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INFORMATION DOCUMENT

COASTAL EUTROPHICATION: LINKING NUTRIENT SOURCES TO COASTAL ECOSYSTEM EFFECTS AND MANAGEMENT – THE INTERSECTION OF SEVERAL UNESCO-IOC PROGRAMMES RELATED TO NUTRIENTS

Summary. There are several IOC activities that currently address issues related to nutrient loading, coastal effects or coastal management (GlobalNEWS, GEOHAB, ICAM, GOOS, LME), yet at the current time they are not linked or integrated. While each of these programmes has independent missions and goals, their intersection would help to advance our understanding of both current and future predicted impacts of nutrient loads in watersheds on coastal water quality, ecosystem function, and policy response.

Justification

It is well-established that eutrophication, due to nutrient over-enrichment, is a major environmental problem in many coastal ecosystems around the world (e.g., National Research Council 2000, Smil 2001, Cloern 2001, Howarth et al. 2002, Seitzinger et al. 2002, 2005, Wassmann 2005). Nutrient sources driving coastal eutrophication are primarily associated with increasing human population, food and energy production in watersheds and, in some cases, coastal aquaculture. The effects of eutrophication are many and include increased algal biomass, high-biomass harmful algal blooms (HABs), hypoxia/anoxia, seagrass decline, increased water turbidity, and change in fisheries yields, among others. Yet, the relationships between nutrient loading and ecosystem effects, such as HABs, are complex and variable and depend on the specific nutrient sources and the physical dynamics of the receiving waters, among many other factors (Glibert et al. 2005, Glibert and Burkholder 2006).

Background

Many coastal systems that exhibit eutrophication effects have been identified and in many cases the nutrient loading rates have also been quantified (NRC 2000; Selman 2007). To date, however, predictive (quantitative) relationships between nitrogen loading rates and ecosystem effects (e.g., algal biomass, HABs, hypoxic/anoxic regions, seagrass decline, increases in turbidity, and changes in fisheries yields) applicable across a range of coastal systems have been lacking. A large amount of data, and increasingly sophisticated analytical approaches are now available to develop such relationships, including not only nutrient loading rates and quantitative measures of eutrophication, but also physical properties (flushing rates, depth, etc.) for a wide range of coastal systems. Through improved global, spatially explicit models of nutrient loading from watersheds to coastal systems, better understanding of coastal dynamics, and the expansion of global databases on coastal algal production, including HAB occurrences and hypoxia, we are now in the position to begin to link patterns of eutrophication with coastal effects around the world in a more rigorous and quantitative way. Enhanced observing systems are also advancing our knowledge base of coastal effects.

Estimating nutrient export to the coastal zone has been a challenge, but enormous advances have been made with respect to global models over the past several years. The first global model of nitrogen loading to coastal systems was published less than 10 years ago (Seitzinger and Kroeze 1998). The IOC Global Nutrient Export from WaterSheds Program (GlobalNEWS) has now developed models of nutrient export for dissolved inorganic, organic and particulate nitrogen, phosphorus and carbon, as well as for dissolved silica. These models account for nutrient sources (natural as well as anthropogenic, including fertilizer, atmospheric deposition, crops, manure and sewage), hydrology, land use, and physical factors in watersheds (see, for example, Fig. 1). Results for estimates of the 1995 global condition were published in a special issue of Global Biogeochemical Cycles in 2005 (see especially Beusen et al. 2005; Bouwman et al. 2005a,b; Dumont et. al. 2005; Harrison et al. 2005a,b; Seitzinger et al. 2005). Since 2005, Global NEWS has advanced models of global nutrient stoichiometry, and have developed preliminary scenarios for nutrient export for the years 2030 and 2050 based on the Millennium Ecosystem Assessment (www.millenniumassessment.org) assumptions.

Nutrient inputs (nitrogen N; and phosphorus P) to watersheds associated with agriculture, sewage and fossil fuel combustion are projected to more than double by 2050 unless technological advances and policy changes are implemented (Tilman et al. 2001; Millennium Ecosystem Assessment 2006). Therefore, understanding the quantitative relationships between nutrient sources throughout watersheds, nutrient transport by rivers to coastal systems, and the effects of that nutrient loading on the receiving coastal ecosystem is critical to effective and integrated management of water resources and coastal zones. Without that quantitative and whole watershed perspective, and without an effective and efficient means of implementing programs that respond to current understanding of watershed-coastal ecosystem linkages, aquatic systems are likely to continue to be degraded by nutrient over-enrichment.

