Restoration of an Impounded Freshwater Wetland in Huntington Beach State Park, Murrells Inlet, South Carolina

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Abstract:

A fourteen-month study was conducted in Murrells Inlet, South Carolina to monitor the success of a community-based wetlands restoration project conducted by the South Carolina State Parks Association and a volunteer group "Friends of Huntington Beach State Park." The restoration was conducted in a freshwater pond that had formerly been connected to the Atlantic Ocean through a tidal inlet. This inlet last closed in 1989 causing the pond to evolve from a marine to a freshwater system. A channel was cut in April 2005 to connect Sandpiper Pond to the Atlantic Ocean. It was hypothesized that this would restore the pond to its former state as a marsh- tidal inlet system thereby improving water quality, increasing the abundance of marine macrofauna and associated shorebird populations and slowing or eliminating the growth of invasive plant species, *Phragmites* and *Typha*, while restoring populations of native plant species such as *Spartina* and Widgeon grass.

Several approaches (e.g. fish surveys, plant experiments) were used to evaluate the success of the restoration. This paper deals exclusively with the water quality analyses. At the conclusion of the project, salinity and pH had increased significantly in Sandpiper Pond. Nutrient levels and ratios had taken on a more marine character. The frequency and intensity of eutrophication and hypoxic events in Sandpiper pond remained unchanged.

Introduction:

A marsh restoration project was conducted at Sandpiper Pond which is located within Huntington Beach State Park in Murrells Inlet, SC. This cat's eye pond lies on a barrier island a short distance (<0.5 km) from the Atlantic Ocean. It was formerly a tidal inlet surrounded by a marine marsh system of approximately 35 acres. Natural coastal dynamics plus the construction of jetties at nearby Murrells Inlet in the 1980s have acted to close the inlet such that the pond has not received tidal flows since Hurricane Hugo in 1989. In response, the ecological dynamics of this area have changed dramatically. The tidal mud flats once supported heavy populations of shorebirds. Least terns and Wilson's plovers once nested here and populations of the federally endangered sea beach amaranth (*Amaranthus pumilus*) occurred near the salt flats and tidal washes of the inlet. Annual park surveys suggest that these species have largely disappeared from this site, and sea beach amaranth has not been recorded since 1998. The flats have been colonized by several invasive species, the common reed (*Phragmites)* and cattails (*Typha*). During the summer of 1993 a major fish die off occurred, which was presumably caused by drought and low dissolved oxygen in the water. The open waters of the pond were also covered by mats of algae, leading to the conclusion that eutrophication was occurring.

The restoration project was led by The Friends of Huntington Beach State Park, in partnership with the South Carolina State Park Service, Brookgreen Gardens, Coastal Carolina University, Waccamaw High School, Waccamaw Audubon Society, Murrells Inlet 2007, and other local volunteer groups. The goal of the project was to create a biologically diverse aquatic ecosystem that would support migratory waterfowl, wood storks, piping plovers, seabeach amaranth and other wildlife. Funding was provided via a grant from the 5-Star Restoration Program which supports community-based projects. The five star partners are the U.S. Environmental Protection Agency, the National Association of Counties, the National Fish and Wildlife Foundation, the Wildlife Habitat Counsel and National Atmospheric and Oceanic Administration's (NOAA) National Marine Fisheries Service. Additional funding was provided by the U.S. Fish and Wildlife Service. This was one of the first projects funded by the 5-Star Program in South Carolina; it was also one of the first projects to employ a formal project assessment guided by NOAA.

The restoration was originally planned around two actions: (1) a channel would be cut, allowing saltwater to enter the ponds banks, and (2) chemical eradication of *Phragmites* via application of glyphosphate followed by mechanical removal of *Typha*. The combined effects of higher salinity and removal of competitors was intended to promote the recolonization of the tidal flats by native species such as *Spartina* and Widgeon grass. At the request of scientists at Coastal Carolina University, it was decided to first attempt reduction of the invasive species by exposure to higher salinity waters. Restoring tidal activity to impacted wetlands has been shown to be extremely important in the rapid re-establishment of a salt marsh environment (Myers, 1996; Brockmeyer et al., 1997). Restoring tidal activity was also expected to reduce the severity and frequency of eutrophication and hypoxic events.

