SOURCES AND CHARACTERIZATION OF DISSOLVED ORGANIC CARBON IN THE TIVOLI BAYS FRESHWATER TIDAL WETLANDS

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ABSTRACT

The Tivoli Bays freshwater tidal wetlands have been shown to export dissolved organic carbon (DOC) into the Hudson River. The intent of this project was to determine the sources of DOC within each bay. The significant sources of DOC were characterized on the basis of bacterial productivity to determine the quality of the DOC derived from each source. In South Bay, the predominant source was found to be sediment pore water diffusion driven by a concentration gradient between the surface water and pore water. The rate of flux from the sediment was 41.7 μM/cm. The Saw Kill, a tributary to South Bay, was not considered a source since the concentration of DOC was lower than that of the main-channel Hudson River. In North Bay there also was a concentration gradient between sediment pore water and surface water resulting in a flux of 128 μM/cm. Additionally, it was found that *Typha angustifolia* leaf litter leaches DOC during flooding of the marsh surface. The standing stock of *T. angustifolia* litter (500 g/m^2) may contribute 1.50 g C/m^2 /day yielding a much larger carbon input than diffusion of DOC from North Bay porewater. Bacterial production was highest in bioassays including North Bay sediment pore water. However, since leaf litter was the major source and supported bacterial production roughly equal to bacterial production in South Bay sediment pore water, DOC exported from North Bay is not necessarily of higher bioavailability than South Bay.

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INTRODUCTION

In aquatic ecosystems organic carbon is a nutrient. Aquatic microbes generally utilize organic carbon for the synthesis of biologically active compounds. In order to be metabolized by the microbial cell, organic carbon must pass through the cellular membrane. For large compounds to be metabolized, energy must be used to catabolize organic carbon extra-cellularly. Hence, differences in the composition of the organic carbon may influence the rate at which it is metabolized.

Organic carbon found in aquatic environments can include both particulate and dissolved forms. Particulate organic carbon is referred to as POC, whereas dissolved organic carbon is referred to as DOC. POC is operationally defined as the fraction of organic carbon that is retained by a 0.45 μm filter. In the Hudson River, the quantity of DOC usually exceeds that of POC. In some instances the amount of DOC may be two-fold that of POC.

Previous studies have shown that POC is exported by some wetlands. Odum (1980) referred to the export of POC as the "outwelling hypothesis." The Tivoli Bays freshwater tidal wetland located on the Hudson River has been shown to export DOC during ebb tide. As a result, the bays are considered to be a source of DOC to the main-channel Hudson River.

Additional studies have shown that wetland derived DOC is as bioavailable as DOC from the main-channel. The quantity of wetland-derived DOC seems to increase bacterial production in the Hudson River (Findlay et al. 1992). Presumably, DOC sources may affect overall rates of bacterial production in the main-channel Hudson River. Significant sources of DOC within the bays may be as available as DOC from the main-channel.

Since the wetland DOC is of significant magnitude and highly available to microbes, the sources of DOC within the bays require attention. If the nature of DOC from various sources affects bacterial production, food web dynamics may be influenced. To be considered a source of DOC, the concentration of DOC must exceed the concentration of DOC in the main-channel.

METHODS

Sample Site

The Tivoli Bays consist of North and South Bay (Figure 1). Both bays exchange water with the Hudson River through openings in the railroad dike. The predominant vegetation in North Bay is *Typha angustifolia* (narrow leaf cattail) while South Bay is dominated by water-chestnut (*Trapa natans*). Both bays have tributary inlets, namely the Saw Kill in South Bay and Stony Creek in North Bay.

Tidal Exchange Survey

Water samples were taken at 1 hour intervals at both bays over an ebbing tidal cycle (6 hours) to confirm that the bays are indeed a source of DOC to the main-channel. Samples were filtered through Whatman 934-AH glass fiber filters and collected in Nalgene bottles.

