**Wastewater Management Validation and Design Committee**
**G. S. Horne – Working Document**
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**Caveat: This document is not final or complete, and is not intended to be used for any purpose other than to facilitate further discussion.**

**Subject: Summary Chapter VII (Assessment of Embayment Nutrient Related Ecological Health)**

Massachusetts Estuaries Project: Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Final Report May 2006

**Key Issues:**

1. The codification of *Zostera marina* (eelgrass) as the sentinel species to evaluate the ecological health of Pleasant Bay.
2. The adequacy and significance of sample collection and analysis of benthic communities within Pleasant Bay by SMAST and MEP as an accurate assessment of the Bay's ecological health.
3. The relationship between nitrogen concentrations in Bay waters and the viability of Zostera.
4. The causal effect of nitrogen concentrations on dissolved oxygen and hypoxia of Bay waters.
5. The ecological impact of recreational boating and mooring density on turbidity and photosynthesis, and on biochemical oxygen demand in Pleasant Bay.

**Tasks to Be Undertaken to Address the Key Issues:**

**Task 1.** Conduct a critical review of pertinent literature on estuaries to evaluate the direct cause and effect relationship between nitrogen concentration, dissolved oxygen levels and benthic health in well mixed and circulated estuaries, particularly as they pertain to the situation in Pleasant Bay as presented in the SMAST-MEP report.

**Task 2.** Evaluate the relative significance of the various ecological parameters that are most critical to the viability and propagation of *Zostera marina.* In that context, conduct a critical analysis of the data, assumptions and conclusions related to Zostera in Pleasant Bay as presented in the SMAST-MEP report.

The purpose of conducting these tasks is to assure and reinforce the assumption that eelgrass distribution within Pleasant Bay is the best measure of the impact of nitrogen concentrations on ecological health.

**Expertise and Experience Required to Complete the Tasks:**

1. Coastal and estuarine marine ecology.
2. Familiarity with benthos/sediment dependencies and relationships.

## APPENDIX

**Commentary:**

Overview of Habitat Health

Chapter VII begins with the statement that estuarine ecologic health can be gauged by the assessment of nutrient, phytoplankton (chlorophyll), and oxygen concentrations, and by the distribution of benthic organisms. The MEP report utilizes three major indicators of ecologic health and habitat quality in Pleasant Bay ( p.151): bottom water dissolved oxygen and chlorophyll, eelgrass distribution, and micro-infaunal communities. It did not consider other sessile benthos, such as shellfish. Based on these assessments it has concluded that small enclosed basins, principally the drowned kettles in the northern part of Pleasant Bay, have seriously impaired ecological attributes and are degraded habitats due primarily to nitrogen overloading (p. 154, p. 182, p. 194).

MEP has employed eelgrass as a sentinel species for indicating nitrogen overloading to coastal embayments and habitat degradation. It also has asserted that the decrease in eelgrass distribution within embayments appears to be caused primarily by increases in nitrogen levels (p.182-193). The stated causal assumption is that since nitrogen is the limiting nutrient in marine systems, higher nitrogen levels promote higher populations of phytoplankton, which raise turbidity of the water column, which in turn shades the substrate and inhibits photosynthesis by benthic plants. The high phytoplankton population turnover results in hypoxic or anoxic bottom waters as a result of organic decay and biochemical oxygen depletion.

Many of these assumptions and assertions seem not to be supported by documented evidence and should be critically examined in detail.

Bottom Water Dissolved Oxygen

Recording sensors of dissolved oxygen (DO) and chlorophyll-a were deployed 30 cm above the substrate for about 30 days each at 20 stations scattered throughout Pleasant Bay between July and mid-September 2003; the data are displayed on p. 157-176. All stations showed high frequency diurnal variations in dissolved oxygen, presumably reflecting daily alternations in respiration-photosynthesis cycles. For the most part, the large basins within the system had fairly healthy levels of DO, generally above the Class SA Waters criterion of 6 mg/l.