After a dredging permit was obtained from the South Carolina Department of Control's Office of Ocean and Coastal Resource Management, a channel was cut to connect the pond to the Atlantic Ocean. This channel was engineered to be 15 m wide and 0.67 to 1.3 m deep at MLW and MHW, respectively, with a 2% slope from the beach to the pond. The first cut was made in April 2005. Due to sediment accumulation, the channel was re-cut in September 2006.

Experimental Design:

To assess the success of the restoration effort, water quality samples were collected biweekly from several sites in the pond. Samples collected prior to restoration were compared to those collected after opening of the tidal inlet. The results were also compared to relevant water quality criteria for eutrophication in estuarine systems (Bricker et al. 1999)

Sediment infill and colonization by *Phragmites* and *Typha* has essentially divided the pond into two parts: a North Pond and a South Pond (Figure 1). The South Pond is greater in volume than the North Pond. The land use around the ponds is geographically variable. The North Pond is adjacent to a parking lot and picnic area while the South Pond is near an RV campground.

Figure 1. Aerial photo of Sandpiper Pond. 1: Parking Lot, 2: North Pond sampling site, 3: Encroaching vegetation, 4: Tidal creek connecting to nearby saltmarsh, 5: South Pond sampling site, and 6: location of dredged outlet.

Baseline or control samples were collected prior to dredging at one site in the North Pond and one in the South Pond. After the initial channel dredging, sampling was continued at these sites with an additional site added near the new inlet (Figure 2). Grab samples were collected from the center of the North Pond using a small boat. The South Pond was sampled from the edge by wading out approximately 5 meters and using an extendable sampling pole to collect water an additional 3 meters from shore . The inlet site was sampled by wading into the channel proper.

Figure 2. Aerial photo of Sandpiper Pond showing the new tidal inlet.

Baseline sampling was conducted from September 2004 until April 2005 for conductivity, salinity, dissolved oxygen (DO), temperature, turbidity, total nitrogen (TN), total phosphorus (TP), chlorophyll, phaeophytin, total suspended solids (TSS) and volatile suspended solids (VSS). Standard quality assurance and quality control techniques were followed including field duplicates, method blanks, and calibration checks where appropriate (Franson et al., 1998). All water samples were collected in 500ml

PE bottles and stored on ice for transport to the lab. As shown in Table 1, sampling was continued after the first and second channel opening in April and September 2005. Sampling was terminated at the end of November 2005.

Table 1. Project Schedule

Action	Date
Start of Sampling	Sept. 28, 2004
1st Channel Opening	April 7, 2005
2nd Channel Opening	Sept. 14, 2005
End of Sampling	Nov. 22, 2005

Methods:

Water quality tests were conducted by APHA-AWWA-WEF standard methods (Franson et al., 1998). Conductivity, salinity, dissolved oxygen, pH, and temperature were measured in the field with Hach-sension meters. Turbidity, chlorophyll, phaeopigment, TSS, VSS, TN and TP analyses were conducted in the laboratory. Rain data was obtained from the National Climatic Data Center.

Results and Discussion:

The water quality results are presented in Figures 3 through 11 as bar charts representing the mean values for the sampling period and as temporal trend graphs. Error bars represent the % relative standard deviation of field duplicates; data symbols may be larger than some error bars. Rain data are shown as total accumulations occurring 7 days prior to the sampling and are represented by vertical black bars along the X-axis. The sampling dates on which major rain accumulations had occurred are shown in Table 2. The dates of the channel openings are marked by two vertical red bars. NOAA's estuarine criteria (Bricker et al., 1999) are included in temporal graphs for reference. Two-sample t tests were used to identify significant differences between the North and South Ponds and within a Pond, for effects of channel dredging.

