Temporal Dynamics of Lipid and Fatty Acid Characteristics of Gulf Menhaden, *Brevoortia patronus*, in the Northern Gulf of Mexico

Dinámicas Temporales de las Características de Lípidos y Ácidos Grasos de la Sardina Lacha, *Brevoortia patronus*, en el Norte del Golfo de México

Dynamique Temporelle des Caractéristiques de Lipides et Acides Gras du Golfe Menhaden, *Brevoortia patronus*, dans le Nord du Golfe de Mexico

ROBERT T. LEAF[1], NANCY J. BROWN-PETERSON[1], MICHAEL J. ANDRES[1], JESSE T. TRUSHENSKI[2,3], and ALEXIS BERGMAN[2]
[1]*Department of Coastal Sciences, University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, Mississippi 39564 USA. *robert.leaf@usm.edu.*
[2]*Center for Fisheries, Aquaculture, and Aquatic Sciences, Southern Illinois University, 1125 Lincoln Drive Room 251, Carbondale, Illinois 62901USA.*
[3]*Eagle Fish Health Laboratory, Idaho Department of Fish and Game, 1800 Trout Road, Eagle, Idaho 83616 USA.*

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EXTENDED ABSTRACT

Gulf menhaden, *Brevoortia patronus*, are considered an important ecological component in the northern Gulf of Mexico (nGOM) and also supports a large commercial fishery in the region. An analysis of the fishery dynamics of the stock indicated that the stock was not overfished and that overfishing was not occurring (SEDAR, 2013). However, an analysis of the historical record of landings indicates that the fishery has consistently harvested, in the last ten years, ~400 to 450×10^5 metric tons (mt) of biomass in the coastal waters of Texas, Louisiana, Mississippi, and Alabama. Gulf Menhaden are caught nearshore, using purse seine vessels and processed in one of three reduction facilities in the nGOM. The products of the reduction processing are mainly fish meal which is used for animal feed in agriculture and aquaculture and high value fish oil that is used as a feed additive in these industries and also used for human consumption. In addition to its value in the commercial fishery, Gulf Menhaden are thought to play an important role as consumers and prey in the trophic food webs of the nearshore and coastal pelagic ecosystem. Olsen et al. (2014) documented, using stable isotope analysis that Gulf Menhaden < 125 mm TL have a mixed diet but feed primarily on phytoplankton and those larger than this size have a mixed diet and feed primarily on zooplankton. Because they feed at low trophic levels and transfer this energy to higher trophic levels, Gulf Menhaden have been termed a wasp-waste species or "forage fish" and are thought to be the prey of numerous coastal resident and transitory predator species in the region. Forage fish species are comprised of fast-growing, early-reproducing, small-bodied individuals and their population growth rates are thought to be determined, in part, by bottom-up processes. In this work we explore how such bottom-up processes, acting at the individual level, effect intra-annual and inter-annual variation in oil density and fatty acid characteristics. Specifically we describe the temporal variability of oil density in Gulf Menhaden, analyze and quantify the environmental determinants that determine the magnitude of this content, and evaluate the intra-annual variability in fatty acid components.

To determine the potential environmental drivers we evaluated the temporal and spatial patterns of a suite of abiotic variables. To determine the temporal dynamics of oil density we identified and evaluated data from multiple sources. The first source of data was the estimated magnitude of oil yield (gallons/10,000 lbs wet weight) of Gulf Menhaden for the years 1963 to 1979 (n = 17), presented by Guillory (1983). We performed an analysis to reconstruct (37 y) trends in inter-annual lipid density (L/kg) of the Gulf Menhaden stock derived from the commercial fishery. A stepwise fitting process was used to evaluate model fit, using Akaike information criteria (AIC), for different combinations of predictor variables. We identified a parsimonious set of predictor variables that had good explanatory power of annual oil yield and were not strongly correlated. The mean and variance of the coefficients of the best fit model were used to extrapolate the time series of mean and 95% prediction interval of oil yield to 2011. The predicted mean oil yield was used as the dependent variable in subsequent analysis.

We defined a nGOM "ecoregion" using remotely-sensed chlorophyll *a* data. We evaluated, qualitatively, the spatial-specific distribution of the first principal component of the spatially-specific 8-day data to determine the extent of the nGOM ecoregion. This area serves as the spatial sampling frame for the subsequent environmental analysis. We analyzed the temporal patterns of chlorophyll*a*, sea surface temperature (SST), and wind direction and speed. Additionally, we examined the variation in the timing of the spring thermal conditions, the magnitude of monthly river discharge in the spring and summer (months April, May, and June) for the Mississippi and Atchafalaya rivers, the magnitude and direction of wind, and the El Niño/Southern Oscillation multivariate index as potential predictors of oil yield.