The availability of environmental data is also rapidly escalating through the advancing Global Ocean Observing System (GOOS). This suite of observations is developing to provide a vast resource of the physical, environmental and biological data. This resource is beginning to be applied in the interpretation of conditions that may favour, accompany, or inhibit specific eutrophication effects, such as the development of specific toxic species.

Several IOC programmes have interests in aspects of the biology, chemistry or management of the coastal zone. The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) programme has as its scientific goal the improved prediction of HABs by determining the ecological and oceanographic mechanisms underlying their population dynamics, integrating biological, chemical and physical studies supported by improved observation and modelling approaches, and specifically has one of its five Core Research Projects on HABs in Eutrophic Systems. The goal of the IGBP Land-Ocean Interactions in the Coastal Zone Program (LOICZ) is to provide the knowledge, understanding and prediction needed to allow coastal communities to assess, anticipate and respond to the interaction of global change and local pressures which determine coastal change. The Integrated Coastal Area Management (ICAM) programme brings natural and social scientists, coastal managers and policy makers together to understand how to manage the diverse problems of coastal areas. Thus, these programmes all share interests in understanding and managing the coastal zone. Specifically nutrient loading and its effects, including the expression of coastal eutrophication, is a common element across these programs.

Strategy

The goal of the joint work of these programs is to develop quantitative relationships between nutrient sources and controlling factors in watersheds and their effects on coastal systems, and then apply those quantitative relationships to inform development and implementation of policies to improve coastal water quality (Figure 2). Effects include development of HABs, hypoxia, loss of seagrass and other known symptoms of eutrophication.

Dominant source of N exported from watersheds to coastal systems from IOC Global NEWS model

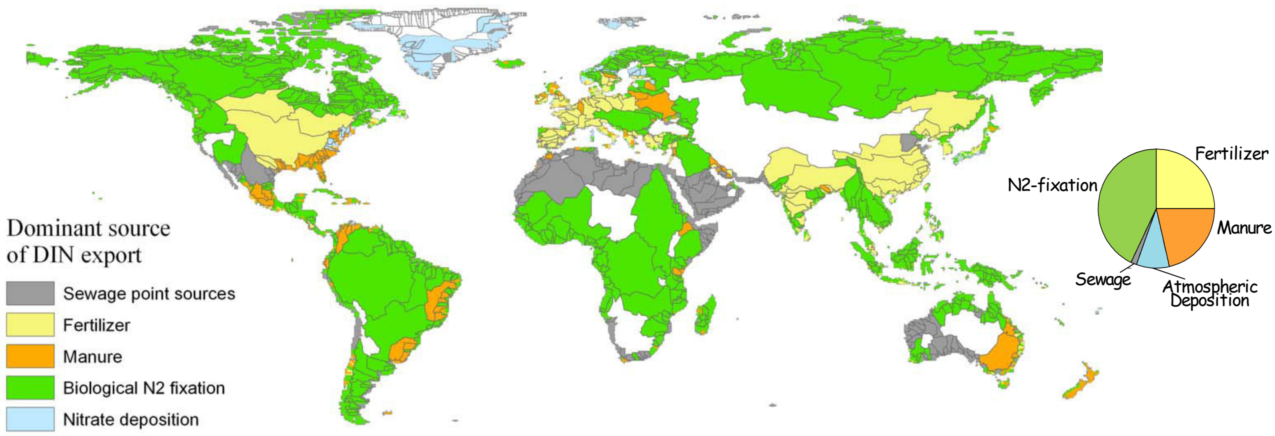

Figure 1. A) Single largest source of DIN in watersheds exported by rivers to coastal systems by large river basin; and B) Global perspective on the relative contribution of different N sources in global watersheds. Output from global watershed DIN model (from Dumont et al. 2005; Seitzinger et al. 2005)

