Even though N is probably the major cause of eutrophication in most coastal systems in the temperate zone, optimal management of coastal eutrophication suggests controlling both N and P, in part because P can limit primary production in some systems. In addition, excess P in estuaries can interact with the availability of N and silica (Si) to adversely affect ecological structure. Reduction of P to upstream freshwater ecosystems can also benefit coastal marine ecosystems through mechanisms such as increased Si fluxes.

128. Howarth, R. W. 2006. The development of policy approaches for reducing nitrogen pollution to coastal waters of the USA. China Science, in press.

Abstract: Two-thirds of the coastal rivers and bays in the United States are degraded from nutrient pollution, and nitrogen inputs these waters continue to increase. The nitrogen comes from a variety of sources, including runoff from agricultural fields, concentrated animal feeding operations, atmospheric deposition from fossil fuel combustion, and sewage and septic wastes. Technical solutions for nitrogen pollution exist at reasonable cost. That most of these solutions have not yet been implemented to any significant extent across the United States suggests that new policy approaches are necessary. *(Please note that China Science has attributed this article to a Chinese lead author, Xie Yingxin)*
http://219.238.6.200/article?code=062005-272&jccode=06

154. Kramer, H. H., M. D. A. Le Tissier, P. R. Burbridge, N. N. Rabalais, J. Parslow and C. J. Crossland (eds.). 2005. Land-Ocean Interactions in the Coastal Zone (LOICZ), Science Plan and Implementation Strategy. The IGBP Report Series, Netherlands Institute for Sea Research, Texel.

187. Mitsch, W. J, J. W. Day, Jr., J. W. Gilliam, P. M. Groffman, D. L. Hey, G. W. Randall and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: Strategies to counter a persistent ecological problem. *BioScience*, **15**, 373-388.

This article is available in its entirely as a PDF:
http://swamp.osu.edu/areducing%20nitrogen.pdf

194. National Research Council. 2000. Clean Coastal Waters: Understanding and Reducing the Consequences of Nutrient Pollution. National Academies Press, Washington, DC.

212. Petrolia, D.R., and P.H. Gowda. (forthcoming) Missing the Boat: Midwest Farm Drianage and Gulf of Mexico Hypoxia. Review of Agricultural Economics.

242. Rabalais, N. N., R. E. Turner, and D. Scavia (2002), Beyond Science into Policy: Gulf of Mexico Hypoxia and the Mississippi River, edited, pp. 129-142.

Abstract: This article is available in its entirety as a PDF:
http://mscserver.cox.miami.edu/MSC410/Articles/Rabalais.pdf

249. Rabalais, N. N. 2003. We All Live Downstream (and Upstream). View Point. Journal of Soil and Water Conservation 58(3) : 52A-53A.

Most U.S. citizens would respond positively to the question "Are you concerned about having a healthy environment in which to live?" The proportion of positive responses grows smaller as the questions shift to "Are you responsible for the quality of the environment in which you live? OR "Are you willing to change your behaviors in order to achieve a healthy environment?" The realization that many of our actions affect not only our immediate environment but also environments far away from the source of the offending pollutant is not a commonly held understanding. In many ways, we...

http://www.highbeam.com/doc/1G1:110531618/We+all+live+downstream+(and+upstream)%7eC%7e+a+guest+editorial+written+by+a+leading+conservation+professional%7eR%7e(View+Point)(Editorial).html

263. Ribaudo, M.O., R. Heimlich, R. Claassen, and M. Peters. 2001. Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin. Ecological Economics 37:183-197.

Abstract: Nutrient pollution is one of the major sources of water quality impairments in the U.S. Agriculture is a major source of nutrients. Two alternative strategies for reducing nutrient loads from cropland are to reduce fertilizer application rates and to filter nutrients coming off cropland with restored wetlands. These two approaches are evaluated in the Mississippi Basin, where nutrient loadings to the Gulf of Mexico have caused a large zone of hypoxic waters. Because of the easement and restoration costs of wetlands, a fertilizer standard was found to be more cost effective than restoring wetlands for achieving a water quality goal up to a particular level of total nitrogen loss reduction. Beyond this point, wetland restorations are more cost-effective.

