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Total System Metabolism of the Plum Island Sound Estuarine System

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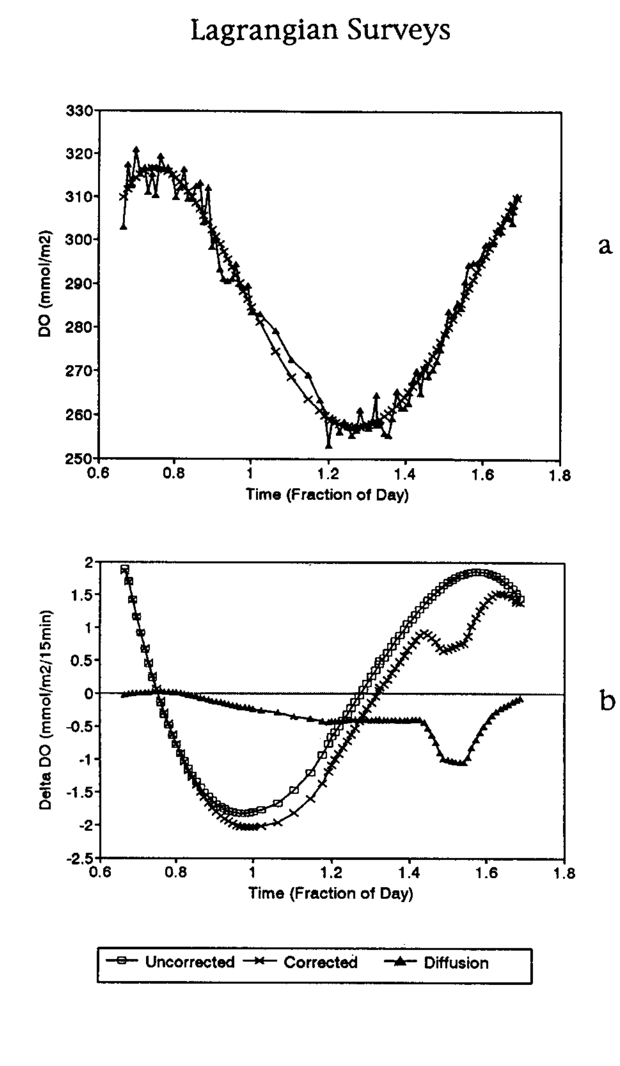
In early summer 1995, we surveyed total system metabolism in the Plum Island estuary. Objectives included (1) estimation of ecosystem metabolism via open-water oxygen measurements, (2) determination of the autotrophic and heterotrophic regions of the estuary, and (3) comparison of the loading of organic carbon from the watershed to measurements of autochthonous production.

Metabolism was calculated using two techniques: (1) 24-h Lagrangian surveys at three points in the riverine portion of the estuary at conductivities 2.7 mS/cm, 20.1 mS/cm, and 38.1 mS/cm, and (2) eight dissolved oxygen (DO) transects along the entire length of the estuary, including Plum Island Sound, from 27 June through 29 June. Respiration, gross daytime production (GDP), net daytime production (NDP), and net community production (NCP) were measured according to the procedure of Odum (1).

Lagrangian surveys demonstrated a dynamic pattern of DO change over the day. For example, in the mid-estuary at 20.1 mS/cm, the mass of DO varied over the day from 360 to 450 mmol/m^2 (Fig. 1a). Rates of DO change corrected for flux across the air-sea interface (2) indicated that primary production was highest in late morning and respiration was nearly constant throughout the night (Fig. 1b). Rates of metabolism were comparable at the three conductivities surveyed (Fig. 1c). Gross production



