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RE: New Hampshire Marine DO Criteria Update

Dear Dean:

I understand that New Hampshire would like to update the State's dissolved oxygen criteria, in particular for Great Bay Estuary. My initial opinions on the issues you listed in your December 28, 2016 letter are attached.

If you need additional detail on any issue please let me know.

Sincerely,

Robert J. Diaz

Reply to New Hampshire Marine DO Criteria Update Letter Dated December 28, 2016

Issue: *Is the existing DO saturation criterion, minimum 75% saturation (daily average) necessary to ensure aquatic life use protection?*
Opinion: A dissolved oxygen (DO) criterion set at 75% air saturation is likely overly protective for almost all estuarine species that would utilize Great Bay. From the 2000 Marine DO Criteria assessment of chronic growth impairment in tests that ranged from 7 to 21 days (Table 2 in EPA 2000), only some larvae and juveniles stages of summer flounder, American lobster, and Say mud crab showed some impairment above 75% saturation, which at summer temperatures is close to 5 mg O_2/L (Figure 1). The impairment was not consistent across all larval and juvenile stages tested. No species evaluated had acute sensitivity (exposure ranging from 24 to 96 hours) above 2 mg O_2/L, which is the most frequently used starting point for hypoxia. Comparing data from Table 1 (EPA 2000) to the nomogram below it would seem that a 50-60% saturation, or 3-4 mg O_2/L, would also be protective for most species.

The use of DO saturation does complicate criteria application as DO saturation is primarily a function of temperature and salinity, with a minor effect from barometric pressure. Current literature (including EPA's freshwater and marine DO criteria documents) would support the use of concentration-based criteria to ensure appropriate criteria are set across habitats. Concentration combined with the proper averaging period for measuring DO will ensure the most defensible criteria that provide an appropriate level of protection for various fishery resources.

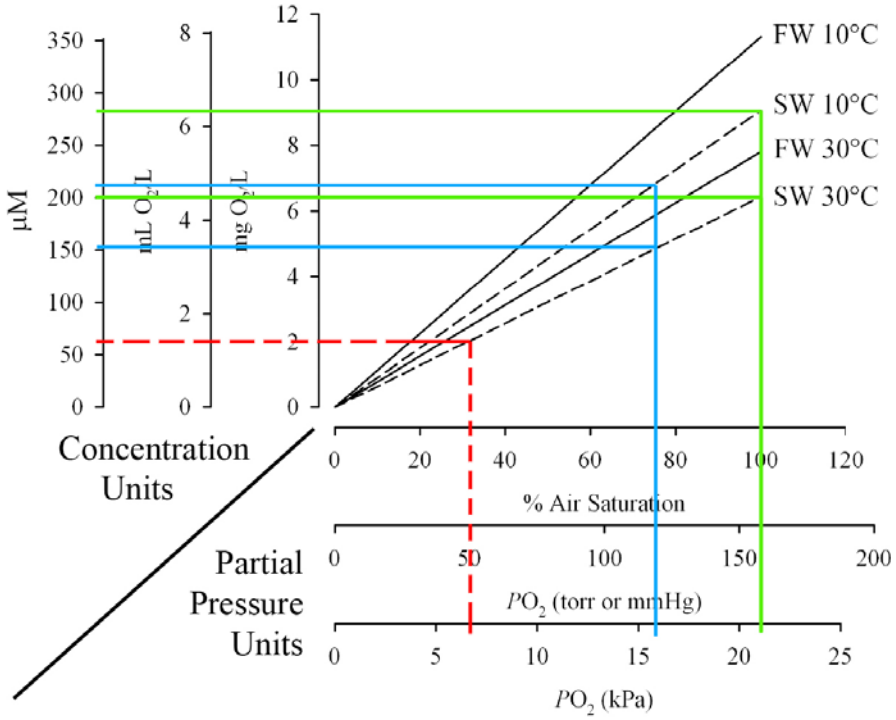

Figure 1. Nomogram for dissolved oxygen in freshwater (FW) and sea water (SW) at 10ºC and 30ºC (from Diaz and Breitburg, 2009). Concentration units are on Y-axis, and partial pressure units are on X-axis. Red line is most frequently used starting point for hypoxia at 2 mg O_2/L. Green line is 100% solubility of oxygen in sea water between 10º to 30ºC. Blue line is existing DO criteria of 75% saturation.

