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Estuarine influence on biogeochemical properties of the Alabama shelf during the fall season

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A B S T R A C T

Estuarine-shelf exchange can drive strong gradients in physical and biogeochemical properties in the coastal zone and exert a significant influence on biological processes and patterns. Physical, biogeochemical, and plankton data from an across-shelf transect extending south of Mobile Bay, Alabama, in conjunction with regional time series data, were used to determine the relative importance of estuarine-shelf interactions on the physical-biological structuring of the shelf environment during fall conditions (i.e., well-mixed, low discharge). This period was also characterized by a relatively unique weather event associated with the remnants of Hurricane Patricia, which drove a meteorological flushing of estuarine water onto the shelf. Survey data indicated generally low N:P ratios across the shelf, with slightly elevated dissolved inorganic nitrogen in the Region of Freshwater Influence (ROFI) that extended approximately 30 km offshore. The ROFI had higher values of chlorophyll-a, diatom-specific production, marine snow, and primary productivity, with notable contributions from the larger size cells (> 5 µm). Furthermore, stratification provided a niche opportunity for *Trichodesmium* sp. aggregates, a typically oligotrophic cyanobacteria, at the offshore edge of the ROFI. The lens of estuarine water may have limited the vertical extent to which this population was mixed, providing enhanced light availability relative to the well-mixed offshore conditions. Following the biogeochemical trend, the highest zooplankton abundances were also located within the estuarine outflow. While limited in spatial extent, the distinct geochemical and biological characteristics within the ROFI demonstrate the ecological impacts that estuarine-sourced waters can have during periods of generally low productivity in the Mississippi Bight.

1. Introduction

Coastal systems are critical to the overall oceanic productivity and subsequent transfer of carbon to higher tropic levels as well as the seabed (Longhurst et al., 1995), which represent a significant component of the global carbon budget. In many systems, a major control on this productivity is freshwater inputs from rivers (Grimes, 2001; Dittmar and Kattner, 2003; Moline et al., 2008). Freshwater discharge exerts this control in multiple ways including through affecting physical (e.g., circulation patterns as well as both horizontal and vertical stratification) and biogeochemical (e.g., nutrient availability) processes. Complicating the shelf biogeochemical and planktonic response to freshwater discharge are estuaries, where increased residence time of river water may radically alter its properties prior to its arrival on the shelf (Shiller, 1993; Pennock et al., 1999). In addition, strong gradients in the physical, biogeochemical, and planktonic characteristics that develop in response to pulses of freshwater are highly variable in space (e.g., horizontal, vertical) and time due to their dependency on the timing and magnitude of river discharge. Nevertheless, understanding the interaction of buoyancy-driven physical processes and the associated biogeochemical and planktonic characteristics within the coastal ocean is essential due to their role in structuring ecosystem processes.

Many studies focus on the role of outflow (riverine or estuarine) during periods of high discharge due to the often clear positive relationship between discharge and nutrient fluxes (e.g., Turner et al., 2003). Kudela et al. (2010) found that the bulge region of the

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Columbia River plume simulated growth across three trophic levels as result of discharge supplied fluvial nitrate. Similar biological activity was observed in a recirculation region of the Hudson River plume as a result of complex physical, chemical and biological interactions (Moline et al., 2008). Other studies have demonstrated that changes in buoyancy, associated with river discharge, can influence across-shelf exchange and the onshore advection of nutrient-rich waters. Using a box model based on the water and salt balance, Chen (2000) determined that reductions in river discharge as a consequence of the construction of the Three Gorges Dam would reduce onshore advection of subsurface Kuroshio waters, a major source of shelf nutrients. Conversely, a large influx of river discharge onto the continental shelf in the southern East China Sea was linked to an upwelling of nutrients (via buoyancy induced across-shelf transport) after the passage of Typhoon Herb (Chen et al., 2003). Thus, shelf productivity has been tied to river discharge both directly (via terrestrial nutrient delivery) as well as indirectly (via modulating across-shelf exchange).

However, certain estuarine systems can experience large volume exchanges with the shelf during periods of low river flow. For example, many shallow lagoonal systems in the northern Gulf of Mexico are particularly susceptible to meteorological flushing (i.e., wind-driven exchange). Examining multiple bays along the Louisiana coastline, Feng and Li (2010) found that wind forcing from strong cold fronts flushed over forty percent of the water volume from some bays onto the shelf within a 40-h period. These wind-forced events are capable of resuspending sediment, which can introduce nutrient-rich pore water to the water column (Fanning et al., 1982) and may represent a significant estuarine source of nutrients and particulate matter to the coastal shelf. Thus, significant nutrient inputs from such processes may influence ecosystem function during periods of low river discharge.

Survey data along a transect south of Mobile Bay from a large-scale field program of the Gulf of Mexico Research Initiative (GoMRI), namely the CONsortium for Coastal River-Dominated Ecosystems (CONCORDE), were serendipitously available and are used here to examine the coupled physical-biogeochemical impacts on the continental shelf that resulted from a major meteorological flushing event during the fall of 2015. This study focuses on the shelf region directly offshore of Mobile Bay, a major source of freshwater input to the Mississippi Bight in the northern Gulf of Mexico (Fig. 1). Mobile Bay is a shallow (average depth 3.0 m), microtidal (tidal range of 0–0.4 m), river-dominated estuarine system having the 4th largest discharge volume in the U.S (~1800 $m^3 s^{-1}$) (Stumpf et al., 1993). However, there is significant seasonal variability in the discharge levels; during the late summer and fall seasons daily averaged values are typically less than 1000 $m^3 s^{-1}$ (Dzwonkowski et al., 2011). The bay is directly connected to the continental shelf through Main Pass, a tidal inlet, about 5.5 km wide and 3–4 m deep outside a narrow (500 m), deep (13–14 m) ship channel, which accounts for an estimated 64% of the freshwater outflow from Mobile Bay (Kim and Park, 2012). A shallow secondary connection, Pass Aux Heron, links the bay to Mississippi Sound and accounts for the remaining exchange.