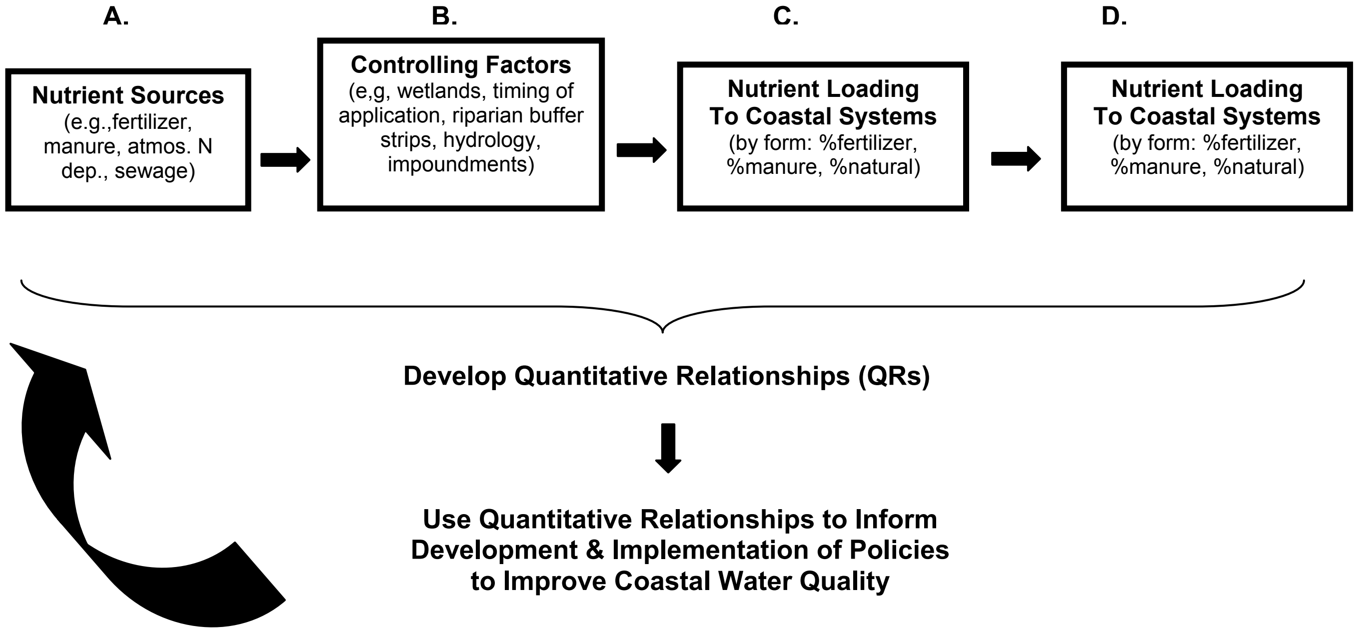

Figure 2. Overview of a quantitative approach to relate land-based nutrient sources to coastal eutrophication and hypoxia, in support of environmental policies.

To establish linkages between watershed nutrient sources, controlling factors, and nutrient loading, established spatially-explicit watershed modelling system (IOC **NEWS**) will be used. The strengths and feasibility have been demonstrated in previous applications using global databases (Seitzinger et al., 2005, Harrison et al., 2005a and b, Dumont et al., 2005, Beusen et al., 2005). The application of the NEWS model in the current project will be significantly enhanced by compiling and applying local and higher resolution model input data.

To develop relationships between coastal nutrient loading and ecosystem response, emerging state-of-the-art relationships that have been shown to be applicable using data from a limited suite of geographical locations will be applied (Beman et al., 2005, Nixon et al., 1992; Madden et al. in press). For example, multi-year relationships have been established between total nitrogen and total chlorophyll in a range of estuaries, but each estuarine class (e.g., lagoonal, riverine, fjord, or embayment) was shown to have a distinctly different relationship. Additionally, the development of these models also allows us to now ask questions about whether different nutrient elements, forms and ratios are related to different functional groups of HABs. Global nitrogen loading models suggested a high degree of correspondence for one group of HABs, as represented by the dinoflagellate *Prorocentrum minimum* (Fig. 3).

