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Isotopic Views of Food Web Structure in the Florida Everglades

Introduction

Nearly one million acres of the Everglades are under a health advisory that discourages the human consumption of largemouth bass and several other fish because of high mercury contents. Food web structure (base of food web, number of trophic steps) plays a potentially critical role in determining the patterns of mercury contamination of the Everglades ecosystem. Methylmercury (MeHg) is present in low concentrations in water, yet after entering the base of the food web it biomagnifies to toxic concentrations in organisms that occupy higher trophic positions (like bass). One of the main research questions under investigation by a multi-agency task force in the Everglades is how MeHg bioaccumulates up the food chain in this complex aquatic ecosystem. Understanding variations in food web structure may help explain mercury patterns in the Everglades and ultimately lead to more effective restoration of Everglades ecosystems.

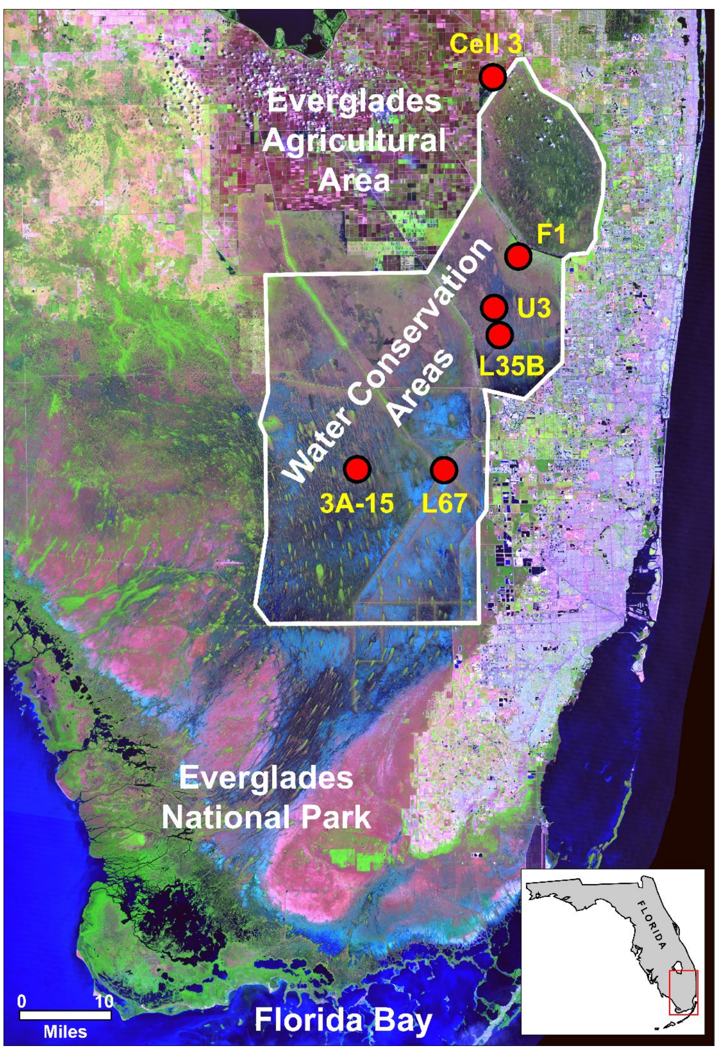

Figure 1. Satellite image of South Florida, showing biota collection sites (image from South Florida Water Management District). The inset map shows the location of the satellite image.

Approach

The primary focus of this study is to determine the trophic structure of aquatic biota in the Everglades ecosystem by analyzing tissue samples for nitrogen and carbon isotopes. Plants, invertebrates, and fish were collected from 16 well-studied USGS ACME (Aquatic Cycling of Mercury in the Everglades) sites throughout the Everglades during 1995-1999 as part of a collaboration between the USGS and the Florida Fish and Wildlife Conservation Commission (FFWCC). Within this data set, we focus on biota collected from six sites during two sampling periods (September 1997 and January 1998) when a sufficient number and variety of aquatic organisms were collected to show the general food web structure (Figure 1).