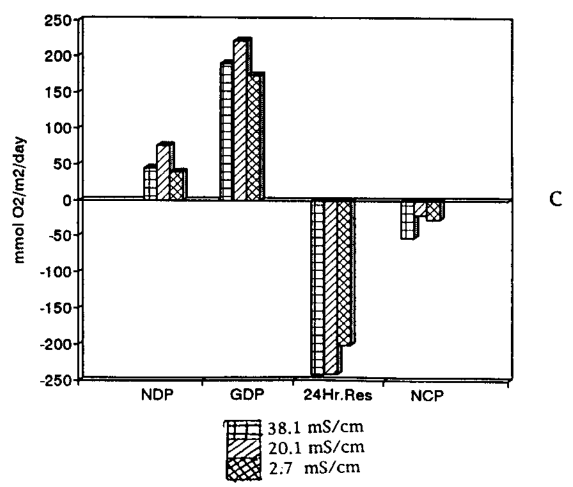


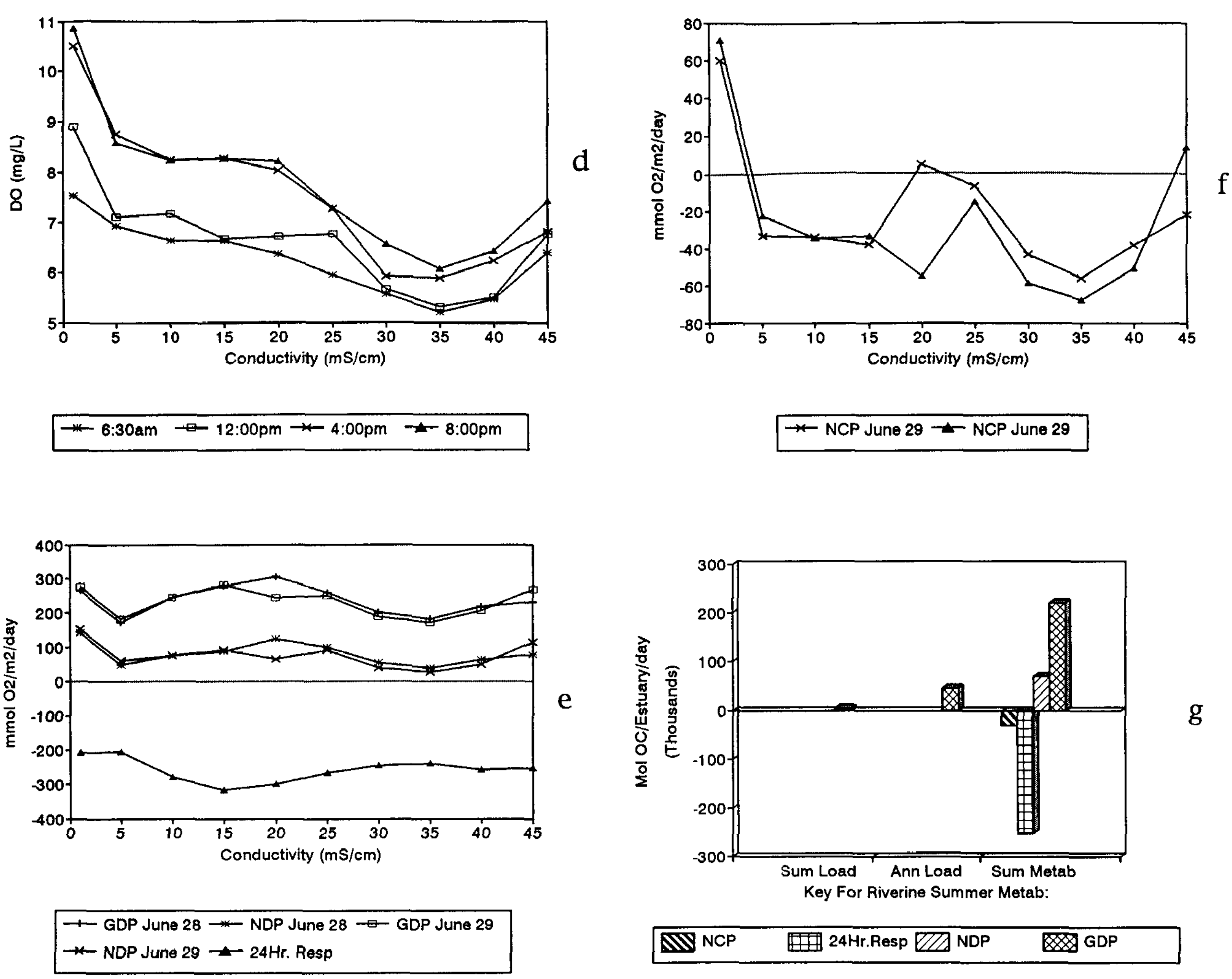
Figure 1. *(a) Diel pattern of dissolved oxygen (DO) measured during a 24-h Lagrangian survey. The best-fit curve overlies actual data. (b) Diffusion correction per 15-min interval of 6/22-3 Lagrangian shown along with the uncorrected and corrected rate of change of DO. (c) Daily measures of net daytime production (NDP), gross daytime production (GDP), 24-h respiration and net community production (NCP) from three regions within the Parker River estuary calculated by Lagrangian surveys. (d) Patterns of dissolved oxygen concentration measured over the course of a day along the entire length of the Plum Island Sound estuary. (e) Spatial patterns of GDP, NDP, and 24-h respiration obtained with the transect approach. (f) Pattern of NCP along the length of Plum Island Sound estuary. (g) Calculated inputs of organic carbon loading to the estuary from the watershed during summer and annual periods compared to transect measures of summer metabolism converted to carbon, assuming an equimolar O_2:CO_2 equivalency.*