Curiously, most stations in the northern portion of Pleasant Bay did not show any apparent correlation between DO and chlorophyll levels, as would have been expected. Moreover, several stations showed a semi-diurnal, perhaps tidal alternation in DO levels. Almost all of the stations showing seriously depleted levels of DO were in the northern sub-embayments or their tributaries. Yet these same stations also showed diurnal or semi-diurnal alternations with high DO levels in bottom water. How is the surface water that is oxygen enriched by phytoplankton photosynthesis displacing the oxygen depleted bottom water, or are these DO excursions reflecting tidal turnover of the enclosed sub-embayments?

Sediment Entrainment and Biochemical Oxygen Demand

Within the northern portion of Pleasant Bay only a single DO station was deployed in the deeper central portion of each sub-embayment, with a second station deployed outside the sub-embayment in the tributary leading to the Bay. These sub-embayments are the major mooring centers for recreational boating within the Bay. For example, in the summer of 2008 the following licensed moorings existed in Orleans sub-embayments: Meetinghouse Pond 172; Arey's Pond 94; Lonnie's Pond 37; Paw Wah Pond 29

The MEP report does not consider the impact of boating activity, although all of the data was collected during the peak of the boating season. Boating activity should have a significant impact on water quality, stirring up and entraining into suspension bottom sediment, which will result in an increase of organic matter and nutrients in the water column. This in turn will increase the biochemical oxygen demand (BOD) and biological activity of the water column resulting in DO depletion. How does boating activity (putting sediment into the water column) contribute to the daily oxygen excursion? What is the impact of boat mooring lines/chains and boat movements in and out of the embayments on dissolved oxygen levels[1]? Put another way, how much of the problem is boating and how much is due to controllable nitrogen loading?

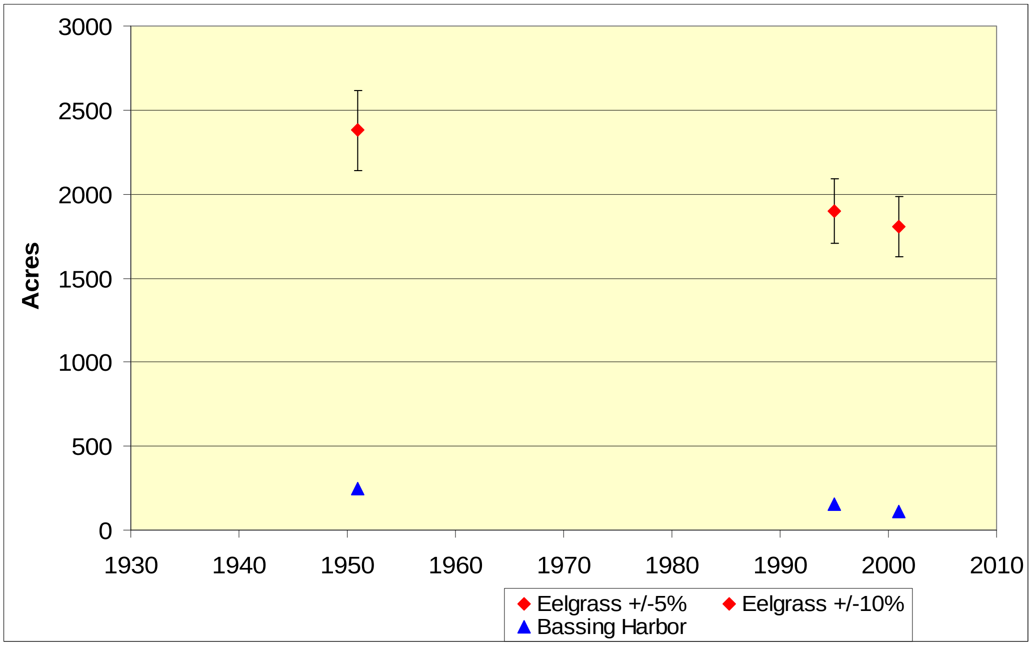
Historical Eelgrass Distribution

MEP compared aerial photographic evidence of eelgrass distribution in Pleasant Bay from 1951, 1995, and 2001. The 1995 and 2001 datasets were of comparable photographic quality: color imagery at a scale of 1:20,000 was taken during calm, cloudless, mid-late summer conditions in the early morning hours. The datasets were visually compared and subjectively interpreted in terms of benthic communities versus barren substrate[2]. Local field validation verified differences between eelgrass, macro-algae, mussel banks, and other areas of dark substrate.

