Discussion of Three Journal Articles Referenced by NHDES as the Basis for Listing Great Bay Estuary as Nutrient-Impaired

NHDES has provided the following three articles as support for declaring Great Bay Estuary nutrient-impaired:

Hauxwell, J., Cebrian, J., and Valiela, I. February 2003. Eelgrass Zostera marina loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. Marine Ecology Progress Series, Vol. 247: 59-73.

Latimer, J.S. and Rego, S.A. 2010. Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuarine, Coastal and Shelf Science, 90 (2010) 231-240.

Valiela, I. and Cole, M.L. 2002. Comparative Evidence that Salt Marshes and Mangroves May Protect Seagrass Meadows from Land-derived Nitrogen Loads. Ecosystems (2002) 5:92-102.

The following provides a summary of each article and details technical issues in citing these articles for this purpose. To provide context, we note that according to a 2014 NHDES report[1], Great Bay Estuary receives an estimated 1,225 tons TN/year or 204 kg TN/ha-yr.

Hauxwell et al.:

Summary:

This study evaluated eelgrass loss between 1987 and 1997 and nitrogen loading rate (kg/ha-yr) in seven estuarine systems in the vicinity of Waquoit Bay, MA. The study looked at various metrics of eelgrass growth (including, but not limited to, shoot density, biomass, and total production). Graphs of these data were presented to claim a logarithmic decrease in eelgrass measurement with increasing nitrogen load (kg/ha-yr) such that all eelgrass was lost when the nitrogen load exceeded approximately 50 kg/ha-yr. Measurements of phytoplankton biomass (µg chlorophyll-a/L), epiphyte biomass (mg DW/cm^2) and macroalgal biomass (cm canopy height) were identified as the route source of light attenuation that caused the observed eelgrass loss, particularly due to macroalgae that adversely affect new shoot recruitment.

> "Recruiting shoots were exposed to under-compensating irradiances for most of the year in Hamblin Pond due to a high, persistent macroalgal canopy, and during the 1998 fall in Jehu Pond due to a concurrent macroalgal bloom." (at 69)

[1] NHDES. June 16, 2014. Great Bay Nitrogen Non-point Source Study. Available at https://www.des.nh.gov/organization/divisions/water/wmb/coastal/documents/gbnnpss-report.pdf

Issues:

- These estuaries differ from Great Bay with respect to tidal range (0.5 meters) and mean depth (0.8 – 1.7 meters), among other hydrodynamic factors.
- The discussion suggests that eelgrass and macroalgae were present year-round. Thus, macroalgae adversely affect regrowth from seedlings. This is not the case in Great Bay Estuary.
- No discussion was presented on the influence of CDOM on water clarity.
- Great Bay Estuary has more than tripled the study's 60 kg/ha^{-1} yr^{-1} "no eelgrass" threshold for decades and still produces dense eelgrass beds every year.

Latimer and Rego:

Summary:

Latimer and Rego studied very shallow (0.3-8 m) small to medium (<19 km^2) New England (CT, MA, RI) estuaries to determine the relationship between eelgrass extent and watershed-derived nitrogen loading. The study evaluated annual nitrogen loading rates, eelgrass cover data from each state, and percent eelgrass lost (based on maximum potential habitat, i.e., where depth ≤ 3 m). Based on nonparametric change-point analysis, the study concludes that, at nitrogen loadings above 50 kg/ha^{-1} yr^{-1}, eelgrass will likely be deleteriously affected and at loading rates above 100 kg/ha^{-1} yr^{-1}, no eelgrass is expected to exist.

