Spatial Changes in Redox Conditions and Food Web Relations at Low and High Nutrient Sites in the Everglades

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A clear understanding of the aquatic food web is essential for determining the entry points and subsequent biomagnification pathways of contaminants such as methylmercury (MeHg) up the food chain. The isotopic compositions of sediment, plant, insect, and fish samples collected at several hundred sites in the Everglades show strong spatial patterns on a landscape scale. Study findings suggest that biogeochemical processes (such as denitrification, sulfate reduction, photosynthesis, respiration, and methane production/oxidation) control the isotopic compositions of dissolved nutrients, and that the local isotopic compositions of biota then reflect those of the nutrients utilized, as modified by trophic fractionations and other factors. In particular, areas dominated by sulfate reduction, which often correlate with high methyl mercury contents, appear to be “labeled” by the carbon (C), nitrate (N), and especially the sulfer (S) isotopic compositions of organisms. The temporal and spatial isotopic patterns caused by environmental conditions must be “subtracted” from the biota isotopic compositions before spatial and temporal changes in trophic relations can be determined.

The traditional method of food web investigation focused on the determination of gut contents (literally, "who ate what"), and is still used today. More recently, stable C, N, and S isotope analyses of plants and animals have been used to establish relative trophic levels among various organisms. At each ascending trophic level (from prey to predator), there is an increase in the ^{13}C content ($\delta^{13}C$ value) and ^{15}N content ($\delta^{15}N$ value) of the organism due to selective metabolic loss of ^{12}C and ^{14}N during food assimilation and growth (fig. 1). Thus, an organism is typically enriched in ^{13}C and ^{15}N relative to its diet by 1 to 3 parts-per-thousand. There appears to be little or no enrichment in ^{34}S with increasing trophic level.

The average $\delta^{15}N$ and $\delta^{13}C$ values of selected fish have been normalized to the compositions of mosquitofish, an important indicator species, to allow direct comparisons of samples collected at different sites and times (fig. 2). Normalization is accomplished by subtracting the average isotopic composition of mosquitofish from the average isotopic composition of the organism of interest, collected at the same site and date. The $\delta^{15}N$ values are in good agreement with suspected trophic positions; primary producers have lower values than herbivores, while omnivores and carnivores have successively higher values. In contrast, the $\delta^{13}C$ values of algae, invertebrates, and fish show considerable variability with little or no consistent increase in $\delta^{13}C$ with increasing trophic level. Hence, bulk carbon isotopes are not very useful for determining trophic position. The generally high $\delta^{13}C$ values of the macrophytes (for example, lily pads, sawgrass) are inconsistent with their being a major food source in most locations.

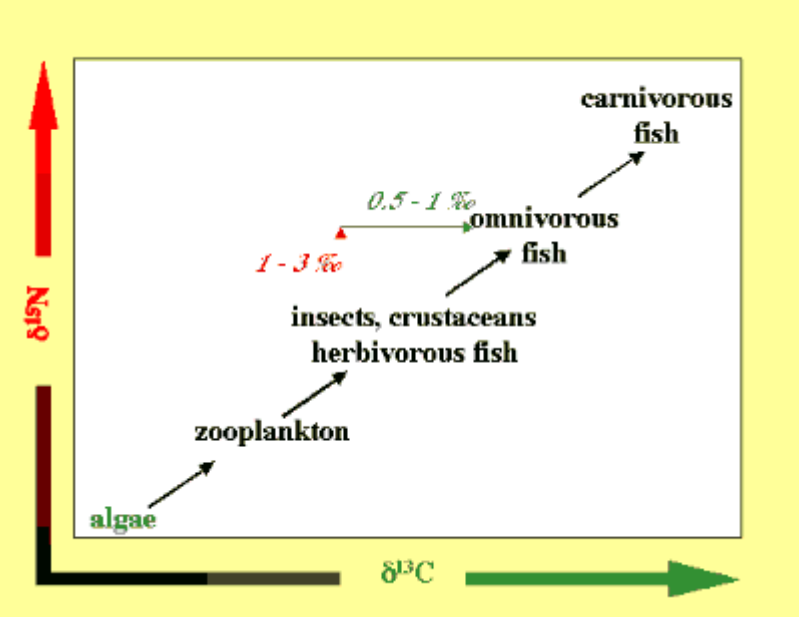

Figure 1. The $\delta^{13}C$ and $\delta^{15}N$ of organisms increase with increasing trophic level.