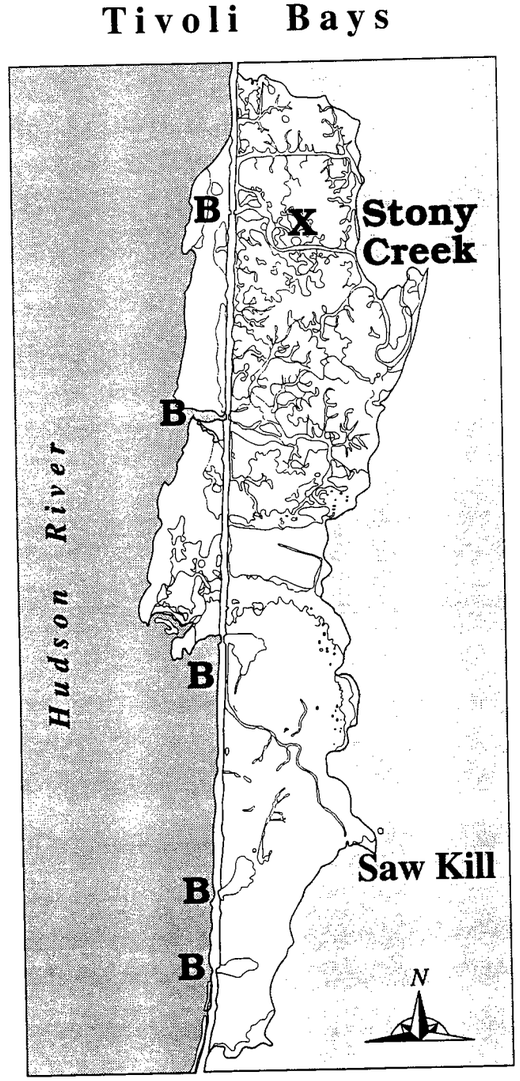

Figure 1: Map of the Tivoli Bays showing bridges allowing exchange with mainstem Hudson (B), tributaries (Saw Kill and Stony Creek) and location of core collection (✖).

Samples were analyzed for DOC on a Shimadzu 5050 Total Organic Carbon Analyzer by combustion/non-dispersive infrared gas analysis.

Source Survey

Potential sources of DOC were surveyed, including sediment pore water, plant leaf litter, and tributaries. Hill slope groundwater may be a source of DOC during high run-off periods. However, low precipitation during the field season excluded the ability to survey groundwater adequately. Tributaries were sampled at the inlet points to the bays and filtered as discussed above.

In North Bay, *T. angustifolia* leaf litter was collected from the marsh surface. Such litter is not abundant in South Bay. The litter was rinsed briefly with deionized water to remove attached sediment. A fresh-to-dry mass conversion was obtained by weighing a set of litter before and after a 24 hour period in a drying oven. The remaining litter was weighed and soaked in 500 ml of bay surface water for a half tidal cycle (6 hours). The initial surface water and litter leached water were analyzed for DOC. Subtracting the initial surface water DOC from the litter leached DOC gives the amount of DOC released by the plant material over a six hour period.

In South Bay, sediment cores were taken from selected points to determine pore water concentrations. The cores were sectioned at 2 cm intervals and centrifuged at 5000 rev/min for 10 min to draw off the pore water. The water was filtered and analyzed for DOC.

Due to an extensive root zone located in the top 10 cm of North Bay sediment, sediment cores for porewater analysis could not be taken because cutting through the roots may have contaminated the pore water, thereby producing exceedingly high DOC values. To minimize destruction of the root zone, 1 cm diameter PVC wells were inserted at 10 cm intervals. Water was pumped out of the wells using a hand-held vacuum pump. The water was collected in Nalgene bottles and filtered for DOC analysis.

Bacterial Production Assay

Significant sources of DOC were assayed for bacterial production. Since bacteria grow at different rates in the presence of various types of DOC, this assay can be used to determine how readily the DOC from different sources is metabolized. Source waters are filtered to remove bacteria, re-inoculated with a small volume of whole water and growth is followed over a 2-3 day period.

The incorporation of tritiated thymidine (^{3}H-TdR) was used to determine rates of bacterial production (Findlay et al. 1984). Thymidine is incorporated into bacterial cells during DNA synthesis. Since the rate of DNA synthesis is directly related to rate of cell division, the amount of thymidine taken up by the cell is a measure of production.

