Updated Comprehensive Analysis of Nutrient Trends and Cultural Eutrophication Indicators for Great Bay and the Piscataqua River

March 19, 2018

Great Bay Municipal Coalition

Introduction

Since the early 2000s, questions have been raised regarding whether the Great Bay Estuary, like many other east coast estuaries is experiencing cultural eutrophication and related use impairment as regulated under the State of New Hampshire water quality standards. The focus of such concerns has generally centered on changing eelgrass populations and the possible relationship to total nitrogen (TN) contributions to the system's ecological health. The following addresses the latest available scientific information and site-specific data on this issue. Presently there are no EPA-approved numeric water quality criteria for nutrient parameters for the State of New Hampshire; narrative criteria are used to ensure adverse ecosystem impacts are not caused by excessive nutrient inputs. New Hampshire's narrative water quality criteria generally regulate pollutants to the threshold level that ensures use protection ("A narrative statement concerning that pollutant that when not exceeded, will protect an organism, a population, a community, or a prescribed water use" (Env-Wq 1702.14.b)). With respect to nutrients in Great Bay Estuary, the narrative criteria provide the following (Env-Wq 1703.14):

> (b) Class B waters shall contain no phosphorus or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring.
>
> (c) Existing discharges containing phosphorus or nitrogen, or both, which encourage cultural eutrophication shall be treated to remove the nutrient(s) to ensure attainment and maintenance of water quality standards.

This criterion reflects the requirements in the Clean Water Act (CWA) and, where necessary, requires the development of a numeric water quality target based on "sound scientific rationale" (40 CFR § 131.11) reflecting the relationship between the pollutant, its impact on the ecosystem, and the use impairment to be protected.

A brief history of TN regulation in Great Bay Estuary is provided in Attachment 1. NHDES initially sought to develop a narrative criteria translator in 2009 through the development of site-specific numeric TN criteria tied to dissolved oxygen and system transparency (which was thought to be the cause of post-2005 eelgrass declines in the estuary). Those criteria were initially used to declare the system nutrient impaired and they formed the basis for proposed TN limitations in the draft 2011 NPDES permit for the City of Dover, although the draft permit was never finalized. However, due to concerns regarding the validity of the regression analyses used to create the 2009 TN Criteria, New Hampshire DES and the Great Bay Municipal Coalition (GBMC) agreed to conduct an independent expert peer review of the proposed TN criteria for the estuary. In 2014 this independent expert peer review determined that the methodology and analyses used to develop the numeric TN criteria were not scientifically defensible, and those criteria were withdrawn. Since then, additional studies and extensive water quality sampling have occurred, providing further insight on the cause(s) of post-2005 eelgrass declines and the effect of nitrogen on phytoplankton growth (the mechanism by which water column transparency and dissolved oxygen may be adversely affected). Research has also been initiated to evaluate macroalgae growth in the system to explore potential changes in this constituent and its influence on ecosystem health. That research has yet to reach any definitive conclusions regarding factors influencing the growth of macroalgae or the influence of macroalgae on ecosystem health.

The following summarizes the new relevant data and information that have been developed concerning potential TN impacts on aquatic life uses (*e.g.*, protection of eelgrass beds and dissolved oxygen) in Great Bay Estuary and the Piscataqua River. None of this information was available or considered when the City of Dover draft NPDES permit was issued in 2011. As discussed herein, the new data and information do not indicate that existing TN levels are stimulating increased phytoplankton growth or otherwise causing nutrient-related narrative or numeric water quality exceedances in the system at this time. Therefore, further restriction on TN loadings to this system are not necessary at this time. However, given ongoing research and questions regarding potential impacts on macroalgae growth, ensuring continued voluntary plant operation to promote TN reduction is a prudent measure pending the outcome of such research.

Background

The Great Bay Estuary (Figure 1) consists of a tidal strait (Piscataqua River) that connects Portsmouth Harbor to the inland bays (Great Bay, Little Bay) and several tidal rivers.

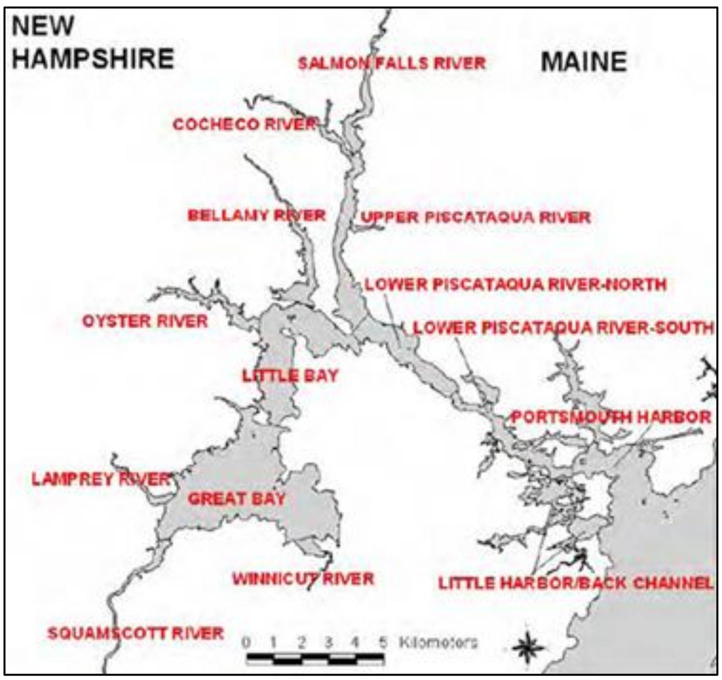


Fig. 1: Great Bay Estuary Map

A. Great Bay Characteristics

The estuary has a drainage area of approximately 2,650 km^2 (1,023 mi^2) and a surface area of 54 km^2 (21 mi^2) (Truslow et al., 2010). A bathymetry map of Great Bay Estuary (Fig. 2; NOAA & Jakobsson, 2000) reveals the generally shallow depths separated by Great Bay's deep (5-20 m) forked central channels (Green & Short, 2003).

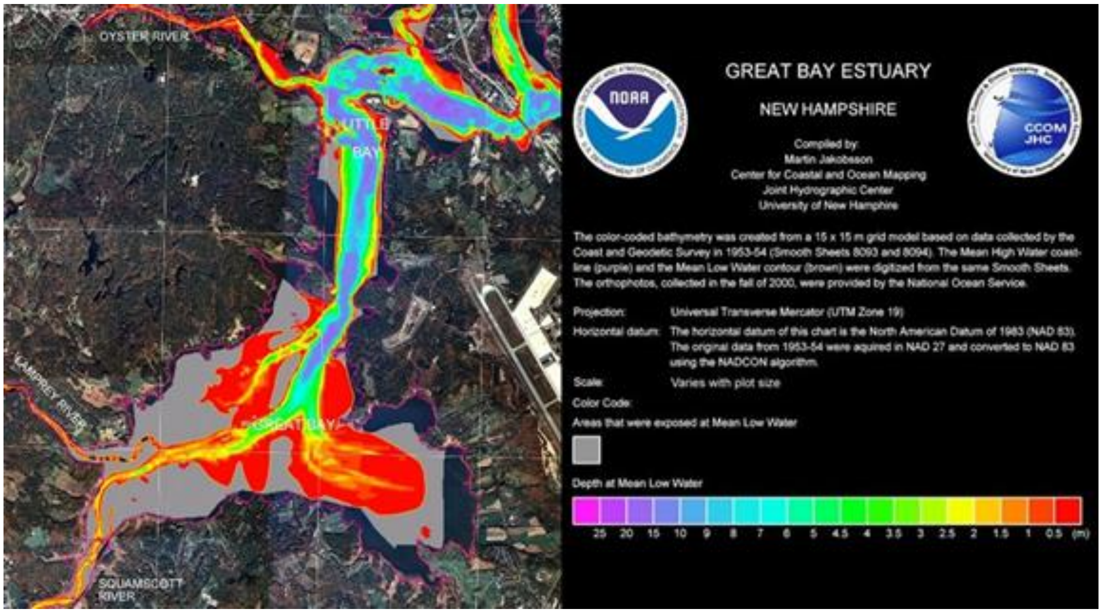


Fig. 2: Great Bay Bathymetry (NOAA & Jakobsson, 2000)

Due to the shallow bathymetry of Great Bay and the large tidal variation (~6 feet), much of Great Bay and the major tidal rivers are tidal flats during low tide, limiting where eelgrasses may grow and exposing the majority of the eelgrass populations to direct sunlight during the low tide cycle. In fact, over 50% of Great Bay's area is characterized as mudflats that become exposed at low tide (Short, 1992).

The tidal amplitude to mean depth ratio of the estuary is 0.18 and the tidal range at the mouth of the estuary is on the order of 2.6 m (Bilgili et al., 2003). Hydrodynamic modeling completed by HDR|HydroQual estimated the average residence times for the estuary are quite short compared to other major east coast estuarine systems (Table 1). Such short residence times, serve to limit phytoplankton growth in the system, and consequently, the ability of any excess nutrients to stimulate elevated phytoplankton growth.

Table 1: HDR|HydroQual Hydrodynamic Model Average Residence Times

Region	**Avg. Residence Time (days)**
Great Bay	~ 3
Great Bay – Little Bay	~ 8
Upper Piscataqua R.	< 1

Another important characteristic of the estuary and its tributaries, influencing plant growth, is the high level of colored dissolved organic matter (CDOM) which enters the estuary from the surrounding watershed. This contribution of CDOM causes the brown-colored water in the system, which naturally reduces water column transparency and restricts light penetration throughout the system (Fig. 3).

Fig. 3: CDOM in Salmon Falls River, October 2012

These characteristics make the Great Bay Estuary relatively unique in comparison to other estuaries along the East Coast. The shallow depth and high tidal range allows eelgrass growth in much of the estuary under reduced light conditions, although mudflats are not ideal habitat for eelgrass. Its northern location makes the estuary more susceptible to severe winter weather and ice scour (further enhanced by the tidal amplitude). As noted earlier, the short residence time influences the ability of phytoplankton to form blooms before they are washed out of the system and generally poor water column transparency further inhibits phytoplankton growth.

B. Aquatic Life Use Attainment

The maintenance of healthy eelgrass beds is defined as a primary aquatic life use indicator for the estuary, since eelgrass beds serve as a foundation for the ecosystem (PREP 2018). Eelgrass beds in the estuary are now primarily confined to the areas around Portsmouth Harbor and Great Bay, with the bulk (>80%) of the beds in Great Bay. The health of these beds is estimated using a measure of acres of cover (See, Attachment 2 concerning eelgrass cover measurements)[1], and an examination of the eelgrass cover record for Great Bay indicates that cover has declined over time (Fig. 4).

Declines in eelgrass cover in the period from 1987-1989, 1995, 1999-2000, and 2002-2003 were caused by wasting disease, as documented by researchers at the University of New Hampshire (UNH). Eelgrass cover in Great Bay recovered in the years following these outbreaks. Unlike the situation in Great Bay, eelgrass beds in Little Bay were completely lost following the 1989 outbreak of wasting disease and these beds have not yet recovered. Subsequent to these outbreaks of wasting disease, eelgrass cover in Great Bay declined significantly in 2006 and has not returned to prior levels. Over this time period, no significant outbreaks of wasting disease have been reported in UNH monitoring reports.