Issue: *If the DO saturation criterion is not necessary to protect aquatic life, is there an alternative 24 hour DO (i.e., chronic) criterion that would be appropriate to ensure aquatic life use protection in this estuarine system? For example, would a 5 mg/l (daily average) concentration be considered protective? Would another chronic DO criterion of a longer averaging period (e.g., 7-day, 30-day) be appropriate to ensure aquatic life protection?*
Opinion: This is a complex set of questions. First, it should be pointed out from the oxygen nomogram that 5 mg O_2/L is about 75% saturation for seawater at 30ºC. For individual species the range of DO between acute and chronic effects can be as large as 3 to 4 mg O_2/L or about a 50% change in saturation. But there is a common and predictable range of responses to declining DO (Figure 2). All but the most sensitive mobile species will not move to avoid habitats that are above 4 mg O_2/L. By the time a habitat is at 2 mg O_2/L mobile fishes have left and by 1.5 mg O_2/L benthic species are showing signs of stress. This basic response model would need to be refined to be more representative of Great Bay species. The best way to approach DO criteria would be a combination that assess temporal concentrations (instantaneous, daily, weekly, etc.) and seasonal use by key species. This is how DO criteria were set in Chesapeake Bay, with the addition of designated use zones (see Figure 3 and Batiuk et al. 2009 for details).

Given the way organisms respond to declining DO, either in a chronic or acute sense, setting a criteria based on a single day average of 5 mg O_2/L would be a very conservative (protective). However, a higher DO protection level should apply when and where migrating fishes spawn as noted in the 2000 Marine DO and Chesapeake Bay criteria. It does not seem appropriate to set a criteria at 5 mg O_2/L for 24-hour interval. As criteria must be met at “all times and places” this would mean that no single 24 hour period may average DO less than 5 mg O_2/L. EPA’s Marine DO and Chesapeake Bay criteria recognize that the “chronic” criteria averaging period should be on the order of 30 days. But it is also important to ensure a protective “instantaneous minimum” is set. Available information would indicate that depending on the organism and habitat, anywhere from about 1.5-4 mg O_2/L instantaneous minimum would ensure that acute impacts are minimal. Our approach in Chesapeake Bay was to set DO levels supported by data from published literature for major habitats within Chesapeake Bay. No new data, outside the EPA sponsored monitoring program, was collected to develop or set criteria.