In this experiment three treatments of equivalent DOC concentration and one control were assayed with three replicates of each treatment. The treatments were North Bay sediment pore water, South Bay sediment pore water, and *T. angustifolia* litter leachate water. Source water was added to 0.22 μm-filtered main channel water such that DOC

concentrations increased about 25%. For a control we used main channel Hudson River water. All treatments were inoculated with whole water (i.e., including planktonic bacteria) from the main channel. After 24 hours ^{3}H-TdR was added to 10 mL subsamples and allowed to incubate for 1 hour. Formalin (37 % formaldehyde) was added to end the incubation and samples were filtered through a 0.2 μm Nucleopore filter to collect the bacteria. In a series of washes and extractions, the DNA was collected from each treatment and radioassayed. The resulting radioactivity measurement was used to determine the rate of ^{3}H-TdR incorporated into DNA.

RESULTS

Tidal Exchange Survey

The data collected during the ebbing tide at both bays showed an increase in DOC from high to low tide, as shown in Figure 2. The increase was statistically significant (North Bay: $p < 0.01$, South Bay: $p < 0.001$). The maximum change in concentration observed in water exiting the bays was about 1 mg C/L.

Survey of Potential Sources

Stream discharge of the Stony Creek was consistently lower than that of the Saw Kill.

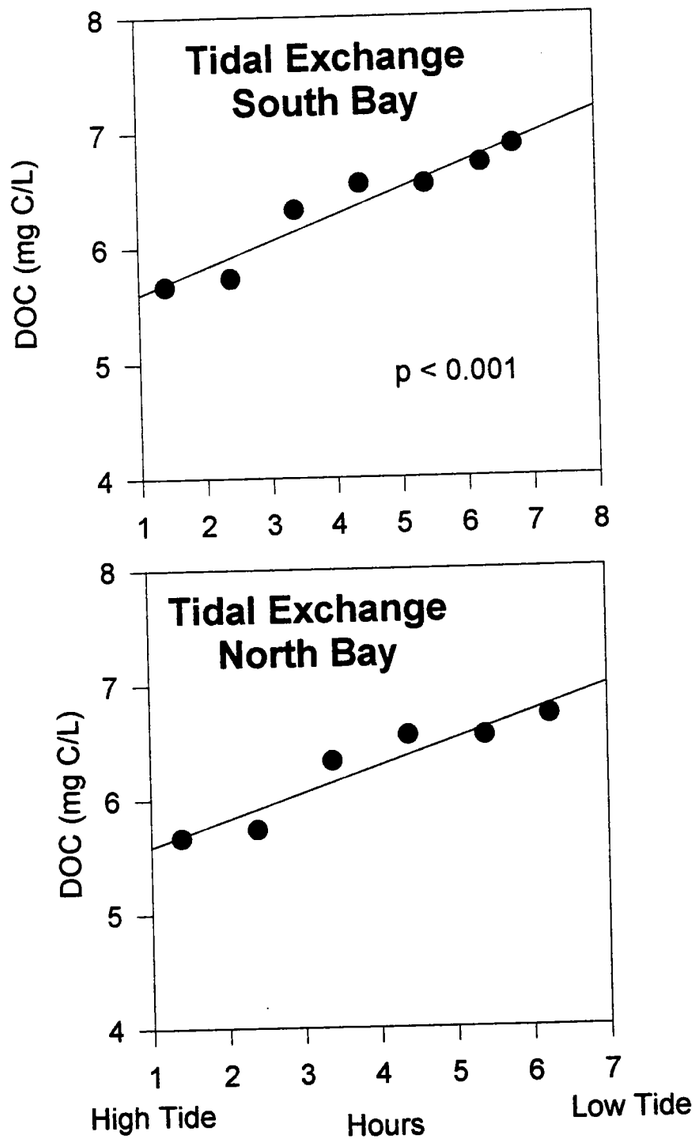

Figure 2: DOC concentrations measured in water ebbing from both North and South Tivoli Bays. Time zero is high tide, increases are significant ($p<0.05$) in both bays.

From June 1991 to May 1992, the Stony Creek discharge was 0.452 m^3/sec while the Saw Kill discharge was 0.772 m^3/sec (Nieder 1995).

The Saw Kill contained 3.32 mg C/L with a range of 0.33 mg C/L over 5 observations from May 1995 through July 1995. The Stony Kill contained 6.40 mg C/L with a range of 1.38 mg C/L. In comparison the Hudson River at Kingston, NY had an average summer concentration of DOC of 3.89 mg C/L (standard deviation: 0.85).

The Saw Kill is not a significant source of DOC in South Bay since the concentration of DOC is less than the concentration in the main-channel of the Hudson River. The higher concentrations of DOC in the Stony Creek are offset by low stream discharge. As a result, the Stony Creek is not considered a significant source of DOC.