Table 2. Major Rain Accumulations

Date	Rain Accumulation (in)
March 29, 2005	3.1
June 7, 2005	2.6
July 5, 2005	3.2
August 4, 2005	3.3
September 5, 2005	3.3
October 13, 2006	6.9

Salinity

Salinity increased in both ponds after the first opening (North: $p = 0.00$, South: $p = 0.00$). Mean salinity pre-opening was 1.5 psu and 5.8 psu for the North and South Ponds, respectively. After the channel was cut, the salinity increased to 5.8 psu and 11.1 psu for the North and South Ponds, respectively. The South Pond is connected to the nearby salt marsh via a small tidal creek (Figure 1); this is thought to be responsible for the higher salinity in this pond throughout the sampling period (Figure 3). The channel closed soon after both openings. The rapid decline in salinity near the inlet site illustrates the importance of the South Pond's connection with the nearby saltmarsh.

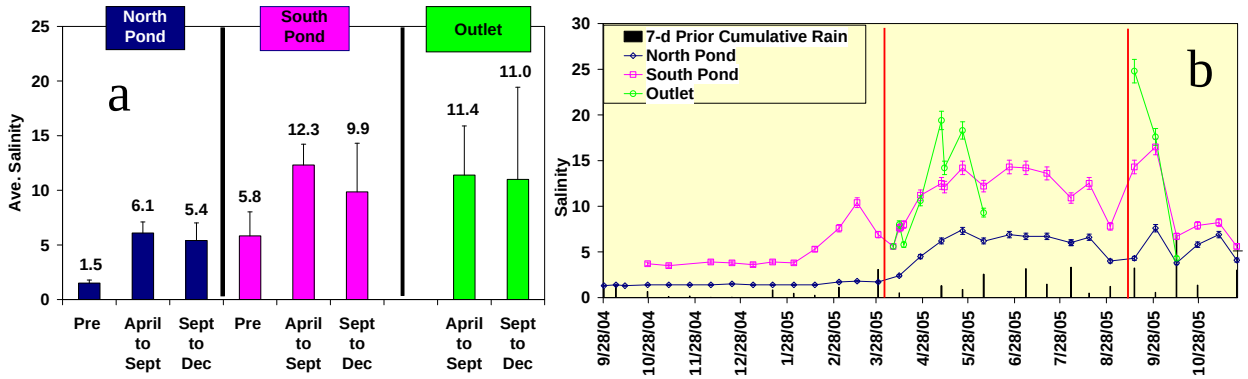

Figure 3. (a) Mean salinity and (b) Salinity over time.

Dissolved Oxygen

With the exception of one sample in the South, both ponds were either saturated or undersaturated (≤100%) with respect to percent saturation of dissolved oxygen (%DO) before the first opening (Figure 4). (%DO = $([DO]_{obs}/[DO]_{eq} \times 100$, where $[DO]_{eq}$ = DO concentration if equilibrium had been attained with the atmospheric levels of O_2 at the observed temperature and salinity of the sample.) After the inlet was cut, supersaturation was frequent and the variability in %DO increased (North: p = 0.00, South: p = 0.00) suggesting a decline in the stability of balance between respiration and photosynthesis. Some very low %DO levels coincided with declines in pH. No consistent correlation was found with temperature, rain or chlorophyll suggesting that rooted plants are the main contributors to %DO rather than phytoplankton. Dissolved oxygen concentrations in the North Pond were low enough to fall below estuarine eutrophication criteria (< 5 ppm). This occurred in five of the samplings: twice before the channel was cut, three times afterwards (Figure 5).