The 1951 survey was not designed for subaqueous habitat analysis, and was of inferior quality and scale. It could only be anecdotally evaluated by memory. It was estimated that the eelgrass distribution in 1951 was about 2390 acres, or approximately 65% of the subaqueous area of Pleasant Bay. Notwithstanding these limitations, the MEP report states that the data are sufficient to determine both short-range and long-range rates of change in eelgrass distribution, and it was concluded that the loss in eelgrass distribution between 1951, 1995, and 2001 has been relatively constant at about 11 acres per year (p.188). The interpreted eelgrass distribution between the surveys of 1995 (1899 acres) and 2001 (1807 acres) was about 5%, not an unreasonable margin of error for subjective aerial photographic interpretation. This amounts to a net loss of subaqueous coverage from 51 to 48 % of the Bay, most of which occurred in the southern half of the Bay. Moreover, the unsubstantiated assertion is made that this loss occurred while nitrogen loading increased several fold within the northern portion of the Pleasant Bay watershed.

[1] Horne, G. S. and C. F. Horne, 2001, Reconnaissance hydrography of the upper reaches of Little Pleasant Bay, Orleans, MA: report to the Pleasant Bay Resource management Alliance.

[2] http://www.mass.gov/mgis/eelgrass.htm




**HISTORICAL EELGRASS DISTRIBUTION IN PLEASANT BAY**

In contrast with the eelgrass surveys by aerial photography throughout Pleasant Bay, the distribution of eelgrass in Bassing Harbor, a sub-embayment complex in southern Pleasant Bay, was surveyed in detail by direct observation from a small boat in 2000. Notwithstanding the contrast in survey methodology, this was compared with the earlier aerial surveys (1951 and 1995) to determine the stability of the eelgrass community. Disregarding the anecdotal data from 1951, from 1995 to 2000 there seems to have been a loss of about 40 acres (~25%) of eelgrass coverage. It is noteworthy that Bassing Harbor includes the largest and busiest boating centers and mooring fields in Pleasant Bay, and the impact of increased boating activity in the relatively shallow harbor was not considered. However, it is asserted that “It is almost certain that a primary cause of the observed eelgrass decline results from increasing water column nitrogen levels …” (p.193), without any supporting evidence.

Two paramount questions loom as a result of this historical analysis:

1- Disregarding the inaccurate and potentially spurious dataset from 1951, the 1995 and 2001 surveys required sufficient water clarity for early morning photography to accurately image the bottom of Pleasant Bay in order to reliably discriminate visually between barren and inhabited substrates. The obvious rhetorical question then remains: how can it be claimed that the decline in eelgrass distribution is a result of shading the substratum by the increased turbidity of enriched phytoplankton populations in surface waters due to nitrogen loading?
2- If the distribution of eelgrass has significantly declined in recent years, what ecological attributes might also affect eelgrass viability in addition to nutrient enrichment?

Eelgrass Ecology

Much of the following is based on a study in 1990 by Dr. Frederick T. Short of the Jackson Estuarine Laboratory at the University of New Hampshire, one of the world's foremost authorities on eelgrass ecology[3]. A major blight in 1931 devastated ninety percent of the eelgrass population along the eastern seaboard of North America, including Pleasant Bay. He reported that eelgrass in Pleasant Bay did not recover until the 1960s (more than ten years after the 1951 survey), and that eelgrass distribution had been relatively stable since the 1970s. This chronology of blight and bust, recovery and stability has occurred over a 60 year period during which there have been dramatic changes in Nauset Spit. Dr. Short indicted that in 1990 eelgrass in Pleasant Bay was infected with *Labyrinthula zosterae*, the infectious organism that is the cause of the wasting disease that resulted in the 1931 blight and die-off of eelgrass. His studies show that wasting disease was affecting eelgrass populations from Nova Scotia to North Carolina, including much of the Massachusetts coastline. Although all of the eelgrass samples he collected from Pleasant Bay were infected with wasting disease, he stated:

> " one of the greatest areas of infection was found on the west side of Strong Island, where the eelgrass is the largest and most abundantly growing population seen in Pleasant Bay, and where the water is clear . Yet the vigorously growing Strong Island eelgrass bed showed a high index of infection." (underlines added)

This is in the area where the eelgrass distribution had declined between 1995 and 2001.