[1] Based on eelgrass percent cover data from SeagrassNet, it is apparent that the timing of eelgrass surveys can skew annual reported "peak" eelgrass cover values. Eelgrass cover survey results in late-July compared with mid-October can vary by a factor of two.

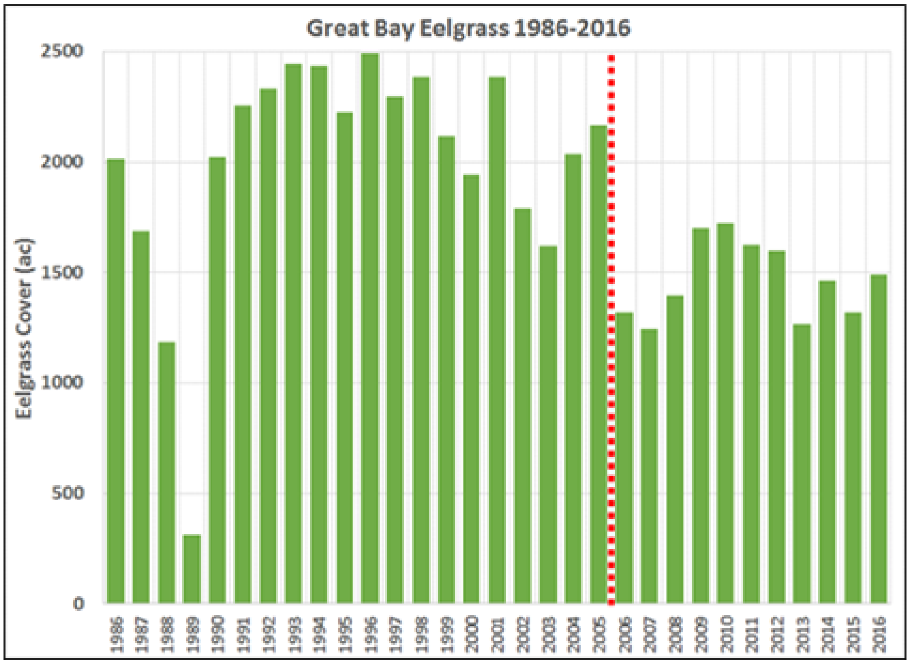


Fig. 4: Great Bay Eelgrass Cover, 1986-2016 (UNH GRANIT)

Multiple factors are reported in the literature as potential causes for this loss of eelgrass cover. These factors can be divided into two general categories: factors that influence light transmittance through the water column and non-light factors. Eelgrass is a submerged aquatic plant that requires sunlight for photosynthesis. If light transmittance through the water column is reduced, eelgrass cannot survive at depths where light is diminished below a certain threshold. Factors affecting light transmittance include phytoplankton, suspended solids, CDOM, and turbidity. In addition, the excessive growth of macroalgae and epiphytes may reduce the amount of sunlight reaching the blades of eelgrass, thus limiting growth. Non-light factors include wasting disease, grazing, extreme storms, low salinity, ice scour, high temperature, sedimentation, and desiccation. See Attachment 3 for additional discussion on eelgrass stressors.

Following the significant decrease in eelgrass cover observed in 2006, DES began developing a criterion for TN under the assumption that the major eelgrass losses observed in 2006 were attributed to cultural eutrophication. The conceptual model relating TN to eelgrass loss is illustrated in Figure 5. Based on this model, nutrient (TN) loads to the estuary can stimulate the growth of phytoplankton (measured as chlorophyll-a), epiphytes (plants that grow on the eelgrass blades), and/or macroalgae. The growth of phytoplankton in the water column adversely affects eelgrass by reducing light penetration. At greater depths, the amount of light available is not sufficient to support eelgrass growth and eelgrass cover is lost. Eelgrass loss from phytoplankton growth is expected to be greatest in deeper waters because light penetration is reduced with depth. Epiphytes naturally occur in all marine waters, where sufficient light is available to support their existence. These organisms may attach to surfaces, such as eelgrass blades, and block light from reaching the blade. If such growth is dense enough, it can prevent sufficient light from reaching the eelgrass and the plant dies. Macroalgae compete with eelgrass for habitat and light. Floating forms, where dense enough, can cover eelgrass bed, blocking light from reaching the eelgrass, causing significant eelgrass losses.

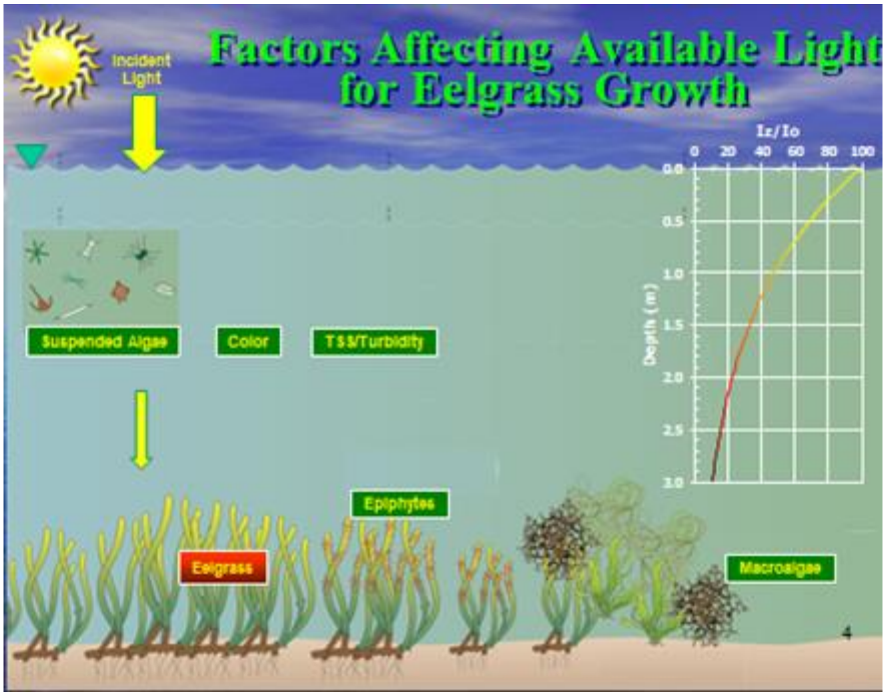


Fig. 5: Conceptual Model for Cultural Eutrophication Impacts on Eelgrass

If cultural eutrophication was responsible for the observed loss in eelgrass cover since 2005, a series of "cause-and-effect" demonstrations would be required, in accordance with the narrative standard and federal regulations. As recommended in USEPA guidance (*e.g.*, USEPA, Nov. 2010, Using Stressor-response Relationships to Derive Numeric Nutrient Criteria; USEPA, July 2000, Nutrient Criteria Technical Guidance Manual Rivers and Streams), "scientifically defensible" growing season data/analyses would evaluate and demonstrate the following:

- TN loads to the estuary increased over time causing TN concentrations to increase in comparison to the timeframe when healthy eelgrass populations existed;
- The amount of light reaching the eelgrass beds diminished over this time period due to excessive plant growth;
  - Phytoplankton chlorophyll-a concentrations in the estuary increased as the TN loads/concentrations increased, causing a significant decline in water column transparency, and/or
  - Epiphyte cover significantly increased as the TN loads increased, and/or
  - Macroalgae occurrence in eelgrass habitat increased as the TN loads increased.
- Eelgrass cover losses generally coincide with the increase in phytoplankton/epiphytes/ macroalgae; and,
- Other known factors that could account for the 2006 eelgrass decline have been considered and were determined not to be responsible for the ensuing eelgrass loss.

Data Summary and Evaluation

Data on the relevant factors necessary to demonstrate cultural eutrophication are presented below along with a detailed review of the eelgrass cover data.

A. Changes in TN Concentration and Loading over Time

Water quality data for TN have only been collected in the Great Bay Estuary since 2003. However, a much longer period of record is available for dissolved inorganic nitrogen (DIN), the form of nitrogen considered readily available for phytoplankton, epiphytes, and macroalgal growth. These data (Fig. 6), collected during low tide at Adam's Point (the entrance to Great Bay), show multiple trends.[2] In the late 1970s, median DIN levels were below 0.1 mg/L while no notable eelgrass declines for the estuary were reported. DIN concentrations below 0.1 mg/L are considered "low," providing good quality for estuarine systems (Bricker et al., 1999 at 49). Routine annual DIN monitoring commenced in the early 1990s, with DIN levels similar to that reported in the 1970s. DIN levels were elevated through the late 1990s and again in the period from 2004-2009. Since then, DIN levels have decreased such that concentrations in 2014-2015 are equivalent to those concentrations seen in the 1970s (PREP 2018 SOOE at 18-19). This significant DIN reduction coincides with load reductions from area wastewater treatment facilities that contribute the majority of the DIN during the summer growing season (Hall et al., 2016).

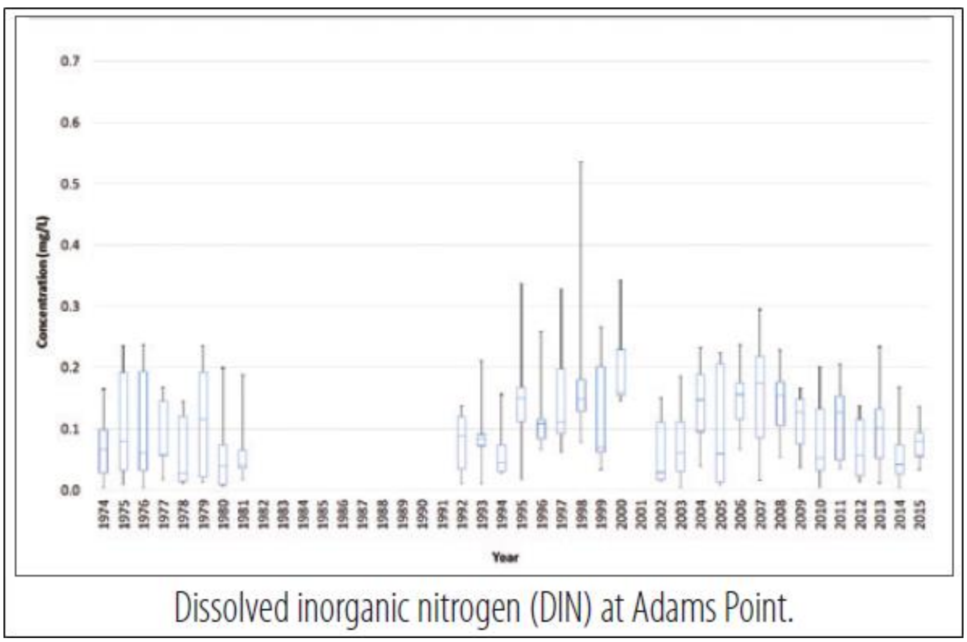


Fig. 6: DIN at Adams Point (PREP 2018 SOOE)

This pattern in water quality is also reflected in the data for TN, as illustrated in Figure 7, with growing season low tide TN now at its lowest level in a decade (approaching 0.3 mg/L TN).