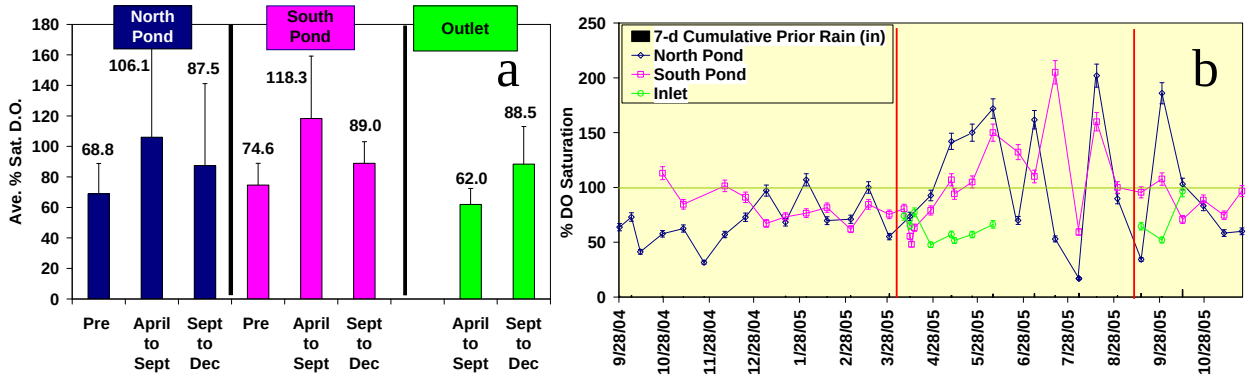

Figure 4. (a) Mean % Saturation of Dissolved Oxygen and (b) % Saturation of Dissolved Oxygen over time. See Figure 5 for rain data.

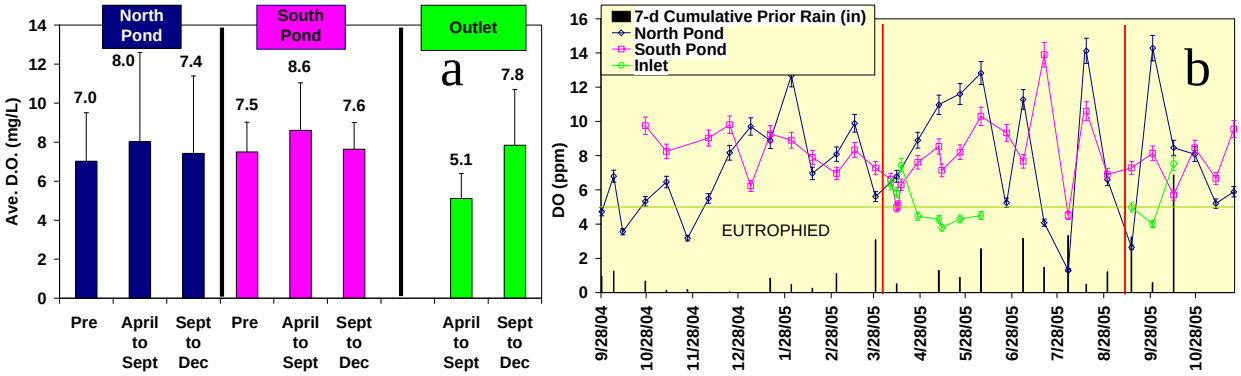

Figure 5. (a) Mean Dissolved Oxygen and (b) Dissolved Oxygen over time.

Chlorophyll

Chlorophyll levels in the North Pond were above estuarine eutrophication levels (20 ppb) for many dates over the entire sampling period (Figure 6). The chlorophyll levels were higher in the North than the South Pond. The South Pond experienced an increase ($p = 0.02$) in chlorophyll levels between the first and second openings. Levels exceeded the estuarine eutrophication criteria on four dates (both ponds) after the second opening.

