Biogeosciences Discuss., 6, C2700–C2707, 2009
www.biogeosciences-discuss.net/6/C2700/2009/

Biogeosciences Discussions

Interactive comment on "Coastal hypoxia responses to remediation" *by* W. M. Kemp et al.

W. M. Kemp et al.

jtesta@hpl.umces.edu

Received and published: 27 October 2009

Reply to "Coastal hypoxia responses to remediation" by W. M. Kemp et al. Reviewer #1 Dr. Robert Diaz

General Comments:

(1) Introductory material in sections 1 through 3 provides detail on why hypoxia is a growing problem in coastal areas and factors that lead to the formation of hypoxia. The material is a bit repetitive, but includes enough information to explain the problems associated with low dissolved oxygen (DO). For trophic effects of hypoxia additional information can be found in Baird et al. (2004).

As the reviewer suggests, it was our intention that these introductory sections would provide background information that would help explain hypoxia trends and related pro-

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

cesses in the case studies presented in Sections 5 and 6. We used our best judgment to provide the appropriate amount of detail needed to interpret trends and other observations for specific systems. We felt that this would be more efficient than repeating similar mechanistic explanations for multiple cases reviewed in the later sections.

(2) All the case studies do a good job of pointing to the need to have knowledge of a system's response to the complex problems associated with eutrophication before conclusions can be drawn as to the effectiveness of management actions. The concluding section provides a good summary of the key points made throughout the paper.

We are pleased that the reviewer approved of our overall approach for explaining observed hypoxia trends and for extracting perspectives that might inform hypoxia management.

Specific Comments:

(1) The topology used for describing four different forms of hypoxia follows what other researchers have used, but with some departure. Permanent used to describe hypoxia that is present all year. Persistent seasonal used to describe a broad range of systems that develop hypoxia typically in the warmer seasons from a combination of stratification and enhanced primary production. Episodic used to describe systems that have several separate hypoxic events per year and also those systems that do not have hypoxia every year. Diel used to describe hypoxia that occurs on a daily basis.

These comments from the reviewer underscore the need for section 2.1 on hypoxia typology, to clarify terms used later in the ms.

(2) Continuous measurement of DO, now possible with the advent of affordable water quality logging equipment, show that high frequency episodic and diel hypoxia are more common then previously thought. Both small and large systems can experience many short-term low DO events in a season (see recent studies by; Verity et al. 2004, Tyler and Targett 2007, Tyler et al. 2009). Diel hypoxia can also occur even in the absence

of water column stratification (Verity et al. 2004). (Page 6, Line 194)

We agree with the reviewer's interpretation of this material, and we have clarified key points raised here with minor changes in the revised narrative.

(3) Diel and episodic hypoxia tend to be less lethal to benthic organisms than permanent and persistent seasonal hypoxia. Physiological and behavioral adaptations appear to be sufficient to allow for survival during the nighttime hypoxic period or short duration episodic events. Mobile fishes migrate out and in of these systems as dissolved oxygen declines and rises again, and may take advantage of stressed prey resources (Pihl et al. 1992, Bacheler et al. 2009, Tyler et al. 2009). Part of the benthic response to diel hypoxia mirrors that of seasonal hypoxia with lower diversity and dominance by tolerant species (Tuzzolino 2008). However, these smaller systems appear to be preconditioned to organic enrichment stress, so mortality is not a typical response.

Although we agree with the reviewer that diel and episodic hypoxia may be less lethal to benthic organisms, we feel that the ultimate ecological effects of fluctuating hypoxic conditions have not been adequately investigated. Resulting changes in benthic faunal communities and biogeochemical processes may prove to be important. In any case, the focus of our manuscript is more about controls on hypoxia rather than its ecological consequences.

