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Seasonal $\delta^{13}C$ and $\delta^{15}N$ isoscapes of fish populations along a continental shelf trophic gradient

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ABSTRACT

The West Florida Shelf, located in the eastern Gulf of Mexico, transitions from a eutrophic ecosystem dominated by the Mississippi River plume to mesotrophic and oligotrophic ecosystems off the coast of peninsular Florida. Three extensive trawl surveys in this region were used to acquire samples of fish muscle, benthic algae from sea urchin stomach contents, and filtered particulate organic matter (POM) to create $\delta^{13}C$ and $\delta^{15}N$ isoscapes. Muscle $\delta^{15}N$ from three widely distributed fish species, *Synodus foetens* (inshore lizardfish), *Calamus proridens* (littlehead porgy), and *Syacium papillosum* (dusky flounder), exhibited strong longitudinal correlations (Pearson's $r=-0.67$ to -0.90, $p<0.001$) that coincided with the principal trophic gradient, whereas $\delta^{13}C$ values of fish muscle and benthic algae were correlated with depth (Pearson's $r=-0.34$ to -0.73, $p<0.05$). Correlations between isotopic values and surface concentrations of chlorophyll and particulate organic carbon (POC) imply linkages between the isotopic baseline and transitions from eutrophic to oligotrophic waters. The $\delta^{13}C$ depth gradient and the $\delta^{15}N$ longitudinal gradient were consistent between seasons and years, providing a foundation for future stable isotope studies of animal migration in the Gulf of Mexico.

1. Introduction

Isotopic spatial gradients have been found on marine continental shelves in the $\delta^{13}C$ and $\delta^{15}N$ values of primary producers, consumers, and organic matter in surface sediments (Weffer and Killingley, 1986; Fry, 1988; Jennings and Warr, 2003; Alt-Epping et al., 2007; Nerot et al., 2012). In consumers, depth-related $\delta^{13}C$ variation may be partially due to consumption of different food sources in inshore and offshore waters (Cherel and Hobson, 2007; Nerot et al., 2012). In primary producers, $\delta^{13}C$ variation is linked to environmental factors regulating species composition, rates of primary production, $\delta^{13}C$ signatures of aqueous CO_2, and the magnitude of photosynthetic fractionation (Fry, 1988; Cooper and DeNiro, 1989; Hofmann et al., 2000; Liu et al., 2007). On a regional scale, marine $\delta^{13}C$ values are generally higher in shallow waters and in areas with high primary productivity (Fry, 1988; Muscatine et al., 1989; Graham et al., 2010).

Spatial gradients in $\delta^{15}N$ are also common in continental shelf waters (Jennings and Warr, 2003; Alt-Epping et al., 2007; Olson et al., 2010; Nerot et al., 2012). Although the specific mechanisms affecting baseline $\delta^{15}N$ gradients on continental shelves vary, the root of this phenomenon is often linked to transitions from eutrophic or mesotrophic conditions to oligotrophic waters (Hansson et al., 1997; Alt-Epping et al., 2007; Harmelin-Vivien et al., 2008; Nerot et al., 2012). Diazotrophs such as the cyanobacterium *Trichodesmium* provide fixed nitrogen with $\delta^{15}N$ values close to 0‰, which can lower the $\delta^{15}N$ baseline in oligotrophic ecosystems (Carpenter et al., 1997; Montoya et al., 2002; Montoya, 2007). In contrast, $\delta^{15}N$ of nutrients and particulate organic matter (POM) in fluvial sources may have higher isotopic values in the range of 5–9‰, particularly if the terrestrial runoff contains sewage or manure (Hansson et al., 1997; Kendall et al., 2001). The POM and dissolved nutrients in river plumes can increase the $\delta^{15}N$ baseline in eutrophic or mesotrophic waters on continental shelves (Alt-Epping et al., 2007; Harmelin-Vivien et al., 2008; Dorado et al., 2012).

Geographic variability in isotope signatures can be displayed graphically as isoscapes (West et al., 2010). Isoscapes are useful for determining the foundation of food webs or the trophic level of a species (Graham et al., 2010; Olson et al., 2010). Isoscapes are also used to trace the origin and migration of animals, as the isotopic composition of an animal's diet is retained in certain body tissues for extended lengths of time (Rubenstein et al., 2002; Hobson et al., 2010). An animal's isotopic signature can be compared to the isotopic baseline to determine its most likely origin (Wunder and Norris, 2008; Hobson et al., 2010). For instance, the δD and $\delta^{13}C$ signatures of bird feathers have been used to estimate breeding

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[1] EBP and DJH conceived and designed the study. KRR conducted fieldwork, isotopic analyses, and data analyses. KRR and EBP wrote the manuscript; DJH provided editorial advice.

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latitudes using simple linear regressions of isotopic gradients (Rubenstein et al., 2002; Wunder and Norris, 2008).

Variations in the marine isotopic baseline provide a similar opportunity to estimate the movements of marine animals (Graham et al., 2010; Hobson et al., 2010). Empirical isoscapes have been created for marine plankton (Graham et al., 2010) and phytoplankton $\delta^{13}C$ values have been modeled at global scales (Hofmann et al., 2000). Consumers provide a time-averaged isotopic signal that is more stable than that of primary producers (Post, 2002), yet only a few isoscapes have been created using marine fish populations (Jennings and Warr, 2003; Graham et al., 2010; Olson et al., 2010). Isotopic analysis of fish populations presents the opportunity to examine the temporal and spatial stability of these marine isotopic gradients.