Sessile benthos (non-moving bottom dwelling organisms) are strongly dependent on their habitat and substrate conditions, and most require substrate stability. Like many other densely populated benthic communities, eelgrass exerts a strong modifying influence on the substrate by baffling circulation and trapping sediment, and it has adapted its ecologic strategy to those modifications. However, all benthic communities are highly susceptible to sudden and extreme changes in erosion-sedimentation processes and the resultant change in substrate conditions. Unfortunately, the MEP analysis has ignored this basic ecologic tenet in its consideration of historic changes in eelgrass distribution. Virtually no consideration has been given to the dynamic changes that have developed along the barrier beaches of the Nauset Spit system (variously referred to as Nauset Spit, Nauset Beach, and North Beach) between 1930 and 1988[4] and subsequent years, and how these changes may have affected the hydrodynamics and the nature of the substrate within the southern portion of Pleasant Bay. The SMAST-MEP report states (p. 86):

> "Nauset Beach has migrated west as a result of episodic overwash events in a process referred to as barrier beach rollover. The "Halloween Storm" of 1991 was an example of this rollover process, where the barrier beach was steepened and **large volumes of sand were deposited into Pleasant Bay**" (bold added)

Following the 2007 breach of Nauset Beach opposite Allen Point in Chatham more than fifty acres of eelgrass were buried by the newly formed flood tidal delta inside the new inlet, and more eelgrass is still being buried further to the north by migrating sand shoals. The resulting increase in circulation within Pleasant Bay has increased the mobility of the

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[3] Short, F. T., 1990, Eelgrass in Pleasant Bay; health status report: report to the Friends of Pleasant Bay: 8p.