[2] Ambient concentrations of DIN and TN are significantly higher during low tide when water quality most resembles conditions in the watershed draining to the estuary. The average tidal concentration is a better estimator of nutrient concentrations stimulating plant growth.

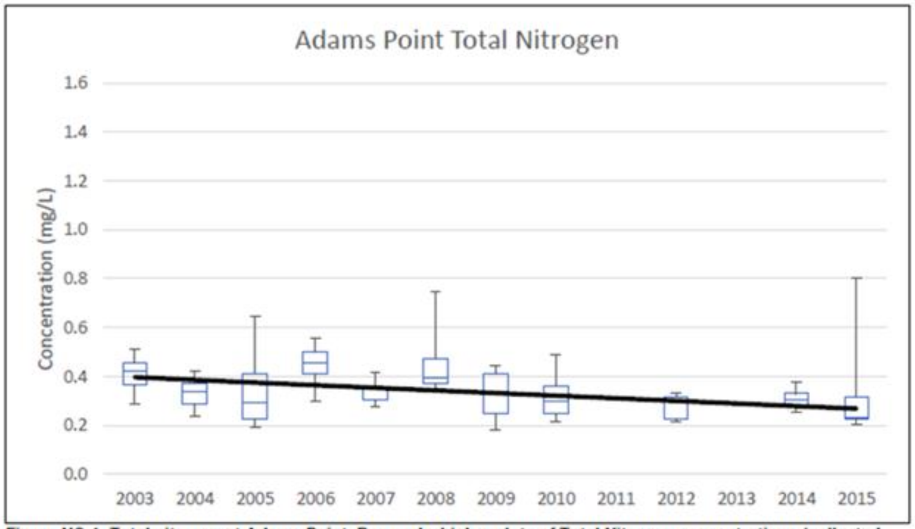


Figure NC-1. Total nitrogen at Adams Point. Box and whisker plots of Total Nitrogen concentrations (collected monthly, April through December, at low tide) between 2003 and 2015. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Years 2011 and 2013 not included due to missing data. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

Fig. 7: TN at Adams Point (PREP, 2017)

In November 2017, NHDES finalized its 2016 303(d) List based on an evaluation of the most recent TN data for the Great Bay Estuary and Upper Piscataqua River. It reported:

> The median total nitrogen from 2011 through 2015 was 337 ug/L (n=45) when considering only the stations in the middle of Great Bay; and 387 ug/L (n=149) when including the boundary stations GRBSQ and GRBAP. In neither case is there a statistically significant trend in total nitrogen over the 2003 to 2015 time period.

It should be noted that the TN and DIN levels were significantly higher during the pre-2005 period when eelgrass cover for Great Bay indicated non-impairment (see, *e.g.*, Fig. 6). Post-2006, the nutrient levels declined significantly, though eelgrass levels have remained reduced. Thus, there is no apparent general relationship between eelgrass acreage and TN loading/concentration for this system.[3] The final Section 303(d) list indicates that Great Bay and the Piscataqua River are no longer listed as impaired for TN. This assessment was made in consideration for the median TN concentrations observed over the five-year period as well as considerations for the response variables. The Great Bay Estuary 303(d) List Technical Support Document (TSD) explained that, concerning Great Bay:

> It is less clear, at this time, whether the response datasets demonstrate sufficient power to determine that the eutrophication effects on designated uses can be attributed to total nitrogen alone. Given that uncertainty, impairment is not warranted under New

[3] Latimer and Rego (2010) reported a potential threshold effect for eelgrass loss where area-wide loading rates increased above 50 kg TN/hectare/year and the complete loss of eelgrass at areal loads in excess of 100 kg TN/hectare/year based on an evaluation of 62 shallow New England estuarine embayments without major tributary inflow (as is the case for Great Bay Estuary). Comparable data for Great Bay show eelgrass cover rates equivalent to the lowest areal loading rates reported by Latimer and Rego while areal loads exceeded 150 kg TN/hectare/year. Thus it is apparent that the simplified loading model does not explain conditions in the Great Bay system.

> Hampshire's narrative standard. As such, this assessment zone has been assessed as Insufficient Information – Potentially Not Supporting (3-PNS) for total nitrogen.

Concerning the Upper Piscataqua River, the TSD similarly stated:

> However, there are insufficient response datasets to determine that the eutrophication by total nitrogen alone is not known to be strong enough to warrant impairment under New Hampshire's narrative standard. Additionally, the nutrient load to this assessment zone is rapidly decreasing due to ongoing work by the municipalities (Rochester reductions in 2014 and Dover began reductions in 2015). As such, this assessment zone has been assessed as Insufficient Information – Potentially Not Supporting (3-PNS) for total nitrogen.

The Section 303(d) TSD's TN discussion for the Lower Piscataqua River echoed that of the Upper Piscataqua River – insufficient data exist to attribute eelgrass declines to TN.

The Piscataqua River Estuaries Partnership (PREP) issued its 2018 State of Our Estuaries (SOOE) report in December 2017. This report also looked at nutrients from the perspective of loading to the Estuary and instream concentration. Over the period from 2012-2016, the TN load decreased by 26% (to 903.1 tons per year) in comparison with the TN loads for 2009-2011. This reduction in TN load was attributed to reduced rainfall (with a corresponding reduction in non-point source TN load) and significant reductions in TN loads from municipal WWTPs. TN concentrations show a statistically significant decreasing trend at Adams Point in Great Bay. PREP also reported the median low tide values for DIN at Adams Point ranged from 0.04-0.1 mg/L for the period from 2012-2015. These concentrations are comparable to median values for the years 1974-1981. In addition, DIN in the Upper Piscataqua River showed a statistically significant decreasing trend, with an average value of 0.04 mg/L. Concentrations less than 0.1 mg/L are rated as "good" (the highest rating) by the EPA National Coastal Assessment Condition Report.

The 2018 SOOE also concluded that TN impacts in the estuary are uncertain and more data are needed:

> [T]he Great Bay Estuary may have traits that *make it more tolerant of high nutrient levels* (such as high flushing rates) […]. (SOOE at 8; emphasis supplied)
>
> Eelgrass decline may relate to episodic stressors, such as storms, but it is equally plausible that chronic stressors, such as decreased water quality, may have limited the resilience of eelgrass to episodic disturbances. *More comprehensive data is needed to better understand the interactive effects of these stressors*. (at 9; emphasis supplied)

Also included in the 2018 SOOE Report was a collective statement from three external advisors (Dr. Jud Kenworthy, Dr. Ken Moore, and Dr. Chris Gobler) with expertise on eelgrass ecology. The advisors agreed that eelgrass in the estuary continues to exhibit signs of stress (based on the still reduced post-2006 eelgrass acreage), but the contribution of TN to this condition is not currently known:

> How much nitrogen reduction is enough or too much? *The data to answer this question do not currently exist*. (SOOE External Advisors at 239; emphasis supplied)
>
> Empirically derived evidence from experimental studies and monitoring programs indicate that eelgrass distribution and abundance in an estuary results from the complex interaction of several physical, biological and process based factors and no two estuaries or sub-embayments of an estuary are identical in all of these factors. To determine if one or more factors are the primary controlling factor it is necessary to either consider all the factors and their interactions or be able to definitively rule out factors as insignificant. The multivariate factors, the linkages between factors and the processes by which they can be evaluated that was identified in the Panel's report provide a basis for developing a comprehensive monitoring and modelling program that could be used to improve our understanding of which physical and biological variables in the system are having the greatest effect on eelgrass distribution and abundance. (SOOE External Advisors at 239-240)

Similar to the SOOE conclusions, the external advisers recommend additional data collection and modeling to determine which stressors are adversely affecting eelgrass dynamics in the estuary.

B. Changes in Phytoplankton Chlorophyll-a over Time

Cultural eutrophication in estuarine systems is frequently manifest as increases in phytoplankton chlorophyll-a concentration. Historical measurements of phytoplankton chlorophyll-a are illustrated in Figure 8 from data collected at Adams Point at low tide. These data show that median phytoplankton chlorophyll-a concentrations are low and relatively constant even though DIN and TN concentrations have increased and decreased by a factor of 2-3 over the period of record. This lack of response is primarily attributed to the short residence time and reduced system transparency caused by naturally-occurring CDOM and non-algal turbidity in the shallow estuary.

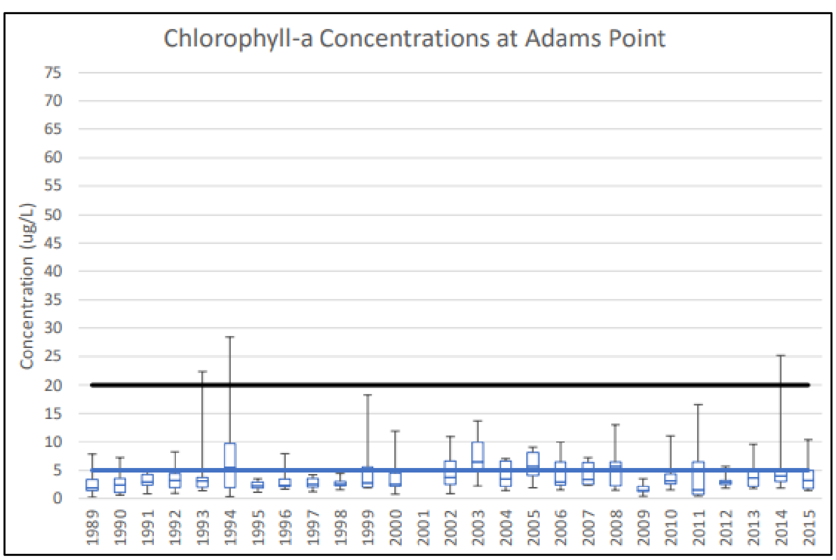


Fig. 8: Chlorophyll-a at Adams Point (PREP 2018 SOOE)

Due to ongoing concerns about cultural eutrophication, the Great Bay Municipal Coalition (GBMC) conducted a detailed evaluation of TN and chlorophyll-a responses in the Upper Piscataqua River for the periods before and after voluntary TN reductions in WWTP loads (Fig. 9). Based on the voluntary efforts of two major facilities (Rochester and Dover) TN loadings (reflecting primarily DIN) to this area were significantly reduced.

