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Baseline

Widespread sewage pollution of the Indian River Lagoon system, Florida (USA) resolved by spatial analyses of macroalgal biogeochemistry

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ABSTRACT

The Indian River Lagoon (IRL) system, a poorly flushed 240 km long estuary in east-central Florida (USA), previously received 200 MLD of point source municipal wastewater that was largely mitigated by the mid-1990's. Since then, non-point source loads, including septic tank effluent, have become more important. Seventy sites were sampled for bloom-forming macroalgae and analyzed for $\delta^{15}N$, % nitrogen, % phosphorus, carbon:-nitrogen, carbon:phosphorus, and nitrogen:phosphorus ratios. Data were fitted to geospatial models showing elevated $\delta^{15}N$ values (> +5‰), matching human wastewater in most of the IRL system, with elevated enrichment ($\delta^{15}N \geq$ +7‰ to +10‰) in urbanized portions of the central IRL and Banana River Lagoon. Results suggest increased mobilization of OSDS NH_4^+ during the wetter 2014 season. Resource managers must improve municipal wastewater treatment infrastructure and commence significant septic-to-sewer conversion to mitigate nitrogen over-enrichment, water quality decline and habitat loss as mandated in the Tampa and Sarasota Bays and the Florida Keys.

Coastal estuaries, world-wide and in particular, the United States, have undergone significant ecosystem decline as a result of human population growth and cascading ecological impacts (Nixon, 1995; NRC, 2000; Bricker et al., 2007). This follows recognition that urbanization and agricultural alteration of formerly natural watersheds has resulted in unsustainable nutrient over-enrichment with water quality decline, harmful algal blooms, habitat loss, and loss of fisheries being well reported symptoms of ecosystem decline and collapse (Nixon, 1995, Vitousek et al., 1997, NRC, 2000).

For estuaries of the southeastern United States, researchers predicted that estuarine ecosystems are not sustainable under the strain of human-induced land-use alterations of watersheds and subsequent water quality and habitat decline (Dame et al., 2000). Specifically, the NOAA National Estuarine Eutrophication Survey in 1997 (NOAA, 1997) indicated that the Indian River Lagoon (IRL) system, along east-central Florida (see Fig. 1), was "hypereutrophic" with respect to excessive carbon fixation (i.e. elevated chlorophyll-a, macroalgal blooms) resulting from nutrient over-enrichment. Indications of excess macroalgal biomass, and precipitous loss of seagrass coverage adjacent to urbanized portions of the watershed have been reported since the mid-1980's (see Virnstein and Carbonara, 1985, Virnstein, 1999, Barile and Lapointe, 1999). In 2011, the northern IRL's "superbloom" was a predictable ecological phase-shift (see Valiela et al., 1992) to a toxic phytoplankton-dominated system (Phlips et al., 2004), which followed the loss of seagrass and benthic macroalgae (SJRWMD, 2012) and occurred, simultaneously, with die-offs of manatee, dolphins, seabirds, and periodic fish kills. However, before the "superbloom" event, toxic phytoplankton blooms had already become a common feature of the IRL system. For example, the toxin producing dinoflagellate species *Pyrodinium bahamense* var. *bahamense* (a saxitoxin producer, see Landsberg, 2002, Landsberg et al., 2006), and other HAB species, such as the diatom *Pseudo-nitzschia pseudodelicatissima* have been reported in bloom concentrations (Phlips et al., 2002, Phlips et al., 2004, Phlips et al., 2006). More recent brown tide outbreaks in the central and northern portion of the system have degraded water quality causing widespread water column oxygen deficits and subsequent fish kills (Gobler et al., 2013, Kang et al., 2015). These ecological indicators have prompted recognition of the role of escalating nutrient over-enrichment as a driver of ecosystem collapse (see Barile and Lapointe, 1999; Lapointe et al., 2015); and mandates by state and federal regulatory agencies for mitigation for land-based nutrient sources loadings into the IRL system.

