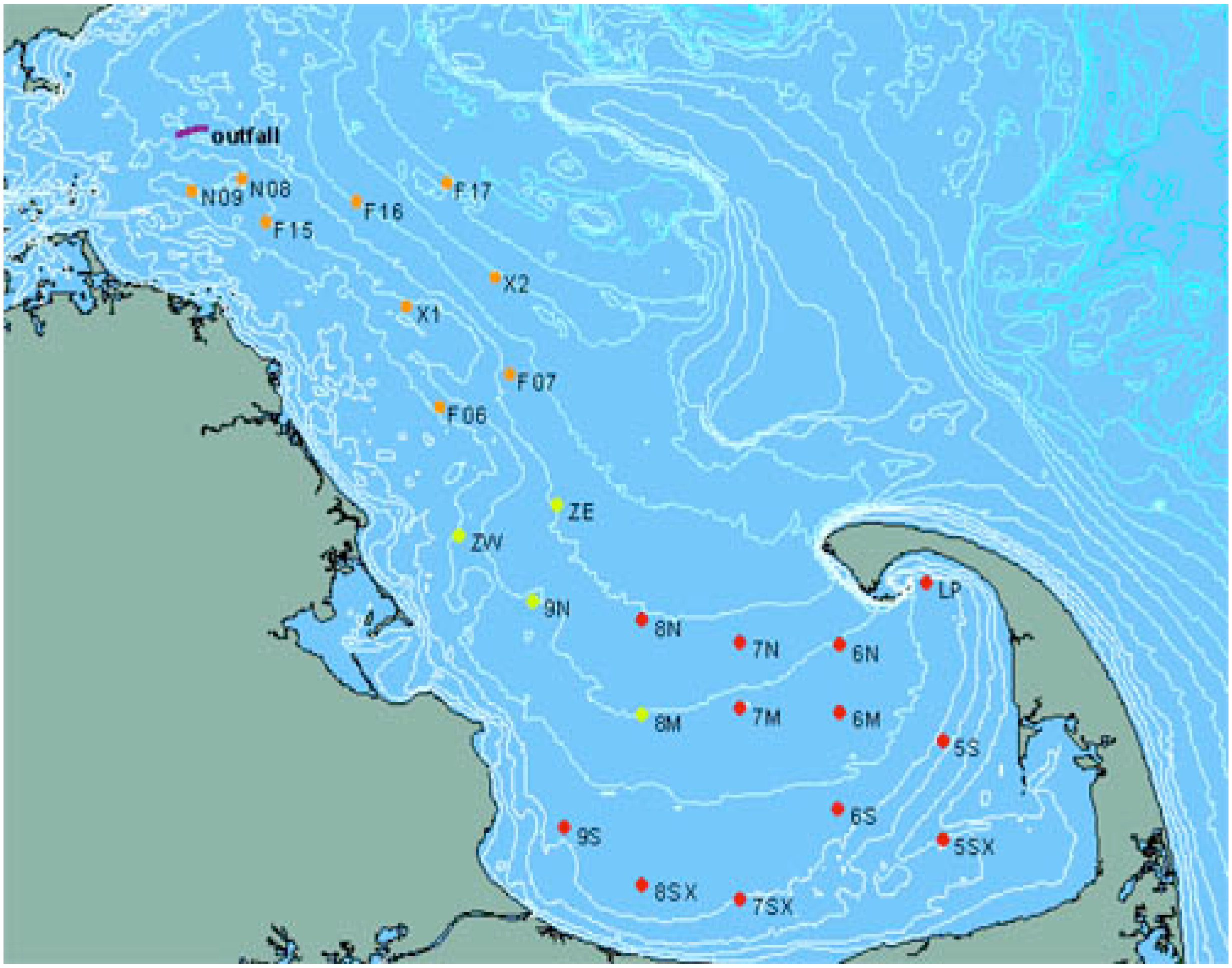

PCCS Monitoring Stations in Massachusetts and Cape Cod Bays

Effects of Boston Outfall on the Marine Community of Cape Cod Bay

March 7, 2005

PROVINCETOWN CENTER FOR COASTAL STUDIES

ABSTRACT[1]

