Restoring Eelgrass to the Neponset Watershed
Part II: The Biological Basis
Salt Marsh Restoration

Project Goals

The main goal of this study is to restore water quality, ecosystem health, and ecosystem function to the Neponset watershed. Like many coastal systems the Neponset is threatened by several drivers including: the effects of climate change, habitat loss and alteration, loss of biodiversity, point source pollution and increased anthropogenic nutrients, among several others (Neponset.org). These drivers often have cascading and/or interacting effects making restoration of ecosystem health a difficult task.

To address some of these issues that are affecting ecosystem health in the Neponset River, the reestablishment of native shellfish populations has been proposed. In laboratory studies oysters have been shown to be important biological filters, decreasing water column turbidity and nutrient levels thus enhancing benthic primary production(Newell et al. 2002). In the case of eelgrass restoration of both of these factors is important. Reduced sediment loads allow higher light concentrations and thus higher photosynthesis while reduced nutrient loads limit phytoplankton growth again allowing higher light concentrations. However, studies show that the efficiency with which oysters remove excess nutrients from the water column may differ based on local conditions. Models suggest that oyster filtration efficiencies are greatest around 5-25 g/m^3 of suspended solids and drop significantly both above and below these threshold limits (Cerco and Noel 2007)(Fig. 1) thus limiting the benefit of restoring these benthic filter feeders.

It is often suggested in the scientific literature that several different strategies be implemented simultaneously to restore ecosystem health and function (example see:(Scavia et al. 2002)). After all there are many drivers that degrade ecosystem function in Neponset, so shouldn't there also be many solutions? This may be particularly true in the case of the Neponset if shellfish reestablishment is to be part of the solution.

The case for going beyond shellfish

Research suggests that oysters have an optimal range of turbidity at which filtration rates are highest (Cerco and Noel 2007). Data from the Neponset estuary (defined as sites with average salinity>5ppt) show that turbidity rates within the estuary often exceed these optimal levels (Fig 2 and Fig 3). Note: The data presented in Figure 2 are in NTUs, nephelometric turbidity units, and have not been translated to suspended solids in g/m^3 (TSS) because the correlation between these units is site specific. Data regarding the correlation between TSS and NTU are not currently available for the Neponset estuary, however data are available from the nearby Boston Harbor, and show TSS to be approximately 2.5*NTU (Dragos and Fitzpatrick 2009). From here on data will be discussed in TSS as translated using this correlation.

The average TSS within the Neponset estuary ranges from 15.5-26.7 g/m^3 (Table 1). Two sites, site 54 and 42, have averages for TSS above 25g/m^3, the maximum for optimal oyster filtering according to Cerco and Noel (2007). Of the 2,703 observations of TSS within the Neponset estuary 726 exceed the 25 g/m^3 maximum, or ~27% of the readings. This analysis shows that, if restored some sites will have more productive oysters than others, but also that on average oysters will only filter sediments and nutrients effectively ~1/4 of the time. It is clear that other restoration efforts that will improve water clarity will have synergistic effects with oyster restoration therefore making our efforts more fruitful.

Marshes- Vegetative filter feeders

Marshes are highly productive ecosystems that are rich in marine life. These areas provide refuge and nursery grounds for many important commercial fisheries and are extremely rich in marine life. Marshes also act as barriers between the land and the sea, buffering shorelines from storm surges and erosion while filtering sediments and nutrients from riverine runoff before entering the coastal ocean. The filtering function of salt marshes makes them a prime candidate for reducing sediment loading to the Neponset estuary. This will directly help to restore eelgrass by reducing sediment and nutrient load, as well as indirectly eelgrass growth by enhancing oyster filtration rates.

The filtering of sediments by marshes occurs through the process of sedimentation where sediment particles suspended by tidal fluxes settle on the marsh surface. Much of this settlement is due to vegetation along the marsh that works to slow tidal flow allowing sediment particles to fall out of suspension. However, a study in Delaware suggests that sedimentation can also be a product of settling due to trapping by marsh vegetation and that suspension does not have to be primarily due to tidal flux, but is highly influenced by the occurrence of storms (Stumpf 1983). Sedimentation is a historic process, and evidence of sedimentation can be seen as far back as 7,000 years (Bloom 1964). Sedimentation has allowed salt marshes to keep pace with sea level rise and is thus a powerful mechanism for filtering of suspended sediments.

Current sedimentation rates are unknown for the Neponset estuary. Since sedimentation is driven by many factors such as flow rate, sediment type and particle size, bathymetry, bottom type, vegetation, storm frequency and severity among others, it is not easy to extrapolate from rates in nearby sites. It is certain however, that increased vegetation along the shoreline will enhance sedimentation thus reducing TSS in the system.

In addition to increases in sedimentation due to salt marsh restoration, nutrient retention is also likely to increase. An early review of marsh system dynamics and nutrient retention potential concluded that artificial wetlands created for the retention of nutrients from point source locations were often poorly designed and therefore generally ineffective (Howard-Williams 1985). However, wetlands that were created along natural waterways to retain diffuse nutrient inputs, as would be the case for marshes along the Neponset, were in general much more effective and in many cases, the only feasible option. The author suggests that "stripping plants" are in general more effective at nutrient removal than wetland systems, however if ecosystem health and function are goals of this project than restoration of natural vegetation would move us closer to achieving all three goals.