1.1. West Florida Shelf

The West Florida Shelf (WFS, Fig. 1), located in the eastern Gulf of Mexico, exhibits a trophic gradient from highly eutrophic waters associated with the Mississippi River and Mobile Bay watersheds to mesotrophic and oligotrophic shelf waters off the coast of peninsular Florida (Rabalais et al., 1996; Del Castillo et al., 2001). High volumes of nutrients in Mississippi River discharge lead to localized high primary productivity and seasonal anoxic zones near the river delta (Baustian et al., 2011). While much of the discharge from the Mississippi River is carried westward, some parcels of nutrient-rich water are carried east and then south along the WFS (Del Castillo et al., 2001). This Mississippi River plume is evident in surface particulate organic carbon (POC) and chlorophyll concentrations on the WFS (Fig. 1b–c).

Along peninsular Florida, the WFS is a broad, gently sloping continental shelf with chlorophyll concentrations that decrease rapidly with distance offshore (Fig. 1c, Del Castillo et al., 2001). Diazotrophs such as *Trichodesmium* are an important nitrogen source in the oligotrophic central and southern regions of the WFS (Mulholland et al., 2006). The continental shelf consists of predominantly sandy substrates, with approximately 35% hard bottom (Parker et al., 1983; Okey and Mahmoudi, 2002). The main primary producers in this region include phytoplankton, benthic macroalgae, benthic microalgae, corals, and seagrass (Okey and

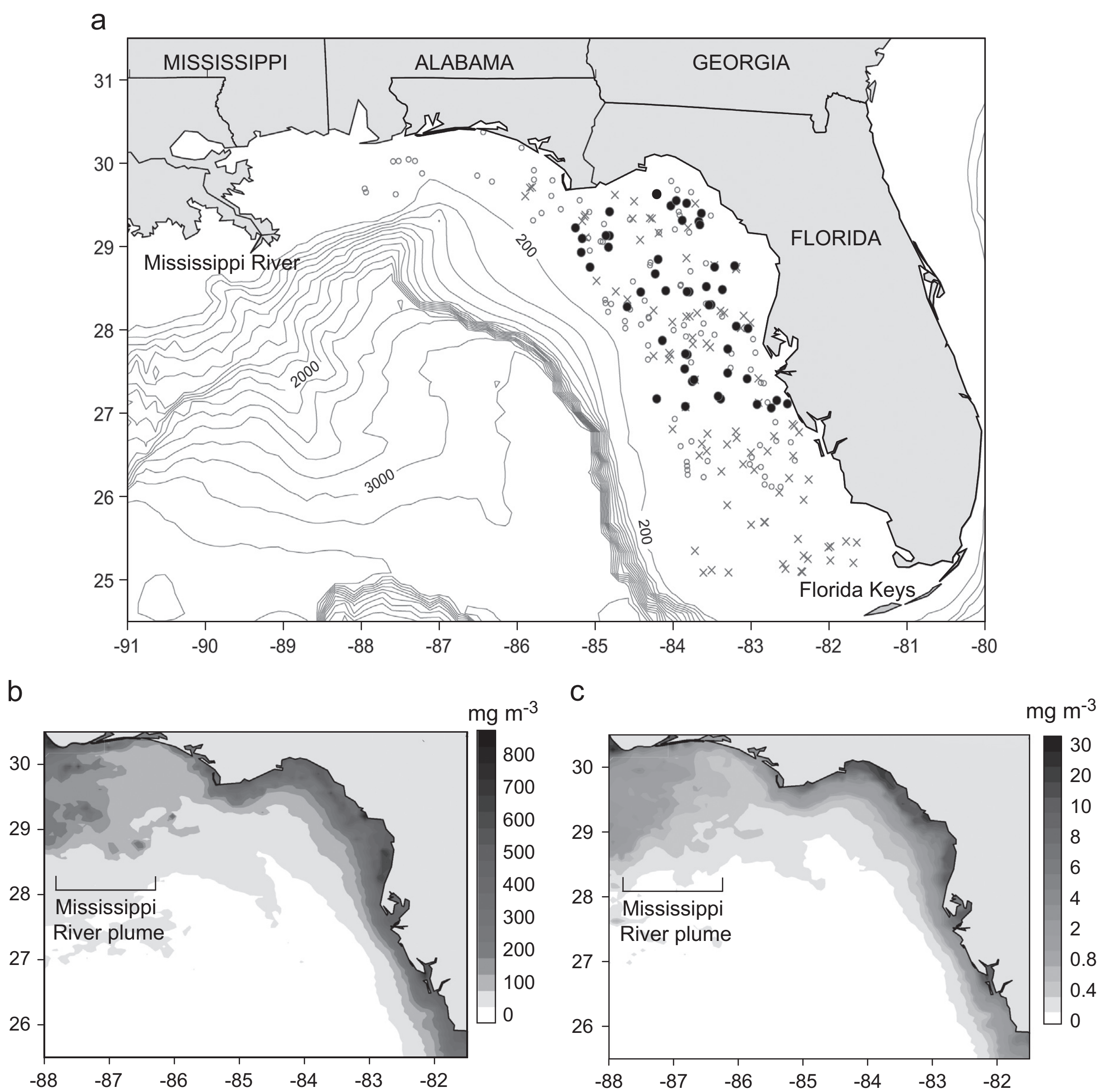

Fig. 1. (a) Spatial extent of sampling on the West Florida Shelf during three time periods. Open circles are trawling sites from summer 2009, crosses are from summer 2010, and filled circles are from fall 2010. Isobaths are shown at 200 m intervals. (b) Particulate organic carbon concentration and (c) chlorophyll concentration in surface waters in the summer of 2009. Note the irregular scale used for chlorophyll concentration.