Not unlike many estuaries around the United States, the watershed of the Indian River Lagoon system has undergone significant land-use alteration (IRL NEP, 1996). Over the past 100 years, the watershed transitioned from a natural wetland with marginal human inhabitation to an agrarian and now growing urban land-use. Because of the long expanse (~240 km), the Indian River Lagoon system has been biogeographically divided into 5 sub-sections to include: the Mosquito Lagoon to the north, the Banana River lagoon to the east, and the northern,

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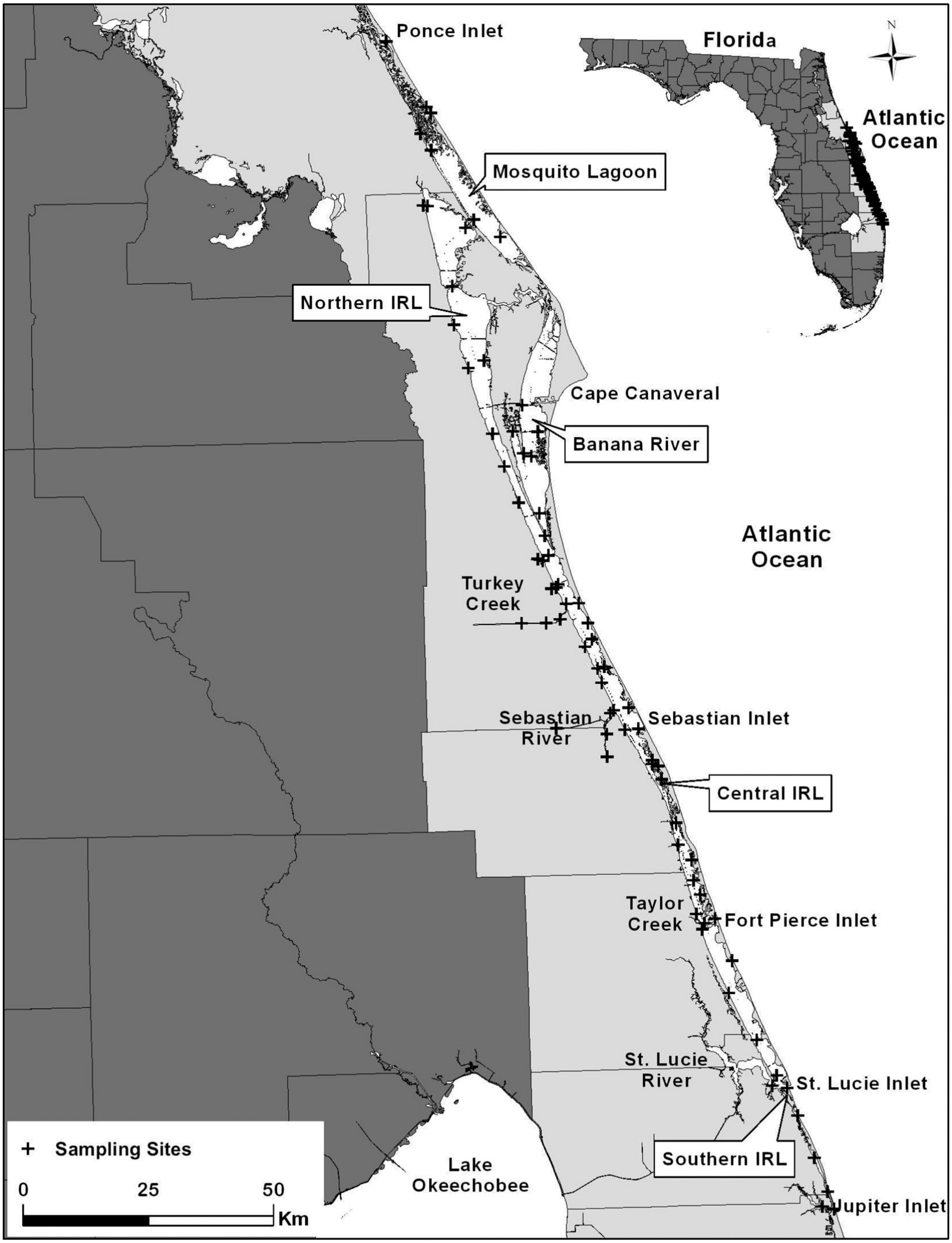

Fig. 1. Map of the Indian River lagoon system. Included are labels for the 5 subsections of the IRL system: Mosquito Lagoon, Banana River Lagoon, Northern, Central and Southern Indian River Lagoon. Sample site locations denoted as (+).

central, and southern portions of the IRL (see Fig. 1).

Panama canal-era (1920‘s) construction of 100’s of kilometers of upland drainage canals converted nearly 1800 km^2 of wetlands to farmlands that provided a surface and groundwater conveyance system downstream in the central and southern portions of the Indian River Lagoon system. This development of upland drainage canals, which drained wetlands formerly flowing west to the St. Johns River and Lake Okeechobee basins, expanded the watershed by three times to nearly 600, 000 ha, particularly in the southern portions of the IRL system watersheds. Alternatively, the central IRL watershed is the most urbanized with ~450 people per square kilometer (Sigua et al., 2000), versus the more sparsely populated northern IRL and Mosquito Lagoon sub sections.