A more recent review examined the evidence from 57 different wetland studies to determine if wetlands were indeed effective at retaining nutrients (Fisher and Acreman 2004). In 80% of the studies there was significant retention of nitrogen and in 84% of the studies there was a significant retention of phosphorus (Table 2). This study was done over both marshes and riparian wetlands, and when broken into these subgroups it appeared that marshes were slightly less effective at nutrient retention than riparian wetlands, but unlike their freshwater counterparts marshes did not increase nutrient loads. In terms of the Neponset, increased nutrient retention would likely decrease the phytoplankton population within the estuary. This would reduce shading to the bottom sediments, which would help to restore the light limited eelgrass population.

Why more marshes?

Aside from the reduction in sediment and nutrient loads that marsh restoration would provide, this would also return the Neponset to a more "natural state." Reductions in marsh cover along the Neponset are a historic trend and the extent of this reduction can be seen in Figure 4 and Figure 5. Marsh loss in this region has been mostly due to land fill for commercial development and the expansion of infrastructure for transportation (Carlisle et al. 2005).

Measurements of marsh loss are not available for the Neponset watershed itself; however, loss throughout the Boston Harbor is well documented. Between 1893 and 1952, the total marsh area in Boston harbor was reduced from 21.5 km^2 to 11.4 km^2. That is a loss of almost half of the marsh area in less than 60 years. The rate of loss was accelerated over the next several years, and by 1971 another 3.2 km^2 was lost. Between 1971 and 1995 the rate of loss declined and only 0.15 km^2 were lost during this time period. As of 1995 total marsh area in Boston Harbor to just 8.1 km^2; just 38% of the marsh land that was present in 1893 is still there today (Carlisle et al. 2005). Though these same numbers are not available for the Neponset estuary Figure 4 and Figure 5 tell much the same story; marsh extent within the Neponset has been greatly reduced in the past century and this reduction has surely had profound impacts on the functioning of this ecosystem.

How much marsh will we need?

It is impossible to say how much marsh will be needed to return the Neponset estuary to its "natural" state, but we can compare nutrient loads within the estuary to nutrient retention rates in other estuaries. Table 3 shows the average nutrient loads to the Neponset estuary at station 140, the mouth of the estuary, between 1994 and 2011, as determined through MWRA water quality tests (http://www.mwra.state.ma.us/harbor/html/wq_data.htm#data). These loads have been translated into yearly volumes by multiplying by high and low estimated flow rates through the estuary.

These yearly rates can be compared to nutrient retention rates on other marshes. A study on Bly Creek in North Carolina calculated nutrient retention rates over a 532 km^2 area of marsh (Dame et al. 1991)(Table 4). On first glance this table clearly shows that the area of marsh that is submerged versus exposed is of huge importance. In general, exposed marsh seems to be a net source of nutrients whereas submerged vegetation is a net sink of nutrients. This will be an important consideration in marsh restoration plans in the Neponset. If we combine the submerged and exposed marsh measurements and correct for a marsh area of 1km^2 we can then compare these numbers to our estimates of nutrient flow through the Neponset estuary. The Bly Creek imported 39.5 kg/km^2 of particulate carbon, 1.1 kg/km^2 of particulate nitrogen, 2.6 kg/km^2 of ammonium, 0.6 kg/km^2 of nitrate+nitrite, 1.6 kg/km^2 of particulate phosphorus, 0.4 kg/km^2 of phosphate, and 2.2 kg/km^2 of total phosphorus while exported 33.3 kg/km^2 of dissolved organic carbon, and 9.0 kg/km^2 of dissolved organic nitrogen.

If 1 km^2 of marsh in the Neponset estuary were to absorb approximately the same volume of nutrients as the marsh in Bly Creek then we would need 1.4 km^2 to absorb all the particulate carbon, 1.9 km^2 to take absorb all of the particulate nitrogen, 11.6 km^2 to absorb all of the ammonium , 62.8 km^2 to absorb all of the nitrate+nitrite, 1.3 km^2 to absorb all of the particulate phosphorus, 21.4 km^2 to absorb all of the phosphate, and 6.1 km^2 to absorb the total phosphorus under high flow conditions. While these numbers are highly variable this analysis shows that between 1-60 km^2 of marsh are needed to handle the current nutrient fluxes.

A review by Fisher and Acreman (2002) provides a different perspective. This review suggests that as the nutrient load on a set area of land increases the efficiency of nutrient absorption, that is the percent of total nutrient load absorbed, goes down. Following the regression lines presented in this review the marsh along the Neponset estuary is absorbing ~40-50% of the nitrogen coming into the systems and ~70% of the phosphorous. According to this model a 100-fold increase in marsh size would allow the marsh to absorb closer to 60-70% of the nitrogen coming into the system, but would have negligible effects on the amount of phosphorus absorbed.