Isotopic Clues to Relative Trophic Position

Analysis of the stable nitrogen and carbon isotopic compositions ($\delta^{15}N$ and $\delta^{13}C$ values, respectively) of organisms in a food web provides information about trophic relationships, or "who eats whom". This method is based on the observation that selective metabolism of the lighter isotopes of these elements (^{14}N and ^{12}C) during food assimilation and waste excretion causes animals to become enriched in the heavier isotopes (^{15}N and ^{13}C) relative to their diets (McCutchan et al., 2003).

The $\delta^{15}N$ and $\delta^{13}C$ values of tissues are integrated measures of diet assimilated over time, with consumers typically enriched in the heavier isotopes of nitrogen by about 3-4‰ and carbon by 0.8-1.2‰ (i.e., higher $^{15}N/^{14}N$ and $^{13}C/^{12}C$) relative to their diet (McCutchan et al., 2003). This expected stepwise isotopic increase through the food chain (Figure 2A) has been used to reconstruct relative trophic positions of organisms and estimate mercury bioaccumulation rates in fish (Cabana and Rasmussen, 1994). Most studies using this approach have focused on applications in northern temperate lakes, whereas relatively few studies have applied these isotopic methods to complex, subtropical wetlands like the Everglades.

Synoptic View of Everglades Food Webs

By comparing $\delta^{15}N$ and $\delta^{13}C$ values for individual organisms, we can gain valuable information about food web structure. Figure 2B shows "average" isotopic relationships among organisms collected from selected marsh sites across the Everglades. For this comparison, isotopic values of organisms were normalized to the isotopic composition of mosquitofish at

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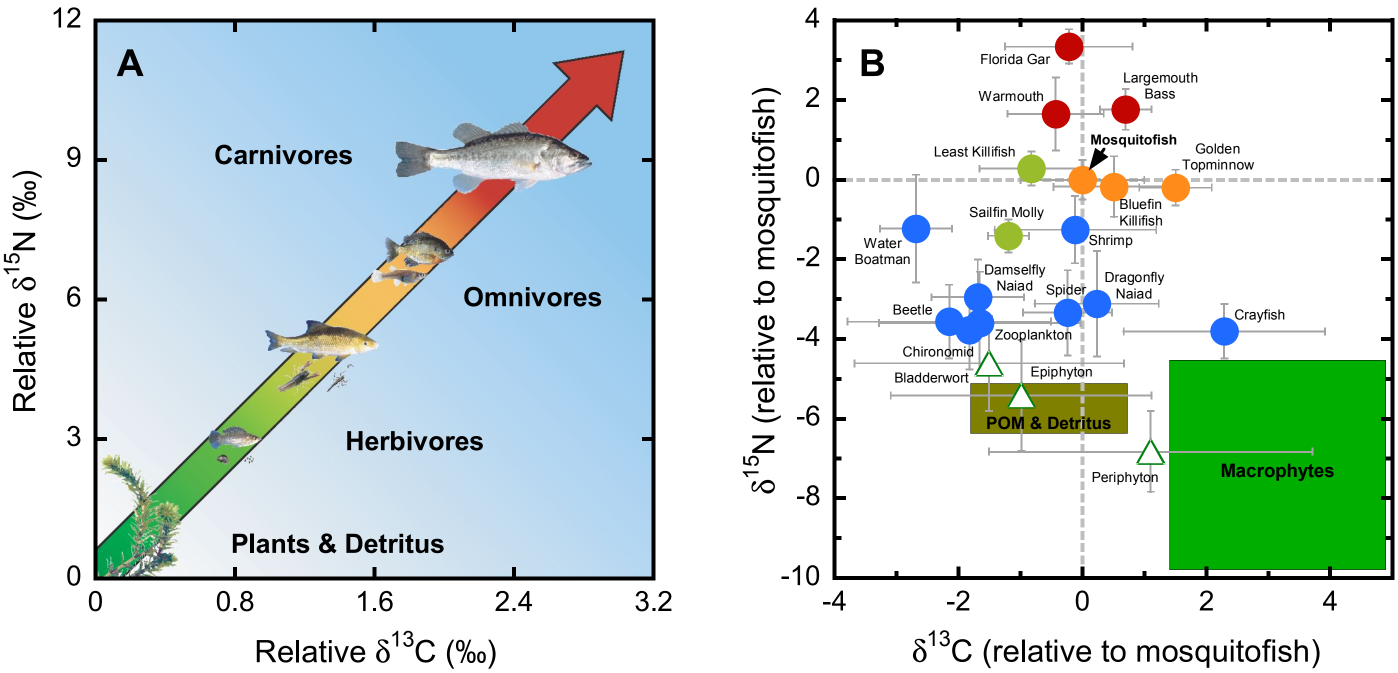