The difference between litter-leached DOC and non-leached surface water DOC was significant ($p<0.05$), with an approximate doubling of concentration after leaching, as shown in Figure 3. The *T. angustifolia* leaf litter at North Bay leached 1.49 mg C/g DW (range: +/- 0.5 mg C/g DW, n = 4) over a 6 hour period.

A concentration gradient was observed in South Bay (41.7 μM C/cm) between the surface water and the sediment pore water with subsurface concentrations reaching 30 mg C/L (Figure 4). North Bay sediment pore water showed higher concentrations of DOC in the first 10 cm of sediment than between 20 cm and 30 cm (Figure 5). The high concentration at fairly shallow depth yields a larger concentration gradient between the surface water and sediment pore water at North Bay (128 μM/cm) than South Bay.

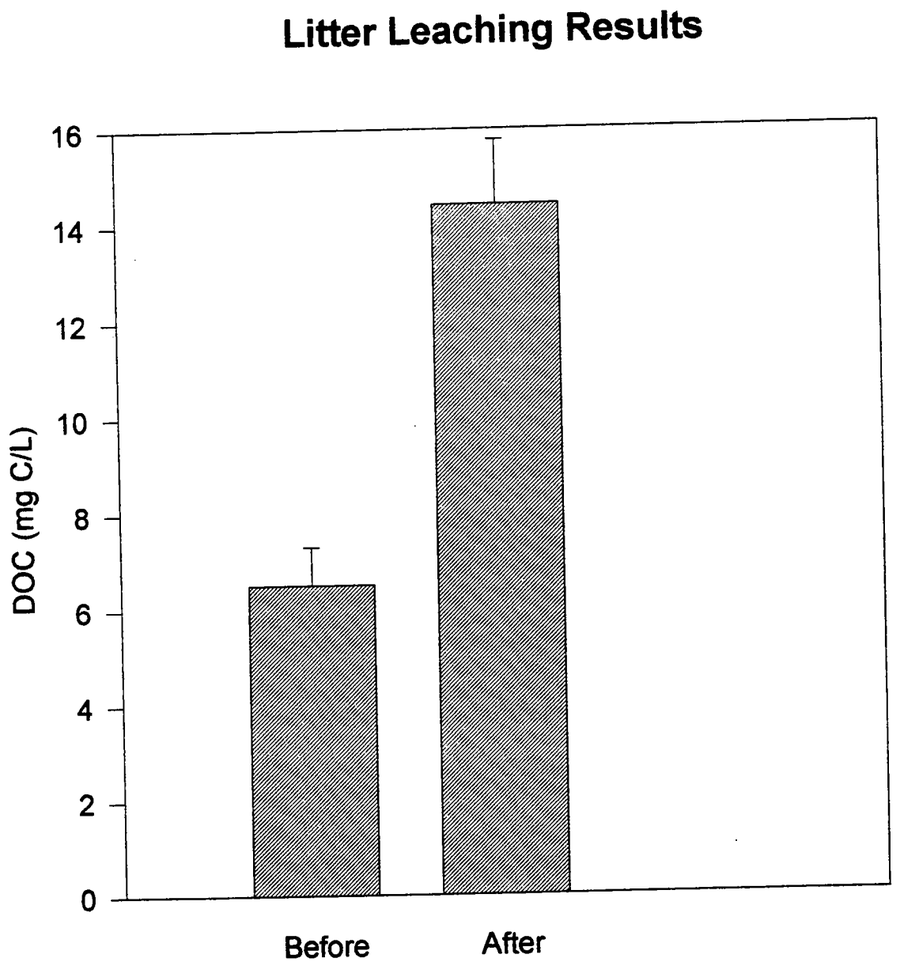

Figure 3: DOC concentrations before and after leaching of *T. angustifolia* litter in Hudson River water for six hours. Increases in concentration are significant ($p<0.05$) error bars are one standard deviation (n=4).

Bacterial Production Assay

Two bacterial production assays were performed, one using North Bay and South Bay sediment pore water, and the other using leaf litter leachate. Hudson River water from Kingston, NY was used as a reference during both assays.

North Bay sediment pore water showed the most productivity ($p<0.02$) in both assays (400 μg C/l/day). As shown in Figure 6, the remaining treatments could not be statistically distinguished from each other in terms of productivity ($p>0.05$).