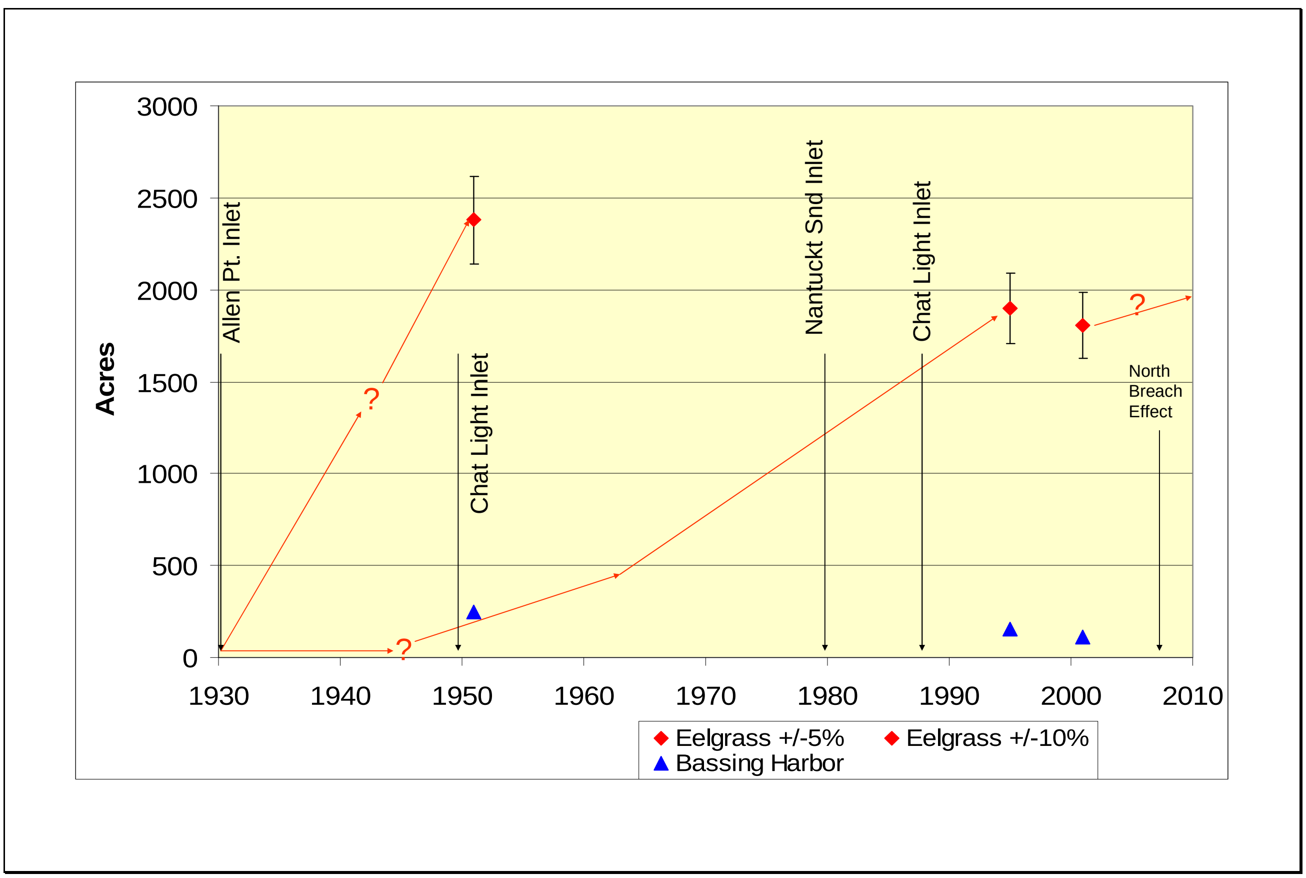
[4] Geise, G. S., 1988, Cyclical behavior of the tidal inlet at Nauset Beach, Massachusetts: in Aubrey, D, and L. Weishar, eds., Symposium on hydrodynamics and sediment dynamics of tidal inlets, Springer-Verlag, NY, p. 269-283.

sandy substrate, thus inhibiting the establishment of new eelgrass coverage. Presumably a similar situation followed the breach opposite the Chatham lighthouse in1987.

For example,, a survey of benthic environments in intertidal and immediate subtidal portions of Pleasant Bay in 2000-2001[5] found the following:

1- With the formation of New Inlet (1987) and increase in tidal energy, large sections of Pleasant Bay have been mobilized into active bedforms and sand shoals which are now highly mobile on a daily basis.
2- Most of the newly-mobilized substrate is flood dominated, indicating an influx of new sediment along with renewed in-filling and shoaling of even the deepest parts of the Bay.
3- The eastern portion of the Bay, directly to the west behind the barrier of Nauset Beach has been mobilized into a flood-tidal sand "conveyor belt", moving large volumes of sediment through New Inlet and up to the north and west into the interior of the Bay.
4- Aerial photographic evidence indicates large areas of eelgrass have been buried by encroaching sand between Barley Neck and Sampson Island, to the east of Strong Island, and to the northwest of Strong Island shoaling into the deeper portion of Pleasant Bay.

These areas coincide with theareas that presumably suffered some of the major loss of eelgrass coverage between 1951 and 2001 (see Fig. VII-44, p. 185).




**HISTORICAL POSITION OF THE CHATHAM INLET**

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5 Capella Consulting Group – Marine Environmental Science & Engineering, Woods Hole, MA, 2000-2001: Progress Reports 1, 2, & 3 to the Pleasant Bay Alliance Technical Advisory Committee

Finally, little attention has been given to the potential impact on eelgrass by the mechanics of shellfish harvesting within Pleasant Bay. This includes the widespread use of bull rakes to harvest hard shell clams, rake/chain dredges to harvest bay scallops, hydraulic dredges to harvest razor clams, or even hand rakes and shovels to harvest soft shell claims. These activities clearly would damage eelgrass rhizomes and inhibit propagation. The magnitude of these activities will be documented subsequently.