ranged from 170 to 210 and respiration from 200 to 250 mmol O_2/m^2/day. Overall, NCP was less than zero at all sites and indicated that the system was net heterotrophic and dependent on allochthonous inputs of organic matter.

The transect surveys covered the entire length of the estuary and showed the clearest spatial patterns of metabolism (Fig. 1f–g). Daily DO levels along the length of the estuary ranged from 5.2 to 10.9 mg/l (Fig. 1d). Almost all waters were undersaturated with oxygen throughout the day. GDP ranged from 180 to 300 mmol O_2/m^2/day and NDP ranged from 20 to 150 mmol O_2/m^2/day (Fig. 1e). Spatial patterns of GDP and NDP were similar, being highest in the mid-riverine portion of the estuary (20 mS/cm) and lowest in the lower riverine portion (35 mS/cm). Daily respiration ranged from 200 to 310 mmol O_2/m^2/day. It was lowest in the upper estuary and highest in the mid-estuary (15–20 mS/cm) (Fig. 1e). Patterns of NCP indicated that only the extreme upper estuary was net autotrophic (60 mmol O_2/m^2 per day) (Fig. 1f). Although the patterns illustrated with the two techniques were similar, the transect approach provided much greater spatial information at lower cost and is the recommended method for future studies.

Spatial patterns of metabolism provide clues about the importance of allochthonous inputs of organic matter and inorganic nutrients to the estuary. This system is clearly dependent on allochthonous inputs of organic matter as almost the entire estuary is net heterotrophic (Fig. 1f,g). The regions of highest GDP may reflect the importance of inorganic nutrient inputs from the watershed (in the upper estuary) and the utilization of nutrients remineralized from organic matter that has been transported downstream to the mid-estuary (Fig. 1e). Average daily watershed inputs of organic matter during the summer are insufficient to sustain estuarine metabolism. NCP and 24-h respiration exceed watershed inputs by more than an order of magnitude (Fig. 1g). Two possible explanations could account for

Transect Surveys



this seasonal pattern: (1) metabolic needs during the summer are met by watershed inputs during the rest of the year, or (2) summer needs are met by inputs from adjacent intertidal marshes.

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Effects of Nitrogen Loading and Salt Marsh Habitat on Gross Primary Production and Chlorophyll *a* in Estuaries of Waquoit Bay

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Nixon (1) showed, using comparative data from different systems, that increased nitrogen load to shallow coastal estuaries increased production of phytoplankton. Furthermore, it has been well established that the growth of coastal producers is nitrogen limited (2). In Waquoit Bay, we have a complex of separate estuaries that are subject to different nitrogen loading rates (3). This variation in loading rate provides the opportunity to test, in one system, whether increased nitrogen loads result in increased production.

