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Hurricane Katrina induced nutrient runoff from an agricultural area to coastal waters in Biscayne Bay, Florida

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ABSTRACT

Water quality surveys conducted in Biscayne Bay, Florida, indicated enhanced nutrient input coupled with increased runoff as a result of precipitation associated with Hurricane Katrina. Nutrient concentrations before Katrina ranged from 0.06–24.2 μM (mean 3.3 μM) for nitrate and 0.01–0.18 μM (mean 0.1 μM) for soluble reactive phosphate. Five days after Katrina, nitrate concentrations ranged from 0.87–80.0 μM (mean 17.0 μM), with a bay-wide mean increase of 5.2-fold over pre-hurricane levels. Soluble reactive phosphate concentrations ranged from 0.07–0.62 μM (mean 0.2 μM), with a bay-wide mean increase of 2-fold over pre-hurricane levels. The maximum concentrations for both nitrate and soluble reactive phosphate were found at a water quality monitoring station near the mouth of Mowry Canal, which drains an agricultural area in the southern Biscayne Bay watershed near Homestead, Florida. At this station, nitrate and soluble reactive phosphate concentrations increased 7- and 10-fold, respectively. Storm-induced fertilizer runoff from this agricultural area caused a bay-wide increase in nutrient concentrations after Hurricane Katrina. Nutrient concentrations in the bay returned to pre-hurricane levels within three months after Hurricane Katrina, showing the resiliency of the Biscayne Bay ecosystem.

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1. Introduction

Coastal regions have become the most densely populated places in the world. Attracted by a mild oceanic climate and unique recreational activities, approximately 53% of the U.S. population lives along coastal regions that account for only 17% of the contiguous U.S. land mass, and coastal populations are expected to grow faster than inland areas, reaching an estimated 165 million people by the year 2015 (NOAA, 1998). In addition, beaches have also become one of the most popular vacation destinations, resulting in approximately 180 million people visiting U.S. coastal regions annually (Cunningham and Walker, 1996). Thus, population growth and its associated industrial, agricultural, and residential development places coastal regions under increasing environmental burden. This increased environmental burden has caused significant degradation to many adjacent aquatic ecosystems.

One of most common symptoms of increasing pressure on nearshore aquatic ecosystems due to population density is eutrophication, which is often the result of excessive nutrient loading (NRC, 2000). Sources of nutrients include fertilizer application for agricultural and landscaping activities, wastewater discharge, urban runoff, land-use practices, and fossil-fuel burning (Lapointe et al., 1990; Lapointe and Clark, 1992; Valiela et al., 1992; Lapointe and Matzie, 1996; Valiela et al., 1997; Brand, 2002; Lapointe et al., 2004; Lapointe and Bedford, 2007). Freshwater flow is usually the major transport mechanism that delivers nutrients from inland watersheds to coastal waters. Because rainfall can effectively leach nutrients from the air and soil and carry them in surface runoff, the heavy rainfall often dramatically increases both freshwater flow and its nutrient concentrations. Therefore, local climate, including meteorological and hydrological conditions, often dominates the seasonal pattern of nutrient flux to coastal waters.

The effect of tropical cyclones on water quality in coastal embayments is variable due to the differing characteristics of individual storms and embayments (Burkholder et al., 2004, 2006; Greening et al., 2006; Mallin and Corbett, 2006; Paerl et al., 2001, 2006). The direction and speed of approach, as well as the point of landfall, intensity, and amount of rainfall all influence a tropical cyclone's environmental impact on a coastal ecosystem (Weisberg and Zheng, 2006; Wetz and Paerl, 2008a, 2008b). Embayments with higher land-use activity, such as Biscayne Bay, typically suffer more severe and longer-lasting environmental damage following tropical cyclone passages (Mallin et al., 1999, 2002; Mallin and Corbett, 2006). On August 25, 2005, Hurricane Katrina made

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landfall just north of Biscayne Bay as a category 1 storm and moved southwest, producing up to 14 inches of rainfall within the Biscayne Bay watershed. This study examines the effect of Hurricane Katrina on nutrient enrichment in Biscayne Bay and discusses the recovery of the bay after Hurricane Katrina.

2. Methods

2.1. Study area

Biscayne Bay is located along the east coast of south Florida, adjacent to the Miami metropolitan area (Fig. 1). The bay is 61 km long and 18 km wide. Its major axis is aligned from north to south with a surface area of approximately 700 km^2. The western boundary is bordered by residential communities in the north and mangrove shoreline in the south. With the exception of Key Biscayne, a chain of uninhabited barrier islands form the eastern boundary of the bay, providing separation from the coastal Atlantic Ocean. However, there is a large section of this eastern boundary without barrier islands that is open to oceanic exchange via tidal flows (Wang et al., 2003). Our study area comprised the central and southern portions of Biscayne Bay from Rickenbacker Causeway in the north to Blackwater Sound in the south.

