A Metabolism-Based Trophic Index for Comparing the Ecological Values of Shallow-Water Sediment Habitats

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ABSTRACT: We determined fluxes of oxygen and nutrients between water and sediments at 21 sites primarily in Virginia and North Carolina estuaries, over the past 15 yr. These sites represented broad ranges in salinity, tidal amplitude, hydrology, nutrient availability, turbidity, light availability, depth, sediment grain size, and anthropogenic disturbance. In general, we found that heterotrophically dominated sediments had the potential to degrade water quality, whereas photoautotrophy in the sediments ameliorated this impact. We propose a benthic trophic state index as a management tool to make general assessments of the degree to which sediments support ecological processes related to photoautotrophy. The index can be based on simple measurements of metabolic parameters. We also evaluated the relative significance of variability in the index across a number of spatial and temporal scales. Reduced photoautotrophy and/or enhanced heterotrophy tended to be associated with finer-grained, organic-rich sediments. This sediment type was common in oligohaline areas at water depths exceeding 2 m. Temporally, autotrophy declined from winter to spring particularly at sandy sites, while interannual variability was more pronounced for mud sites.

Introduction

In the York River estuary in Chesapeake Bay and the Neuse River estuary in Ablemare-Pamlico Sound, euphotic sediments extend to 2–3 m in water depth and occupy ca. 40% of the total benthic area (Rizzo 1990; Rizzo et al. 1992). These estimates are consistent with earlier ones for the mid-Atlantic states (Connecticut to North Carolina) where shoal areas ≤2 m in depth comprise 23–42% of the total estuarine area (shoals + tidal marshes + deeper open waters; Fig. 1, derived from Spinner 1969). While the significance of shoal areas to fisheries has long been appreciated (Spinner 1969), the description of other functions and values of shallow areas has been much more recent. Shoal areas serve an important function as a primary successional stage for salt marsh development (Coles 1979). Most lay people consider recreation to be the primary value of shoal areas, but shoals may also support photoautotrophy, which fuels the estuarine food web and ameliorates water quality by immobilizing inorganic nutrients and by producing oxygen.

The value of organic matter produced by benthic microalgae arises from three major attributes: quantity, lability, and availability. Benthic microalgal primary productivity in sediments not vegetated by macrophytes is typically ca. 100–340 g C m⁻² yr⁻¹ (Marshall et al. 1971; Davis and McIntire 1983; Nienhuis and de Bree 1984; Nowicki and Nixon 1985a; Shaffer and Onuf 1986; Wasmund 1986; Murray and Wetzel 1987; Fielding et al. 1988; Sundbäck and Jonsson 1988; Moncreiff et al. 1992; Rizzo et al. 1992). This is similar to the phytoplankton production of many estuarine areas on an areal basis (Marshall et al. 1971; Cadee and Hegeman 1974; Joint 1978; Murray and Wetzel 1987; Fielding et al. 1988; Pinckney
Benthic microalgae can also ameliorate water quality by stabilizing sediments and altering sediment-water nutrient fluxes. Biofilms produced by benthic microalgae stabilize sediments (Holland et al. 1974; Grant et al. 1986; Paterson et al. 1990), thus reducing sediment resuspension, improving water clarity, and preventing or reducing release of nutrients from resuspended sediments. Sediments dominated by benthic microalgae have lower rates of ammonium, phosphate, and nitrate + nitrite release to the water column, and in many cases become sinks for nutrients rather than sources (Nowicki and Nixon 1985b; Sundbäck and Granéli 1988; Rizzo 1990; Nilsson et al. 1991; Sundbäck et al. 1991; Rizzo et al. 1992). Phosphate fluxes may be affected directly by active microalgal uptake or indirectly by the sequestering of phosphate in iron and manganese hydroxide complexes in oxic sediments (Carlton and Wetzel 1988; Chambers and Odum 1990; Sundbäck et al. 1991). Decreases in ammonium released to the water column by sediments may be particularly important in estuaries where nitrogen limits phytoplankton production, because ammonium is preferred as a nitrogen source relative to nitrate (McCarthy et al. 1977; Paerl et al. 1990).

The trophic status (i.e., photoautotrophy versus heterotrophy) of unvegetated sediments thus affects a number of ecologically important functions. However, unlike macroscopic seagrasses, the trophic status of unvegetated sediments cannot be determined by visual inspection. Such evaluations generally involve time-consuming and relatively costly estimates of primary productivity or indicators of benthic microalgal biomass (e.g., cell numbers, cell volumes, chlorophyll a). An early effort to develop a classification system with general applicability to tidal flats (both intertidal and shallow subtidal) based on measuring sediment metabolism (1–8 sample dates; 2–4 h incubations) was unsuccessful (Rizzo and Wetzel unpublished data). At that time (1978), the extent of spatial (small-scale, latitudinal scale, depth related and substrate related) and temporal scales of variability was so poorly known that the resultant data could only be interpreted in a site-specific and temporally specific context. Managers of estuarine systems need methods for descriptive classification of resources. One recently developed benthic index classifies macrofaunal communities as degraded or not degraded based on a suite of environmental characteristics (Engle et al. 1994). Based on the results of a number of studies of the metabolism of shoal environments, we develop, herein, a benthic trophic state index (BTSI) as a tool for the general assessment of the trophic state of shoal environments by management agencies. We base the index on metabolic