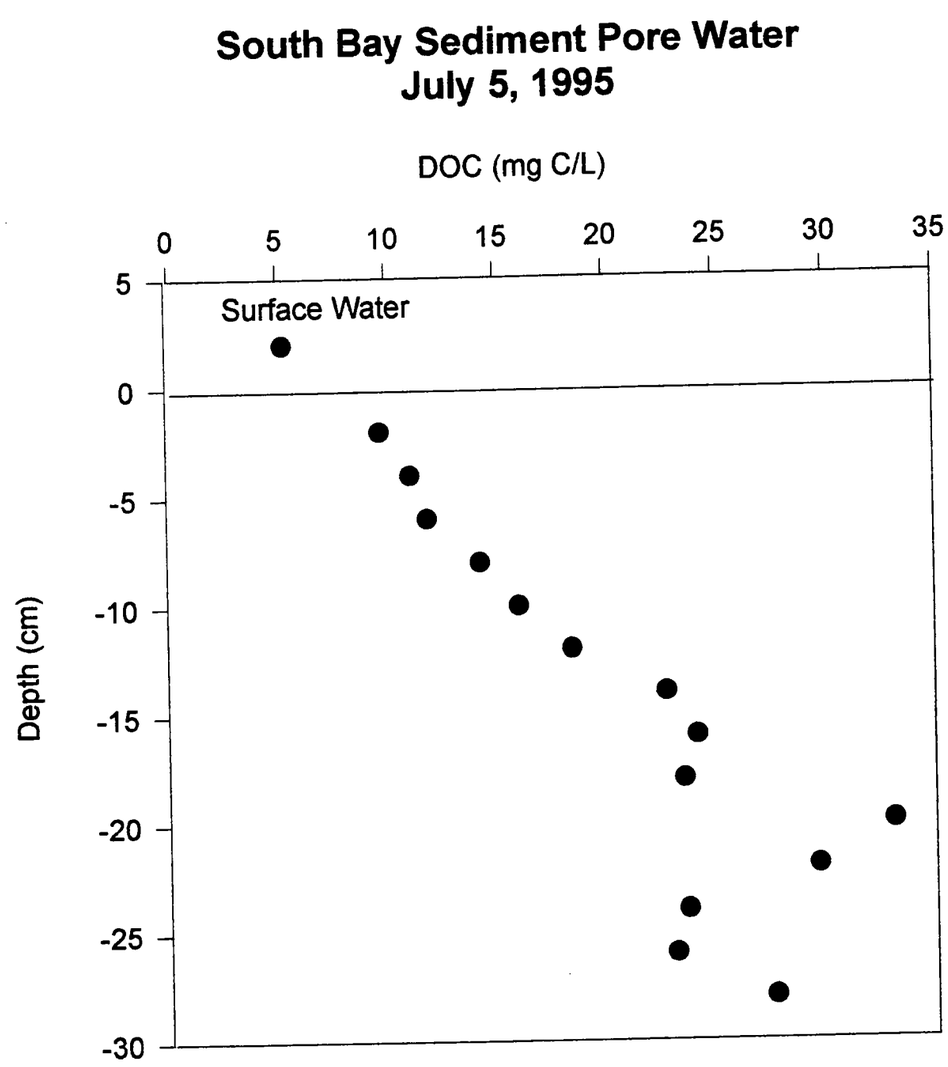

Figure 4: Profile of porewater DOC in sediments of Tivoli South Bay. Surface water concentration is shown above the zero cm line.