Restoration of marshes

Marsh restoration is not always straight forward, however we can look to the literature for examples what has and has not worked in the past in order to guide our marsh restoration along the Neponset estuary. A general review of marsh restoration suggests that some of the most important factors influencing marsh restoration include position and landscape context, as well as hydrologic regime (Zedler 2000). This means that when we choose a site for marsh restoration we should be careful that this is an appropriate site where a marsh can flourish and that alterations to water flow will work to enhance marsh restoration. Furthermore, Zedler (2000) warns that management goals should reflect the idea that different attributes develop at different paces, and that nutrient supply will affect the recovery of biodiversity. Furthermore, this review points out that disturbance can work to enhance biodiversity within recovering systems and the use of transplants and lack of dispersal and in fact limit increases in biodiversity.

Case studies in marsh restoration often show positive results. Restoration of an impounded marsh in New England showed quite drastic responses in local vegetation. Once tidal flow was restored marsh vegetation was able to reclaim the majority of the marsh area and the amount of open space was not only reduced, but broken into smaller segments (Sinicrope et al. 1990). Another study conducted along six different segments of a restored salt marsh in Long Island Sound suggested that restoration of several ecosystem functions was possible over this long term study (Warren et al. 2002). The authors did note however, that some sections of the marsh recovered more quickly than others and, as mentioned by Zedler (2000), indicators of restoration tend to respond on different time scales.

However, some marsh managers are not so positive regarding the outcome of restoration efforts. A study in the Sweetwater Marsh in San Francisco Bay returned rather negative results when changes in soil chemistry did not match restoration trajectories (Zedler and Callaway 1999). The authors further regarded this restoration attempt as a failure due to the inability to restore the endangered Light-footed Clapper Rail. These may not have been the most appropriate goals to test if marsh restoration was indeed a success, however, and other indicators may tell a different story. The lack of success of de-embankment of marshes in Europe may also be due to the indicators used to measure restoration. In this review marshes were monitored for restoration of native target species and may were considered to have underperformed as the percent cover was often less than that of undisturbed marshes (Wolters et al. 2005). If examined under a different light these projects could however be seen as a success as de-embankment has encouraged the restoration of native plants, albeit not the threshold specified.

The issue of establishing goals in salt marsh restoration is clear. Goals need to be informative, but also attainable. Goals will not only guide a project, but also be the criterion on which that project is evaluated. Without clear goals it is difficult to refine and adjust future actions. In addition, management plans need a conceptual model around which they may create plans to implement their goals. A conceptual model will allow informed decisions about how to obtain goals and will help in implementation. Finally a decision framework is an essential part of every management plan. This framework will allow managers to incorporate new information as a system responds to management plans and aid them in adjusting their actions based on these responses (Thom 2000).

Restoration of the Neponset marsh

In terms of the Neponset estuary, marsh restoration is feasible. In fact, two restoration plans have already been implemented. Both of these plans have used dredging techniques as much of the coastal area in Boston was filled in the 1800's to increase available land area. In 2005, 0.06km^2 of salt marsh was restored to the Neponset estuary (http://www.neponset.org/Restoration-SaltMarsh.htm). This small project supposedly took 5 years of planning, but was relatively successful. In response, another, slightly larger project was under taken in 2011 where 0.2km^2 of salt marsh was restored at the Broad Meadows site in Quincy. This project cost $5.4 million, but in addition to restoring marsh area was further intended to restore native salt marsh species, add tidal pools to the area, reduce the mosquito population and reduce fire hazard (2011).

Moving forward with future restoration projects the real issue will be space. The Neponset estuary is a highly developed and urbanized system and much of the area surrounding the estuary is covered with impervious surface (Figure 6) (2004). To find existing lands that are suitable for marsh restoration will be a challenge in this highly developed environment. For this reason, much of the emphasis for future restoration projects will likely be on dredging. This is not necessarily ideal however, as increased changes to hydrology throughout the Neponset will affect already existing ecosystems.

Conclusions

Restoration of ecosystem function in a degraded system is often a difficult task. Just as many drivers often lead to this degradation, many drivers may lead to restoring the system. In the Neponset estuary oysters have been proposed as a means to increase water clarity and quality in an attempt to restore eelgrass populations. While oysters are excellent natural filters, the addition of restored salt marsh will help aid this cause by increasing water clarity and quality while additionally stimulating higher filtration rates in oysters.

Like oysters, marshes are a natural filter for both sediments and are often proposed as a means to restore water quality in degraded systems. While marsh restoration is sometimes seen as "unsuccessful" this is highly depended on the goals to the marsh restoration. A good restoration project will have attainable goals, a conceptual model in which to build the plan and a decision framework to help guide future decisions.

Restoration of marshes in the Neponset will require all three of these elements as well as space in which to create said marshes. Small restoration projects have already been undertaken, yet they take a good deal of time and are relatively expensive. As restoration efforts have already been made in this area it is likely that future plans are both feasible and likely to find support within the community. In addition to restoring oysters, restoring salt marsh will aid us in restoring eelgrass to the Neponset estuary.

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Appendix

Figure 1. Effect of suspended solid on oyster filtration rate. From Cerco and Noel (2007).