(4) Section 4 deals with theoretical trajectories for hypoxia response to remediation and is based on Scheffer et al. (2001) catastrophic shifts in ecosystems. As pointed out hypoxia is but one of many undesirable problems associated with eutrophication and linking hypoxia to nutrients with catastrophe theory may be more complex than presented. Catastrophe theory provides a topological approach to analysis of dynamic systems that exhibit large, abrupt change in response to stressors (Jones and Walters 1976). An early application was that of Jones and Walters (1976) to fishery development and collapse. Catastrophe theory provided a graphical model to illustrate the relationship between stock size, fleet size, and efficiency of fishery gear. In the ap-

proach taken by Scheffer et al. two factors are plotted against each other. One factor is External Condition (nutrient loading) and the other is Ecosystem State (in this case hypoxia intensity). It is important that the external condition not be an interactive part of the system (Schaffer and Carpenter 2003). While Schaffer and Carpenter (2003) point out that the effect of nutrient load on a lake would be a reasonable example of and external condition, given the complex interactions of nutrient load with biological and physical processes in the formation of hypoxia, I do not think catastrophe theory fits well as presented. There are too many interconnected and interacting external condition variables for the ecosystem state relative to hypoxia intensity to be reliably tracked by only nutrient load. The complexity of the situation can be in Figure A were hypoxia is just one many variables responding to nutrients. (Page 12, Line 359)

This section is not meant to be an interpretation of potential hypoxia responses to changes in nutrient loading strictly from the perspective of catastrophe theory. While we do draw some examples and perspectives from this theoretical foundation, our goal is to lay out a range of potential trajectories of how hypoxia (one measure of system state) might respond to changes in nutrient loading (one of many external drivers). In all but the linear case, these apparent hypoxia responses to nutrients involve (a) associated changes in internal ecological processes (e.g., changing sediment biogeochemistry, changes in benthic filter-feeding) and/or (b) parallel changes in other external drivers (e.g., climatic conditions, fisheries harvest). This section is meant to consider a wide range of internal ecological processes which change in response to nutrient loading and other external drivers. The section is also meant to consider other external drivers which may be changing contemporaneously. In the revised manuscript, we have clarified the goals of this section, and we have also edited many of the case studies to suggest possible response trajectories expected under future conditions with changes in climate and management.

(5) In section 5 on the observed hypoxia responses remediation Kemp et al. do a good job linking nutrient load control through management actions to reduction in hypoxia.

BGD

6, C2700–C2707, 2009

The best example for this comes from the implementation of the Clean Water Act in 1972 in the US. A decade after the CleanWater Act municipal biological oxygen demand (BOD) decreased by 46% and industrial BOD by 71% (Smith et al. 1987). Smith et al. (1987) analyzed trends in water quality from 1974 to 1981 using 380 stations from all over the US and found control of point sources was biggest factor in improved water quality, mostly from industrial and municipal discharges. Nonpoint pollution from urban and agricultural runoff increased over this period and will prevent achievement of national water quality goals as set out in the Clean Water Act. (Page 13, Line 408)

The reviewer's comments are useful, particularly with regard to the history of hypoxia in rivers and lakes in the USA. The revised ms references these points; however, we retain our broader international perspective in this analysis.

(6) Case Studies: The case studies selected to show the complexities between nutrient load and hypoxia do provide good detail but they are variable in detail and terminology used to describe the systems. (Page 17, Line 525)

We feel that our treatment of cases studies (in Section 6) is as balanced and even as possible, given variations in available information and ecological and oceanographic complexity among these five systems. However, we have edited the revised ms to improve on this overall balance.

(7) Patuxent River: In a small tributary like the Patuxent River the idea that nutrients must be managed from both landward and seaward sources is good. At times there is little attention give to the interaction of smaller systems with their connections to the sea. This may become a more important connection for systems affected by upwelling as has been recently reported for the Yaquina Estuary, Oregon (Brown et al. 2007). (Page 17, Line 529)

We agree that the importance of seaward sources of nutrients and organic matter maybe more widespread among small coastal systems than is evident in the literature. In the revised ms, we have added reference to a few additional systems with

BGD

6, C2700–C2707, 2009

published information related to this phenomenon.