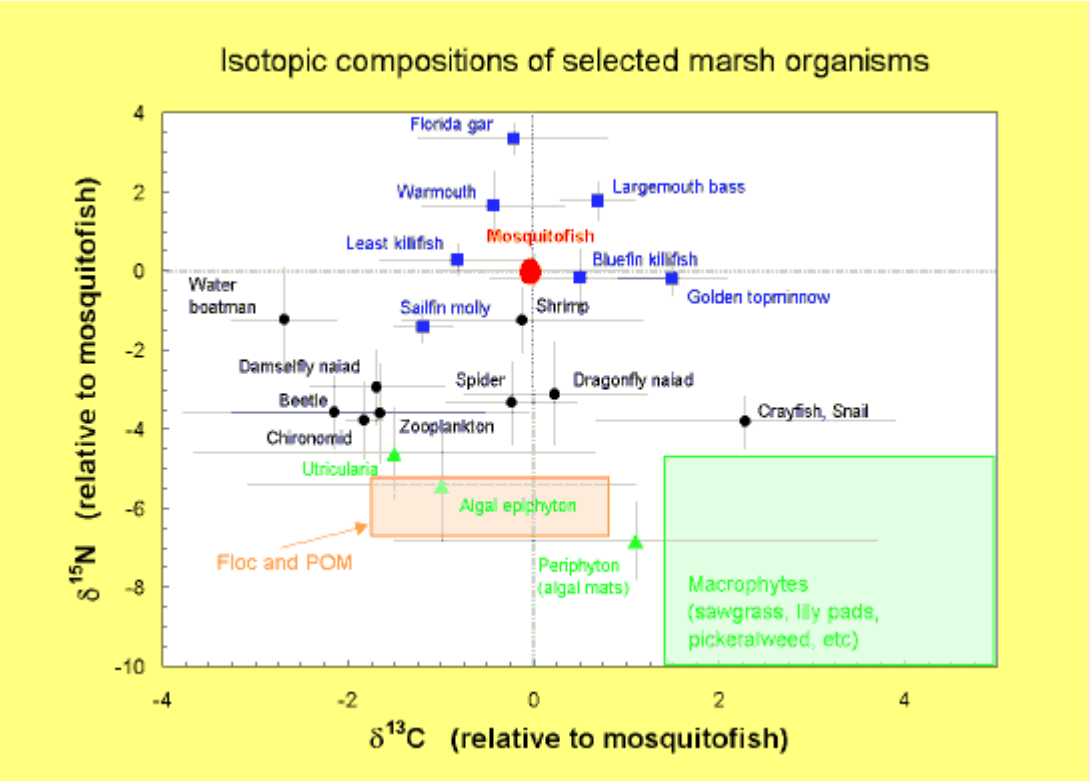

Figure 2: The average isotopic compositions of selected marsh organisms (with ranges shown as error bars), normalized to the composition of mosquitofish. The shaded zones show the range of large numbers of samples that can be grouped together.

Isotopes can be used to distinguish between what a fish eats and what it assimilates. For example, the $\delta^{15}N$ values of organisms can be used to test the diet estimates determined by gut contents analysis. Using this approach, we find that although algae (periphyton) often is a major component of the stomach contents of mosquitofish, it appears to be only a minor component of what is actually digested (fig. 3). This is an important observation, since the MeHg content of algae can be high in some environments; however, it is not known whether MeHg within the algal mats can be absorbed by the fish even if the algae is not assimilated.

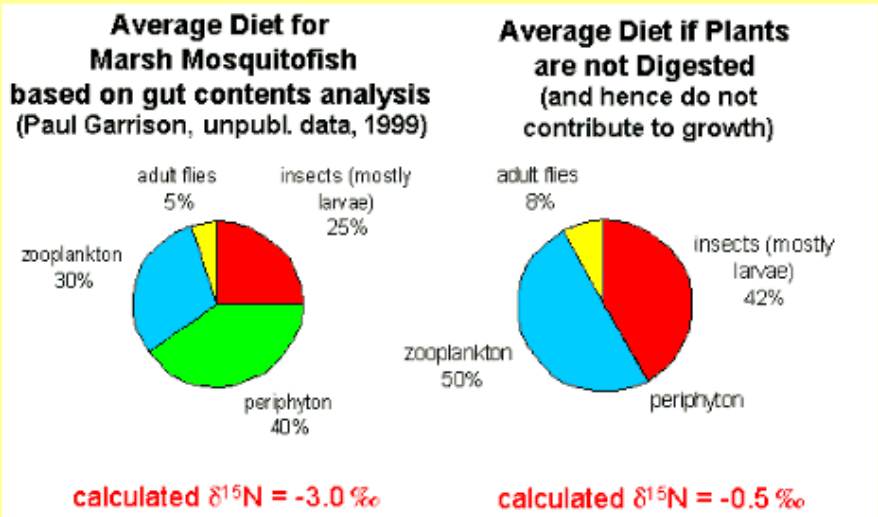

Figure 3. The isotopic values in figure 2 were used to calcualate the average 15N values of mosquitofish based on gut contents data.

In general, organisms collected in high-nutrient sites near the Everglades Agricultural Area have higher $\delta^{15}N$ values than ones collected in more pristine areas to the south. Near the agricultural areas, organisms in the canals generally have higher $\delta^{15}N$ values than samples from adjacent marshes, and the $\delta^{15}N$ values decrease with distance from the canals. This difference probably reflects denitrification and ammonium uptake in anoxic waters and sediments in stagnant parts of the canals.