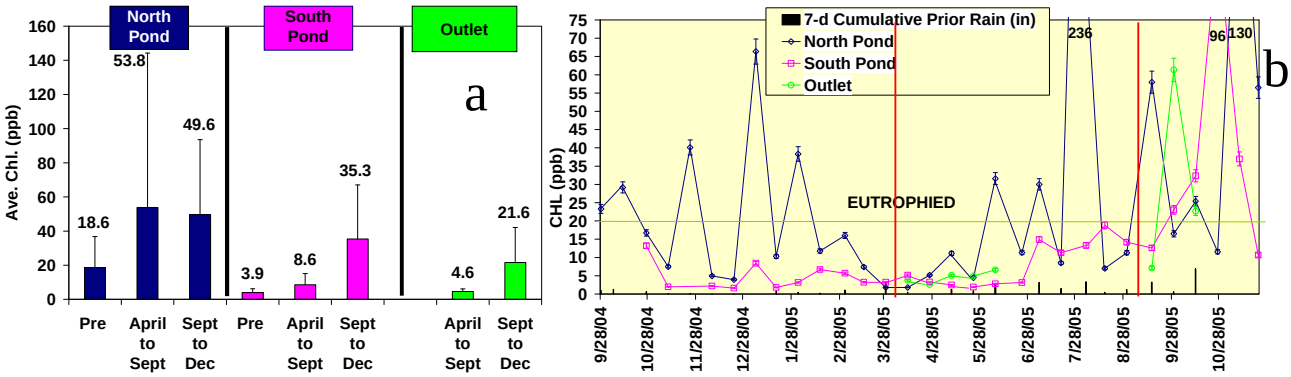

Figure 6. (a) Mean Chlorophyll and (b) Chlorophyll over time

pH

There was a significant increase (North: $p = 0.00$, South: $p = 0.01$) in pH for both ponds after the channel was first cut. The mean pH for both ponds after the opening was 8.9 with the maximum value reaching 9.6 (Figure 7). This is thought to reflect an increase in photosynthesis. The low pH in the inlet was coincident with the lowest DO and highest VSS levels. This suggests the site was net heterotrophic due to VSS loading and water stagnancy. The latter was a consequence of the rapid closing of the inlet channel.

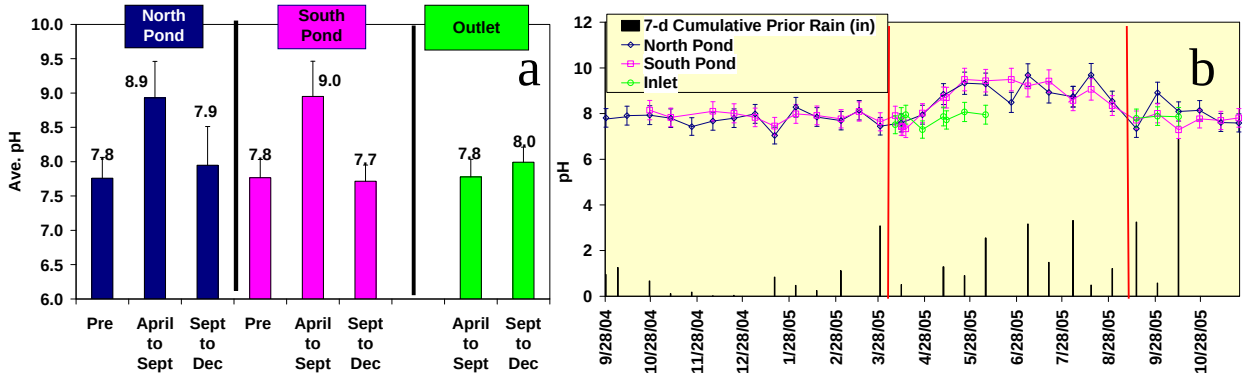

Figure 7. (a) Mean pH and (b) pH over time

Nutrients

Total nitrogen concentrations were above estuarine eutrophication levels (>1.0 ppm) for most of the sampling dates (Figure 8). Mean concentration of the pre-channel samples was 1.2 ppm in the North Pond and 1.1 ppm in the South Pond. After the channel was cut, these concentrations increased to 1.4 ppm and 1.5 ppm, respectively (North: $p = 0.03$; South: $p = 0.01$). Variability also increased significantly (North: $p = 0.02$; South: $p = 0.00$) after the channel was cut.