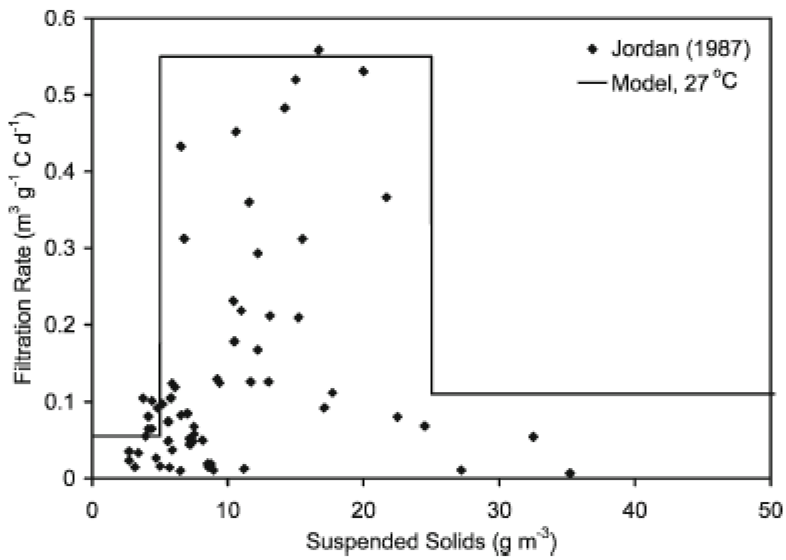


Fig. 1. Observed and modeled effect of suspended solids concentration on filtration rate.

Figure 2. Map of nutrient sampling location along the Neponset estuary.