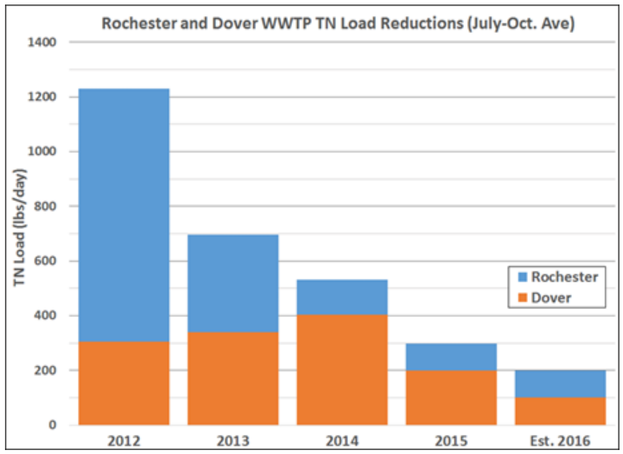


Fig. 9: Rochester and Dover TN Load Reductions (Rochester and Dover DMR Data)

The resulting instream TN and algal concentrations are reflected below (Fig. 10). While TN decreased significantly, no corresponding reduction in chlorophyll-a was detected in 2015 (Fig. 10). This mirrored the algal response in Great Bay, which was also not responsive to DIN concentration changes. DO concentrations in these waters were also demonstrated to be insensitive to the change in ambient TN and DIN levels (Hall et al., 2016). Over the next 5 years, TN and DIN will be further reduced due to nitrogen reductions being implemented by the Exeter, Newmarket, and Portsmouth facilities.

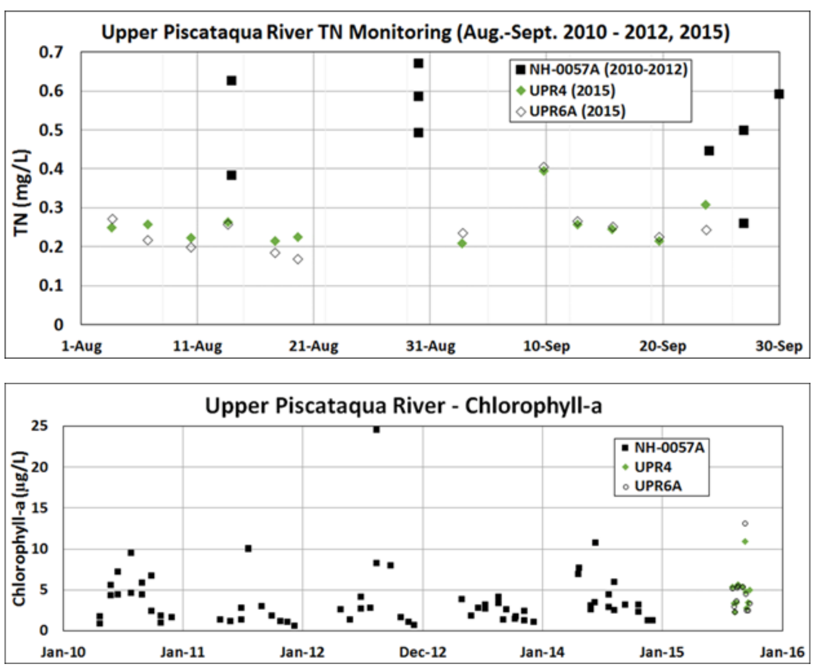
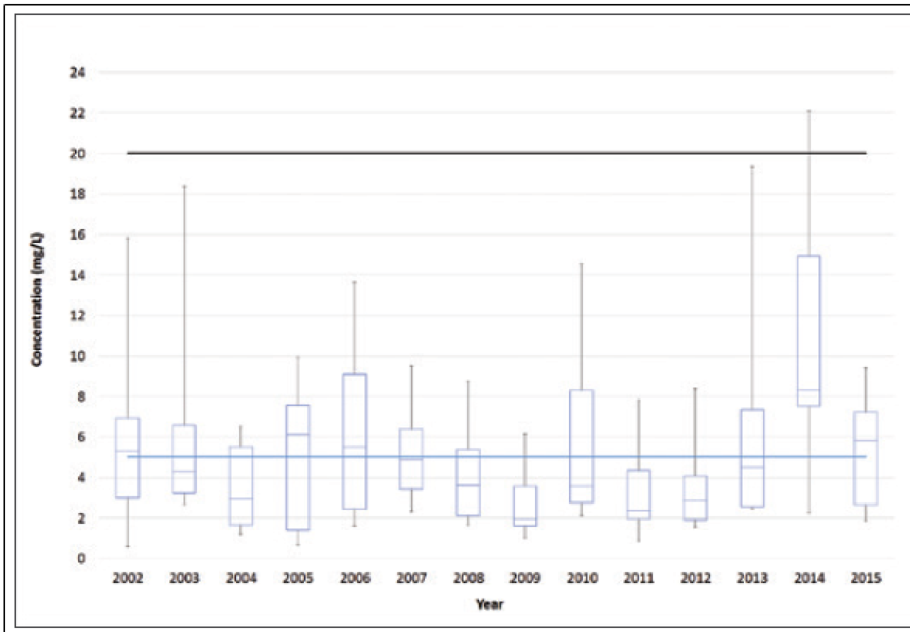


Fig. 10: Upper Piscataqua River TN and Chlorophyll-a Concentration (Hall et al., 2016)

The NHDES 2016 303(d) List evaluated the most recent chlorophyll-a data for Great Bay. This assessment calculated the 90th percentile concentration at 10.7 µg/L, which is slightly higher than the NHDES chlorophyll-a indicator threshold of 10 µg/L to avoid low dissolved oxygen conditions. Since low dissolved oxygen is not a concern in Great Bay and the 90th percentile concentration is close to the assessment threshold, chlorophyll-a was assessed as insufficient information to assess impairment status. As demonstrated by the range of data (under low tide "worst case" conditions) for a given year, "high" chlorophyll-a concentration (*i.e.*, >20 ug/L; Bricker et al., 1999) is a relatively rare event. Using a tidally averaged condition, it becomes an even rarer event. Under the NOAA assessment system this would be considered "good" water quality for an east coast estuarine system and among the best for mid-Atlantic systems (Chesapeake Bay, Delaware Bay, Long Island Sound).

The 2018 SOOE report looked at chlorophyll-a trends in the estuary over the period from 2003-2016 and reported no statistically significant trends at any of the eight stations in the estuary despite the significant reduction in available inorganic nitrogen. Over the most recent monitoring period (2012-2015), median low tide concentrations ranged from 2.9-4.0 µg/L at Adams Point and from 2.9-8.3 µg/L at the Great Bay station (Fig. 11). National assessments note that less than 5 µg/L is considered "good." The report further notes that dissolved oxygen levels, measured at the Great Bay station, are consistently above 5.0 mg/L and the most recent data collected in 2015 show that DO concentrations never fell below 6.0 mg/L.



Chlorophyll-a concentrations at Great Bay.

Fig. 11: Chlorophyll-a at Great Bay Station (PREP 2018 SOOE)

As discussed herein, given the lack of change in phytoplankton, before and after the 2006 eelgrass decline, a nutrient induced chlorophyll-a based transparency reduction is not demonstrated and therefore the typical conceptual model regarding nutrient induced eelgrass loss (via transparency) did not occur in this system. Moreover, UNH researchers (Morrison et al.,

2008) have confirmed that phytoplankton biomass is a minor contributor to the light extinction coefficient in this system. CDOM and non-algal particulates have a much greater effect on light extinction. Under these circumstances, chlorophyll a data do not indicate concerns regarding "cultural eutrophication" (Env-Wq 1703.14).

C. Changes in Epiphyte Cover over Time

As noted earlier, epiphytes are present in all surface waters and can be stimulated by a number of factors including lack of grazers or excess nutrients. Epiphyte cover is not addressed in either the 2016 303(d) List or in the 2018 SOOE report. However, the Consolidated Listing and Assessment Methodology (CALM) considers epiphytes as an indicator in an overall weight of evidence for cultural eutrophication. The CALM notes there are no set break points for how much epiphyte growth is acceptable and how much is unacceptable.

Routine monitoring for epiphyte cover is not conducted as part of the monitoring program in the estuary. Anecdotal information collected as part of the UNH eelgrass surveys indicate that epiphyte cover is not a significant concern in the estuary (NDHES and GBMC, 2011). This could be a function of the generally reduced transparency occurring throughout the system that would have epiphytes subject to lower light conditions throughout much of the tidal cycle. Moreover, epiphytic growth is dependent on water column DIN. During the 1990s when eelgrass growth was the most robust, higher DIN levels were prevalent. If epiphytic growth was adversely affecting eelgrass survival, one would presume it would have been manifested at that time. Presently, DIN levels are at their lowest since the 1970s. Thus, increased epiphyte stimulation would not be anticipated at this time. Further consideration of this factor as a cause for the observed eelgrass loss is not indicated at this time.

D. Changes in Macroalgae Occurrence over Time

Routine monitoring for the occurrence of macroalgae is a recent addition to the monitoring program in the estuary (See, Att. 4). Data show that macroalgal growth on the tidal mudflats is ephemeral, with robust late season growth one year followed by minimal growth in a subsequent year. Much of the data indicate that native and invasive species of macroalgae inhabit the littoral zone in areas not serving as eelgrass habitat. Those surveys are not designed to address whether or how macroalgae may impact eelgrass populations. Other data, collected as part of the SeagrassNet program, show that macroalgae and eelgrass can share habitat in a seasonal succession pattern with eelgrass growth occurring in the early part of the growing season and macroalgae cover increasing once the eelgrass have waned – particularly in the shallower waters where eelgrass survival and propagation is more tenuous (PREP, 2016). This "co-existence" has potentially existed in the system for decades, and aerial photography would have been unable to distinguish between macroalgal and eelgrass growth in these shallow waters (See, Att. 2). Since 2013, eelgrass surveys have been conducted with ground-truthing that includes diver inspections and underwater camera surveys to document macroalgae in subtidal areas (See, Att. 2, 2013 QAPP). These surveys have documented mats of macroalgae even below dense eelgrass beds. In this case, it appears that eelgrass and macroalgae apparently co-exist in such a way that it is possible for complete coverage by both plant types (PREP, 2016).

The NHDES 2016 303(d) List does not explicitly include evaluations of macroalgae for impairment listings. However, the CALM does address macroalgae as an indicator in an overall weight of evidence for cultural eutrophication. The CALM notes there are no set break points for how much macrophyte growth is acceptable and how much in unacceptable.

The 2018 SOOE report considered the available data for macroalgae and reported these data are limited and most ongoing research looks at intertidal areas. The dataset is not comprehensive in time and space, and more research is required to verify trends. Important steps to establish a baseline in the subtidal area have occurred, but more monitoring is necessary, as there are only a few data points in this area.

E. Changes in Eelgrass Cover over Time

The eelgrass cover data in Figure 4 show that eelgrass cover was relatively stable and meeting designated use area targets over the period from 1990 through 2005, when eelgrass cover generally ranged from 2000-2500 acres in Great Bay. A prolonged reduction in cover (to about 1500 acres) began in 2006 and has remained relatively constant through 2016. If the widespread wasting disease event culminating in 1989 is ignored, it is apparent that eelgrass cover has declined over the period from 1986 to 2016. This level of decline meets the definition of impairment in the 2016 303(d) List, which identified impairment as a decline in excess of 20% based on a linear regression of eelgrass cover versus year. It is noteworthy that a decline would not be considered an impairment for Clean Water Act purposes if it were the result of a natural event (*e.g.*, an extreme storm) and subsequent recovery was not prevented by a man-induced condition.