Over a four-year period (2000-2004), the Provincetown Center for Coastal Studies (PCCS) and Massachusetts Water Resources Authority (MWRA) examined potential changes to the composition and distribution of planktonic species associated with the relocation of the MWRA's municipal wastewater discharge outfall pipe within the waters of Massachusetts Bay, Cape Cod Bay, and the Stellwagen Bank National Marine Sanctuary. Compared to pre-relocation data collected by MWRA and others, both groups concluded that there were no statistically significant adverse effects on the composition or distribution of planktonic species identified over a broad range of sampling locations within these marine ecosystems. Despite this general conclusion, a variety of anomalous and/or fine-scale findings studies suggests that further work may be required to fully assess the potential impacts of the outfall on plankton over the long-term. Furthermore, these potential impacts must be considered as they relate to higher trophic levels, such as marine mammals that depend on seasonal assemblages of specific plankton species.

---

[1] This summary was prepared by Dr. Gregg Moore of the Provincetown Center for Coastal Studies. Collaborators in this study included Dr. Charles Mayo, Jamie Collier, and Moriah Bessinger also of the Provincetown Center for Coastal Studies and Dr. Joseph Montoya of Georgia Institute of Technology.

INTRODUCTION

The Cape Cod Bay Monitoring Project (CCBMP) began in 1999, in direct response to public concerns over the relocation of the Massachusetts Water Resources Authority (MWRA) municipal wastewater discharge outfall tunnel and its potential to contribute sewage effluent into the waters of Cape Cod Bay. This project has been a closely related extension of PCCS's 20-year study of North Atlantic right whale habitat within Cape Cod Bay and the Stellwagen Bank National Marine Sanctuary. As designed, the operational specifications of the treatment plant and outfall include an *average* operating discharge of 350 million gallons of treated effluent per day. This discharge occurs nine miles into Massachusetts Bay in a minimum of 100 feet of water, a distance of approximately 36 miles from Cape Cod Bay. Based on the predicted water circulation of hydrodynamic models produced by the United States Geological Survey (USGS), the potential of nitrogen-rich effluent entering Cape Cod Bay could significantly impact water quality, marine habitat, and the species contained within this exceptional marine natural resource.

Data collection for the project began just prior to the startup of the outfall on September 6, 2000 and involved a multifaceted approach to evaluating the potential impacts of the relocation of the sewage outfall. Following standard Environmental Protection Agency (EPA) guidelines, the study complemented and expanded upon the MWRA's monitoring program by adding a significant number of monitoring sites within Cape Cod Bay. At ten sites within Cape Cod, ten in Massachusetts Bay and two within the Stellwagen Bank National Marine Sanctuary, PCCS monitored the zooplankton community (using surface and oblique net tows and a vertical pump sampling system) at various depths, tracked the ratio of nitrogen isotopes (_N) within plankton (Montoya et al. 2003), and recorded basic oceanographic parameters (including conductivity, temperature, and depth) throughout the year from 2000 through 2004.

Like the MWRA, PCCS sought to examine the presence of, and potential impacts of treated effluent on the marine community within Massachusetts and Cape Cod Bays using zooplankton diversity and distribution as biological indicators of anthropogenic perturbations to the system. Selection of zooplankton as an indicator species more directly reflects significant changes to limiting nutrients, such as sewage-derived nitrogen, that could be readily sampled using common, reproducible methods. Furthermore, historic assessment of zooplankton had already been completed. This would served as a strong experimental control with a broad and rich data set allowing comparisons between pre and post-relocation ambient environmental conditions and nitrogen isotope ratios sequestered by plankton species.

For each of the four years studied, PCCS and MWRA concluded in year-end reporting that while variation in phytoplankton and zooplankton diversity was observed across the sampling sites, no statistically significant differences in overall plankton assemblages could be discerned from the data. These consistent findings, coupled with a distinct, declining _^{15}N gradient from the outfall south towards and into Cape Cod Bay support the conclusion that sewage nitrogen is being assimilated by autotrophic organisms without a measurable change to the widely variable plankton community. Associated measurements of oceanographic parameters (i.e., water temperature and salinity at varied depths) conducted by PCCS as well as various water quality parameters measured by MWRA, also support relative system stability within the representative sampling locations throughout these marine systems.