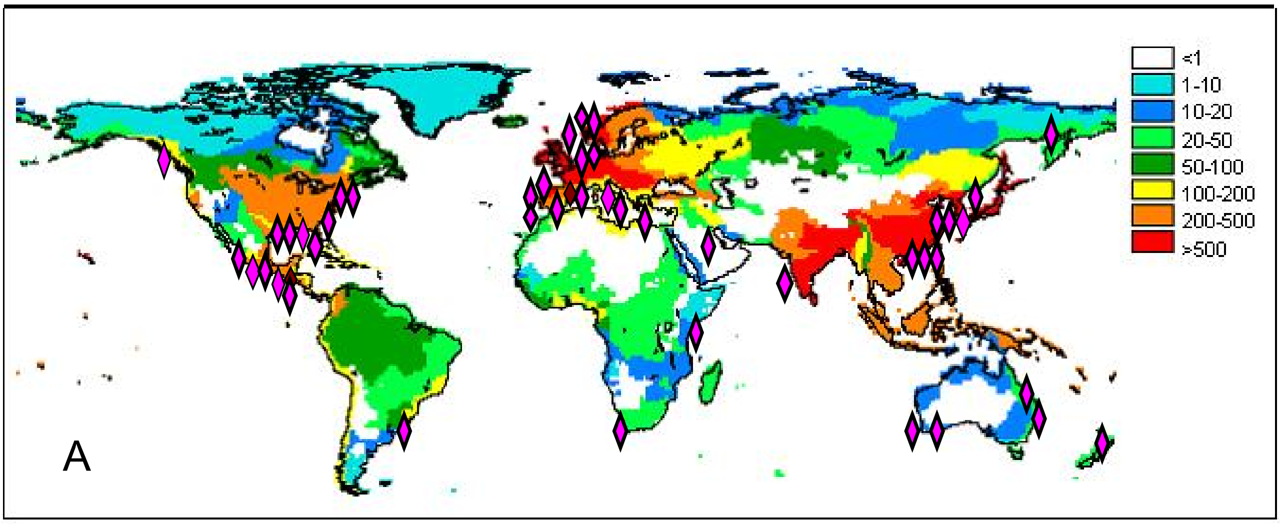

Figure 3. Global distribution of recorded incidences of the dinoflagellate *Prorocetnrum minimum* super- imposed on a global map of modelled nitrogen export (base map from Seitzinger et al. 2002). Nitrogen export is calculated as kg N · km^{-2} watershed · $year^{-1}$. Documented occurrences of *P. minimum* are based on the review by Heil et al. (2005).

Outreach

The linkage among these programs based on nutrient loading and coastal effects has broad opportunities for capacity building. Knowledge transfer and outreach will be accomplished by involving scientists and policy specialists from developed and developing regions in all phases of the project. Data from their local regions will be essential in developing this assessment tool. This assessment tool will be formatted into a user friendly interface for maximum utility and transparency.

Training workshops will be developed in which scientists and policy specialists from the study regions would be trained in the use of this assessment tool. We have conducted a number of highly successful capacity building workshops at IOC with the **NEWS** model for policy makers and scientists from countries in economic transition for 7 Large Marine Ecosystem regions (**LME**s) (Seitzinger and Lee 2007), and such a format would be highly effective in this project as well. Trainees from these prior workshops are working to incorporate model-based insights into the long-term development of knowledge and governance of their respective world regions.

The web will be used for documenting model implementation, will serve as a clearinghouse for modeling results, and as a forum for discussion among model user groups.

Expected Benefits

This integrative activity would facilitate science-based solutions to coastal eutrophication for countries around the world by contributing to a greatly enhanced knowledge base, a modelling framework, and a community of model users. The goal is a self-sustaining community of model users in developed and developing countries who use the resulting models to attribute sources of N and P within watersheds, quantify past and potential future export of N and P to the coastal zone, and develop estimates of the relative effectiveness of possible policy decisions on coastal water quality at regional to international scales. Specifically, the benefits would include:

- Improved long-term data records of coastal environmental conditions
- Improved quantitative relationships between nutrient loads and effects
- Improved regional models of coastal effects under different physical regimes

- Improved global models of nutrient loads and export and improved predictive capability
- Improved tools for integrated eutrophication assessment and nutrient criteria development
- Improved public health an environmental risk management

Deliverables of the integrating activity:

The IOC product resulting from this integrating project would be an assessment tool for use by policy specialists from developed and developing regions to use in the evaluation and implementation of policies to improve coastal water quality.