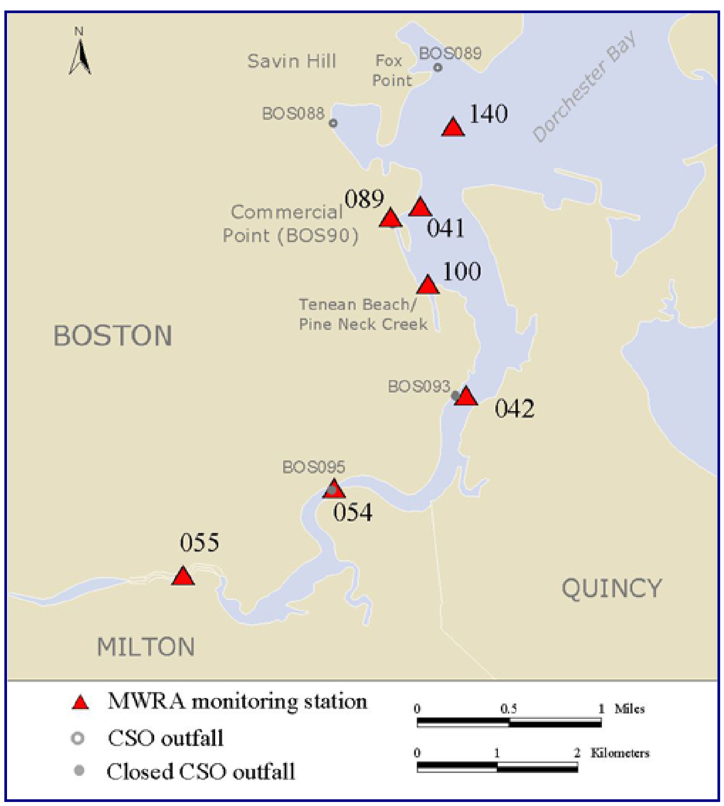
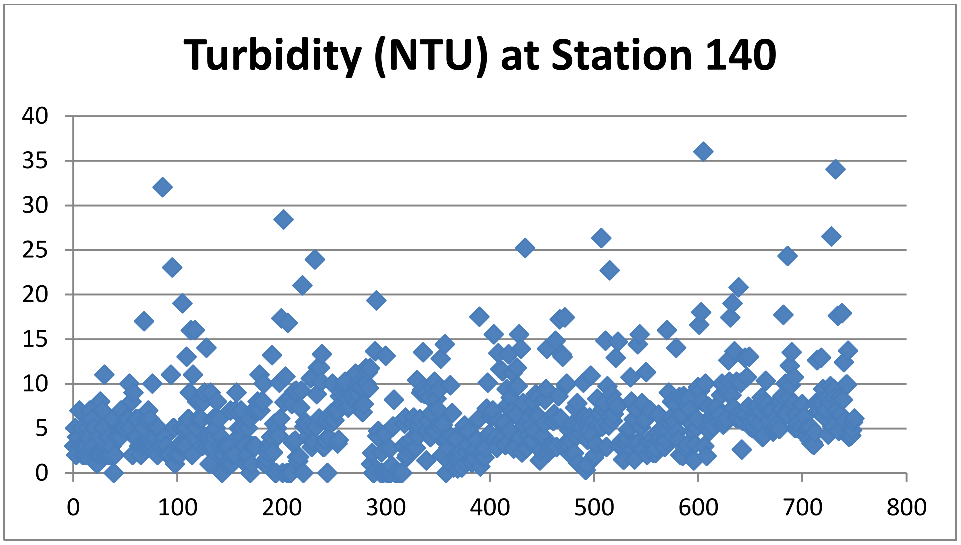
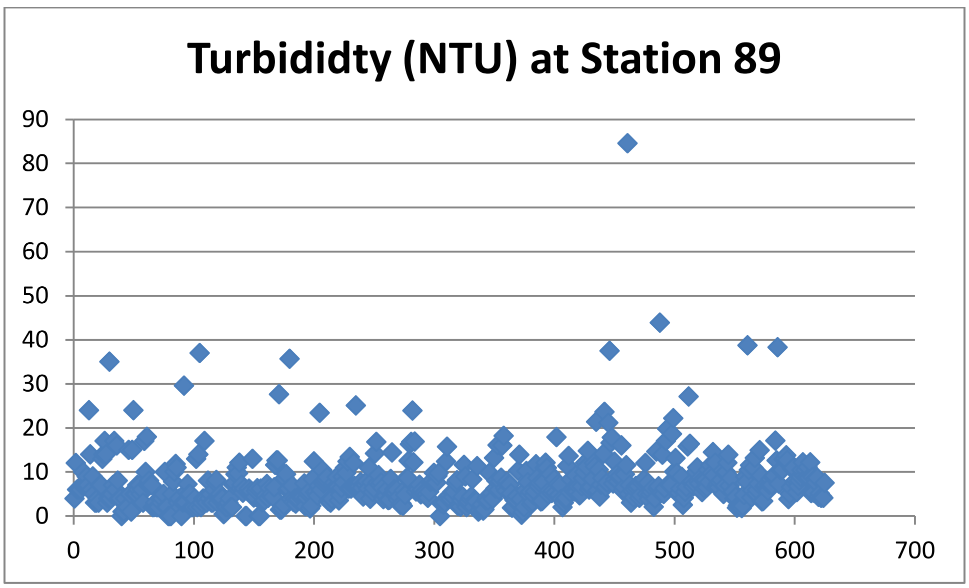
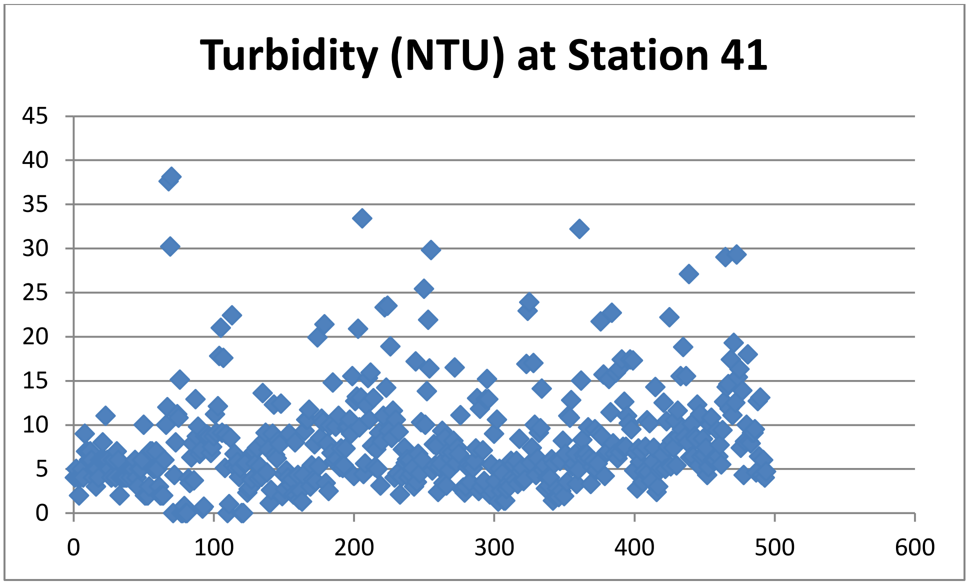
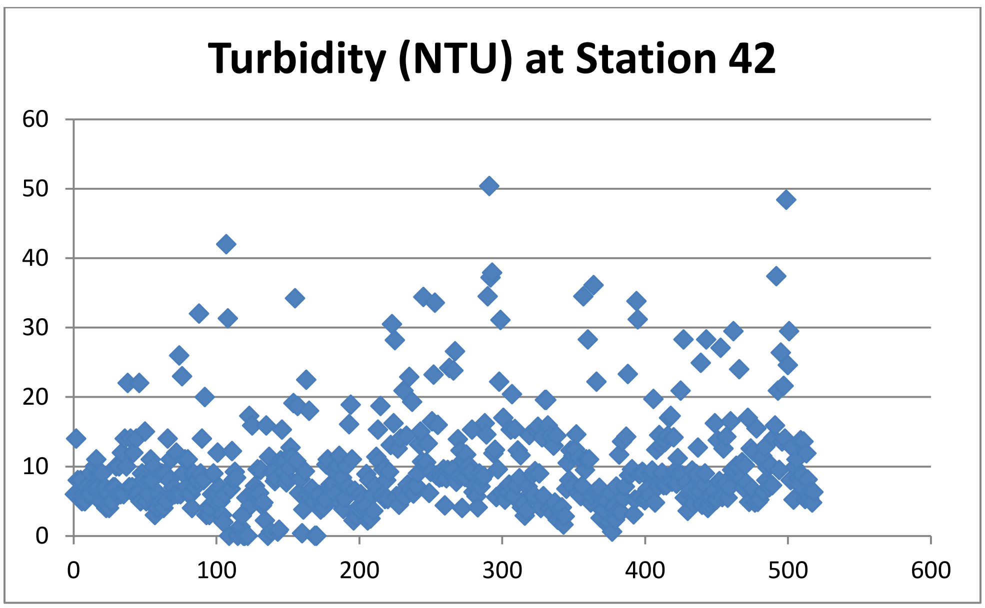


Figure 3. Turbidity at selected nutrient sampling locations along the Neponset estuary over time.