These data have been encouraging to the resource management, scientific, advocacy community, and concerned citizens within the region. However, these results should not be perceived as absolute, nor indicative of a continued, temporal *status quo* as marine ecosystems are dynamic and complex. Monitoring of changes to this system along an ecological time scale has only just begun.

In light of these limitations, PCCS is considering the future of research-based monitoring within Cape Cod Bay with a research focus upon the potential cumulative or chronic effects of the outfall on the bay's inherent ability to buffer significant effluent additions over the long-term. Moreover, PCCS is integrating these data into an ecosystem scale context linked to ongoing study of right whale habitat and potential impacts on this fragile component of the Cape Cod Bay system. Likewise, MWRA (Werme and Hunt 2004) has shifted its focus to long-term impacts and management.

CONSIDERATIONS AND HYPOTHESES

Duration of Study

The ability for dynamic ocean systems to buffer ecological perturbations over the short-term is well documented. Since the relocated discharge outfall went on-line, only three years of data collection have been analyzed. Acute effects were not determined to have occurred within the sample sites, but chronic effects could not yet be measurable or detectable. Could the reported lack of significant changes to plankton diversity and distribution at the sites sampled within this system be linked to the brevity of the impact on ecological time scales, or the sample size itself?

In the case of PCCS plankton and oceanographic data collection, several monthly data sets were forgone due to prohibitive weather, sea state, and other safety considerations. While these gaps in data are likely insignificant in the larger scheme, it is possible that they compromise the predictive value of the yearly or multiyear assessment of impacts. In this regard, the PCCS study maintained larger sample sizes and frequency that that reported by MWRA for the same parameters. In light of the documented spatial variability within the system, short-term effects on plankton particularly could be underestimated in early stages of change due to: 1) relative degree of change or scale of measurement, 2) spatial distribution of potential effects, 3) or a combination of both.

EPA approved protocols were employed by both groups with the added assistance and input of scientists and resource managers from a broad diversity of agencies and research institutes. The appropriateness or validity of these methods is not disputed here. Rather, the inherent shortcomings of a relatively short-term study are merely noted to underscore the possibility that the present, short-term status of change or impact in this system due to the addition of sewage nitrogen is not necessarily a valid prediction of future conditions which may develop with cumulative additions of effluent over longer time periods.

Spatial Variability and Standard Error

Despite relatively predictable seasonality of individual species aggregations annually, Massachusetts and Cape Cod Bays are characterized by both MWRA and PCCS as having a widely variable spatial distribution of plankton. Such variability was shown to produce mean values with broad standard error, limiting the predictive value of statistic comparisons. As a result, could the conclusion that plankton species composition and distribution did not significantly differ within these waters over the study period be misleading? Is this particularly true over the short-term because the widely overlapping error from year to year effectively hides acute, small-scale variability? Could increasing the number of sample stations improve the predictive value of statistical comparisons?

For example, Kropp et al. (2003) reported that zooplankton communities demonstrated a pronounced similarity throughout the Gulf of Maine, despite widely variable conditions throughout. In fact, it was the consistent finding that high variability existed on both local and regional scales that led to the conclusion that all sites were similarly variable, with only temporal shifts in species groups being well correlated. This finding calls into question the suitability of using zooplankton as a biological indicator for anything other than catastrophic nutrient inputs. They concluded that determination of a defined threshold to predict shifts in zooplankton abundance or community structure at local or regional scales related to the outfall is unlikely. Certainly at the scale of the study thus far, this conclusion appears valid until sample size or overall study duration is significantly increased to better account for inherent variability over large spatial and temporal scales.

The cost of additional sample stations to reduce this effect is likely a limiting factor, however, the effect this logistical or budgetary restriction has on the quality of the data cannot be overlooked. In the absence of higher sample numbers or more frequent sampling, the statistical value of empirical work can be augmented with sampling longevity, relating back to the considerations expressed above.