Despite being part of the "fertile crescent" of fisheries in the northern Gulf of Mexico (Gunter, 1963), only a limited number of studies have documented the physical or biogeochemical conditions of the inner to mid-shelf of the Mississippi/Alabama coast during low discharge conditions. Of interest are smaller sources of estuarine-shelf exchange associated with numerous tidal inlets throughout the northern Gulf of Mexico that may be seasonally important during periods of reduced discharge from the Mississippi River. These sources of exchange may be of particularly interest for the Alabama-Mississippi shelf during the fall when the predominant shelf currents typically advect the Mississippi River discharge southwestward around the bird-foot delta (Morey et al., 2003; He and Weisberg, 2003) and meteorological flushing/mixing events associated with cold-front passage are common (Feng and Li, 2010). For example, Dzwonkowski et al. (2011) showed physical impacts of estuarine-shelf exchange from Mobile Bay

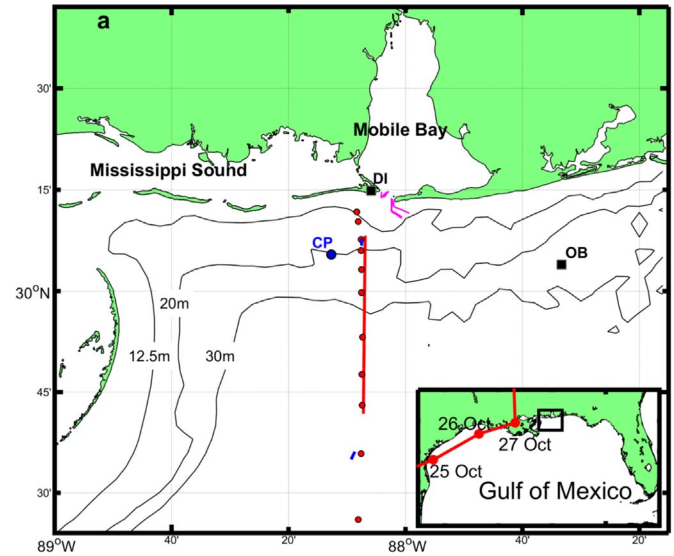

Fig. 1. Study area in the Mississippi Bight off the Alabama coast and the associated regional bathymetry (black lines). Sampling along the MCORR survey line from the Fall 2015 CONCORDE field campaign is shown including the ISIIS transect (red line), location of net-tows (blue hashes), and water sample stations (red circles). The tracks from a drifter release at Main Pass on 29 Oct. (magenta lines) are also provided. Wind data were obtained from NDBC stations (■) at station DPIA1 on Dauphin Island (DI) and station 42012 offshore of Orange Beach, AL (OB). Water level and salinity data were obtained from an NDBC station (DPIA1) and an ARCOS water quality station, respectively, in very close proximity on Dauphin Island (DI, ■). Water column temperature data were obtained from site CP (blue circle). The inset shows the study site (black box) in relation to the northern Gulf of Mexico. The red line shows the approximate track of the remnant low pressure system resulting from Hurricane Patricia. The circles indicate the location on the given dates. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

on the Alabama shelf during the dry season (Fall/Early winter), when the water column was stratified within ~ 20 km of the coast while the offshore shelf was relatively well-mixed. The biogeochemical and planktonic patterns and processes on the shelf, critical aspects of ecosystem functioning, may also be affected by estuarine-shelf exchange during low river flow conditions. To our knowledge, no studies in this region have addressed the coupled physical-biogeochemical and planktonic conditions on the shelf during low discharge conditions typical of the fall season.

Even during low river discharge conditions, the estuarine-shelf exchange is expected to generate a strip of coastal water that reflects the influence of these relatively fresher estuarine waters, with demonstrable biological impact. The primary objective of this study was to examine the effects of estuarine-shelf interactions on the physical and biological structuring of the shelf environment during fall conditions typical of the central northern Gulf of Mexico (i.e., well-mixed, low river discharge period). This study uses a diverse array of interdisciplinary data to characterize the relationships between the hydrographic conditions and biogeochemical variables, including nutrients and plankton data, in a region directly impacted by outflow from Mobile Bay (i.e., a region of freshwater influence (ROFI), Simpson (1997)). Occurring in the wake of a strong weather event (i.e., the passage of Hurricane Patricia's remnants), the study provides a novel view of the shelf structure following a large meteorological flushing event. As a result, the scale of the ROFI is as large as might be expected during a period of low river discharge. Under these conditions (large flushing, but low river flow), our observations reveal that the region of the shelf impacted by estuarine-shelf exchange was subject to concomitant alteration of biological properties and nutrient levels relative to offshore characteristics. While the survey period occurred after a large event, the common occurrence of cold fronts (and the associated estuarine-shelf exchange) in this region suggest that the enhanced