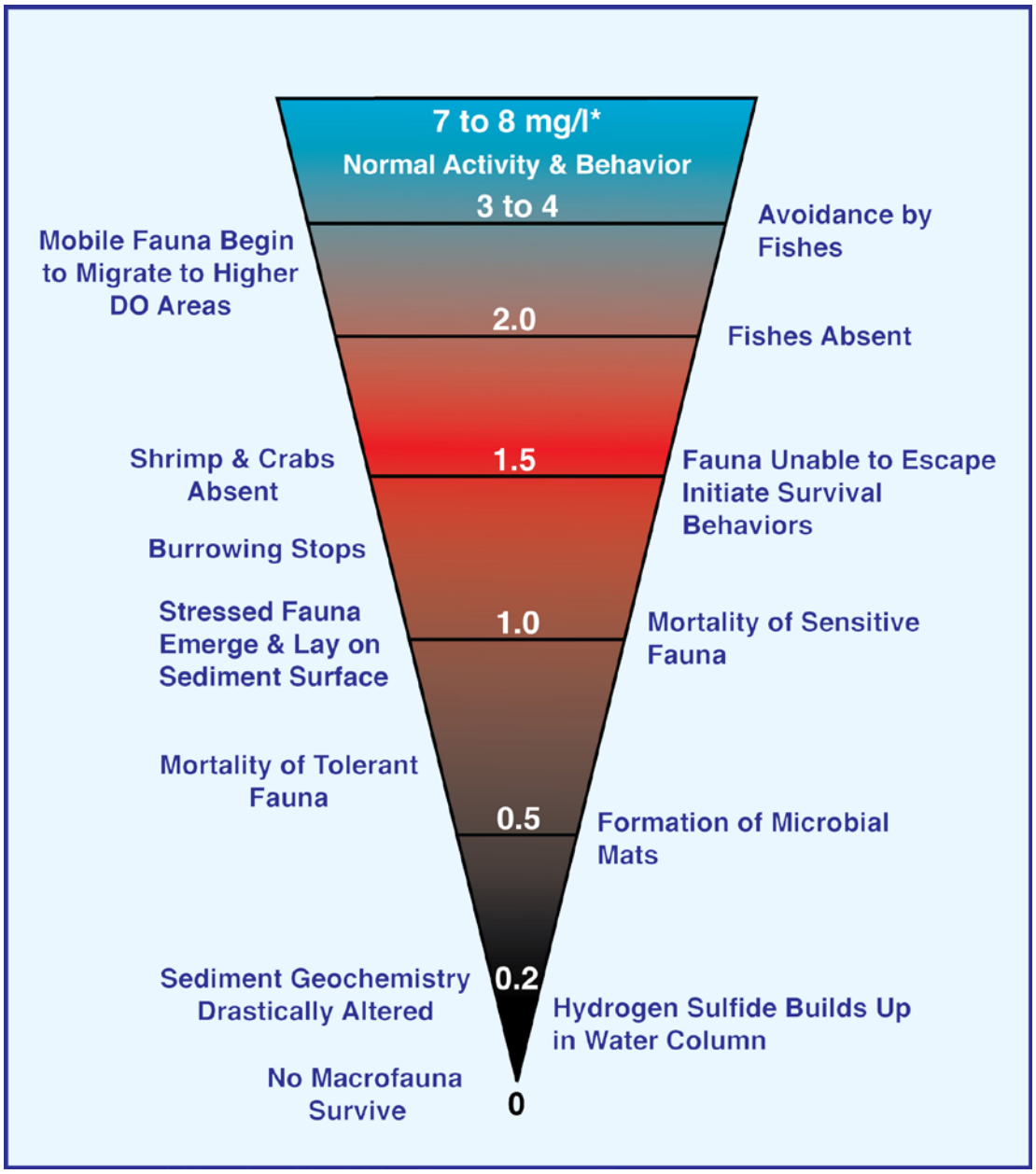

Figure 2. Cone of faunal response to declining oxygen concentration. Based on data from Díaz and Rosenberg (1995), Rabalais et al. (2001), Vaquer-Sunyer and Duarte (2008).