Figure 2. Isotopic views of food webs in the Everglades: (A) Expected increase in $\delta^{15}N$ and $\delta^{13}C$ of tissue with trophic level, based on field and laboratory studies (McCutchan et al., 2003). (B) Average biota isotopic compositions from selected marsh sites across the Everglades. Values are relative to mosquitofish. Error bars indicate one standard deviation. Organisms occupying relatively higher trophic positions have higher $\delta^{15}N$ values, as predicted.

each collection site to eliminate inter-site biogeochemical differences. As a check on the isotope-based reconstructions, we use color-coded symbols on the isotopic plots to suggest general trophic groups of the organisms analyzed:

- ● Mostly Carnivorous Fish (fish and decapods)
- ● Mostly Omnivorous Fish (<25% plants & algae)
- ● Herbivorous-Omnivorous Fish (>25% plants & algae)
- ● Invertebrates
- △ Plants & Algae
- ✚ Particulate Organic Matter (POM) & Detritus

The definitions of these groups are modified slightly from those of Loftus et al. (1998), which were based on stomach content data obtained in the Shark Slough region of Everglades National Park, south of our study area. Stomach contents analysis provides direct information about an organism's recent foraging preferences. However, unlike isotopic analysis, this method does not distinguish between what an organism ingests and what it assimilates (metabolizes) to make new tissue.

In general, organisms occupying relatively higher trophic positions have correspondingly higher (less negative) $\delta^{15}N$ values, as expected according to Figure 2A. For example, invertebrates that eat plants and detritus (or other organisms with that diet) typically have the lowest $\delta^{15}N$ and $\delta^{13}C$ values of the fauna sampled. The $\delta^{15}N$ values of fish noticeably increase as the relative proportion of plants and algae in their diets decreases. For example, sailfin molly (an herbivore) has relatively low $\delta^{15}N$ values and Florida gar (a carnivore) has the highest, whereas mosquitofish (an omnivore) has intermediate values. The invertebrates generally have $\delta^{13}C$ values similar to those measured for particulate organic matter (POM) and detritus, which suggests that macrophytes cannot be a major food source to these marsh food webs. A notable exception is crayfish, which has $\delta^{13}C$ values more consistent with a macrophyte food source.

Differences in Food Webs Among Sites

The food webs fall into two general categories, depending on whether or not $\delta^{15}N$ values can be used to distinguish among relative trophic positions. An organism's diet typically consists of multiple food items of potentially different trophic positions, so there is some expected overlap in $\delta^{15}N$. However, for sites 3A-15, U3, L35B, and F1, organisms occupying relatively higher trophic positions have higher $\delta^{15}N$ values (Figure 3). For these sites, $\delta^{15}N$ can potentially be used to investigate MeHg bioaccumulation pathways through the food web. Interestingly, site F1 shows an apparent reversal of expected $\delta^{13}C$ patterns, whereby lower $\delta^{13}C$ values are found for higher trophic positions (Figure 3). The reasons for this are unclear, but it is possible that multiple bases of the food web with different $\delta^{13}C$ values (e.g., plants and detritus) could contribute to this pattern. This could also result from seasonal variations in the isotopic composition of dissolved inorganic carbon and nitrogen in the water column, which affect the $\delta^{13}C$ and $\delta^{15}N$ values of plants at the base of the food web.