264. Ribaudo, M.O., R. Heimlich, and M. Peters. 2005. Nitrogen sources and Gulf hypoxia: potential for environmental credit trading. Ecological Economics 52:159-168.

Abstract: A zone of hypoxic and anoxic waters has become a dominant feature of the northern Gulf of Mexico. Nitrogen draining into the Gulf from the Mississippi Basin has been identified as the primary source of the problem. Reducing nitrogen loads from point and nonpoint sources in the basin is the primary goal of an action plan developed to address the problem. In this paper, we use data on point source dischargers and a model of the agriculture sector to examine whether the purchase of nitrogen reduction "credits" from nonpoint sources would reduce the cost of nitrogen control if point sources are required to reduce nitrogen discharges. Results indicate that a substantial degree of credit trading could affect agricultural commodity prices, thereby affecting agricultural production outside the basin.

265. Robinson, J. R., and T. L. Napier (2002), Adoption of nutrient management techniques to reduce hypoxia in the Gulf of Mexico, Agricultural Systems, 72, 197-213.

Abstract: Data were collected from 1011 land owner-operators within three watersheds located in the North Central Region of the USA to examine use of selected water protection practices. A theoretical model developed from selected components of the traditional diffusion paradigm and the farm structure model was used to predict adoption and use of conservation practices at the farm level within the study watersheds. Study findings revealed that factors commonly purported to be highly correlated with adoption of conservation production systems were not useful for predicting use of conservation production practices assessed. The production practices examined in the study were percent of cultivated fields surrounded by grass filter strips, percent of waterways in cultivated fields protected by grass, use of banded fertilizer, use of side dressing of fertilizer, and use of nitrification inhibitor. Study findings revealed that the theoretical model developed to guide the study was relatively ineffective for predicting adoption of the conservation practices assessed in the study. None of the statistical models developed from analysis of study data explained more than nine percent of the variance in any of the conservation practices assessed. Research findings suggest that existing conservation programs are no longer useful policy instruments for motivating land owner-operators to adopt and use production systems designed to reduce agricultural pollution of waterways.

300. Turner, R. E. and N. N. Rabalais. 2003. Linking landscape and water quality in the Mississippi River basin for 200 years. BioScience 53: 563-572.

Abstract: Two centuries of land use in the Mississippi River watershed are reflected in the water quality of its streams and in the continental shelf ecosystem receiving its discharge. The most recent influence on nutrient loading-intense and widespread farming and especially fertilizer use-has had a more significant effect on water quality than has land drainage or the conversion of native vegetation to cropland and grazing pastures.

The 200-year record of nutrient loading to offshore water is reflected in the paleoreconstructed record of plankton in dated sediments. This record illustrates that the development of fair, sustained management of inland ecosystems is linked to the management of offshore systems. Land use in this fully occupied watershed is under the strong influence of national policies affecting all aspects of the human ecosphere. These policies can be modified for better or worse, but water quality will probably change only gradually because of the strong buffering capacity of the soil ecosystem.

301. Turner, R. E., N. N. Rabalais, D. Justić and Q. Dortch. 2003. Global patterns of dissolved N, P and Si in large rivers. Biogeochemistry 64: 297-317.