Figure 12 presents the eelgrass data eliminating years when eelgrass losses were attributed to wasting disease.

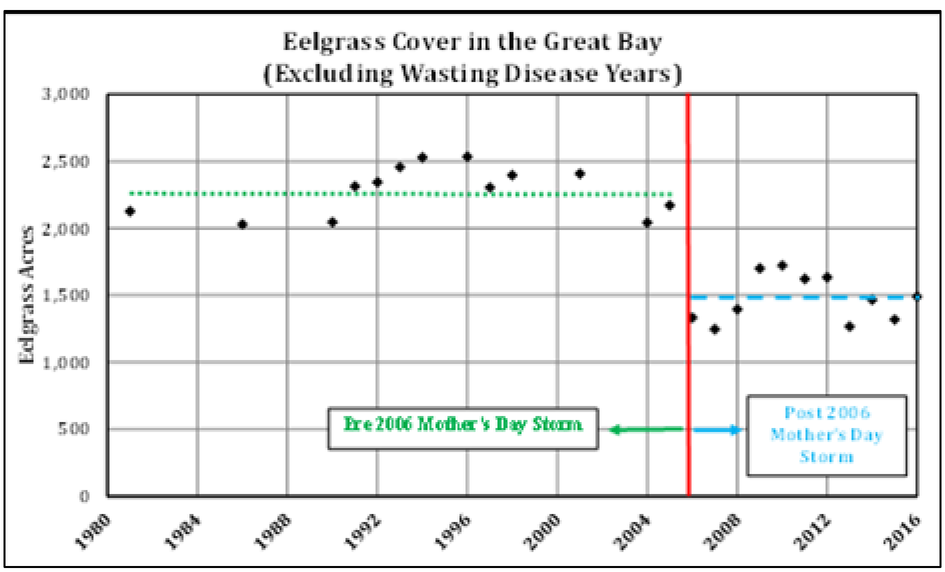


Fig. 12: Great Bay Annual Eelgrass Cover Excluding Wasting Disease Years (UNH GRANIT and Dr. F. Short)

The data indicate a bimodal condition with stable acres of cover from 1981-2005 and 2006-2016. Following 2006, eelgrass cover in Great Bay was significantly reduced. This change occurred rapidly over the course of one growing season (2006) and unlike prior major system losses due to wasting disease, eelgrass acreage has remained approximately 30% lower than observed prior to 2006. During the early 2006 growing season, there was a catastrophic flood that affected the entire region. As discussed in detail below, this historic flood widely known as the Mother's Day storm was a natural event and the apparent cause of the 2006 eelgrass decline.

As noted earlier, if cultural eutrophication did cause the observed 2006 loss of eelgrass, increases in TN load and concurrent increases in nuisance plant growth (phytoplankton, epiphytes, macroalgae) should have been documented – but were not. These cause-and-effect demonstrations are not observed in Great Bay Estuary either before or after 2006. As demonstrated in Figure 13, the 2006 pattern of eelgrass loss was higher near the tidal river entrances to Great Bay, where salinity reductions were most drastic (see subsequent discussion regarding salinity), and was also extensive in shallow habitats (Table 2) – indicating a non-nutrient factor was the significant trigger for the extensive losses.

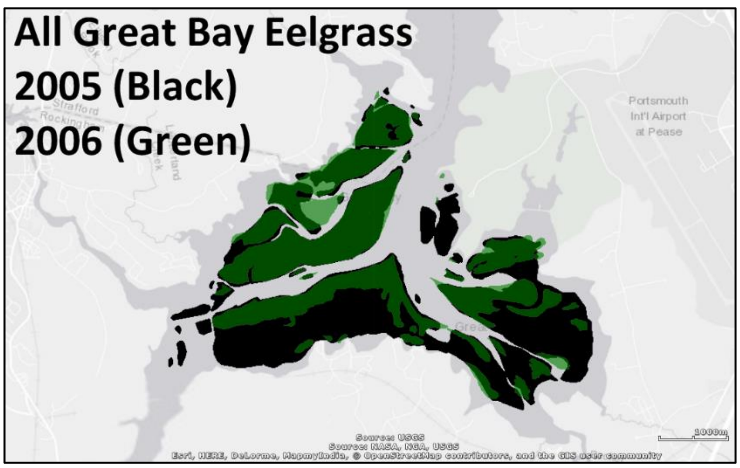


Fig. 13: Great Bay Eelgrass Cover, 2005 (Black) and 2006 (Green) (UNH GRANIT)

Table 2: Eelgrass Loss with Depth between 2005 and 2006

Depth below Mean Tide Level (meters)	Eelgrass Cover		
	2005 (acres)	2006 (acres)	Change (%)
<1.0	441	237	-46%
1.0 – 1.3	706	490	-31%
> 1.3	1,025	606	-41%

This initial loss coincides with record rainfall and flooding that occurred in May 2006 and subsequent major storm in mid-June. The historic "Mother's Day" storm passed through New England, with greatest intensity over coastal New Hampshire. At its most intense, areas of New Hampshire and surrounding states received up to 15 inches of rain over the course of a few days (Fig. 14). Three weeks later, another major storm hit the system – the first time in the existing eelgrass record when two extreme storm events occurred in succession during the critical early growing season for the eelgrass seedlings.

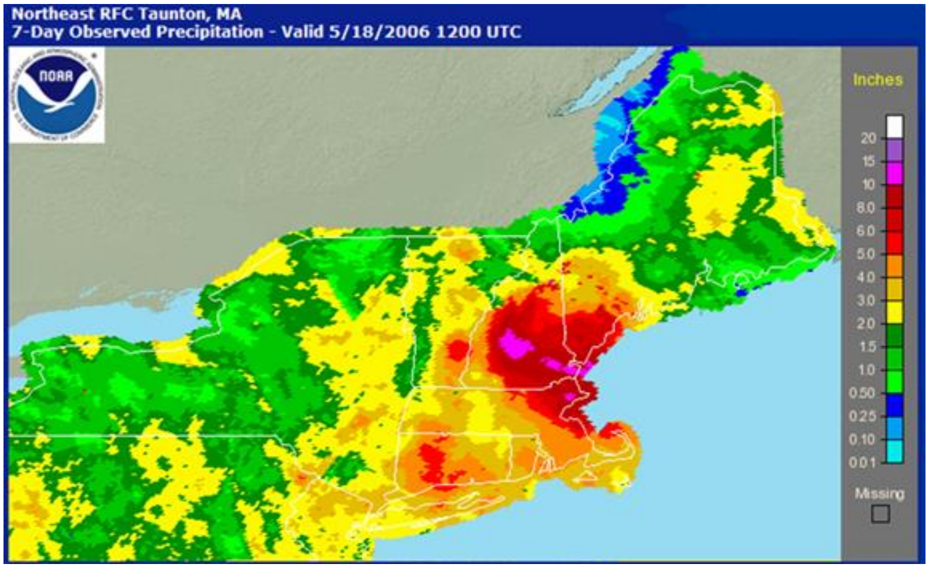


Fig. 14: Precipitation Totals Resulting from Mother's Day Storm (Olson, 2007)

This historic rainfall resulted in record tributary flows to the estuary. Figure 15 illustrates the effect of this storm on flows in the Lamprey River, which discharges directly to Great Bay and is the largest fresh water flow source to the estuary.

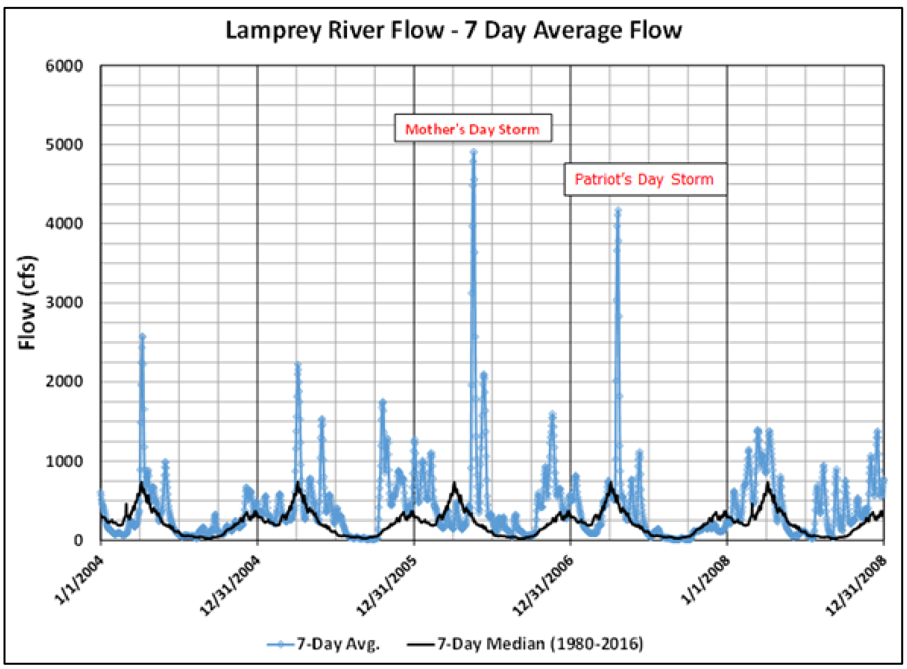


Fig. 15: Lamprey River 7-Day Average Discharge 2004-2009 (Blue) and 1980-2016 7-Day Median Discharge (Black) (USGS)

These elevated flows increased turbidity, CDOM, and sediment load while dramatically reducing salinity in central Great Bay for a 30-day period. All of these parameters have the documented potential to stress and kill eelgrass.

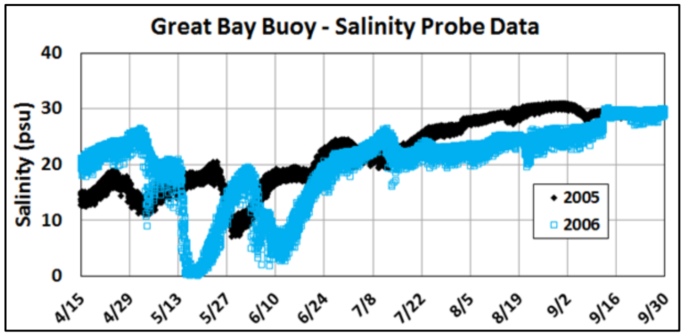


Fig. 16: Salinity at Great Bay Buoy Station (UNH)

Following the storms, the salinity in Great Bay decreased from typical seasonal concentrations (18.5 psu daily average; range: 21-13 psu) to five days with a maximum salinity <5 psu and eight days with average salinity <5 psu (Fig. 16). Overall salinity was reduced to an average of 10 psu for 30 days. Salinity near the tidal rivers where the major eelgrass losses occurred (Fig. 13) would have been significantly lower than the central Great Bay station. Dr. Chris Gobler, an eelgrass researcher and expert used by PREP, noted that the low salinities in 2006 alone may have caused the major eelgrass decline (Pers. comm. with PREP, 4/23/17).