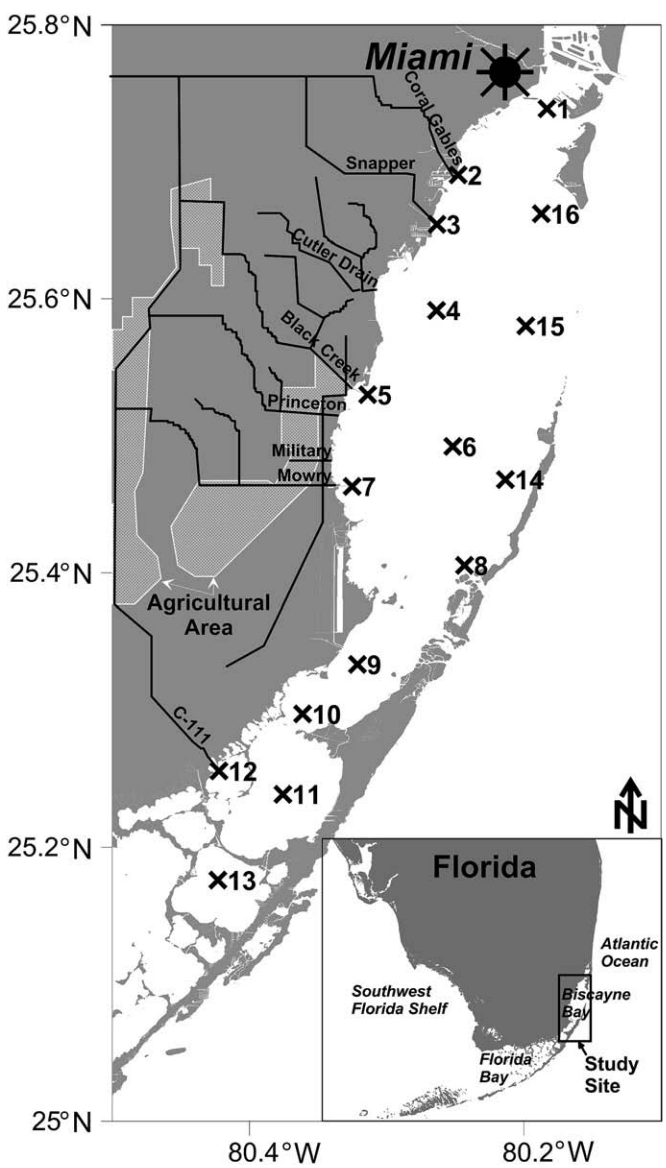

Fig. 1. Enlarged view of Biscayne Bay depicting its watershed and the location of major canals, an agricultural area, and water quality monitoring stations (1–16). The inset shows the location of Biscayne Bay on the south Florida peninsula.

Biscayne Bay was geologically formed by rising sea levels that filled a limestone depression (Wanless, 1969). The average water depth in the bay is about 2 m, with a maximum depth of approximately 4 m (Roessler and Beardsley, 1974; Cantillo et al., 2000). Unlike many estuaries, the bay does not receive significant sediment loading from large river systems. Instead, most sediment in the bay is produced through internal processes by local biota (Wanless, 1976). Because of the bay's shallow depth and low light attenuation, primary productivity is dominated by submerged aquatic vegetation (SAV) (Roman et al., 1983). In nearshore waters, the dominant component of the SAV community shifts from seagrass in the dry season to macroalgae in the wet season, particularly near canal mouths (Lirman and Cropper, 2003; Lirman et al., 2008). This shift is potentially the result of terrestrial nutrient input to nearshore waters through both surface flow and submarine groundwater discharge (Kohout, 1960; Brand, 1988; Brand et al., 1991). Biscayne Bay also provides the primary habitat for a wide variety of organisms including endangered species such as the American crocodile and Florida manatee (Deutsch et al., 2003; Mazzotti et al., 2007). Moreover, it serves as the nursery grounds for many commercial and recreational fisheries in the region (Serafy et al., 1997, 2003).

Since the early 20th century, Miami's population has increased 215-fold and expanded along the Biscayne Bay coastline and watershed (U.S. Census Bureau, 2000). The associated urban development, land-use changes, and changes in water management practices have resulted in considerable environmental perturbations, as evidenced by algal blooms, seagrass die-offs, coastal hypersalinity, and contamination (Brand et al., 1991; SFWMD, 1995; Lirman et al., 2008). Changes in land-use patterns within Biscayne Bay's watershed include wetlands converted for urban and agricultural uses, resulting in the loss of much of the bay's coastal wetlands and a shift from disperse sheet-flow runoff to point-source canal discharges and a decrease in fresh groundwater discharge. The end result has been a significant decrease in the areal extent of estuarine salinities within Biscayne Bay. Currently, freshwater input to the study area is via the Coral Gables, Snapper, Cutler Drain, Black Creek, Princeton, Military and Mowry canals along the coast (Fig. 1). These canals can cause rapid fluctuations in nearshore salinity and nutrient distributions (Sklar et al., 2002).

An area of 80,000 acres of agricultural land (Fig. 1) that produces about half of the nation's winter vegetables (Howie, 1986) is located near the Mowry Canal drainage basin in the southern Biscayne Bay watershed. This farmland sits atop the highly porous Biscayne Aquifer, and the soil in the area is primarily comprised of oolitic limestone with a low organic and nutrient content. Frequent and intensive fertilization is required to grow vegetables in such nutrient-poor soil. Annually, about 13.6–20.4 kg acre^{-1} of nitrogen and 13.6–40.9 kg acre^{-1} of phosphorus have been applied to the soil in this agricultural area (DERM, 1978).

2.2. Hurricanes Katrina and Wilma

Hurricane Katrina made landfall in southeast Florida near the border of Miami-Dade and Broward counties at approximately 19:30 EDT on August 25, 2005 as a category 1 hurricane on the Saffir–Simpson Hurricane Scale with maximum sustained winds of 70 knots. As Katrina crossed south Florida, the convection pattern was asymmetric due to northerly wind shear, which placed the