Abstract: The concentration of dissolved inorganic nitrogen (DIN), dissolved nitrate-N, Total-N (TN), dissolved inorganic phosphate (DIP), total phosphorus (TP), dissolved silicate-Si (DSi) and their ratios in the world's largest rivers are examined using a global data base that includes 37% of the earth's watershed area and half its population. These data were compared to water quality in 42 subbasins of the relatively well-monitored Mississippi River basin (MRB) and of 82 small watersheds of the United States. The average total nitrogen concentration varies over three orders of magnitude among both world river watersheds and the MRB, and is primarily dependent on variations in dissolved nitrate concentration, rather than particulate or dissolved organic matter or ammonium. There is also a direct relationship between the DIN: DIP ratio and nitrate concentration. When nitrate-N exceeds 100 mug-at l(-1), the DIN: DIP ratio is generally above the Redfield ratio (16:1), which implies phosphorus limitation of phytoplankton growth. Compared to nitrate, the among river variation in the DSi concentration is relatively small so that the DSi loading (mass/area/time) is largely controlled by runoff volume. The well-documented influence of human activities on dissolved inorganic nitrogen loading thus exceeds the influences arising from the great variability in soil types, climate and geography among these watersheds. The DSi: nitrate-N ratio is controlled primarily by nitrogen loading and is shown to be inversely correlated with an index of landscape development-the "City Lights" nighttime imagery. Increased nitrogen loading is thus driving the world's largest rivers towards a higher DIN: DIP ratio and a lower DSi: DIN ratio. About 7.3 and 21% of the world's population lives in watersheds with a DSi: nitrate-N ratio near a 1:1 and 2:1 ratio, respectively. The empirical evidence is that this percentage will increase with further economic development. When the DSi: nitrate-N atomic ratio is near 1:1, aquatic food webs leading from diatoms (which require silicate) to fish may be compromised and the frequency or size of harmful or noxious algal blooms may increase. Used together, the DSi: nitrate-N ratio and nitrate-N concentration are useful and robust comparative indicators of eutrophication in large rivers. Finally, we estimate the riverine loading to the ocean for nitrate-N, TN, DIP, TP and DSi to be 16.2, 21, 2.6, 3.7 to 5.6, and 194 Tg yr(-1), respectively.

Scientific Basis for Goals and Management Options (Continued)

(< 2000)

39. Burkart, M. R., and D. E. James (1999), Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico, Journal of Environmental Quality, 28, 850-859.

Abstract: Nitrate (NO3) is the principal nutrient transported through the Mississippi River basin that is related to hypoxia in the Gulf of Mexico. Agriculture is a major contributor to the N load. Knowledge of the geographic distribution of NO3 sources and losses within the basin is critical to understanding the problem and identifying potential solutions. This paper defines the geographic distribution, by hydrologic unit, of major agricultural sources and dominant losses of N in the basin. Sources include imported N such as inorganic fertilizer, manure, and atmospheric deposition, and in situ sources such as mineralized ed N from soil organic matter, N-2 fixed by legumes, and redeposition of locally derived ammonia (NH3). The dominant N losses include crop harvests, losses to the atmosphere through volatilization of manure and inorganic fertilizer, plant senescence, and denitrification of soil NO3. National data bases used in the analysis include the State Soils Geographic Database, 1992 Census of Agriculture, and the National Atmospheric Deposition Program/National Trends Network. The hydrologic units with the largest residual N contributions available to streams are located in the Upper Mississippi River and the Ohio River basins. Mineralizable soil N, inorganic N fertilizer. legume fixation, and redeposition of locally derived NH3 constitute the major sources in this part of the basin, although manure is a minor source. However, these northern hydrologic regions use a greater fraction of the sources to produce crop N than do the southern hydrologic regions. Residual contributions to the Tennessee, Arkansas/Red, and Lower Mississippi hydrologic regions are greatest when analyzed as a percentage of the total sources.

118. Howarth, R. W. 1998. An assessment of human influences on inputs of nitrogen to the estuaries and continental shelves of the North Atlantic Ocean. Nutrient Cycling in Agroecosystems 52: 213-223.

Abstract: Our analysis for the International SCOPE Nitrogen Project shows that the fluxes of nitrogen in rivers to the coast of the North Atlantic Ocean vary markedly among regions, with the lowest fluxes found in northern Canada (76 kg N km(-2) yr(-1)) and the highest fluxes found in the watersheds of the North Sea (1450 kg N km(-2) yr(-1)). Non-point sources of nitrogen dominate the flux in all regions. The flux of nitrogen from the various regions surrounding the North Atlantic is correlated (r(2) = 0.73) with human-controlled inputs of nitrogen to the regions (defined as net inputs of nitrogen in food, nitrogen fertilizer, nitrogen fixation by agricultural crops, and atmospheric deposition of oxidized nitrogen), and human activity has clearly increased these nitrogen flows in rivers. On average, only 20% of the human-controlled inputs of nitrogen to a region are exported to the ocean in riverine flows; the majority (80%) of these regional nitrogen inputs is stored in the landscape or denitrified. Of all the nitrogen inputs to regions, atmospheric deposition of NOy is the best predictor of riverine export of nitrogen from