Turbidity (NTU) at Station 41
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600


Turbidity (NTU) at Station 42
60
50
40
30
20
10
0
0
100
200
300
400
500
600

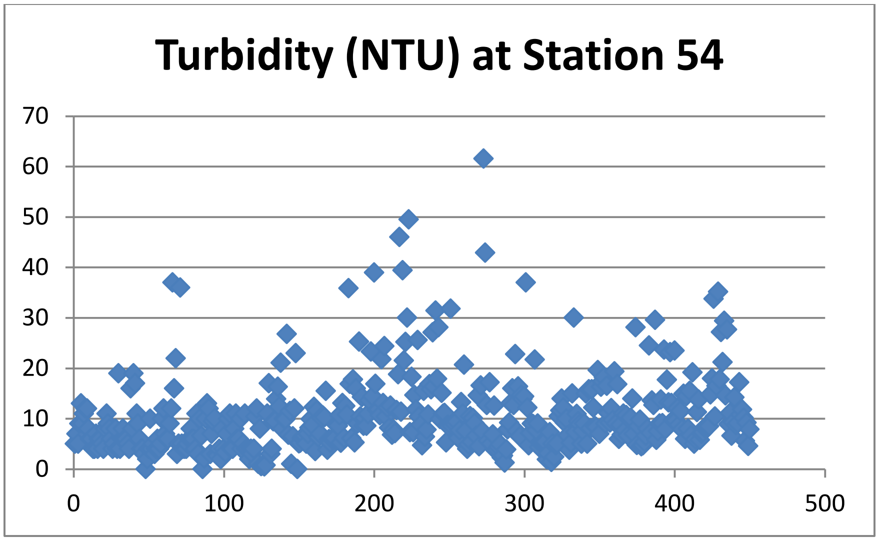


Figure 4. Map of loss of marsh 1893-1952. From Carlisle et al 2005.

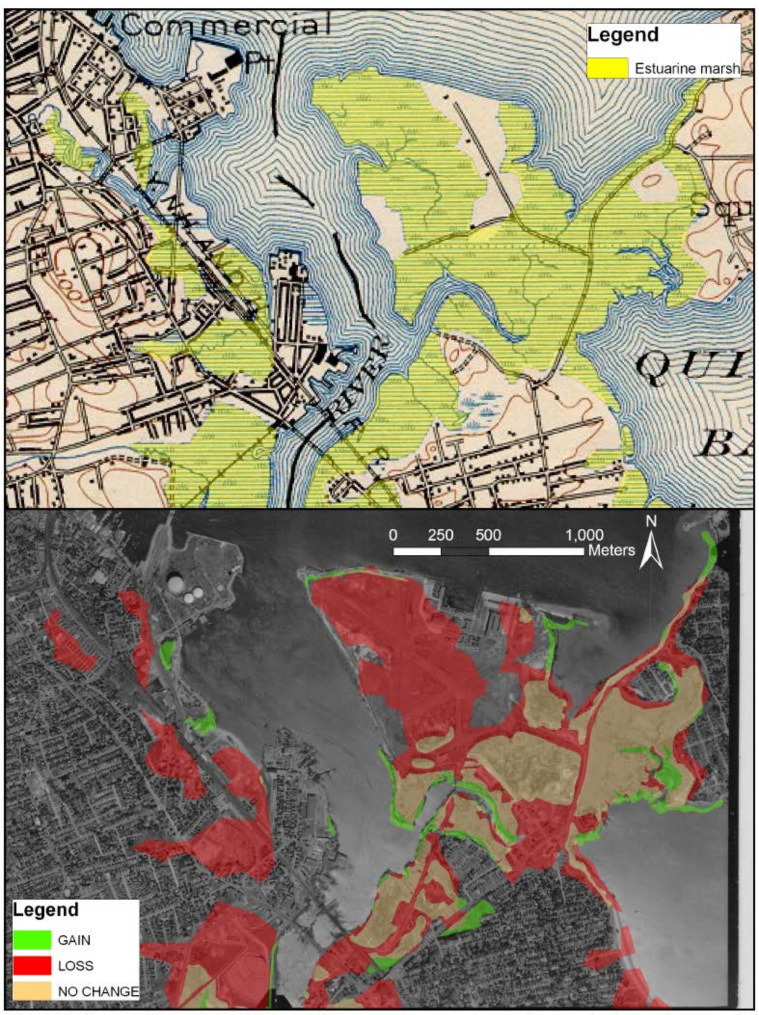


Figure 9. Neponset River, Boston/Quincy: 1893 map with mapped estuarine marsh (top) and 1952 aerial photograph showing 1893-1952 trends (bottom).

Figure 5. Map of loss of marsh 1971-1995. From Carlisle et al 2005.

