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Stable isotope compositions of aquatic flora as indicators of wetland eutrophication

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ABSTRACT

Carbon and nitrogen stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) have been used as indicators for environmental changes in aquatic ecosystems. In this study, $\delta^{13}C$ and $\delta^{15}N$ values of select flora taxa were evaluated as indicators of human-induced eutrophication in an Everglades wetland which has been impaired by the source and quality of inflow and the alteration of hydrological pattern. Results showed that $\delta^{13}C$ of cattail (*Typha domingensis* Pers.) increased with the decrease in total phosphorus (TP) concentration. Limited data for sawgrass (*Cladium jamaicenses* Crantz) collected at three study sites along the nutrient gradient also show a similar change in $\delta^{13}C$. However, $\delta^{13}C$ of periphyton and bladderwort (*Utricularia* sp.) decreased with the decrease in TP concentration. The elevated $\delta^{13}C$ values of emergent vascular plants (cattail and sawgrass) were likely the results of decreases in stomatal conductance, carboxylation and ^{13}C fractionation under nutrient stress. This is supported by corresponding decreases in photosynthetic rate of cattail along the decreasing nutrient gradient. In contrast, $\delta^{15}N$ values of all flora taxa increased with the increase in TP concentration. Findings from this study indicate that $\delta^{13}C$ of emergent plants is a sensitive indicator for nutrient stress while $\delta^{15}N$ of major flora species may serve as a robust indicator for wetland eutrophication.

1. Introduction

Current indicators of environmental changes in lacustrine and wetlands focus on the impacts of nutrient loading such as soil and water total phosphorus (TP) and total nitrogen (TN) concentrations, species composition, biomass and primary production. These indicators often reveal the changes in the impacted systems that have taken place. Ecological research and restoration efforts indicate that it is extremely difficult to restore ecosystems that have been severely disturbed. Therefore, the identification of early symptoms of environmental change, prior to major damage, is critical for the restoration of disturbed systems to conserve natural resources (Carpenter and Brock, 2006).

Carbon and nitrogen stable isotope compositions of organic matter offer an alternative means to detect early signs of environmental changes in aquatic ecosystems (Hofmann et al., 1997; Risk and Erdmann, 2000; Vermeulen et al., 2011). The ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ (defined as $\delta^{13}C$ and $\delta^{15}N$) may provide insight into the sources, sinks and cycling of carbon and nitrogen in aquatic ecosystems as biota interact with their physical and chemical environments (McKee et al., 2002; Cole et al., 2004). Studies on mangrove trees (*Rhizophora mangle*) indicated that the $\delta^{13}C$ in nutrient-poor regions is enriched, compared to that measured in nutrient-rich regions (Lin and Sternberg, 1992; McKee et al., 2002). The ^{13}C depletion in the mangrove trees has been attributed to reduced stomatal conductance and greater isotopic fractionation under environmental stressors such as nutrients and salinity. With a reduction in nutrient stress, isotopic fractionation during carbon transport into the stomatal cells decreases and CO_2 assimilation increases and thus mangrove trees are enriched in $^{13}C/^{12}C$ in the nutrient impacted regions. Herzschuh et al. (2010) used $\delta^{13}C$ of macrophyte remains in lake sediment to infer nutrient dynamics and primary productivity. Using a two end-member ^{13}C mixing model, Troxler and Richards (2009) identified the important roles of *Nymphaea* and *Utricularia* species in ecosystem

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dynamics of deep water sloughs of the Everglades National Park. Nitrogen stable isotopes, as indicators for sources of nitrogen, are based on the fact that the $\delta^{15}N$ values of the major sources of nitrogen, such as fertilizers derived from the fixation of atmospheric nitrogen and animal wastes are often isotopically different, with enriched values in animal wastes and depleted values in fertilizers (Kohl et al., 1971; Heaton 1986; Bateman and Kelly 2007). The $\delta^{15}N$ values of various plant species have been used as indicators for the sources and magnitude of wastewater discharge into estuaries and coast ecosystems (Cole et al., 2004; García-Sanz et al., 2011), and inland waters (Hall et al., 1999; Lake et al., 2001; Kohzu et al., 2008). Savage (2005) found that the $\delta^{15}N$ values of a marine macroalga (*Fucus vesiculosus*) could be used to trace sewage-derived nitrogen. Cole et al. (2005) found that the $\delta^{15}N$ values of macroalgae and higher plants increased with wastewater inputs, but macroalgae provided more reliable indicators. Biota $\delta^{15}N$ has also been used as an indicator of eutrophication, especially under increased P loading. Studies show that primary producers respond to P enrichment with rapid nitrogen uptake, thereby resulting in decreases in ^{15}N fractionation. McKee et al. (2002) attributed the low $\delta^{15}N$ of the red mangrove in the transition zone and the dwarf trees to slow growth and low nitrogen demand, and the high $\delta^{15}N$ in the fringe to nutrient enrichment that stimulates tree growth in the mangrove islands in Belize. Positive relationships between soil TP and the $\delta^{15}N$ of cattail, sawgrass and periphyton are found in two Everglades wetlands. Inglett and Reddy (2006) found higher $\delta^{15}N$ in cattail than in sawgrass along a P gradient in the Water Conservation Area 2A (WCA-2A) of the Everglades and attributed the difference to the faster growth of cattail compared to sawgrass. Chang et al. (2009) found that sawgrass $\delta^{15}N$ is correlated with cattail $\delta^{15}N$ in WCA-1, suggesting similar responses to environmental variations in the two macrophytes.