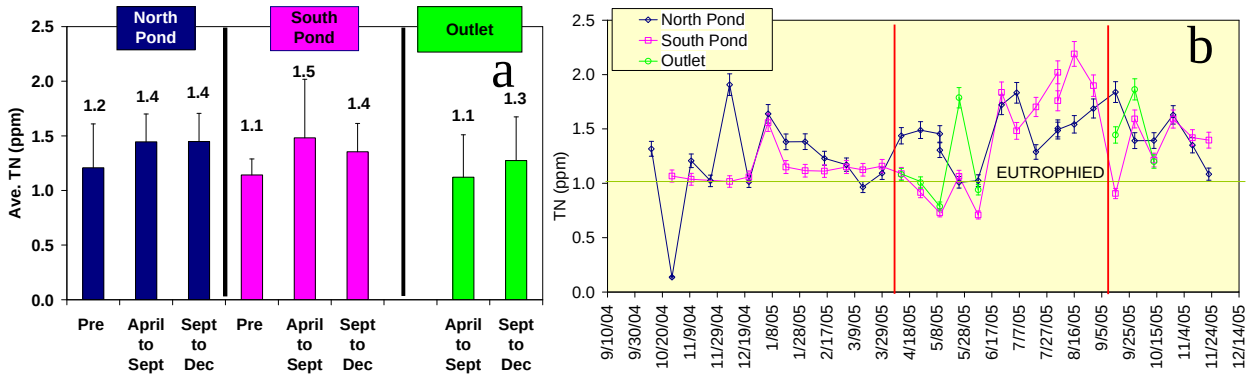

Figure 8. (a) Mean TN and (b) TN over time

Phosphorous concentrations fell in the medium range (0.01 to 0.10 ppm) for estuaries for all but one sample (8/4/05); this was above the eutrophication limit (Figure 9). Prior to channel construction, the mean TP concentrations were 0.038 ppm and 0.024 ppm for the North and South Ponds, respectively. No significant change was observed after channel dredging although the variance significantly increased in both ponds (North: $p = 0.00$; South: $p = 0.03$).

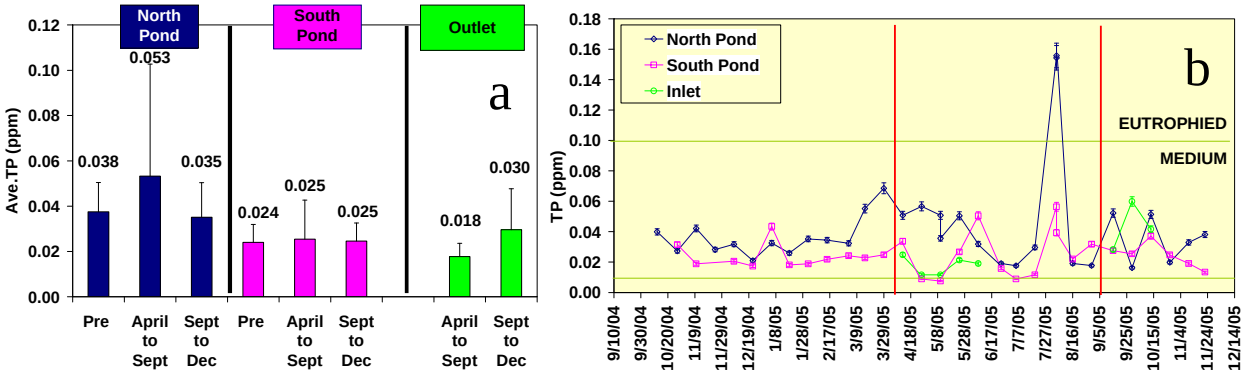

Figure 9. (a) Mean TP and (b) TP over time

Molar nutrient ratios for both ponds exceeded the Redfield Richards ratio (TN/TP > 16) found in marine waters suggesting terrestrial nutrient input (Figure 10). The variability of the ratios increased significantly (North: $p = 0.01$; South: $p = 1.42E-5$) after channel dredging. Nutrient ratios in the North Pond were typically lower than in the South Pond reflecting higher TP concentrations in the former. The TN to TP ratio increased after the first opening of the channel but this increase was significant only in the South Pond ($p = 0.02$).