This tool would provide:

(i) maps on the contribution of different nutrient sources in watersheds to coastal nutrient loading and the coastal effects that the current nutrient loading is having on the receiving water;

(ii) a model to estimate the magnitude of the expected effect of further changes (reductions or increases) in nutrient loading on the coastal system under a range of scenarios.

Modalities to achieve the deliverables:

Steps to achieve the development of this tool include the following:

(i) Organizational workshop bringing together key people from the existing IOC activities (NEWS, GEOHAB, ICAM, GOOS, LME, LOICZ) plus other scientists with specific expertise as needed. One of the outcomes of this organizational workshop would be establishment of a Steering Committee that will further refine the goals, information needs, additional expertise, resources, and steps needed to achieve the goals. An overall workplan and terms of reference will be developed for the project.

(ii) Compilation and synthesis of existing data from around the world which is then used to develop models that will be used in the assessment tool (NEW-USE; Nutrient Export from Watersheds- User Scenario Evaluation). Workgroup meetings over a 3-4 year time period will be held (preferably at IOC) for integration among the project team and that focus on specific key questions, region, model components, etc. Workgroups would need to bring additional expertise as required (i.e. beyond the steering committee) to address focused issues. The steering committee will refine the workplan annually based on workgroup progress;

(iii) Development of the assessment tool consistent with the goals defined step 1 and based on the work conducted in step 2.

(iv) Training workshops for scientists and policy specialists from IOC member countries.

A web facility will be developed in parallel with these activities that initially serves as a source of documentation on model development and a forum for communication among project members, as well as general information on project goals and progress for the broader community. As the tool develops, the web facility could serve as a mechanism for beta testing by the broader community. Eventually the web facility will be the platform for open use by all IOC member countries, and a forum for discussion among model user groups (scientists, policy makers, educators, etc.).