The isotopic compositions of organisms from areas of high and low nutrient concentrations are very different. We observed the expected increases in $\delta^{13}C$ and $\delta^{15}N$ with increasing trophic level at low-nutrient marsh sites. However, at high-nutrient marsh and canal sites, the $\delta^{13}C$ values consistently decrease with increasing trophic level, producing food web structures that are not consistent with the trophic enrichment theory. While is not yet clear what causes the striking isotopic difference between nutrient-impacted sites and more pristine sites, isotopes appear to provide a quick and easy method for determining if high-nutrient areas might be causing significant changes in food web relations.

Spatial variability of $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ values in the Everglades reflects spatial variability of reducing conditions in the marshes that promote methane production, sulfate reduction and denitrification. The isotopic compositions of aquatic plants integrate the variability in water column isotopic compositions and these same patterns are incorporated throughout the food web. Therefore, organisms that live in sites where geochemical conditions are dominated by particular redox reactions have distinctive isotopic compositions. The **"isotopic labeling"** of different environments suggests that isotopic techniques could be useful for determining whether fish migrate in and out of the marshes in response to hydrologic or nutrient-level conditions. Furthermore, because MeHg concentrations are a function of local environmental conditions, these isotopic data should prove useful for determining where some populations of game fish are acquiring elevated levels of MeHg. Stable isotope analyses distinguish fish populations and offer a more **cost-effective** alternative to tag-and-release programs for the determination of migration habits. Furthermore, stable isotope analyses complement gut-content-based food web studies, provide an independent check on diet estimates, and provide insight into the difference between what an organism eats and what it actually assimilates. Such an assessment should prove useful for the better regulation of hydrologic, geochemical, and biological conditions most favorable to the restoration of the Everglades.

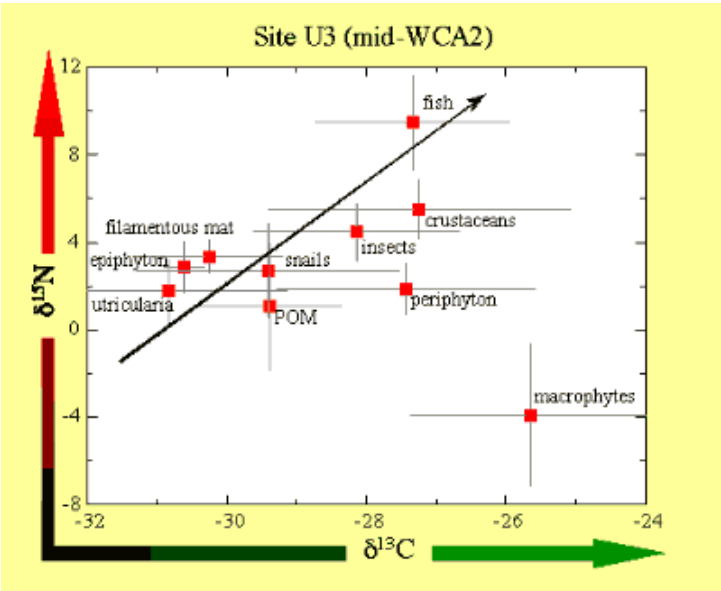

Figure 4. The isotopic compositions of organisms collected January 1998 at site U3.

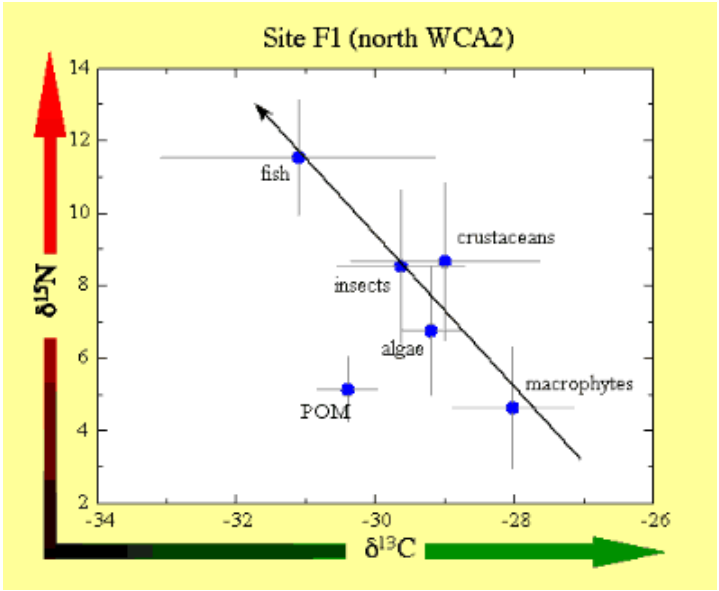

Figure 5. The isotopic compositions of organisms collected in January 1998 from F1.