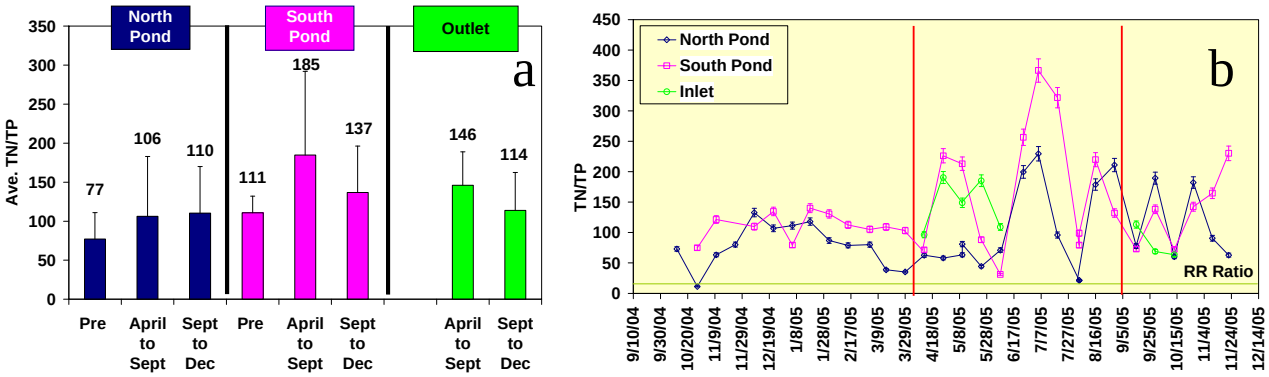

Figure 10. (a) Mean TN/TP and (b) TN/TP over time

Turbidity, TSS and VSS

Turbidity was initially greater in the North Pond (Mean = 4.0 NTU) than in the South Pond (Mean = 2.3 NTU) (Figure 11). After the inlet channel was cut, the mean turbidity of the South Pond increased significantly ($p = 0.001$) as did the temporal variability ($p = 0.003$).