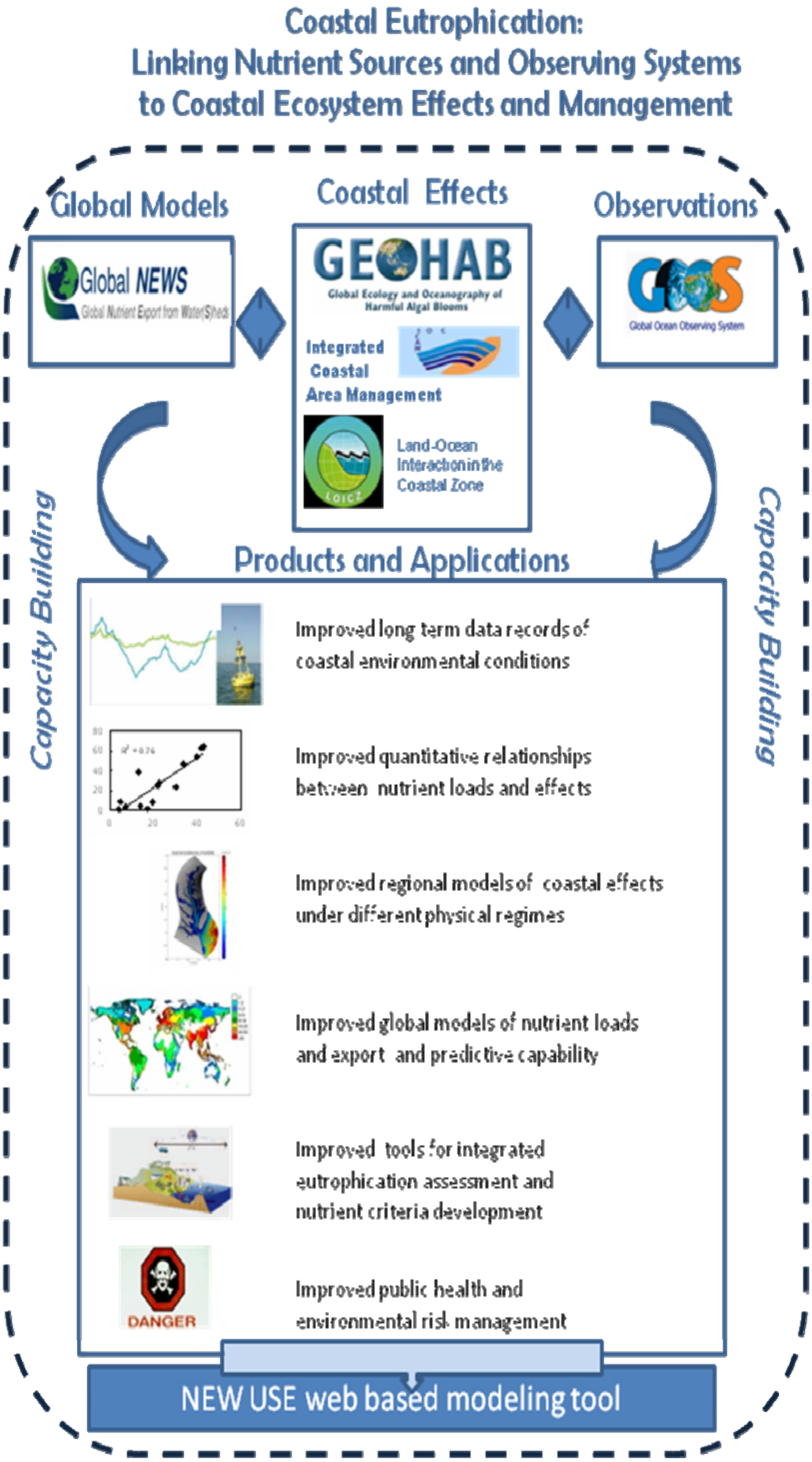

Figure 4. The integration of IOC programs on Coastal Eutrophication, including Global Modelling, Observational Systems and Coastal Effects

Funding requirements:

The extent to which the above can be accomplished will depend in part on the level of funding available to conduct the work. We anticipate 4-5 year time-frame will be required.

The organizational workshop and Steering Committee activity (#1) are anticipated at a level of 90K USD.

A level of support of approx. 450K-600K USD/yr direct costs (plus any indirect costs) will be required during steps #2, #3 and #5 for 3 full-time post-docs/junior scientists to work under the direction of the overall working groups, to support travel and facilities for the workgroup meetings, computer support, communications, web facility development, etc..

Additional costs for the training workshops will be required to support travel, food and lodging for the participants and trainers, development of training manuals, software and computer support, organizational support, etc.

Funding for workshops, working groups, development of training manuals, organizational support and secretariat staff time is expected to be managed via the IOC Trust Fund. Funds for post-docs/junior scientists, software and computer support can be provided via/to host scientific institution.

Literature Cited:

Beman, J. M., K. R. Arrigo, and P. A. Matson. 2005. Agricultural runoff fuels large phytoplankton blooms in vulnerable areas of the ocean. *Nature* 434 (7030):211-214.

Beusen, A. H. W., A. L. M. Dekkers, A. F. Bouwman, W. Ludwig and J. A. Harrison. 2005. Estimation of global river transport of sediments and associated particulate carbon, nitrogen, and phosphorus, *Global Biogeochemical Cycles,* 19, GB4S05, doi:10.1029/2005GB002453, 1-19.

Bouwman, A. F., G. Van Drecht, J. M. Knoop, A. H. W. Beusen, and C. R. Meinardi. 2005a. Exploring changes in river nitrogen export to the world's oceans, *Global Biogeochem. Cycles*, 19, doi:10.1029/2004GB002314.

Bouwman, A. F., G. Van Drecht, and K. W. Van der Hoek. 2005b. Nitrogen surface balances in intensive agricultural production systems in different world regions for the period 1970-2030, *Pedosphere*, *15*(2), 137-155.

Cloern, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Mar. Ecol. Prog. Ser*. 210: 223-253.

Dumont, E., J. A. Harrison, C. Kroeze, E. J. Bakker and S. P. Seitzinger. 2005. Global distribution and sources of DIN export to the coastal zone: results from a spatially explicit, global model (NEWS-DIN), *Global Biogeochemical Cycles, 19*, GB4S02, doi:10.1029/2005GB002488, 1-14.