<u>Benthic Infauna</u>

Substrate sediment samples were collected at 34 stations scattered throughout Pleasant Bay for benthic infaunal analysis in the MEP study (p. 193-195). The date of sampling and the volume and depth of the samples were not stated, and the occurrence and distribution of species were not provided. Analysis of evenness and diversity of the interstitial micro-fauna community was conducted as a measure of benthic health. Samples from the deep centers of several of the enclosed sub-embayments in the northern portion of Pleasant Bay were found to have depleted communities dominated by opportunistic species tolerant of environmental stress. These were the same areas with dense mooring fields and reduced DO levels in bottom waters. No effort was made to evaluate the benthic health of the shallower margins of these sub-embayments. Moreover, no consideration was given to the relative health of shell fish and other macro-benthos in Pleasant Bay.

<u>Shell Fish Harvests</u>

The abundance of shell fish from Pleasant Bay has been a primary food resource for cultures on Cape Cod for thousands of years. It seems obvious that there could be no better measure of ecologic health in the Bay than an historical look at shell fish harvests. However, as shell fishing methodologies have improved and become more efficient in recent decades, overfishing potential has stressed various shell fish populations resulting in alternating population booms and busts. The Pleasant Bay Resource Management Alliance has compiled records on shell fish harvests in Pleasant Bay since the 1970s[6], and the following account is from their summary.

<u>Razor Clams</u>: Commercial fishing for razor clams commenced in the latter part of the $20^{th}$ Century. Peak harvests of about 475,000 lbs. occurred in 1996 and 675,000 lbs. in 2004. Field surveys in 2007 indicated a large census of razor clam larvae in the Bay.

<u>Quahogs</u>: The hard shell clam harvest in Pleasant Bay in 1975 was about 11,000 bushels, and harvests have declined progressively since then to a base harvest of about 1,000 bushels/yr. Various theories advanced to explain this decline include:

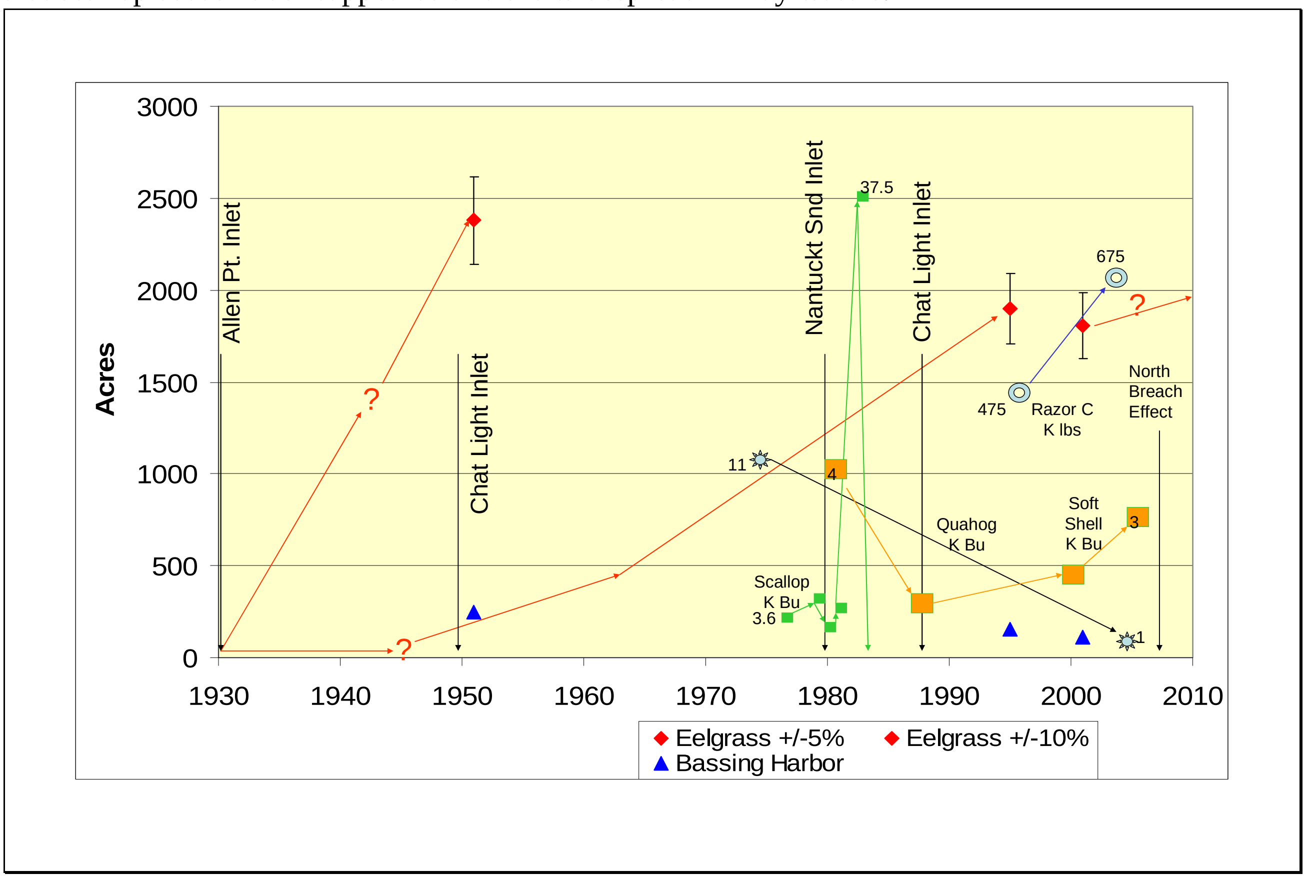
1-increase in Bay water salinity following the 1987 breach of Nauset Spit;
2-harvesting of smaller clams resulting in a population crash;
3-increased efficiency of harvesting by bull raking and overfishing.