Issues:

- The estuaries in this study differ from Great Bay in that the Great Bay Estuary experiences a large tidal range with a shallow mean depth, particularly in Great Bay (where the bulk of the eelgrass cover is found).
- Great Bay Estuary has more than doubled the study's 100 kg/ha^{-1} yr^{-1} "no eelgrass" threshold for decades and still produces dense eelgrass beds every year.
- The study concludes that nitrogen indirectly causes adverse impacts on eelgrass through light attenuating phytoplankton, macroalgae, and/or epiphytes. Great Bay Estuary does not have documented excessive levels of phytoplankton, macroalgae, or epiphytes.
- "[T]here is considerable science that describes the causal mechanisms between excess nitrogen, eutrophication, and seagrass effects... However, in this study we use a simplified approach that involves nitrogen loading => seagrass coverage using a comparative systems approach." This ignores the conceptual model and may at most demonstrate covariation.
- "Direct determination of eelgrass loss was not possible because quantitative data on historical eelgrass extent were not available for any of our estuaries. We calculated eelgrass loss as the difference between potential eelgrass habitat area (i.e., area of estuary with water depth ≤ 3 m from optical considerations alone, see above) and actual eelgrass extent." This ignores natural light attenuation (e.g., CDOM), sediment/substrate

suitability, current velocity, and other factors influencing the occurrence and maintenance of eelgrass meadows.

- "Finally, for anomalous category 3 estuaries, in addition to uncharacterized nitrogen inputs and hydrodynamic effects, factors such as substrate characteristics, non-algal particle water clarity effects, availability of seed stock for reproduction, predator activity, and even boat propellers, docks and moorings, can all reduce the viability of eelgrass, even when nitrogen-derived water quality may be good or improving (Fonseca et al., 1998; Burdick and Short, 1999; Bell et al., 2002). If all of these factors could be incorporated into the analysis it is likely that they would no longer be anomalous. … At low nitrogen loading rates, eelgrass levels varied markedly, signaling that other variables such as extent of fringing marshes (which mitigate nitrogen from watershed), non-algal particles, colored dissolved organic matter (Vaudrey, 2008b) and substrate type, which are not considered, are likely to have an effect on eelgrass." This is an acknowledgement that confounding variables may be significant but were not assessed.

Valiela and Cole:

Summary:

The goal of this study was to determine the level of protection from nutrient overenrichment fringing wetlands and salt marshes provide to seagrass meadows using published data from estuaries throughout the world. In conducting the study, Valiela and Cole evaluated and regressed various metrics including annual total nitrogen loading, seagrass production, seagrass production as percent of total primary production, area of wetland, denitrification rates, and percent of eelgrass cover lost over the last 10-30 years. One finding was that "production per unit area by seagrasses increased and losses of seagrass habitat were lower in estuaries with relatively larger areas of fringing wetlands." Valiela and Cole also "concluded that there was a 50%-100% reduction in seagrass production and habitat area as land-derived N loads exceed 100 kg N ha^{-1} y^{-1}. Land-derived N loads from 20 to 100 kg N ha^{-1} y^{-1} therefore seem to be a critical range for seagrass meadows in shallow coastal waters."

Issues:

- The study listed Great Bay at 252 kg N/ha-yr based on Short and Mathieson, 1992, in general agreement with the NHDES 2014 TN loading estimate. Based on the study's conclusions, it would be expected that Great Bay would have no eelgrass after decades of exceeding the "critical range" of TN loading by more than twofold.
- The study included estuaries throughout the world with substantially differences including different climates, algal species, seagrass species, and light regimes. These include estuaries in the northeastern US, Florida, Texas, Mexico, Australia, England, Germany, and Italy. Given the wide assortment of estuarine settings grouped together in the study results, the applicability of this study to Great Bay is not apparent.
- The study paired the percent of area of seagrass habitat lost in an estuary over the last 10-30 years with total nitrogen loadings from unspecified time periods. Seagrass area in an

estuary can fluctuate widely over the span of a few years, unrelated to TN. Moreover, the study does not evaluate other changes in the estuaries over three decades which may have caused changes in seagrass (e.g., wasting disease, dredging, extreme storms).

- The study acknowledges that "many additional variables (water residence times, hypsometry, sediment loads, area of the estuary, and so on) must also affect the status of eelgrass meadows" and "in our analysis, we did not ignore the other estuarine variables; we merely asked whether we could see significant relationships between areas of wetlands and seagrass survival that emerged above the scatter created by the many additional variables…The weakness is that it is difficult to identify cause-effects given the large scatter of the data…" The study acknowledges that it did not account for confounding variables with regard to nutrient impacts on seagrass.