non-point sources (r(2) = 0.81). Atmospheric deposition of this oxidized nitrogen, most of which derives from fossil-fuel combustion, may be more mobile in the landscape than are regional inputs of nitrogen from fertilizer, nitrogen fixation in agriculture, and nitrogen in foods and feedstocks. Agricultural sources of nitrogen, although larger total inputs to most temperate regions surrounding the North Atlantic Ocean, appear to be more tightly held in the landscape. Deposition of ammonium from the atmosphere appears to be a very good surrogate measure of the leakiness of nitrogen from agricultural sources to surface waters. This suggests a management approach for controlling 'surplus' nitrogen used in agricultural systems. The sum of NOy and ammonium deposition proves to be an amazingly powerful predictor of nitrogen fluxes from non-point sources to the coastal North Atlantic Ocean for temperate-zone regions (r(2) = 0.92; p = 0.001). By comparing fluxes with some estimates of what occurs in watersheds with minimal human impact, it appears that human activity has increased riverine nitrogen inputs to the ocean by some 11-fold in the North Sea region, by 6-fold for all of Europe, and by 3-fold for all of North America. These increased flows of nitrogen have clearly led to severe eutrophication in many estuaries, and have probably contributed to some eutrophication on the continental shelf in the North Sea and in the Gulf of Mexico. In other regions, however, the input of nitrogen to continental shelves is dominated by cross-shelf advection from deep-Atlantic waters, and the increased inputs from rivers are relatively minor.

138. Justić, D., N. N. Rabalais, and R. E. Turner (1994), Riverborne nutrients, hypoxia and coastal ecosystem evolution: biological responses to long-term changes in nutrient loads carried by the Po and Mississippi Rivers, in Changes in Fluxes in Estuaries: Implications from Science to Management, edited by K. R. Dyer and R. J. Orth, pp. 161-167, Olsen and Olsen, Fredensborg.

155. Kumpf, H., K. Steidinger, and K. Sherman (1999), The Gulf of Mexico Large Marine Ecosystem-Assessment, Sustainability and Management, 736 pp., Blackwell Science, Malden, MA.

205. Paine, R. T., M. J. Tegner and E. A. Johnson. 1998. Compounded perturbations yield ecological surprises. *Ecosystems*, **1**, 535-545.

Abstract: All species have evolved in the presence of disturbance, and thus are in a sense matched to the recurrence pattern of the perturbations. Consequently, disturbances within the typical range, even at the extreme of that range as defined by large, infrequent disturbances (LIDs), usually result in little long-term change to the system's fundamental character. We argue that more serious ecological consequences result from compounded perturbations within the normative recovery time of the community in question. We consider both physically based disturbance (for example, storm, volcanic eruption, and forest fire) and biologically based disturbance of populations, such as overharvesting, invasion, and disease, and their interactions. Dispersal capability and measures of generation time or age to first reproduction of the species of interest seem to be the important metrics for scaling the size and frequency of disturbances among different types of ecosystems. We develop six scenarios that describe communities that have been

subjected to multiple perturbations, either simultaneously or at a rate faster than the rate of recovery, and appear to have entered new domains or "ecological surprises." In some cases, three or more disturbances seem to have been required to initiate the changed state. We argue that in a world of ever-more-pervasive anthropogenic impacts on natural communities coupled with the increasing certainty of global change, compounded perturbations and ecological surprises will become more common. Understanding these ecological synergisms will be basic to environmental management decisions of the 21st century.

210. Pelley J (1998) Is coastal eutrophication out of control? Environ Sci Tech 32:462-466

This article is available as Full-Text HTML:
http://pubs.acs.org/cgi-bin/article.cgi/esthag-a/1998/32/i19/html/pelley.html/QueryZIP/A-pages/(((((is@@<AND>@@coastal@@<AND>@@eutrophication)<IN>(atl,title)))<AND>(PUBYR@@>=@@1996)))<OR>((((is@@<AND>@@coastal@@<AND>@@eutrophication)<IN>(atl,title)))<AND>(ASAP@@<IN>@@VOL))