<u>Soft Shell Clams</u>: Soft shell clam harvests have been quite variable over the past several decades. Peaks occurred in 1981 at over 4000 bushels, in 1987 at 1500 bushels, in 1997

[6] Ridley & Associates, 2008, Pleasant Bay Resource Management Plan 2008 Update, 74 p.

at 1800 bushels, and most recently in 2005 at over 3000 bushels. Recent surveys indicate large amounts of larvae in the Bay.

Bay Scallops: Bay scallop harvests oscillated through the latter part of the 20th Century with an all time peak harvest in 1983 of over 70,000 bushels. Since then bay scallops have virtually disappeared from the Bay, perhaps the consequence of that boom harvest. But the bay scallop population crash was also widespread throughout southeastern Massachusetts. Juvenile bay scallops attach to eelgrass blades while they mature, leading to the speculation that the die off was related to eelgrass stress. However, the boom harvest in 1983 was before the 1987 breach of Nauset Spit when nitrogen levels in Pleasant Bay were 45-50% higher than after the breach (p. 222). Recent reports indicate that scallop seeds have reappeared and are widespread in Bay waters.




**HISTORICAL SHELLFISH BOOM HARVESTS**

## Reviewer Questions

**Re: Dissolved Oxygen:**

p. 151, para.3 states:

"Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate being nitrogen loading)."

> What is the relationship between nitrogen in the water column and "depleted oxygen concentrations"?
>
> Chemically and biologically, how does nitrogen cause reduced oxygen concentrations?
>
> Can oxygen depletion occur in coastal embayments in the absence of excess nitrogen?

What role does the capacity of suspended and substrate sediment to absorb oxygen have on the water column?

p. 153, para. 1 states:
"Nitrogen enrichment of embayment water generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion."

How does the chemistry and biology work to affect a reduction in oxygen?

p. 154, para. 1 states:
"The general pattern is for the high level of oxygen stress (frequent hypoxia or anoxia) in the bottom waters of small enclosed basins (groupA) which tend to have higher nitrogen levels and high rates of sediment metabolism…."