Glibert, P.M. and J.M. Burkholder. 2006. The complex relationships between increasing fertilization of the earth, coastal eutrophication and proliferation of harmful algal blooms. pp 341-354 in: E. Graneli and J. Turner (eds), *Ecology of Harmful Algae*. Springer.

Glibert, P.M. S. Seitzinger, C.A. Heil, J.M. Burkholder, M.W. Parrow, L.A. Codispoti, and V. Kelly. 2005b. The role of eutrophication in the global proliferation of harmful algal blooms: new perspectives and new approaches *Oceanography* 18 (2): 198-209.

Harrison, J. A., N. F. Caraco and S. P. Seitzinger. 2005. Global distribution and sources of dissolved organic matter export by rivers: results from a spatially explicit, global model (NEWS-DOM), *Global Biogeochemical Cycles*, 19 (4), GB4S04, doi:10.1029/2005GB002480, 1-16.

Harrison, J. A., S. P. Seitzinger, A. F. Bouwman, N. F. Caraco, A. H. W. Beusen and C. Vörösmarty. 2005. Dissolved inorganic phosphorus export to the coastal zone: results from a spatially explicit, global model (NEWS-DIP), *Global Biogeochemical Cycles, 19*, GB4S03, doi:10.1029/2004GB002357, 1-15.

Heil, C.A., P. M. Glibert and C. Fan. 2005. *Prorocentrum minimum* (Pavillard) Schiller –A review of a harmful algal bloom species of growing worldwide importance. *Harmful Algae* 4: 449-470

Howarth R.W., E. Boyer, W. Pabich and J.N. Galloway. 2002. Nitrogen use in the United States from 1961-2000, and estimates of potential future trends. *Ambio* 31: 88-96.

Madden, C. R. Smith, J. Kurtz, N. Detenbeck, E. Dettman, W. Nelson, J. Latimer, and S. Bricker. 2008. Development and application of a typology for estuarine classification. In: Glibert, P., C. Madden, W. Boynton, D. Flemer, C. Heil, and J. Sharp (ed.), Estuarine Nutrient Criteria Developmetn: State of the science. US EPA Office of Water. In review.

Millenium Ecosystem Assessment. 2006. www.millenniumassessment.org/.

National Research Council. 2000. *Clean Coastal Waters. Understanding and Reducing the Effects of Nutrient Pollution.* National Academy Press, Washington, D.C.

Nixon, S.W. 1992. Quantifying the relationship between nitrogen input and the productivity of marine ecosystems. Pro. Adv. Mar. Tech. Conf. 5:57-83.

Seitzinger, S. P., J. A. Harrison, E. Dumont, A. H. W. Beusen, and A.F. Bouwman. 2005. Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of Global NEWS models, *Global Biogeochemical Cycles*, GB4S05, doi:10.1029/2005GB002453, 1-11.

Seitzinger, S.P. and C. Kroeze. 1998. Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. *Global Biogeochemical Cycles* 12(1): 93-113.

Seitzinger, S.P. and R. Lee. 2007. Eutrophication: Filling Gaps in Nitrogen Loading Forecasts for LME's. Component 3 Final Report for GEF MSP, Promoting Ecosystem-based approaches to Fisheries Conservation and LME's.

Selman M. 2007 Eutrophication: an overview of status, trends, policies, and strategies. Water Resources Institute report. 91 pp.

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

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, R. Howarth, D. Schindler, W.H. Schlesinger, D. Simberloff, D. Swackhamer. 2001. Forecasting agriculturally driven global environmental change, *Science*, 292, 181-284.

Wassmann, P. 2005. Cultural eutrophication: perspectives and prospects, pp. 224-234. In: *Drainage Basin Inputs and Eutrophication: An Integrated Approach*, by P. Wassmann and K. Olli (eds.). University of Tromso, Norway. Available at: www.ut.ee/~olli/eutr/.

Intergovernmental Oceanographic Commission (IOC)
United Nations Educational, Scientific and Cultural Organization
1, rue Miollis
75 732 Paris Cedex 15, France
Tel.: +33 1 45 68 10 10
Fax: +33 1 45 68 58 12
http://ioc.unesco.org