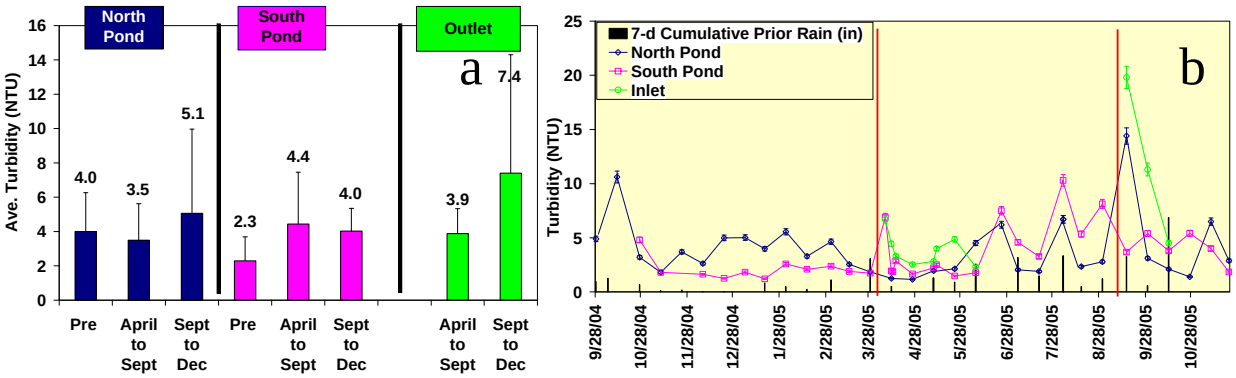

Figure 11. (a) Mean turbidity and (b) Turbidity over time

The TSS and VSS results were similar to that of turbidity. Both TSS and VSS were greater in the North Pond than in the South Pond before the channel was cut (TSS: $p = 0.03$, VSS: $p = 0.01$). The South Pond experienced a significant increase (TSS: $p = 0.03$, VSS: $p = 0.01$) after the channel was cut. The mean TSS in the North Pond and South Pond prior to the channel cut was 6.9 $\pm$ 7.1 and 2.4 $\pm$ 0.8 ppm, respectively. After the cut, the mean TSS was 5.5 $\pm$ 3.7 and 6.5 $\pm$ 4.5 ppm, respectively. The mean VSS in the North Pond and South Pond prior to the channel cut was 4.1 $\pm$ 3.4 and 1.5 $\pm$ 0.5 ppm, respectively. After the cut, the mean VSS was 4.5 $\pm$ 3.0 and 8.1 $\pm$ 2.4 ppm, respectively. The mean VSS-to-TSS ratio in the North Pond and South Pond prior to the channel cut was 0.65 $\pm$ 0.80 and 0.80 $\pm$ 0.13, respectively. After the cut, the mean VSS-to-TSS ratio was 0.60 $\pm$ 0.10 and 0.66 $\pm$ 0.15 ppm, respectively.

Conclusions

The cutting of a channel appears to have given Sandpiper Pond a slightly more marine character. Maximum salinities were 7.6, 16.5, and 24.8 in the North Pond, South Pond, and at the Outlet. The outlet closed within days of both openings so salinities overall increased only slightly ($p < 0.00$), rising from 1.5 to 5.8 psu in the North Pond and 6.1 to 12.3 psu in the South Pond. The higher salinity in the South Pond is attributed to the tidal creek connecting this pond to a nearby salt marsh.

Overall, the North Pond was more eutrophied than the South Pond having a lower %DO and higher chlorophyll concentration. Elevations in chlorophyll and depressions in %DO were observed in the North Pond following four of the six periods of highest rain accumulation phytoplankton activity (6/7/05, 7/5/05, 8/4/05 and 9/15/05) suggesting a response to stormwater runoff. Other markers of eutrophication in the North Pond include an elevated VSS/TSS, with mean values increasing from 66% before the channel was cut to 88% after the second inlet opening. The TSS was also higher in the North Pond but decreased after opening of the inlet. The TP in the North Pond was greater than in the South Pond.

The South Pond's lower degree of eutrophication is attributed to better tidal flushing from the nearby salt marsh and closer proximity to the new inlet. Nevertheless, several water quality indicators declined over time in the South Pond. Namely, chlorophyll, VSS, TSS and total nitrogen concentrations increased after inlet construction.

Nutrient concentrations were in the eutrophied range for TN and in the medium range (for estuaries) for TP in both ponds suggesting that nutrient loading is a particular concern, especially for TP in the North Pond.

Project timing and funding did not enable sampling over long enough timescales to more clearly assess seasonal or inter-annual variations at Sandpiper Pond. Funding was also too limited to provide for companion monitoring at a control site. It is hoped that The Friends of Huntington Beach State Park will initiate a volunteer-based monitoring program to further assess their restoration project and thereby gain

insight into seasonal and inter-annual variability. The Sandpiper Pond restoration was one of the first projects in the 5-Star program to perform any assessment. NOAA is currently developing an internet-based tool to help other community-based projects develop and implement project assessments.

The Future of Sandpiper Pond

Although further monitoring is required to identify changes in water quality attributable to the restoration, it appears that introducing salt water into the pond solely via a beach channel may not be the best course of action. Soon after each dredging, sand began to re-accumulate and impede the passage of water into the pond except during very high tides. If this management strategy of repeated dredging is continued, the channel should be widened to more closely resemble its original size which was several times wider than the artificial channel cut for the purposes of this restoration. The use of culverts as described by Brockmeyer (1999) and Myers (1996) is not an option; during the public review period, a primary concern was the impact on beach quality for recreational use.

The possibility of introducing a greater volume of brackish or saltwater to Sandpiper Pond via the marsh creek (Site 4 on Figure 1) may provide a more consistent, and less labor intensive means of restoring the saline nature of the pond. This channel would also act to introduce marine flora and fauna to Sandpiper Pond. The connection of the tidal creek to the nearby saltmarsh is currently maintained by a 12-inch diameter pipe that lies under the road that divides the salt marsh and the pond. Plans have been made to replace this with two 18-inch diameter pipes. While this should increase and stabilize the flow of salt water to Sandpiper Pond, it also raises concerns about the impact of ebb tide flows from the Pond into the nearby saltmarsh.

Acknowledgements:

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