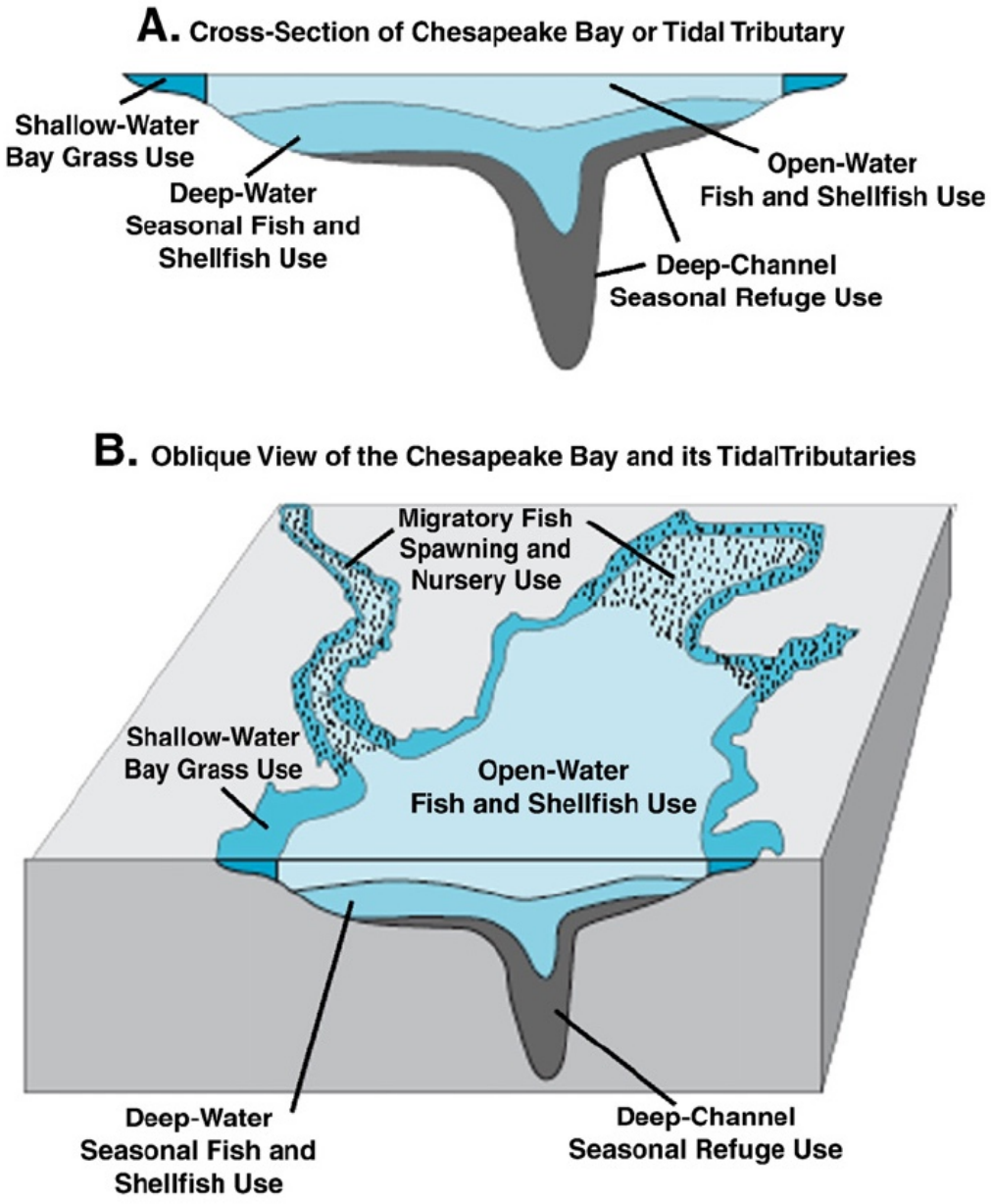

Figure 3. Conceptual illustration of the five Chesapeake Bay tidal water designated uses zones (From Batiuk et al. 2009).

Issue: *Is a 5 mg/L instantaneous minimum DO necessary to ensure aquatic life use protection in estuarine waters?*
Opinion: Based on the 2000 Marine DO Criteria and other literature summaries of DO impacts, 5 mg O_2/L is overly protective of all species for acute impacts and most species for chronic impacts. In Chesapeake Bay, a concentration of 5 mg O_2/L and above were set as criteria only for migratory fish spawning and nursery designated use zones by season. See Table 1.

Table 1. Chesapeake Bay dissolved oxygen water quality criteria for the protection of tidal water designated uses against adverse effects on survival, growth, larval recruitment, freshwater species and threatened/endangered species (From Batiuk et al. 2009).

Designated use	Criteria concentration/duration	Protection provided	Temporal application
Migratory fish spawning and nursery use	7-day mean ≥ 6.0 mg L^{-1} (tidal habitats with 0–0.5 salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species	February 1–May 31
	Instantaneous minimum ≥ 5.0 mg L^{-1}	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species	
	Open-water fish and shellfish designated use criteria apply		June 1–January 31
Shallow-water bay grass use	Open-water fish and shellfish designated use criteria apply		Year-round
Open-water fish and shellfish use	30-day mean ≥ 5.5 mg L^{-1} (tidal habitats with 0–0.5 salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species	Year-round
	30-day mean ≥ 5 mg L^{-1} (tidal habitats with>0.5 salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species	
	7-day mean ≥ 4 mg L^{-1}	Survival of open-water fish larvae	
	Instantaneous minimum ≥ 3.2 mg L^{-1}	Survival of threatened/endangered sturgeon species[a]	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg L^{-1}	Survival and recruitment of bay anchovy eggs and larvae	June 1–September 30
	1-day mean ≥ 2.3 mg L^{-1}	Survival of open-water juvenile and adult fish	
	Instantaneous minimum ≥ 1.7 mg L^{-1}	Survival of bay anchovy eggs and larvae	
	Open-water fish and shellfish designated-use criteria apply		October 1–May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥ 1 mg L^{-1}	Survival of bottom-dwelling worms and clams	June 1–September 30
	Open-water fish and shellfish designated use criteria apply		October 1–May 31

[a] At temperatures considered stressful to shortnose sturgeon (29 °C), DO concentrations above an instantaneous minimum of 4.3 mg L^{-1} will protect survival of this listed sturgeon species. Source: U.S. EPA, 2003a.