How does the nitrogen concentration compare with sediment metabolism; can the latter dominate, even in the presence of elevated concentrations of nitrogen?

p. 154, para. 2 states:
"Salt marsh creeks (that do not empty at low tide) frequently become hypoxic in summer as a result of the high organic matter loading associated with marshes."

Is this independent of nitrogen loading, and could not this same effect be attributed to the small enclosed basins (group A)?

p. 157, Fig. VII-3, and p. 167, Fig. VII-23, Meetinghouse Pond:

What is the cause of the large changes in DO between mid-August and late August; and between early September and later in September?

Chlorophyll-a does not show a similar variation over the same periods. Why?

p. 159, Fig, VII-8, and p. 169, Fig. VII-28, Arey's Pond:

Fig VII-8 shows large daily oxygen excursions starting from 11 July to end July; however, the Chlorophyll-a levels drop significantly from levels prior to 11 July. What is happening?

Would you not expect the oxygen excursions to accompany high Chlorophyll-a levels?

p. 159, Fig. VII-7, and p. 169, Fig. VII-27, Pochet:

Similar observation as for Areys above except DO excursions seem to change little over the 1 August to 20 September period whereas Chlorophyll-a spikes in mid-August and is relatively flat at just less than 5 µg/l before and after the mid-August period. What is happening?

**Re: Eelgrass:**

p. 151, para. 3:
Eelgrass mapping has been used to indicate the health of the greater Pleasant Bay system. Between the first unvalidated measurements in 1951 and the second in 1995, 44 years elapsed with no measurements of eelgrass area or density. The same is true of observations in Bassing Harbor.

How can one conclude that the apparent decline is due only to increases in nitrogen when there is no available data on nitrogen concentrations during this time period? What about the possible effects of disease and or other biotic interactions?

In 1983 Pleasant Bay had a boom harvest of more than 70,000 bushels of scallops which are dependent on eelgrass. Would not this indicate that the eelgrass community was healthy in 1983?

p. 182, ¶ 2 states:

"However, it is clear from the 1951, 1995 and 2001 temporal sequence that the eelgrass areas in each basin, except Chatham Harbor, are declining in coverage. In The River and Pochet the eelgrass areas were always patchy and in the shallows. By the 2001 survey this pattern continues, but the beds appear to be declining, although they persist."

Is it clear? On what objective basis?

Do the 1951 photographs provide sufficient resolution to support this conclusion? Or to support the comment specifically regarding the Pochet and The River eelgrass habitats.

Paragraph 1, p188 dismisses the idea that other factors may have impacted the eelgrass over 50 years and states: "It is not possible at this time to determine the potential effect of shell fishing on eelgrass bed distribution."

p. 188, ¶ 6 states:

"It is possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, although there are only 3 surveys. Over the 50 year period1951-2001 the Pleasant Bay System has lost ~583 acres of eelgrass habitat. Interestingly, the rate of loss has been relatively constant at ~11 acres per year. This loss has occurred as watershed nitrogen loading rates gradually increased several fold due to changes in land use within the Pleasant Bay watershed."

Considering :

1. the inferior quality and scale of the photographs utilized to estimate eelgrass habitat area in 1951;
2. an unknown margin of error on all three estimates (1951, 1995 and 2001);
3. the report does not consider the impact of shellfishing activity or natural phenomenon such as disease and hydrology; how is it possible to conclude that eelgrass habitat has decreased "at a relatively constant" 11 acres per year?

On what data is the statement "nitrogen loading rates gradually increased several fold" based? How much is known about the nitrogen loading (natural and human-made) in 1951?

In fact, the report states that eelgrass is present in all of the areas where it was in 1951. For The River and Pochet, the two areas suspected to have suffered decline in the 50 year period, the report acknowledges that the "eelgrass areas were always patchy" and in the following sentence states that " the beds appear to be declining". The report does not provide objective evidence for this conclusion; nor does the report give meaningful consideration to the possibility that other factors may have played a part in any changes in the eelgrass coverage.

Where can one find absolute and definitive evidence bearing on the relationship between dissolved nitrogen concentrations in estuaries and eelgrass viability? Does such exist?