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Estuarine, Coastal and Shelf Science 67 (2006) 450–460

ESTUARINE COASTAL AND SHELF SCIENCE

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Tidal fluxes of dissolved oxygen at the North Inlet-Winyah Bay National Estuarine Research Reserve

L.R. Gardner [a,*], B. Kjerfve [b,1], D.M. Petrecca [a]

[a] Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA
[b] Marine Science Program, University of South Carolina, Columbia, SC 29208, USA

Received 9 June 2005; accepted 12 December 2005
Available online 27 January 2006

Abstract

Advective, dispersive and total dissolved oxygen (DO) fluxes from 1297 complete tidal cycles were analyzed to test the "outwelling" hypothesis as it pertains to DO. A 910 day time series of meteorological and water quality data (approximately 35,000 half-hourly observations) was used to assess DO fluxes and dynamics at Crab Haul Creek, a small (1.1 km^2) tidal salt marsh basin at North Inlet, South Carolina, within the North Inlet-Winyah Bay National Estuarine Research Reserve.

A basin storage curve, derived from water velocity measurements made across a permanent transect in the tidal creek every half hour for eight semidiurnal tidal cycles, enabled water discharges to be estimated from tide height readings in the 910 day time series. The discharges along with DO concentration measurements were used to calculate DO fluxes for each tidal cycle in the series.

The long-term mean dispersive and advective DO fluxes were $-0.281\ g\ O_2\ s^{-1}$ and $-0.375\ g\ O_2\ s^{-1}$, respectively. Based on "t" tests both means are significantly less than zero ($p < 0.02$), indicating exports. Furthermore a significant correlation was found between the dispersive DO export and the tidal mean solar radiation, indicating that photosynthesis is the principal process driving the dispersive export of DO. On the other hand no significant correlations were found between the advective export of DO and solar radiation or between the dispersive fluxes of DO and salt. The absence of such correlations indicates that the advective export of DO is simply an artifact of a slight ebb sampling bias in our computation of the tidal mean discharge. On a unit area basis the average annual dispersive export of DO is 8.9 $g\ m^{-2}\ yr^{-1}$ or 0.28 mol DO $m^{-2}\ yr^{-1}$. This is a small fraction of the oxygen produced in the basin by phytoplankton (18 mol DO $m^{-2}\ yr^{-1}$) and its contribution to the DO resources of the receiving waters is far exceeded by the oxygen demand associated with the concurrent export of dissolved organic carbon (200–300 $g\ m^{-2}\ yr^{-1}$).

Keywords: salt marshes; dissolved oxygen; transport; salt advection; outwelling; USA; South Carolina; North Inlet

1. Introduction

1.1. Background and rationale

The oxygen cycle in aquatic ecosystems is governed by various abiotic and biotic processes that produce or consume DO (Fig. 1). Significant inputs of DO are photosynthesis by plants, algae and phytoplankton and the diffusion of O_2 gas across the air–water interface during intervals of undersaturation. Other processes act to deplete the water column of DO. Resident nekton and plankton consume DO through aerobic respiration. Although biological and chemical oxidation of suspended particulate matter also may consume water column DO, 30–50% of the total oxygen uptake can be attributed to the sediment oxygen demand, SOD (Mancini et al., 1986; James, 1986), which is due to various DO consuming reactions that take place in the bottom sediments.

* Corresponding author.
E-mail address: gardner@geol.sc.edu (L.R. Gardner).
[1] Department of Oceanography, College of Geosciences, Texas A&M University, College Station, TX 77845, USA.

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doi:10.1016/j.ecss.2005.12.002

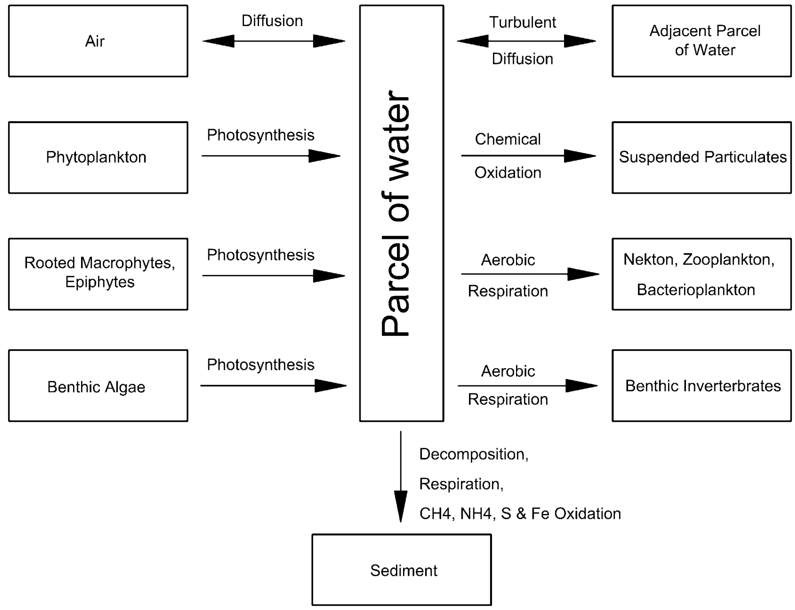

Fig. 1. DO dynamics in aquatic ecosystems.