The storm also contributed a tremendous amount of CDOM and suspended solids to the estuary. Measurements of the light attenuation coefficient show that transparency in Great Bay was significantly reduced over an extended three-month period of time. This reduced transparency would certainly exacerbate the stress on the eelgrass population at the time when sharp losses in cover occurred.

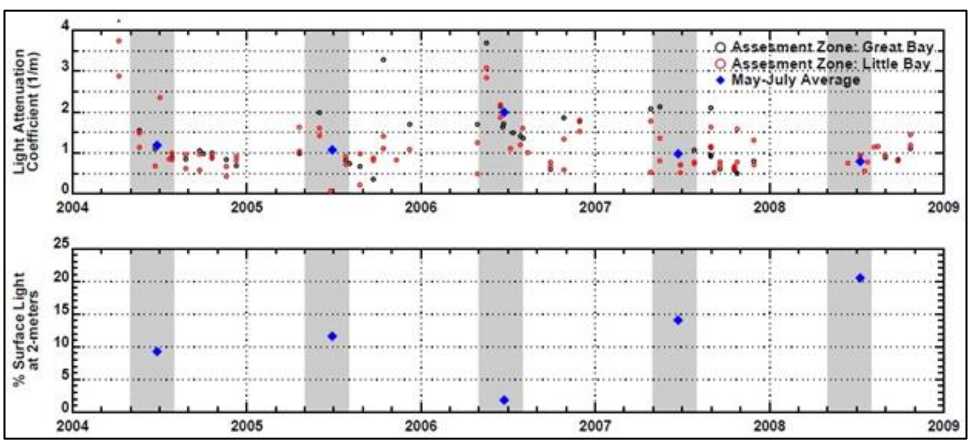


Fig. 17: Light Att. Coefficient and % Surface Light at 2 Meters (HDR|HydroQual 2013)

Figure 17 shows that water clarity in the estuary is very poor (May-July $K_d \approx 2$/m) and the 2016 303(d) List identifies Great Bay as impaired for this parameter. This impairment listing and the impairment threshold for this factor ($K_d > 0.75$/m) is based on an eelgrass habitat restoration depth of 2 meters, presuming that light attenuation below this level adversely affects eelgrass cover. As noted in the chart below, the 2006 eelgrass loss occurred at all depths, with decreases between 30-50%, including the shallowest regions, which does not support the nutrient-transparency-eelgrass loss conceptual model for this event.

Post-2006 Recovery Evaluation

A review of Great Bay eelgrass cover GIS data from year to year reveals spatial patterns in eelgrass occurrence that warrant consideration. Eelgrass cover in Great Bay fell to a minimum in 1989 due to wasting disease, when the measurable cover fell to 313 acres. Eelgrass cover rebounded sharply the following year, when eelgrass cover in Great Bay increased to 2,024 acres (Fig. 18). This increase of 1,700 acres illustrates the potential for eelgrass to recolonize an area. This recolonization is almost certainly due to re-seeding. Within four more years, eelgrass acreage in Great Bay exceeded 2,400 acres.

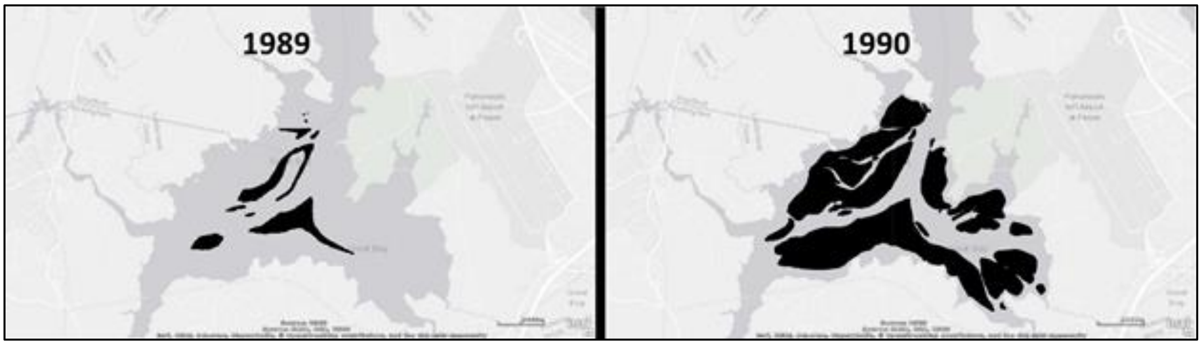


Fig. 18: Great Bay Eelgrass Cover, 1989 vs. 1990 (UNH GRANIT)

By comparison, following the 2005 growing season, eelgrass cover in Great Bay was reduced from 2,166 acres to 1,320 acres. Although eelgrass cover at this time was significantly greater than the cover in 1989, it has been unable to rebound beyond 1,725 acres for a period exceeding 10 years.

The spatial pattern also shows that, following 2006, eelgrass losses have been persistent in several areas that routinely supported measurable eelgrass cover in past years (Fig. 19).

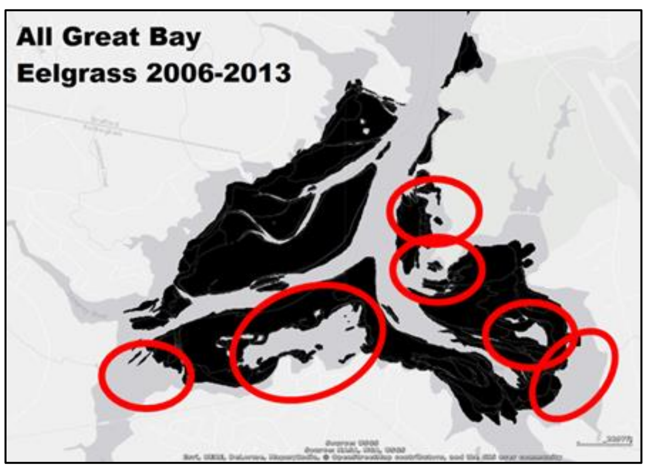


Fig. 19: Great Bay Eelgrass Cover 2006-2013; Red Circles Indicate Former Eelgrass Habitat (UNH GRANIT)

Eelgrass cover data from the subsequent eight-year period, 2006-13, show areas throughout Great Bay where measurable eelgrass cover no longer occurs. The red circles indicate sizeable regions where measurable eelgrass was mapped for at least one year between 1998-2005 but failed to reappear for any survey in the following eight years. More recent data (2014-16) show some of these areas are still filling in, though major areas remain apparently devoid of eelgrass.

Water quality is not expected to vary significantly between the eelgrass voids and the areas of measurable cover. Consequently, water quality is unlikely to explain why these voids persist. These maps suggest that the areas persistently devoid of measurable eelgrass, totaling over 200 acres, may no longer be suitable eelgrass habitat. This could also explain why re-seeding has been unable to establish measurable eelgrass cover in these areas.

The most recent eelgrass cover GIS data (2014 and 2015) are illustrated below (Fig. 20). This update shows that measurable eelgrass beds have returned to several of the eastern and southeastern areas that did not support measurable growth over the past eight years. However, the largest void along the southern shore, measuring approximately 150 acres, still does not support measurable eelgrass beds. This persistent spatial pattern over the last decade suggests a habitat issue that warrants additional research (*e.g.*, substrate quality and chemistry) to determine the cause.

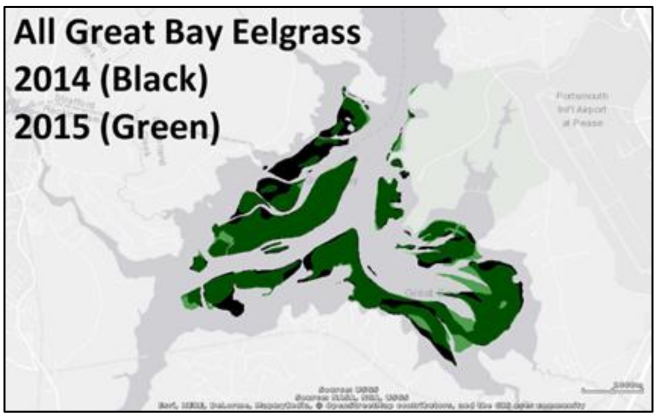


Fig. 20: Great Bay Eelgrass Cover, 2014 (Black) and 2015 (Green) (UNH GRANIT)

While the 2016 eelgrass cover GIS data are unavailable, a PREP report presenting the 2016 eelgrass cover map was published in 2017. The 2016 eelgrass survey was conducted by Kappa Mapping, not UNH (Dr. Short) as with previous surveys. The Kappa surveys used different equipment and similar but not identical quality assurance plans. The 2016 eelgrass cover map (Fig. 21) again illustrates the continued persistence of the ~150-acre void in southern Great Bay.

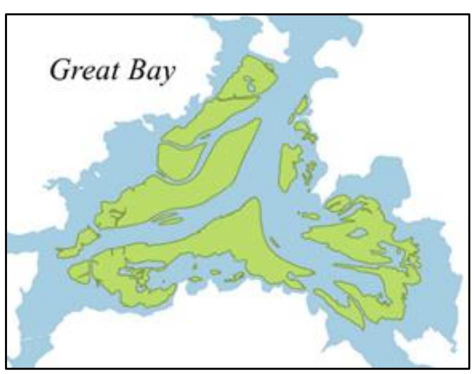


Fig. 21: 2016 Great Bay Eelgrass Cover (Barker, 2017)

Conclusions

The historical data for water quality and aquatic life use attainment in Great Bay Estuary show that this system is complex and does not respond in a manner consistent with other east coast estuaries. It is apparent that a series of natural events triggered the major decline in eelgrass population in 2006. The failure of the system to rebound, following the 2006 events is apparent, though the cause is unknown. While TN concentrations have decreased to historically low levels indicating good water quality for eelgrass propagation, eelgrass cover remains depressed. Nonetheless, the available data support certain technically defensible conclusions at this time:

- The 2006 major decline in eelgrass was not caused by a nutrient impairment, and nutrient conditions are significantly better than they were prior to the 2006 eelgrass decline.
- TN loads to the estuary have decreased substantially over the past several years to below levels when eelgrass historically thrived in the estuary.
- DIN concentrations are currently at historic low levels and reflect "good" water quality.
- Phytoplankton chlorophyll-a concentration has remained steady over 25 years – and reflects "good" water quality in Great Bay and the Piscataqua River.
- Growing season water clarity in the estuary is primarily controlled by CDOM and non-algal particulates, not nutrient induced phytoplankton growth.
- Eelgrass cover has remained relatively constant since the 2006 eelgrass losses, though slow recovery is indicated.
- Eelgrass and macroalgae appear to coexist in the subtidal zone, and the extent to which such competition impairs eelgrass growth or recovery is unknown.