In contrast with the other sites discussed so far, sites L67 and Cell 3 do not show distinct $\delta^{15}N$ values among different trophic groups (Figure 4). For example, at both of these sites, sailfin molly (an herbivorous fish) has the same $\delta^{15}N$ value as that of largemouth bass (a top predator). Does this result mean that the two fish had eaten the same diet (i.e., only plants or large fish)? Obviously, that conclusion is unrealistic.

A more likely explanation for the poor separation of trophic groups by $\delta^{15}N$ is that mobile, longer-lived fish like bass (i.e., those occupying the upper trophic positions) migrate as water levels change in the Everglades. As they forage in regions with different biogeochemical reactions, their tissues begin to acquire the isotopic values of their new diet. Thus, the relatively low $\delta^{15}N$ values of largemouth bass, Florida gar, warmouth, bowfin, and chain pickerel at L67 and Cell 3 (compared with those expected based on the more herbivorous biota) probably reflect isotopic labeling in other local food webs. For the dates collected, these

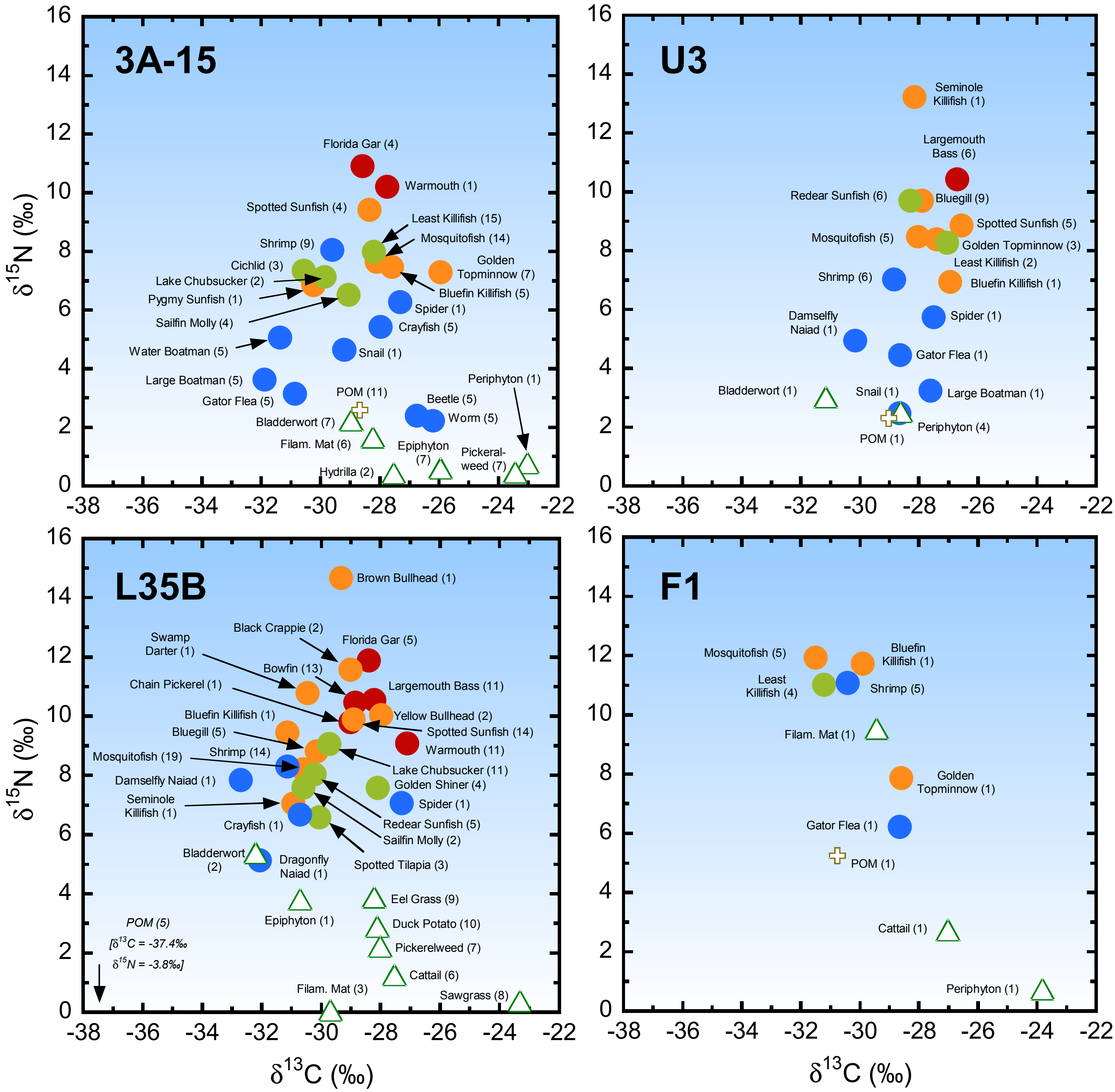

Figure 3. Collection sites for which $\delta^{15}N$ differentiates organisms occupying different trophic positions. Symbols are averages, with the number of organisms analyzed shown in parentheses. 3A-15 (January 1998); U3 (September 1997); L35B (January 1998); F1 (September 1997).

sites appear not to be amenable to isotopic reconstruction of food web structure.

The Influence of Local Biogeochemistry

In addition to providing clues about food web structure, this dataset also provides valuable information about biogeochemical processes in the Everglades environment. Differences in the $\delta^{15}N$ and $\delta^{13}C$ ranges of organisms among sites (Figures 3-4) suggest that isotopic values largely reflect local biogeochemical differences in the water column or sediments. Such processes include denitrification, which increases the $\delta^{15}N$ value of dissolved nitrate, and methane production and subsequent oxidation, which decrease the $\delta^{13}C$ value of dissolved CO_2. The isotopic compositions of aquatic plants and detritus appear to integrate these isotopic signatures, and the patterns are reflected in the $\delta^{15}N$ and $\delta^{13}C$ values of higher-level consumers in the aquatic food web. Because there is considerable spatial variability in nutrient sources and biogeochemical processes across the Everglades, it is difficult to determine the trophic relationships in many locations. The large $\delta^{15}N$ variation in organisms throughout the food web at a given site makes $\delta^{15}N$ values more useful than $\delta^{13}C$ for establishing relative trophic positions. In contrast, the smaller trophic influence on $\delta^{13}C$