In this study, we compared $\delta^{13}C$ and $\delta^{15}N$ values of a common wetland plant collected along a nutrient enrichment gradient in the WCA-2A. Isotope data for several other aquatic plants from limited sites were also described. The purposes of this study were (1) to understand the responses and mechanisms controlling the isotope variations along the nutrient gradient, and (2) to evaluate which stable isotope is more reliable and feasible candidate as an indicator of human-induced environmental changes in Everglades wetlands. We hypothesized that both carbon and nitrogen stable isotope compositions of major wetland plants would increase in response to the increases in ambient nutrient concentrations. This hypothesis was tested by the collection of plant tissues of the dominant species for isotope analysis along with the measurements of photosynthesis rate, ambient nutrients and related biogeochemical variables along a nutrient gradient in WCA-2A of the Everglades. This study provides insightful information on biota isotopic responses to changing water sources and quality, which may be used as biogeochemical indicators for environmental changes, particularly wetland eutrophication.

2. Materials and methods

2.1. Site description

The Florida's Everglades is the largest subtropical peatland in the United States, it was historically an oligotrophic ecosystem (Richardson, 2010). The water column total phosphorus (TP) concentration, a limiting nutrient in inland waters, was typically low ($<10\,\mu g\,L^{-1}$) and the plant community was dominated by sawgrass (*Cladium jamaicense*), water lily (*Nympheae odorata*), spikerush (*Eleocharis* spp.), bladderwort (*Eutricularia* spp.) and calcareous periphytic algae adapted to the low nutrient environment (Sklar et al., 2005). Since human settlement, a large portion of the Everglades peatland immediately south of Lake Okeechobee has been converted into farmlands, i.e., Everglades Agricultural Area (EAA). The remaining Everglades has been divided by drainage canals, levees and water control structures into three Water Conservation Areas (WCAs), and Everglades National Park.

Altered patterns of sheet flow and the source of flow in the present Everglades have been exacerbated by eutrophication. Increased nutrient loads and concentrations in surface runoff have shifted portions of the ecosystem from oligotrophic to eutrophic states. TP and TN concentrations in the water column and soil near the inflow regions have been elevated. Elevated TP concentrations are found near inflow regions in all impoundments (Wright et al., 2008). The influence of the EAA runoff containing high TP concentrations on the WCAs is especially pronounced at the northern region of WCA-2 (Fig. 1 and DeBusk et al., 2001). The sawgrass in northern WCA-2A, an area that has received EAA discharge, has been replaced by cattail (*Typha domingensis*) which was not present in large quantity in the historic Everglades. Nutrient enrichment has also resulted in an increase in periphyton nutrient content, a reduction in calcareous floating and epiphytic periphyton, and an increase in filamentous algal species in impacted areas (McCormick et al., 1996, 1998).

2.2. Sample collection and analyses

A total of 7 sites along the flow path (transect or nutrient gradient) in the WCA-2A (Fig. 1) were selected in this study. Samples were collected on 11th August and 3rd September, 2009. Except soil samples which were collected in duplicate, all biota samples were collected in triplicates. Soil samples from each site

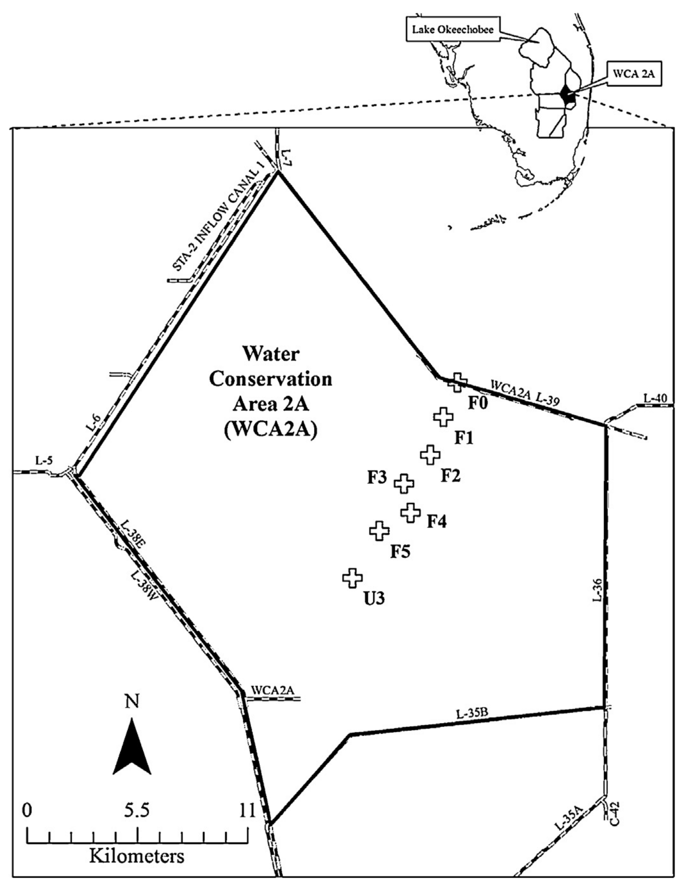

Fig. 1. Map showing sampling sites in Water Conservation Area 2A, Florida's Everglades.