Salt marshes are sites of intense biogeochemical activity (Valiela et al., 1978; Nixon, 1980; Dame et al., 1986, 1990). The coupling of biogeochemical activity with tidal flushing led Odum (1968) to hypothesize that salt marshes in the southeastern United States produce more organic material than can be consumed or stored within the marsh, such that any excess is exported to the coastal ocean. The export of excess material was thought to support productivity in the nearby coastal ocean. Even though Odum had no supporting data, his so called "Outwelling Hypothesis" became the focus of intensive study for the next two decades (Nixon, 1980). Investigations have examined the tidal fluxes of different forms of carbon, nitrogen, phosphorous, sediments and some metals (Settlemyre and Gardner, 1977; Valiela et al., 1978; Kjerfve and McKellar, 1980; Ward, 1981; Gardner et al., 1989; Dame et al., 1986, 1990). Other than measurements over a few summer-time tidal cycles by Gardner and Gorman (1984), little attention has been paid to DO fluxes in salt marsh basins. Considering the importance of adequate DO concentrations to the health and vitality of marine ecosystems, we test here the "Outwelling Hypothesis" as it applies to dissolved oxygen in a southeastern (USA) marsh–estuary system.

2. Methods

2.1. Study area and NEERS measurements

The site of this study is a small, salt marsh basin within the North Inlet-Winyah Bay National Estuarine Research Reserve System (NERRS/NOAA) near the University of South Carolina Marine Laboratory at North Inlet, South Carolina (Fig. 2). The North Inlet system consists of 32 km^2 of salt marsh drained by numerous meandering tidal creeks. It is typical of the marsh–estuary systems located between Cape Hatteras and Cape Canaveral on the southeastern Atlantic coast (Kjerfve, 1986). The dominant marsh plant is *Spartina alterniflora* with *Salicornia* and *Juncus* at higher elevations along the marsh edge (Dame and Gardner, 1993; Thibodeau et al., 1998). The mean semidiurnal tide range is about 1.5 m with peak currents usually around 1.4 m s^{-1}. However, on spring tides, currents occasionally exceed 2.3 m s^{-1} (Kjerfve et al., 1981). With creek depths of only 3–8 m, the tidal range accounts for a significant fraction of the total water depth. As a result, 40% of the total water volume leaves the estuarine system with each ebb tide (Kjerfve, 1986). This leads to a hydrodynamic residence time of only 15 h (Kjerfve, 1986). The shallow depths and intense tidal turbulence also make the tidal creeks well-mixed and almost vertically homogeneous with respect to dissolved constituents (Kjerfve, 1986). Salinity usually falls between 30 and 34 ppt due to very low fresh water input, estimated between 1 and 5 $m^3\ s^{-1}$. After periods of intense rainfall, though, salinities can drop to 4 in the landward reaches of the creeks.

The Crab Haul Creek basin is the landward-most salt marsh basin at the North Inlet site (Fig. 2) and was the focus of this study. This small tidal basin (1.1 km^2) is drained by a terminal tidal creek. Flanking the basin are forested, relic beach ridges that form the drainage divides between adjacent basins (Gardner and Bohn, 1980; Miller and Gardner, 1981; Gardner and Porter, 2001). Crab Haul Creek flows past the Oyster Landing pier, where NERRS meteorological and water quality data are collected, and joins other tidal creeks approximately 300 m further seaward. Extrapolation of the fresh water input given by Dame et al. (1991) for the adjacent Bly Creek basin to the Crab Haul Creek basin indicates an inflow of $2.7 \times 10^6\ m^3\ yr^{-1}$ via direct rainfall and surface plus groundwater runoff from the adjacent forest. This input is offset by a loss of $1.4 \times 10^6\ m^3\ yr^{-1}$ via evapotranspiration (Gardner and Reeves, 2002) leaving a net input of fresh water of about $1.3 \times 10^6\ m^3\ yr^{-1}$. This is about 0.9% of the total tidal water that enters the basin each year ($1.8 \times 10^8\ m^3\ yr^{-1}$). Detailed