Based on all of the available information for Great Bay Estuary, there is no scientific basis to establish a TN threshold for aquatic life impairment at this time. No documented statistical relationship exists between TN/DIN and chlorophyll-a, eelgrass, or macroalgae in the estuary. The DIN concentration is now lower than when eelgrass historically thrived in the 1990s. In addition, the TN concentrations in Great Bay are at levels local researchers have determined to be protective of aquatic life and supportive of eelgrass in proximate estuarine systems (<0.39 mg/L TN, Howes et al., 2003 at 20-21). The applicability of the cultural eutrophication conceptual model to conditions in Great Bay is, at this time, undemonstrated. Therefore, in accordance with the conclusions of 2016 303(d) list, there is no basis to impose restrictive TN limits on other municipal facilities in the watershed. System response to the planned load reductions should be evaluated before more TN reductions are included in NPDES permits.

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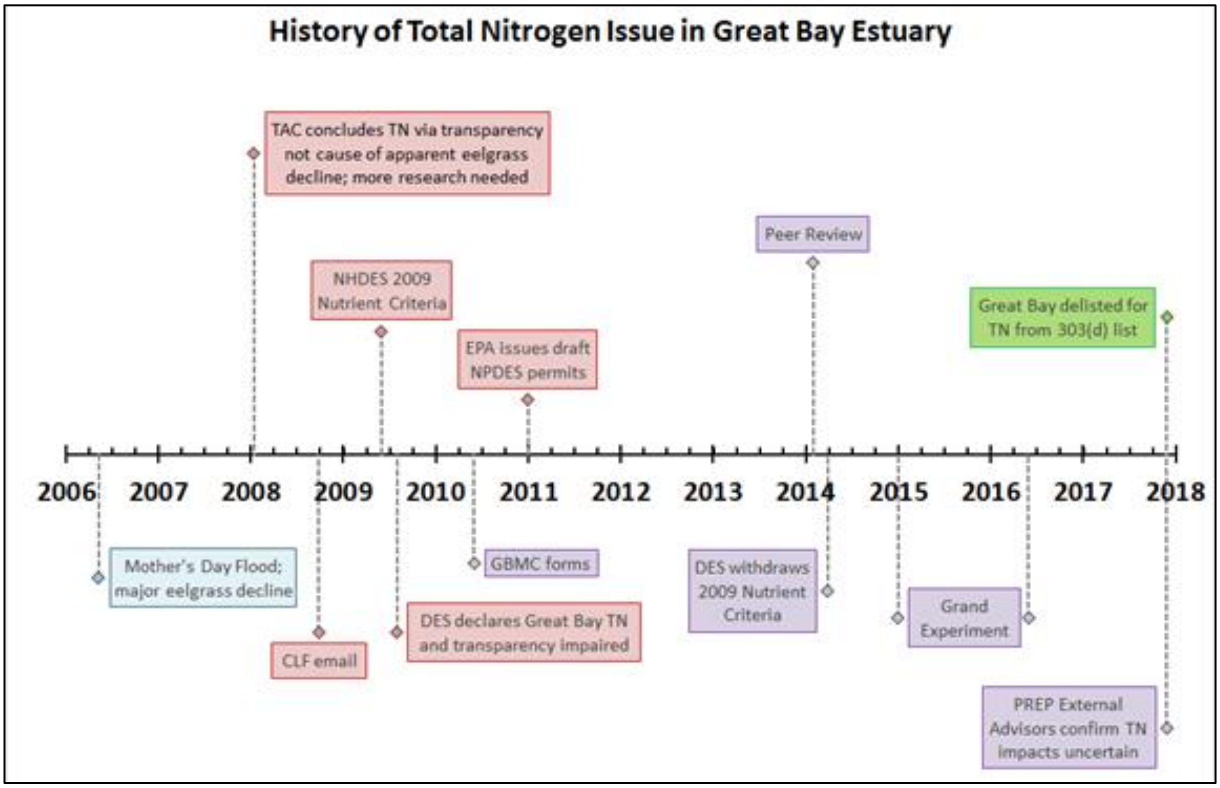
Attachment 1 –

Historical Regulatory Issues Timeline

The following provides a brief history of total nitrogen regulation in Great Bay Estuary (see Timeline).



Prior to the 2006, Great Bay Estuary was not considered impaired for eelgrass. Following the major eelgrass decline in 2006, regulators considered the system eelgrass-impaired. In June 2006, NHDES concluded that:

> any increase in nitrogen concentrations has apparently not resulted in increased phytoplankton blooms. The only increasing trend for chlorophyll-a was observed at a station with very low concentrations already.

In 2008, PREP's Technical Advisory Committee (TAC) again concluded that total nitrogen was not the apparent cause of eelgrass declines. However, regulators faced mounting pressure from environmental organizations to declare Great Bay total nitrogen impaired, including the threat of litigation from the Conservation Law Foundation (CLF). Soon thereafter, DES' focus in Great Bay shifted to total nitrogen and light attenuation impairments due to alleged nutrient-driven cultural eutrophication – contrary to the prior TAC conclusions. In 2009, DES published the 2009 *Numeric Nutrient Criteria for the Great Bay Estuary* document, deriving alleged impairment thresholds for TN to protect eelgrass in the estuary.

The Great Bay Municipal Coalition (GBMC), a group of cities with wastewater discharges in the Great Bay Estuary watershed, formed in 2010 to contest the 2009 Nutrient Criteria and resulting

NPDES TN permit limits. After years of debate, DES and the GBMC agreed to organize an independent peer review to review the scientific basis of the 2009 Nutrient Criteria. The peer reviewers concluded that the 2009 Nutrient Criteria were not scientifically defensible. As a result of the Peer Review conclusions, DES agreed to rescind the 2009 Nutrient Criteria in April 2014.

2013-14 Independent Peer Review of 2009 Nutrient Criteria

In an effort to settle the debate on whether or not TN was causing eelgrass declines in accordance with the conceptual model, NHDES and the Great Bay Municipal Coalition agreed to organize an independent expert peer review to assess available information and data for Great Bay Estuary and evaluate the scientific basis of DES' 2009 Nutrient Criteria document. The selected peer reviewer experts were:

- Victor J. Bierman, Jr., Ph.D., BCEEM (Senior Scientist, LimnoTech; estuary modeling expert),
- Robert J. Diaz, Ph.D. (Professor Emeritus, Virginia Institute of Marine Science, College of William and Mary; DO expert),
- Kenneth H. Reckhow, Ph.D. (Professor Emeritus, Nicholas School of the Environment, Duke University; statistics expert), and
- W. Judson Kenworthy, Ph.D. (eelgrass expert).

The peer reviewers concluded the following:

> DES 2009 Report did not adequately demonstrate that nitrogen is the primary factor in the Great Bay Estuary because it *did not explicitly consider any of the other important, confounding factors in developing relationships* between nitrogen and the presence/health of eelgrass. (Bierman at 18; emphasis supplied)
>
> There is *no basis for a scientifically defensible linkage* between nitrogen impairment and eelgrass impairment presented in the report. (Kenworthy at 19; emphasis supplied)
>
> The results in the 2009 report *are not acceptable or reliable* for setting nutrient criteria. (Reckhow at 38; emphasis supplied)
>
> […] the DES "weight of evidence" *does not support the conclusion that excess nitrogen was the primary factor* that caused the decline of eelgrass and the inability of eelgrass to repopulate specific areas. (Kenworthy at 46; emphasis supplied)

The consensus opinion was that the 2009 DES Nutrient Criteria were not scientifically defensible. Following the Peer Review, the State agreed that further application of the 2009 Numeric Criteria will not occur and the Coalition and DES would work collaboratively and fund additional research into eelgrass conditions in the estuary.

Municipalities Voluntarily Conduct Grand Experiment Due to Ongoing Concerns

Following the publication of the Peer Review, some stakeholders continued to assert that TN was the cause of eelgrass declines in this system. During the Peer Review, Dr. Reckhow suggested, given the voluntary nitrogen reductions being implemented by the Cities of Dover and Rochester:

> This is a great opportunity for a before-after assessment to observe the effects of TN load reductions. You could use the model to evaluate the before and after conditions. Then you could design a monitoring program to reflect those results.

The GBMC agreed with Dr. Reckhow's recommendation and purchased data sondes to deploy in the Upper Piscataqua River to observe the impacts, if any, of the Cities' TN reductions on eutrophication response variables in 2015. The monitoring data indicated no quantifiable environmental improvement in DO or algal growth despite the major TN load reductions and corresponding instream TN concentration reductions. Investigating the impacts at Adams Point reveals the TN concentration continued to decline while chlorophyll-a remained stable and low.

The Grand Experiment provided a valuable opportunity to directly test various hypotheses regarding TN impacts in the estuary. The results provided no evidence of algal response to major TN reductions in the estuary.

Attachment – 2

Eelgrass Cover Survey and Eelgrass Biomass Data Reliability Concerns

Evaluations of eelgrass in Great Bay Estuary are premised on the assumption that the eelgrass cover survey results, primarily conducted by Dr. Fred Short (UNH), are accurate and reliable as a basis for assessing inter-annual changes. However, concerns regarding this assumption have been raised by the Great Bay Municipal Coalition. The information presented below describes the methods used to measure eelgrass cover in Great Bay Estuary and the concerns with the reliability of these data for use in impairment determinations.

A. Eelgrass Cover Measurement Procedures

Routine monitoring for eelgrass cover in Great Bay Estuary by UNH researchers (Dr. Short) began in the 1980s, with continuous annual measurements from 1986 to present. Prior to 2002, Dr. Short mapped eelgrass in Great Bay Estuary based on aerial photos in a process described by Short and Burdick (1996) for estimating eelgrass cover in Waquoit Bay, MA. The method described in the Short and Burdick (1996) manuscript indicates that near-vertical aerial photography was taken with a hand-held 35 mm camera from a light plane flying at an elevation of 1,000 meters. Photography was obtained by Dr. Short as true color transparencies. Ground-truth assessments were made from a small boat during mid-to-low tide, monitoring the extent of eelgrass beds along the deep edges for 10-20% of the cover area. Images were analyzed on a computer to count the number of pixels in each sub-basin designated as eelgrass using IMAGE software.

In 2003, the New Hampshire Estuaries Project committed to support the annual monitoring program for eelgrass starting with aerial photography of eelgrass cover for the 2003 growing season and mapping of eelgrass cover data collected in 2002. The methods for the 2002 survey followed procedures specified in an approved QA Project Plan (Short and Trowbridge, 2003). The 2003 QAPP specifically notes that aerial photographs will be taken in late summer, usually late August or early September, depending on tides and weather, to reflect the maximum eelgrass annual biomass. These photographs will be converted into digitized maps and verified using ground truth data by placing the ground-truthing locations onto the digital image using ArcInfo software. Ground-truth surveys assessed 10-20% of the eelgrass beds to confirm the edge of the beds along the deep central channels.

Future mapping was conducted under revised QAPPs (2010, 2013). The 2010 QAPP is nearly identical to the 2003 Plan. The section on Ground-truthing was revised to note that 10 locations in the Estuary would be evaluated from a small boat to determine the eelgrass bed boundaries and to note the presence of macroalgae.

The 2013 QAPP (Trowbridge, 2013) contained significant changes in comparison with the earlier QAPPs. The aerial surveys will be completed by Kappa Mapping, Inc., using updated photography and GPS navigation support with images taken at 3,000 meters. Ground-truth surveys will be completed by PREP with data collected by divers and by drop camera, with 60 stations surveys. All stations will be assessed by drop camera, 20 stations will be assessed by divers, and the edge of the eelgrass bed will be assessed at 10 stations. The camera and diver assessments will document eelgrass and macroalgae cover.