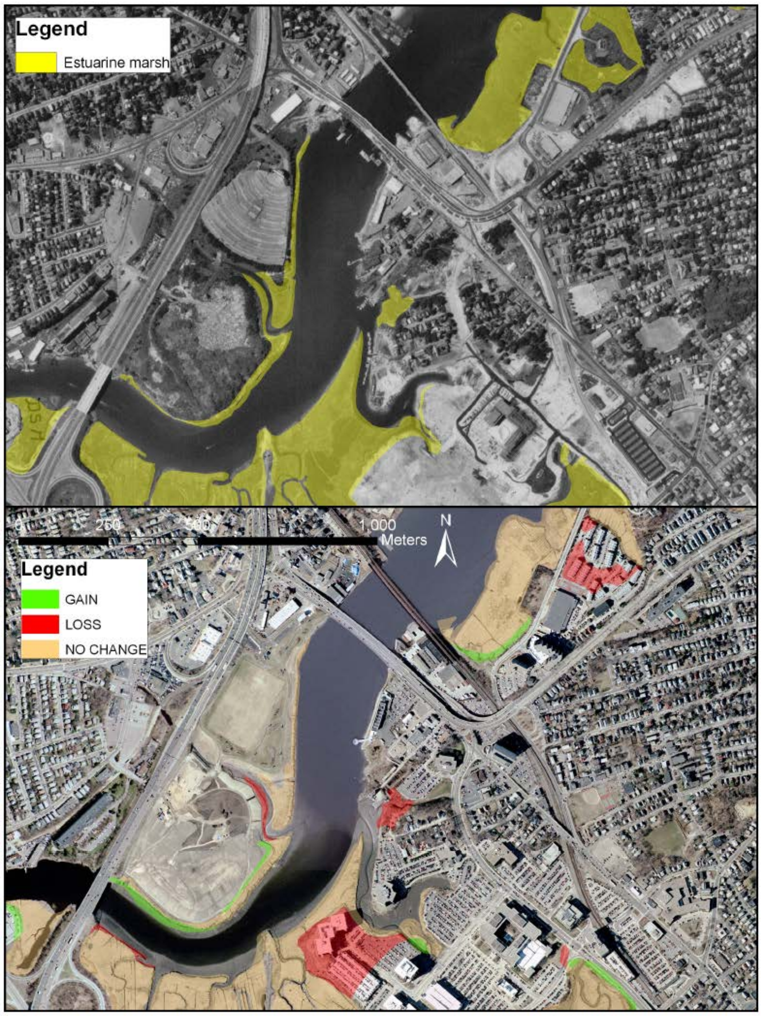


Figure 11. Neponset River, Boston/Quincy: 1971 aerial photograph with mapped estuarine marsh (top) and 2001 aerial photograph showing 1971-1995 trends (bottom).

Figure 6. Map of impervious surface around the Neponset estuary. From Neponset River Watershed 2004 Assessment Report.