The range of nitrogen loading to the estuaries extended from a high rate of 8.1×10^3 kg N y^{-1} in Childs River to approximately 0.051 kg N y^{-1} in Sage Lot Pond. Because phytoplankton growth in shallow estuaries is nitrogen limited (2), increased loading rates are likely to affect activity and abundance of these primary producers.

Salt marsh habitats are active sites of denitrification and nutrient uptake (2). A strip of salt marsh located between the watershed and the estuary could, therefore, intercept incoming nitrogen and significantly reduce estuarine nitrogen loading. The estuaries of Waquoit Bay are surrounded by different areas of salt marsh. We could, consequently, also evaluate the effects of salt marsh on interception of nitrogen by comparing phytoplankton abundance and activity in estuaries with different extents of fringing salt marsh.

In this paper we ask, first, whether there is a relationship between nitrogen loading rate and phytoplankton abundance and productivity; and second, whether the presence of a salt marsh fringe decreases the nitrogen loading rate and, accordingly, lowers phytoplankton abundance and productivity.

We measured gross primary production (GPP) and chlorophyll *a* concentration at two stations in each of five estuaries of Waquoit Bay (Childs River, Quashnet River, Jehu Pond, Hamblin Pond, and Sage Lot Pond). We used standard light/dark bottle technique with 5-h *in situ* incubation period, and the Winkler titration method to determine primary production of the estuaries. Chlorophyll *a* concentration was measured by the Lorenzen method (4). The nitrogen loading rate was calibrated based on total dissolved nitrogen (DIN) at shore edge, rate of water recharge, and total area of the estuary.

GPP and chlorophyll *a* increased significantly with higher nitrogen loads (Fig. 1, top panels). For the regression of phytoplankton and loading, $P < 0.003$ for both GPP and Chl *a*. In Childs River, for example, the average chlorophyll *a* concentration and GPP levels were about three times as high as those in Sage Lot Pond.

Both GPP rates and chlorophyll *a* concentration decreased in estuaries with larger areas of fringing salt marsh (Fig. 1, middle panels). The cause of this decrease is not well established. The salt marshes could be physically removing phytoplankton from the flooding estuarine water during high tide and, thus, lowering

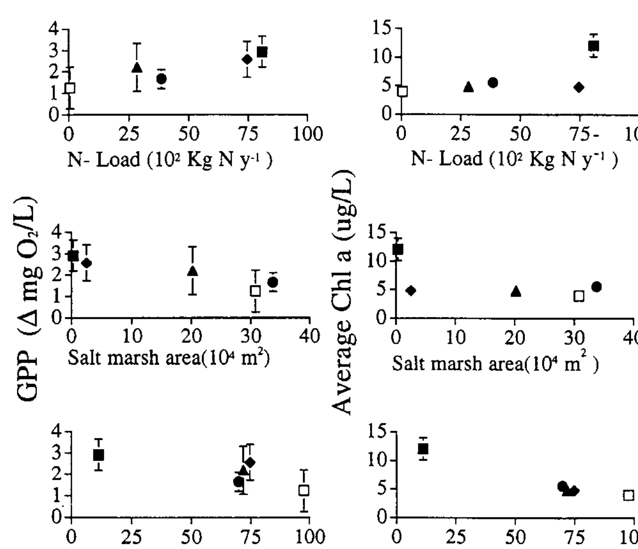

Figure 1. *Gross primary production (left panels) and chlorophyll concentration (right panels) plotted versus nitrogen load (upper panels), salt marsh area (middle panels), and percentage of the periphery of each estuary that is made up of salt marsh. Data from estuaries of Waquoit Bay, including Childs River (black squares), Quashnet River (black diamonds), Jehu Pond (black circles), Hamblin Pond (black triangles), and Sage Lot Pond (open squares).*