B. Basis for Reliability Concerns

Measurements of eelgrass cover in Great Bay were based on aerial photography analyses primarily made by one UNH researcher. Assessments of eelgrass health in Great Bay are premised on the assumption that the eelgrass cover survey results are accurate and reliable. However, there are significant concerns regarding this assumption.

The surveys conducted prior to 2002 were not accompanied by survey reports discussing the survey results. Dr. Short acknowledged that prior to 2002, funding was limited and the aerial surveys were conducted without a QAPP and no technical reports were prepared. This failure violates federal law regarding data practices conducted by government agencies (40 CFR 130). Moreover, the original photographs or ground-truthing notes are unavailable for any of Dr. Short's annual eelgrass surveys and therefore cannot be reviewed for accuracy or reliability, contrary to the requirements of the CALM.

In addition, more recently the Army Corps of Engineers has concluded that aerial surveys alone cannot distinguish between different species of eelgrass and other forms of aquatic vegetation – including macroalgae:

> "It is not possible to reliably distinguish between eelgrass and macroalgae, or between different species of eelgrass or other seagrasses, using aerial imagery." (Army Corps of Engineers, 2016).

As such, the Great Bay Estuary eelgrass cover estimates likely include macroalgae which would artificially inflate eelgrass cover estimates to varying degrees in each year. This makes it impossible to confidently compare inter-annual variability in these eelgrass cover data.

C. Other Concerns with Inter-annual Cover Comparisons

The eelgrass cover estimates from aerial photography are intended to compare the maximum growth in each year as asserted in the 2003 QAPP. The fly-overs used to generate the aerial photos are typically conducted in late August or early September (Table A), but recent studies conducted by Dr. Short on quadrats within Great Bay, as part of the SeagrassNet program, show that the time of maximum eelgrass growth varies (Table B). Consequently, direct comparisons of the data presented in Figure 4 may yield erroneous results.

Table A: Date of Aerial Photography for Eelgrass Cover Estimates

Year	Aerial Photo	Year	Aerial Photo	Year	Aerial Photo
2002	Not identified	**2007**	August 30	**2012**	August 18
2003	August	**2008**	August 4	**2013***	August 23; November 9
2004	September	**2009**	August 23	**2014**	September 12
2005	August 22	**2010**	August 10	**2015**	August 15
2006	August 13	**2011**	September 1	**2016**	August 5

* The August 23 aerial photo was used by Dr. Short to evaluate eelgrass cover using the 2010 QAPP. The November 9 aerial photo was used by Kappa Mapping, Inc. To evaluate eelgrass cover using the 2013 QAPP.

Table B: SeagrassNet Eelgrass Percent Cover Measurements

Year	Late July	Mid-October	Change
2007	35.4	71.3	+101
2008	86.8	59.7	-31
2009	47.1	33.6	-29
2010	57.3	66.9	+17
2011	43.9	74.7	+70
2012	45.8	-	-
2013	48.5	-	-
2014	-	25.8	-
2015	26.8	40.6	+51
2016	35.6	44.9	+26

As indicated above, significant changes in eelgrass cover and density can occur between the time of fly-over and the time to maximum growth. Use of a single measurement to characterize eelgrass cover and the health of the estuary may not give an accurate picture of use attainment.

Attachment 3 –

Evaluation of Other Factors Potentially Influencing Great Bay Eelgrass Cover

Grazers - Geese

Another confirmed cause of eelgrass decline in Great Bay Estuary is grazing due to geese. Rivers and Short (2007) observed over the course of 3-4 months a flock of approximately 100 Canada geese completely consuming a 25-acre eelgrass bed in Portsmouth Harbor that had existed for decades.

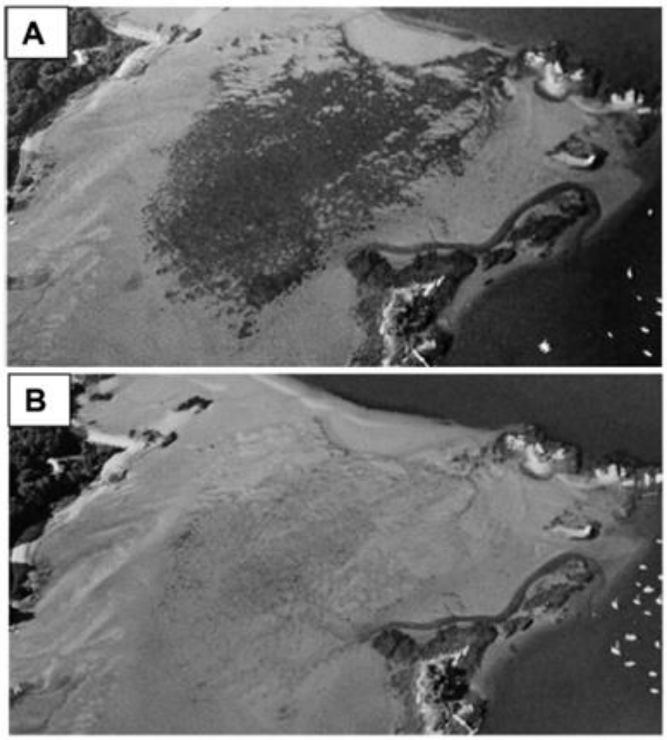


Fig. 3. *Zostera marina*. Aerial photographs of the Fishing Island eelgrass meadow, from (A) August 2001 and (B) August 2002. The dark area on the mud-flat is the eelgrass

It is hypothesized that the geese grazed on this eelgrass bed during the study but not previously on record because Great Bay and other areas of the estuary were frozen over, preventing geese from feeding in these areas. In the search for food, the geese were forced to graze in the non-frozen waters in Portsmouth Harbor. The researchers also noted that the eelgrass bed failed to show signs of recovery after three months. The lack of recovery was attributed to the feeding habits of Canada geese – they tend to eat the lower portions of the eelgrass plants, including the meristem, precluding individual eelgrass plants from producing new leaves necessary for healthy growth and propagation.

Sediment Burial

A 2017 study (Munkes et al., 2015) on sediment burial impacts on eelgrass concluded that burying eelgrass under 5-10 cm of sediment caused minor to moderate adverse impacts on eelgrass while a 20 cm burial caused severe adverse impacts and mortality (Figure below).

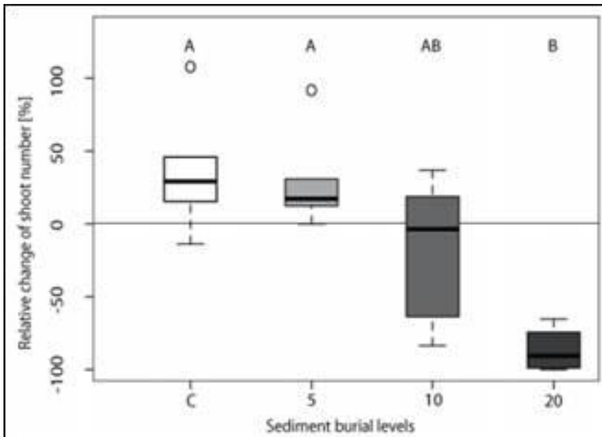


Fig. 2: Box plot of change of shoot number between start and end of experiment by sediment burial level (control, 5, 10, and 20 cm). Centre line: median, box limits: 1[st] to 3[rd] quartile, whiskers: range of values. Letters indicate significant results of pairwise Tukey-Kramer HSD *post-hoc* test.

Munkes et al. 2015

Attachment 4 –

Summary of Macroalgae Investigations in Great Bay

Increasingly, macroalgae has been the focus of researchers and regulators in the context of potential adverse impacts on eelgrass in the estuary. Low to moderate levels of macroalgae are ubiquitous in estuarine environments. High levels of macroalgae can smother eelgrass and block sunlight necessary for photosynthesis or outcompete eelgrass for habitat. Red and green macroalgae are classified as nuisance macroalgae while brown macroalgae are not. The majority of macroalgae discussion in the estuary has been anecdotal in nature with few full-fledged studies and surveys.

In 2011, Nettleton et al. studied the prevalence of and tissue nutrient content in macroalgal species occurring at five locations throughout Great Bay and northern Little Bay from 2008-2010. The study identified the presence of invasive macroalgal species and noted that macroalgal blooms peaked in November, well after the peak of annual eelgrass growth. The majority of the photographed sampling quadrats in the report appear to be at elevations at which eelgrass do cannot grow. Moreover, the study and subsequent photographs taken at the report’s sampling locations by D. Peschel (GBMC) reveal the ephemeral nature of macroalgae growth – sometimes a location is covered in macroalgae and in subsequent years the same location is devoid of macroalgae (Figures A and B). Accordingly, this study has very limited utility in evaluating potential adverse impacts of macroalgae on eelgrass or interannual trends in macroalgae in the estuary.

Figure A: Macroalgae at Lubberland Creek (Nov. 2008 (Nettleton et al., 2011) and Oct. 2012 (D. Peschel))

Dr. Fred Short has also noted macroalgae conditions as part of SeagrassNet eelgrass surveys. From 2007-present, Dr. Short has conducted quarterly eelgrass surveys, including photographic documentation, along three 50-m transects located roughly between the mouth of Squamscott River and Adams Point. In 2017, Dr. Short published a review of SeagrassNet survey photos in the estuary from 2007-2014. Dr. Short reported that seaweed along the transects significantly increased over time. However, in Dr. Short’s methodology, a qualitative level of eelgrass was recorded while only the presence or absence of seaweed was noted.

Figure B: Macroalgae at Depot Road (Summer 2009 (Nettleton et al., 2011) vs. Oct. 2012 (D. Peschel))

Most recently, Burdick et al. (2017) reported the results of the fourth year (2016) of annual macroalgae transect surveys in Great Bay Estuary, recording types of macroalgae, percent cover, biomass, and depth of sample. Burdick et al. identified several introduced, invasive species of macroalgae in Great Bay Estuary:

> Based upon this short-term data set we found significant cover and biomass of nuisance algae, some of these are recognized as *introduced, invasive* species. (at 2; emphasis supplied)

This is important that, under the Clean Water Act, NPDES permittees are not responsible for impairments due to invasive, nuisance species.

The conclusions of Burdick et al. acknowledge that, despite anecdotal reports of increasing macroalgae in the estuary, the macroalgal data for the estuary are insufficient to claim any statistical trend or determine the cause of any changes:

> Visual examination of our intertidal transect data along with anecdotal observations suggest that algal populations are changing, but *long-term collections will be needed* to determine whether significant differences in intertidal macroalgal populations are occurring over time. (at 2; emphasis supplied)
>
> The temporal trends in the red algae are interesting, but *we are unable to assign a cause or mechanism for these changes*. (at 10; emphasis supplied)
>
> From 2013 to 2016 *we have not observed dramatic increases in macroalgae* in the Estuary. (at 12; emphasis supplied)