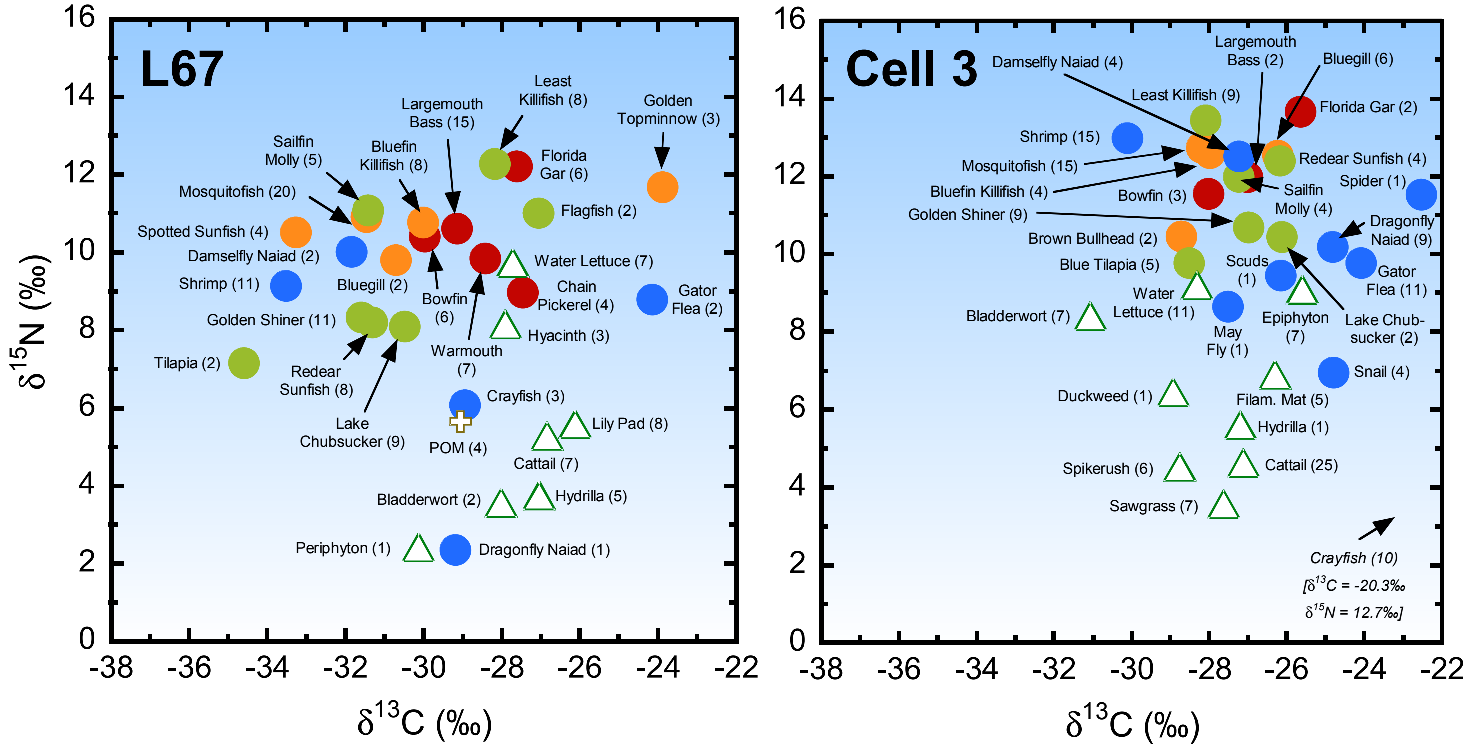

Figure 4. Sites for which $\delta^{15}N$ does not help distinguish organisms occupying different relative trophic positions. Symbols are averages, with the number of organisms analyzed shown in parentheses. L67 (January 1998); Cell 3 (January 1998).

values (Figure 2A) and the large range of biota $\delta^{13}C$ values caused by various environmental effects mean that the different trophic positions within the food web do not separate significantly by $\delta^{13}C$. Instead, $\delta^{13}C$ appears to better reflect food web base (e.g., algae or detritus).

Food Web Structure and Everglades Restoration

Improving the water quality in the Everglades is a critical goal of restoration efforts in this ecosystem. Part of this effort has focused on monitoring mercury concentrations in sport fish and other organisms, with the goal of understanding the response of the ecosystem to changes in water levels, contaminant loads, and other factors. To provide the context for these measurements, we must address how mercury accumulates to toxic levels in higher trophic positions within the food web.

Nitrogen isotopes of organisms can discriminate among relative trophic positions at some Everglades sites (and therefore describe food web structure and bioaccumulation pathways), but not at others. Spatial differences in biogeochemical reactions across the Everglades complicate our ability to use isotopes for this purpose. More importantly, monitoring chemical indicators in organisms collected at a given site (e.g., isotopes, mercury concentration) may result in misleading conclusions about what those indicators mean if one assumes that the organisms do not move. Longer-lived organisms that migrate seasonally and feed in different regions of the Everglades likely reflect a weighted average of chemical "labeling". The implications of this effect are that monitoring mercury concentrations in large sport fish like largemouth bass may not be an accurate measure of mercury responses to restoration efforts at that site. Monitoring shorter-lived species that do not migrate into and out of a given collection site may be a more effective approach toward assessing the success of Everglades restoration.

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The data on which this Fact Sheet is based are available at the website http://wwwrcamnl.wr.usgs.gov/isoig/projects/Everglades.

Related information is available at the website http://sofia.usgs.gov/people/kendall.html.

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