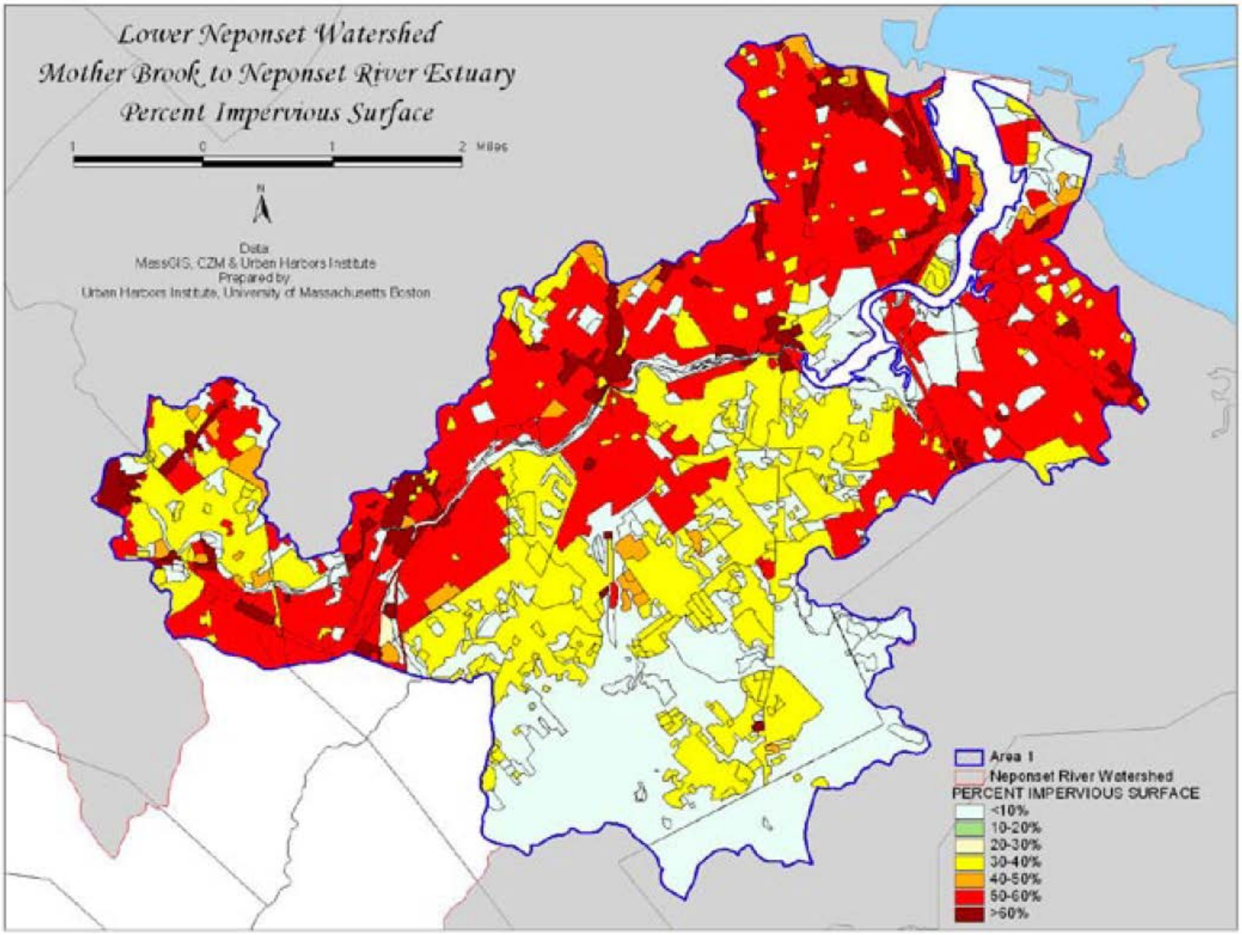


Table 1- Average TSS from selected sites along the Neponset estuary.

Site Number	Average TSS*	Minimum TSS*	Maximum TSS*	Obs. Over 25 TSS*	% Over 25 TSS*
140	15.5	0	90	106/750	14%
89	19.1	0	211.5	133/492	27%
54	26.7	0	154	187/450	42%
42	25.3	0	126	180/518	35%
42	19.7	0	94	120/493	24%

*TSS calculated at NTU*2.5

Table 2- Summary of Fisher and Acreman's findings on nutrient retention in wetlands. From Fisher and Acreman 2002.

Table 2. Summary of the number and percentage of studies of wetlands which reduced, increased or resulted in no change to N or P loading

	Nitrogen species				Phosphorus species			
	No. wetlands	*% wetlands*	*Mean % change*	*SD of mean % change*	*No. wetlands*	*% wetlands*	*Mean % change*	*SD of % change*
Retention	43	80	67	27	41	84	58	23
Release	7	13	351	432	5	10	221	328
No net change	4	7	n/a	n/a	3	6	n/a	n/a

Table 3- Average nutrient loads from station 140 on the Neponset estuary averaged over 1994-2011.

Nutrient Concentrations at Station 140- 1994-2011 Average		**Average uM multiplied by MW**	**Yearly volume based on low river flow (0.6m^3/s)**	**Yearly volume based on high river flow (3.1m^3/s)**
Ammonium	3.84(uM)	307.01 (ug/m^3)	5.81 (kg)	30.03 (kg)
Nitrate+Nitrite	6.21 (uM)	385.00(ug/m^3)	7.29 (kg)	37.66 (kg)
Total Dissolved N	25.71(uM)	360.17 (ug/m^3)	6.82 (kg)	35.23(kg)
Particulate N	6.10(uM)	85.42(ug/m^3)	1.62(kg)	8.36 (kg)
Phosphate	0.92 (uM)	87.59 (ug/m^3)	1.66 (kg)	8.57 (kg)
Total Dissolved P	1.15(uM)	35.75(ug/m^3)	0.68(kg)	3.50 (kg)
Particulate P	0.68 (uM)	21.10 (ug/m^3)	0.40 (kg)	2.06 (kg)
Total Phosphorus	4.44(uM)	137.50(ug/m^3)	2.60 (kg)	13.45 (kg)
Particulate C	47.20(uM)	566.88 (ug/m^3)	10.73(kg)	55.46 (kg)

Table 4- Nutrient fluxes in Bly Creek, North Carolina. From Dame et al 1991.

Table 1. Annual material fluxes for the Bly Creek system in kg. Export = + (no sign shown) and import = −. *Fluxes significant at 5% level

Component[a]	H_2O ($m^3\ yr^{-1}$)	ISS	POC	DOC	PN	NH_4	$NO_2 + NO_3$	DON	PP	PO_4	TP	ATP	Chl *a*
Tides	1.2×10^7	-9.8×10^5	-2.0×10^4	1.8×10^5*	−1540	433	−158.0	7780*	−673.2	224.8	−781.5	-1.2×10^4	−140.6
Stream	-7.7×10^5	–	–	-1.9×10^4	–	−6.6	−5.2	−892	–	−13.4	−23.3	–	–
Groundwater	-1.2×10^5	–	–	-1.1×10^3	–	−60.3	−3.2	−152	–	−11.3	−13.6	–	–
Rain	-7.9×10^5	–	–	–	–	−11.1	−10.5	−189	–	−1.9	−11.9	–	–
Marsh (submerged)		-3.7×10^5*	-3.7×10^4*	-1.3×10^3	−1730	−1500*	−330*	3140*	−1068.9*	−244.6*	−1425.2*	−2.8	−154.9*
Marsh (exposed)		1.4×10^5	1.6×10^4	1.9×10^4	1170	122	11	1660	218.0	42.5	276.5	–	–
Oyster reef		-3.0×10^4	-3.4×10^3*	2.5×10^3	−222	125*	1	−127	−70.0	7.7	−98.0	−6.4*	−23.7*

[a] See Table 2 for areas