Fine-Scale Effects or Localized Coincidences

The overall finding of no significant differences between plankton species composition and distribution buffers the potential importance of fine-scale observations of anomalous, but potentially significant variability in plankton species within regions of the study area. While arguably negated by the conclusions reported by Kropp et al. (2003) above, this may be particularly relevant to migratory species at higher trophic levels that follow specific planktonic food sources. Could PCCS's observation of a *coincidental* correlated shift in plankton species and foraging right whales be a localized effect of more subtle changes to the planktonic food web? Or could it be indicative of a trend that may continue as the natural buffering capacity of the Cape Cod Bay ecosystem is hindered by chronic inputs of sewage nitrogen over the long-term?

In 2002, PCCS tracked a significant shift from the predominant winter-spring zooplankton resource *Calanus finmarchius* to the estuarine copepod *Acartia* spp. in Cape Cod Bay (PCCS 2003). This shift was limited to the 2002 season, but was accompanied by an early departure of foraging right whales that, if occurring annually, would significantly impact habitat for this critically endangered species. PCCS did not conclude that this event was necessarily correlated to the outfall, as no direct data supported an increase in sewage-derived nitrogen in the bay's system, based on sort-term analyses. However, significant levels of the nuisance algae *Phaeocystis pouchetti* also occurred in the bay during this time. Related studies have shown that increases in nutrient availability and productivity can cascade up marine food webs to affect higher trophic levels, but that zooplankton then control population growth and extort nutrients back into the system. Despite these environmental controls, changes in available nutrients *do* account for general patterns of community change (Micheli 1999). The occurrence of both these phytoplankton and zooplankton species in 2002 was either a random event, or the scale of our ability to detect causative perturbations within the system was not fine enough to render a statically robust conclusion. Recent evidence suggests that global climate change could account for suboptimal shifts in desired species for right whales which could explain or contribute to the effect observed in Cape Cod Bay (Greene et al. 2003, Greene and Pershing 2004, Richardson and Schoeman 2004). Given the dire status of the right whale, these findings are cause for concern and should be considered in future monitoring studies within Cape Cod Bay and the Sanctuary.

Seasonal Variation in _^{15}N

Based upon isotopic fractionation (_^{15}N), MWRA and PCCS data show a clear gradient in sewage nitrogen from the outfall southward to Cape Cod Bay. This gradient is reduced to trace amounts within 20-40km from the source at the outfall. These data confirm that plankton are assimilating sewage-derived nitrogen as predicted and on average, there have been no measurable adverse impacts to this dynamic food web within the locations sampled. That said, the extent of the _^{15}N gradient demonstrated seasonal variability that may be more significant than had been discussed in earlier reporting on this topic.

Montoya et al. show that after one year there was no appreciable change to the sources of nitrogen to the food web. That is, when archived (pre-outfall) zooplankton were compared with post outfall zooplankton, _^{15}N values were not significantly different (at the depths sampled. The PCCS-sponsored study concluded that zooplankton in Massachusetts Bay continues to reflect the isotopic composition of marine sources of nitrogen. In general, summer sampling results within Cape Cod Bay are correlated with the MWRA results, showing an incremental return to expected _^{15}N ratios within 20-40km, just entering Cape Cod Bay. In cooler winter months however, migration of sewage-N as far as 80km was reported by the PCCS-Georgia Tech study, presumably when uptake by phytoplankton is significantly reduced.

Could sewage-N be contributing to far-field N concentrations beyond the reported gradient, and therefore be contributing to the occurrence of nuisance phytoplankton species, acute shifts in species zooplankton composition and distribution, and changes to right whale foraging habits? Over time, could these seasonal pools of far-migrating sewage-derived nitrogen contribute to measurable changes in plankton species composition and distribution within Cape Cod Bay? Again, short-term analysis of data, limited to the sites sampled would suggest that these findings are of anecdotal concern. However, over longer periods of time, excess sewage-derived nutrients could be transported into Cape Cod Bay and the Sanctuary relatively unnoticed and affect water quality, marine food webs, and foraging habitat for right whales in a manner in which the current monitoring perspective would not readily detect.

DISCUSSION

Thanks to rigorous planning and an active response to widespread public concern, the marine environments of Massachusetts and Cape Cod Bays have been fortunate not to have been significantly impacted by the relocation of the MWRA discharge thus far. The impact of acute additions of sewage-derived nitrogen appear to be attenuated by the system, but further work may be required to fully assess cumulative or long-term impacts to plankton and higher trophic levels within this dynamic system.