In addition, we analyzed the fatty acid composition of Gulf Menhaden collected from the commercial fishery and fishery-independent samples monthly from August 2014 to June 2015. Total lipids were extracted from freeze-dried fillets using a chloroform-methanol procedure (Folch et al. 1957). Fatty acid methyl esters were prepared via acid-catalyzed transmethylation and analyzed by gas chromatography. We used PCA to determine the temporally-specific patterns in fatty

acid composition.

We find that there is considerable inter-annual variation in lipid content, and that the contrast in oil yield is strongly correlated to the magnitude of regional river discharge ($p < 0.05$). There was no significant correlation of mean oil yield to variations in the timing of the spring thermal conditions, the magnitude and direction of wind, or the El Niño/Southern Oscillation multivariate index. We found temporal differences in fatty acid composition and lipid density (Figure 1) but there were no significant differences in mean muscle lipid density between males or females. Fatty acid analyses suggest the presence of more long-chain polyunsaturated fatty acids (LC-PUFA) during the winter spawning period indicative of homeoviscous adaptation for maintenance of cell membrane flexibility and the provisioning of oocytes (Figure 2). In contrast, we found decreased LC-PUFA during spring, consistent with the reduced availability of LC-PUFA in the algal food source (Figure 2). The analyses presented here indicate that inter- and intra-annual variations in fatty acid and lipid content of Gulf Menhaden may have implications related to the trophic web in the northern GOM. Such results are consistent with other findings by Pethybridge et al. (2014) who documented variations in forage fish feeding conditions in the Mediterranean Sea.

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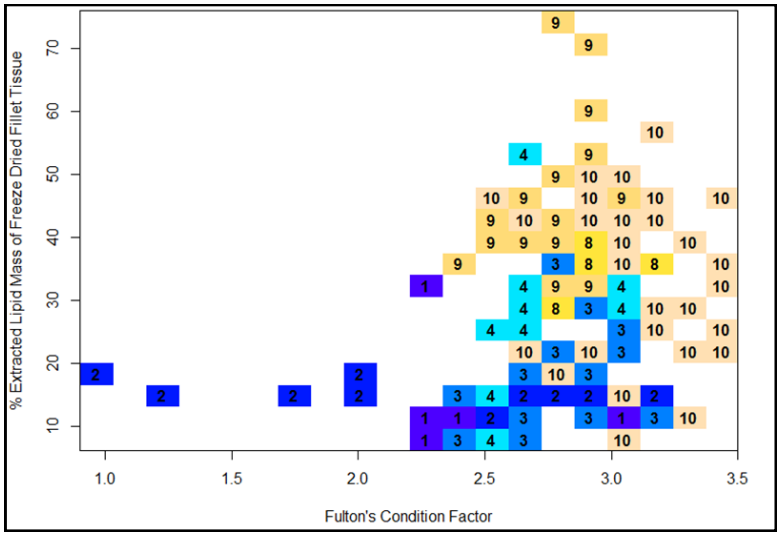

Figure 1. Temporal variation in condition (Fulton's Condition Factor) and the magnitude of lipid extracted from freeze dried tissue. The numbers in each cell represent the capture month of a single Gulf Menhaden.

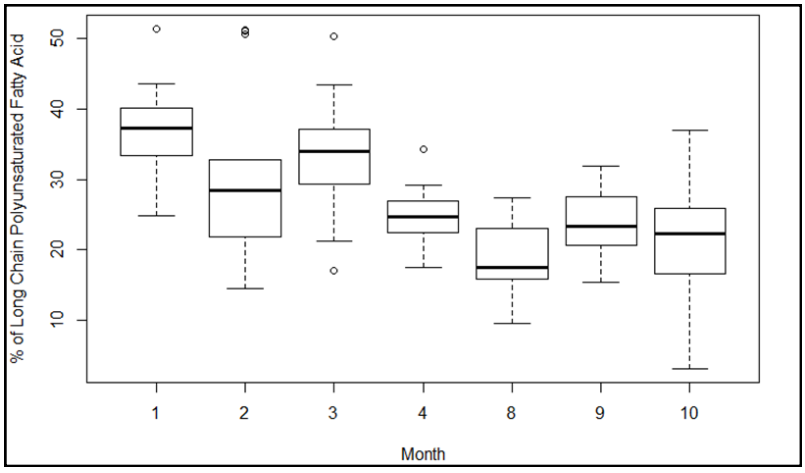

Figure 2. Monthly patterns of the percent of long chain polyunsaturated fatty acids in Gulf Menhaden.