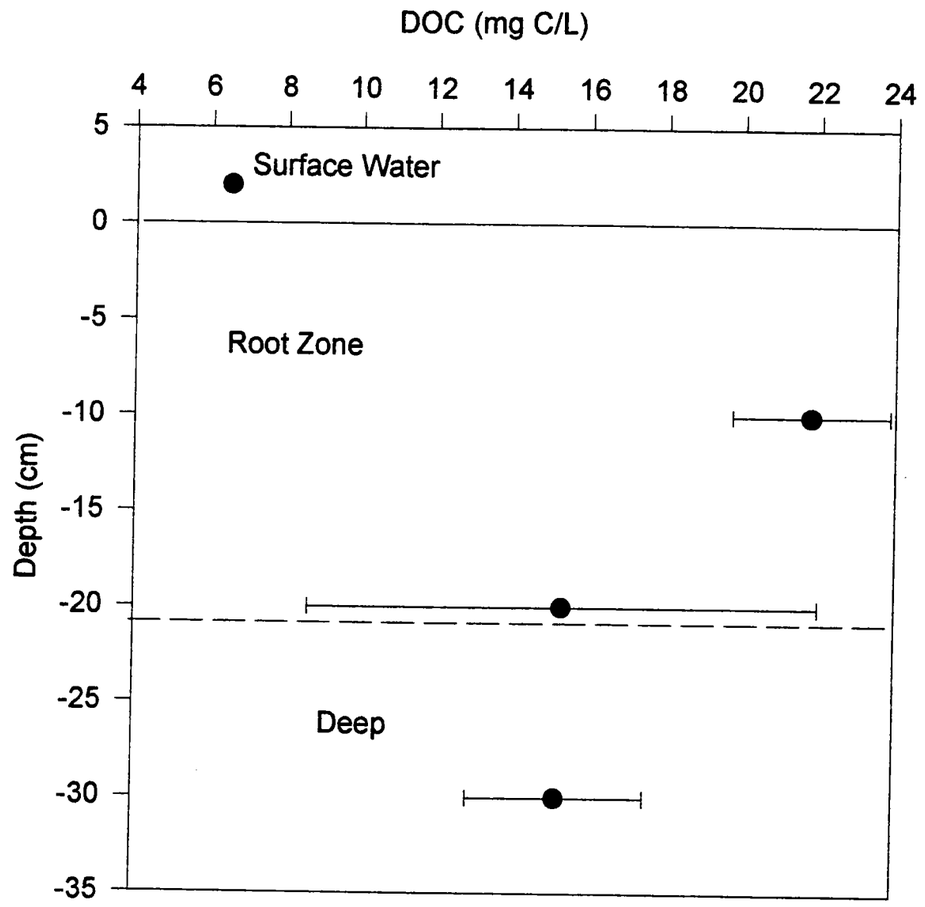

Figure 5: Profile of porewater DOC in sediments of Tivoli North Bay. Surface water concentration is shown above the zero cm line. The boundary between the rooting zone and deeper sediments is shown with a dashed line.