The North Atlantic right whales stand precariously in the face of potential habitat degradation and loss within Cape Cod Bay, inextricably linked and dependent upon a seasonal stock of planktonic species that have consistently been available within these limited and irreplaceable waters (Greene and Pershing 2004). The bay and the Stellwagen National Marine Sanctuary are among the most important and frequented habitat of this critically endangered marine mammal species which has been extensively studied and protected by the ongoing research and rescue efforts of PCCS. While much of the efforts to protect this charismatic species have focused upon reducing mortality due to entanglement and ship strikes (Mayo et al 2001), recent efforts to track essential elements of right whale habitat (such as desired food sources) are showing promise as a potential predictor of right whale presence and distribution. The relationship between whale food and whale distribution is widely established (Mayo et al 2001), and in like manner, external factors which have the potential to negatively impact the seasonal patterns of food sources inherent pose a threat to foraging whale species. As our ability to understand, model, or potentially predict the relative distribution of whales grows, so too should our ability to detect and predict potential impacts to the basic food sources that form the core of their migratory foraging. Continued monitoring of the outfall, on various ecological scales is at the heart of this dire conservation issue.

From a water resource management standpoint as well as that of conservation biology, it is imperative that even minor disruptions to spatial and temporal biological processes be carefully monitored, analyzed and documented to directly protect water quality and the full range of organisms that rely upon this basic factor. Based on this review and the potential significance of the outfall discharge on ecosystem-scale processes and organisms spanning all trophic levels, significant ecological and management considerations remain for the continued maintenance of water quality within Massachusetts Bay, Cape Cod Bay, and the Stellwagen Bank National Marine Sanctuary.

Responsible resource management requires the continued exploration of biological assimilation of discharge flows within these waters. Examination of these processes over the long-term will help identify potential small and large-scale perturbations to the system that may be over looked using infrequent or broad-scale monitoring methods. An effective monitoring program must maintain fine resolution observations to identify potential or realized ecological changes *before* they may become ecologically significant at small or large trophic and ecosystem scales.

LITERATURE CITED

Greene, C.H. and A.J. Pershing, Climate and the conservation biology of North Atlantic right whales: the right whale at the wrong time? Frontiers and Ecology, 2004. **2**(1): p. 29-34.

Greene, C.H., R.D. Kenney, and J.W. Jossi, Impact of climate variability on the recovery of endangered North Atlantic right whales. Oceanography, 2003. **16**(4): p. 98-103.

Kropp, R.K., et al., *A review of zooplankton communities in the Massachusetts Bay/Cape Cod Bay system.* 2003, Massachusetts Water Resources Authority - Environmental Quality Department Report ENQUAD 2003-06. p. 38.

Lawrence, D., I. Valiela, and G. Tomasky, Estuarine calanoid copepod abundance in relation to season, salinity, and land-derived nitrogen loading, Waquoit Bay, Massachusetts. Estuarine Coastal and Shelf Science, 2004. **61**: p. 547-557.

Mayo, C. and M. Bessinger, *Cape Cod Bay Monitoring Project - Annual Report.* 2002, Provincetown Center for Coastal Studies. p. 38.

Mayo, C. and M. Bessinger, *Cape Cod Bay Monitoring Project Final Report*. 2003, Provincetown Center for Coastal Studies. p. 13.

Mayo, C., M. Brown, A. DeLorenzo, and M. Bessinger, *Using food density to predict right whale occurrence and movements in Cape Cod Bay*. Final Report, October 31, 2001. Provincetown Center for Coastal Studies. p. 19.

Micheli, F., Eutrophication, fisheries, and consumer-resource dynamics in marine pelagic ecosystems. Science, 1999. ***285****: p. 1396-1398.*

Montoya, J.P., et al., Isotopic tracking of sewage nitrogen in Massachusetts Bay. In Review, 2003: p. 42.

MWRA, Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1, March 2004. 2004, Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-092. p. 65.

Werme, C. and C.D. Hunt, *2003 Outfall monitoring overview. Boston: Massachusetts.* 2004, Massachusetts Water Resources Authority - Environmental Quality Department Report ENQUAD 2004-13. p. 97.