(8) Black Sea: For the Black Sea, I would disagree with Kemp et al. when they say 'The development, variability, and ultimate removal of the hypoxic zone in the northwester shelf is an example of how the extent of hypoxia can respond to changes in nutrient loads, as mediated by climatic variability and food web shifts resulting from over-fishing.' Mee (2006) presents a very strong case linking the reduction in hypoxic area from 40,000 km2 in 1990 to 0 km2 in 1993 to economic forces and not climate. This response of improved DO over the northwest Black Sea continental shelf was not climatic or food web related. (Page 19, Line 582)

The sentence that the reviewer references is at the end of the first paragraph in this section, and it was intended to provide a broad summary of this case study and a transition to the following paragraphs that include greater detail. In the revised ms, this sentence is simplified and clarified. This is discussed in greater detail in the final paragraph of this section where two key points are emphasized. The first of these emphasizes that this example shows that when nutrient inputs to a large system are decreased dramatically hypoxia can disappear. The second focuses on the fact that previous interannual variations in hypoxia appeared to be related to both physical factors (wind-induced winter mixing that injects deep nutrient pools into the euphotic zone), and food-web interactions (e.g., top-down control mediated by ctenophore invasion and fisheries exploitation).

(9) Baltic Sea: Over the last 15,000 years the Baltic Sea has alternated between being either a freshwater and a brackish marine system. The Baltic's present brackish water condition is about 2,000 year (Karlson et al. 2002) so it does not seem relevant to the current DO conditions in the Baltic to discuss events in the Holocene as an indication that hypoxia was always present. Recent assessments of eutrophication and hypoxia/anoxia in the Baltic all point to greatly deteriorated bottom habitat quality since the 1930s (see Karlson et al. 2002). The Baltic Sea is clearly prone to development of hypoxia but its geological history has little to do with today's DO conditions. (Page 20,

Line 617)

We agree and note the depressed O2 conditions since the first part of the 20th century. We included the information on millennial changes in circulation, salinity and O2 as background to introduce the modern hypoxia story in the Baltic and to emphasize the natural tendency for hypoxia in the system. This statement is relevant to our conclusion that natural, physical conditions are fundamentally important controls, together with eutrophication, on oxygen conditions in the Baltic Sea and other coastal systems as well.

(10) Chesapeake Bay: I would not characterize the shift in volume of hypoxia before and after 1985 as a regime shift. Models developed by Hagy et al. (2004) show an increasing volume of hypoxia but not shift in the mid 1980s. After 1985 there does appear be an increase in the variability of hypoxia from year to year (Figure B). I would argue that by 1985, given the geomorphology and physics of the main stem Chesapeake Bay, the Bay reached it's capacity for holding the given hypoxic water volume and that variation from year to year reflected changes in weather. As pointed out in the concluding section, 'Physical features of the ecosystem appear to set limits on hypoxia extent...' After 1985 the Chesapeake Bay oscillated around a mean of 8.4 (SD= 2.2) x 103 km3 (data from Hagy et al. 2004) with little upward trend in volume (Figure B). (Page 22, Line 682)

The reviewer makes some valid points here; however, we suggest that his conclusions are not consistent with the data. We agree that, although the increasing polynomial model provides a significant description of the hypoxia volume time-series in Hagy et al. (2004), an alternative view is that there are two clusters of data before and after 1984, with little significant trend in either data group. The latter view would be consistent with a "regime shift" of some sort. Hagy et al. 2004 concluded, as noted in the abstract, that "Hypoxia was positively correlated with NO32 loading, but more extensive hypoxia was observed in recent years than would be expected from the observed relationship. The results suggested that the Bay may have become more susceptible to NO32 loading."

BGD

6, C2700–C2707, 2009

This indicates a shift. However, to see this as a regime shift in hypoxia response to nutrient loading, one needs to look at the time series for hypoxia volume per N-loading. This view is provided in Fig. 6c of our ms, and it is consistent with previous considerations by Conley et al. (2009). We are very confident in this interpretation, which is backed by other recent analyses that are beyond the scope of this ms.

(11) Gulf of Mexico: Continental shelf hypoxia was first reported in the northern Gulf of Mexico associated with the Mississippi/Atchafalaya Rivers in the early 1970s (Rabalais et al. 1999). (Page 25, Line 761)

OK, we have clarified this in the revised manuscript.

Interactive comment on Biogeosciences Discuss., 6, 6889, 2009.

BGD

6, C2700–C2707, 2009

Interactive Comment