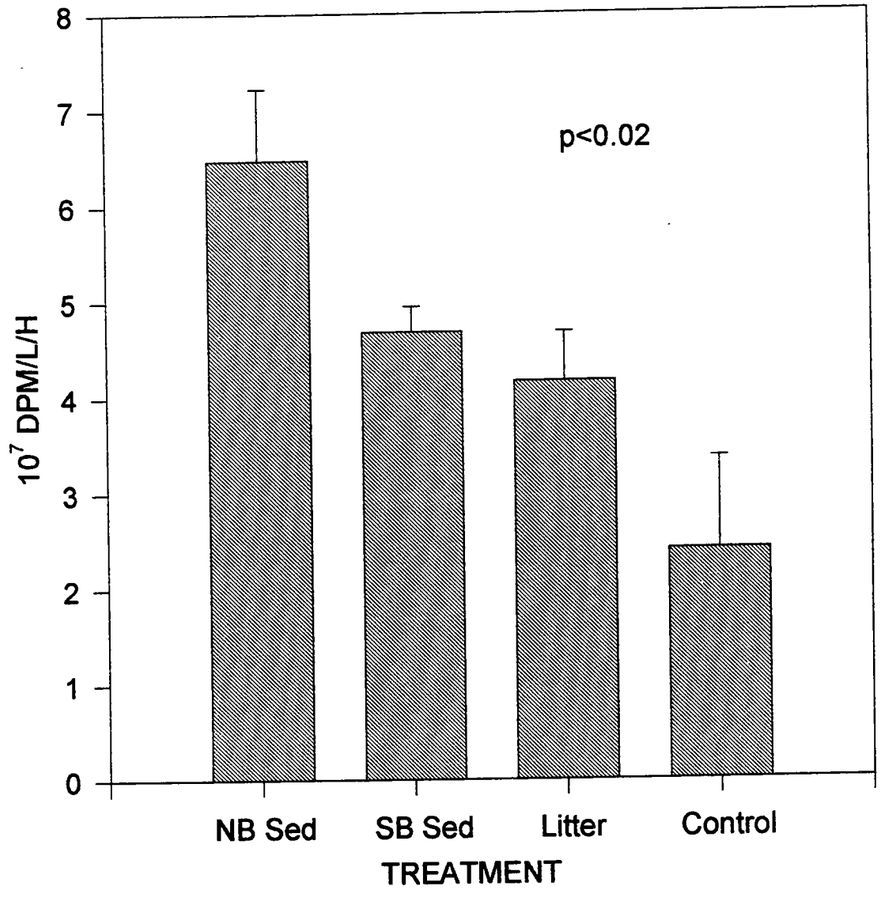

Figure 6: Bacterial productivity results for different DOC sources including North Bay porewater (NB Sed), South Bay porewater (SB Sed), litter leachate and main channel Hudson River water (control).

DISCUSSION

Based on the low concentration of DOC in the Saw Kill and low loading from the Stony Creek, it appears that neither tributary can be a major source of DOC to the Tivoli Bays. Litter leachate during flooding of the marsh surface may contribute to the export of DOC from Tivoli North Bay. Based on a standing stock of litter of 500 g DW/m^2 (Findlay et al. 1990), it can be calculated that the litter source contributes 1.5 g C/m^2 /day. This value is about three times greater than areal phytoplankton production in the main channel of the Hudson River (Cole et al. 1991).

In South Bay, sediment pore water diffusion due to a concentration gradient is probably the most significant source of DOC. Since litter is not abundant and tributaries have been ruled out, no other potential sources exist within South Bay. Live water-chestnut exudation of DOC during the late summer is not likely to be a source since the tidal exchange survey in early June documented a export of DOC before the emergence of water-chestnut.

Pore water diffusive flux of DOC is proportional to the concentration gradient of the pore water with the surface water. Flux can be determined by the following equation (Aiken et al. 1991):

$$\text{Flux} = (\varphi^3)\,(D_0)\,(dc/dz).$$

where: φ = porosity,

D_0 = diffusion coefficient

dc/dz = concentration gradient

Porosity was determined by finding the volume of water to total volume ratio for the sediment sample. The mean porosity for the samples collected was 0.9 (Findlay, unpublished data).

Assuming that for both bays porosity is 0.9 and the diffusion coefficient is 10^{-5} cm^2/s, it was calculated that the pore water diffusive flux of DOC from North Bay was 9.3 mg C/m^2/day while the flux at South Bay was 3.1 mg C/m^2/day. It is apparent that not only does North Bay have a larger pore water flux than South Bay, but both fluxes are much smaller than the litter leachate source (1.5 g C/m^2/day). At least on a per unit area scale, the litter source seems to be a larger contributor to the DOC exported from North Bay. Assuming that the surface area of litter at the marsh is 5×10^5 m^2 and the tidal export is 2×10^9 L/d, it was calculated that the theoretical export of DOC based solely on the litter source is 0.5 mg C/L. This value is close to the observed increase in concentration of ebb-tide DOC (Fig. 2).

We considered the possibility that porewater seeping from creekbanks during ebb tide could transport DOC to the stream channels. This advective flux may be larger than the estimated diffusive flux. Sampling of many (n=28) small seeps and surface trickles showed DOC concentrations (5.25 mg C/L, range: +/- 2.2 mg C/L) no greater than concentrations in the open-channel water within the bays (c.f. Fig. 2). Although we could not find high-DOC seeps, it is possible that they may be localized.

DOC bioavailability of North Bay sediment pore water is significantly higher than litter leachate. This increase in quality is counterbalanced by the small diffusive flux relative to the supply of litter leachate. In fact, bioassays show no difference in bioavailability of DOC exiting North Bay versus South Bay (Findlay, unpublished data). If sediment pore water

diffusion were the predominant source in North Bay, one would expect that the exported DOC would be of higher bioavailability than that of South Bay.

The data compiled in this project may be of value in constructing a carbon budget in the Tivoli Bays wetlands. Also, research into the usage of fluorescent techniques may helpful in tracking various components of DOC as described by Thurman (1985). However, present tracking techniques using fluorescence or absorbance spectroscopy have been unreliable. This is probably due to the complexity of chemical properties of organic carbon in the environment. Lastly, chemical assays of the carbon sources may elucidate the chemical properties of DOC that influence bioavailability.

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