Issue: *If the 5 mg/L instantaneous minimum DO criterion is not necessary to protect aquatic life, is there an alternative short-duration (i.e., acute) DO concentration that would be appropriate to ensure aquatic life use protection from such short term DO variations? For example, would a 3.5 mg/l or 4 mg/l 1-hour average standard be considered protective?*
Opinion: This is an interesting question. For benthos and most pelagic species, 5 mg O_2/L is protective based on published laboratory and field data. But what combination of concentration and exposure would be workable for protecting species in the field? A big part of these issues involves where DO is measured (surface, midwater, 1m off bottom, 10cm off bottom), when (day vs. night), for how long a period (instantaneous, hours, days, weeks, months), at what intervals (minutes to hours). There is little consistency in the literature as to how DO is measured and how low DO is assessed, so some thinking will be needed to answer these questions. From all the DO time-series I have seen there are obvious daily fluctuations in DO and most have an obvious tidal components along with season. In Chesapeake Bay a combination of instantaneous minimum, 1-day, 7-day, and 30-day means were used to set criteria based on species sensitivity and habitat use. Whether an organism is benthic or not, the criteria apply to the overlying water column the organism is exposed to. However, DO requirements for deep-channel refuge are different from overlying open-water column that would be well aerated (Figure 3 and Table 1).

Issue: *The USEPA 2000 Marine DO Criteria and 2003 Chesapeake Bay DO criteria address a number of components (chronic, acute, stratified conditions, spawning areas, etc.) that appear to require some detailed knowledge of the system to properly apply. Please address the following questions:*

1- Are there components of the 2000 Marine DO Criteria or 2003 Chesapeake Bay criteria that could be applied to New Hampshire waters without substantial changes; for example, due to similarity of taxonomic groups to be protected?
Opinion: I think a hybrid of the 2000 Marine DO Criteria and Chesapeake Bay criteria would fit New Hampshire's needs. The start would be to identify key species in Great Bay and determine what is know about their DO requirements.

2- What changes (e.g., studies, data collection, organism adjustments), if any, are required to make other components of these criteria applicable to the Great Bay Estuary?
Opinion: To combine elements from both sets of DO criteria will require that you consider the following:

1. Understand the dynamics of DO within Great Bay to included temporal and spatial elements. A thorough evaluation of NEERS water quality data for Great Bay would be a starting point.
2. Identify key species that need protection with an understanding of support species they need.
3. Identify when and where key species and their life-histories use Great Bay.
4. Set realistic DO concentrations that are obtainable through best management practices. By this I mean do not set criteria above what is natural for Great Bay.

3- How should standards application vary in stratified versus unstratified waters?
Opinion: I am not sure this will be a problem. It is rare for an unstratified waterbody to have low DO or become hypoxic. Chesapeake Bay did partition the Bay into zone based on species use. The boundary between the open-water fish and shellfish use zone and the deep-water seasonal fish and shellfish use zones do correspond roughly to where the summer pycnocline lies. If Great Bay has a similar structure then separate DO criteria could be used.

Citations:

Batiuk, R. A., D. L. Brietburg, R. J. Diaz, T. M. Cronin, D. H. Secor, and G. Thursby: Derivation of habitat-specific dissolved oxygen criteria for Chesapeake Bay and its tidal tributaries. J. Exp. Mar. Biol. Ecol. 381:S204-S215, 2009.

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

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

U.S. EPA: Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras. EPA-822-R-00-012. Office of Water, Office of Science and Technology, Washington, D.C. and Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, Rhode Island. 2000.

Vaquer-Sunyer, R. and Duarte, C. M.: Thresholds of hypoxia for marine biodiversity, Proc. Natl. Acad. Sci., U.S.A., 105, 15452–15457, 2008.