MASGC-T-05-001 C2

FISHERIES RECRUITMENT IN THE NORTHCENTRAL GULF OF MEXICO: CAN IMPORTANT GEOGRAPHIC SOURCES OF JUVENILE NURSERY HABITAT BE DETERMINED USING OTOLITH MICROCHEMISTRY?

PROJECT NUMBER: R/SP-4

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Sea Grant
Mississippi-Alabama

MASGP-05-008

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ACKNOWLEDGMENTS

This study would not have been possible without the help of many individuals. Prior to the initiation of this study we were given much needed technical advice from Scott Baker and Will Patterson, who at the time were both affiliated with Louisiana State University. Numerous graduate students participated in field sampling efforts, including Paul Grammer, Gretchen Waggy, Glenn Zapfe, Nicole Crochet, Samantha Griffith and Christa Woodley. Paul Grammer, with help from Gretchen Waggy, must also be commended for the many tedious hours spent preparing otoliths for chemical analyses. David Winter of the University of California at Davis provided invaluable assistance analyzing otoliths for isotope ratios, and Lyndsie Gross from the University of Southern Mississippi's Department of Marine Science helped with trace element analyses of otoliths. Adult spotted seatrout catch data was kindly provided by Lisa Hendon and James (Tut) Warren of the Gulf Coast Research Laboratory, and by Michael (Buck) Buchanan and William (Corky) Perret of the Mississippi Department of Marine Resources. Several local fishermen were also invaluable for supplementing our collections of adult spotted seatrout with their recreational catches.

ABSTRACT

Spotted seatrout are one of the most highly prized inshore game fish throughout the northern Gulf of Mexico. This is the only species of the drum family (Sciaenidae) that spawns primarily in shallow inshore waters and remains in inshore waters throughout life. It is known that juveniles require shallow marsh-edge or seagrass habitat, but in Mississippi we do not know where the most important nursery source areas for these young fish are located. The premise of our study was that if juveniles exposed to discharge from different watersheds can be distinguished by the elemental "fingerprint" of otoliths, then the inner portion of adult otoliths can be analyzed to determine where these fish developed as young juveniles. Young juvenile spotted seatrout (n=199) were collected during late summer 2001 from shoreline habitat in coastal sub-regions bordering Mississippi Sound. Cleaned otoliths from the left side of juveniles were assayed using inductively coupled plasma-mass spectrometry. Cleaned otoliths from the right side of the same juveniles were analyzed for the stable isotope ratios of carbon and oxygen using a gas ratio mass spectrometer. The suite of otolith microchemical variables thus included element/Ca ratios of Ba, Li, Mg, Mn, Na, Sr, as well as $\delta^{13}C$ and $\delta^{18}O$. Because five of the eight otolith variables were significantly related to log otolith weight, all otolith variables were standardized with respect to otolith weight using standardizing residuals from regressions of otolith variables on log otolith weight. Standardized otolith variables (n=8) were subsequently used in a Canonical Discriminant Function Analysis (CDFA). The first three discriminant functions accounted for 96.4% of the cumulative variance in the eight otolith variables. Using the "Leave-one out" classification procedure, each case in the CDFA (i.e., individual fish) was classified by functions derived from all remaining individuals. Based on this procedure, 93.5% of the 199 juvenile speckled trout from the original CDFA were correctly classified with respect to their coastal sub-region (n=9). In addition, misclassified specimens were typically assigned to regions geographically proximate to their known sub-regions. The mean distance among sub-regions was only 25 km. Such discernable fine-scale differences in the microchemistry of juvenile spotted seatrout was likely made possible because the Mississippi coastline is influenced by freshwater discharge from eight rivers. During the

second phase of this study, adult spotted seatrout (n=205) were collected in 2002 and 2003 from the same regions as juveniles were collected. Of particular interest were age 1 fish collected in 2002 and age 2 fish collected in 2003, because these specimens (n=81) belonged to the same year class as juveniles collected in 2001 for which regional otolith elemental signatures were determined. The inner portion of adult otoliths that formed during the early juvenile life-stage was extracted with six precision cuts from each otolith, and otolith cores were treated the same way as juvenile otoliths. Strongest site fidelity was inferred for adults collected in Grand Bay. Eleven of 13 adult fish collected in Grand Bay were predicted, based on the microchemistry of otolith cores, to have developed as young juveniles in Grand Bay. This sub-region comprises an extensive area of nursery habitat for juvenile spotted seatrout that extends along the shoreline of eastern Mississippi and includes a section of the Alabama coastline. Fish that ostensibly developed as juveniles in Grand Bay were also found across much of the Mississippi coastline, indicating that this sub-region may be an important source area of spotted seatrout. Numbers of fish predicted to have developed in the Grand Bay sub-region as juveniles decreased as collection locations progressed westward away from Grand Bay. Contrary to our expectations, results of this study failed to confirm that extensive salt marsh habitat in the eastern areas of Louisiana or the large areas of submerged aquatic vegetation bordering the western side of the Chandeleur Islands serve as major source areas for the spotted seatrout stock structure along the Mississippi coast. In addition, otolith microchemistry indicated that the Pearl River region, which includes the marshes of Hancock County in western Mississippi, has only a relatively small influence as a source area for spotted seatrout along the Mississippi coastline. Elemental signatures of adult otolith cores also showed more mixing of fish between adjacent estuarine subregions during the first two years of life than has been shown with tagging studies. However, one and two-year-old spotted seatrout did show strong regional affinities, particularly when neighboring subregions were combined. Considering the current strong interest in stock-enhancement of spotted seatrout in Mississippi, regional influences would need to be taken into consideration for determining release locations for hatchery-reared young juveniles. Additional comparative studies of sub-regional differences in vital rates such as settlement, early growth, and mortality are needed to fully understand stock-recruitment dynamics of this fish in Mississippi. Knowledge of spotted seatrout population structure, including movements between regions and utilization of areas by juveniles as nursery habitat, will provide fisheries managers with important life history information needed for management decisions. Additionally, monitoring studies of spotted seatrout populations along the Mississippi coast need to include all sub-regions in sampling designs.

INTRODUCTION

The degradation of coastal ecosystems and habitats will likely continue to increase with expanding coastal development. This is particularly evident along the coast of Mississippi which is experiencing unprecedented population growth. It is known that estuarine nursery habitats are essential for the growth and survival of the juveniles of many species (Rakocinski et al., 1992; Hoss & Thayer, 1993; Turner et al., 1999), but it is important to spatially delineate these vital habitats and determine their relative importance as source nursery areas. This can be accomplished at both small scales such as microhabitat, and large scales, such as landscape or regional. For example, Mississippi Sound is a large estuarine system in the northcentral Gulf of Mexico which receives freshwater input from eight watersheds, but the relative importance of the different habitat regions within this system is not known. Indeed, different habitat regions likely contribute disproportionally to fisheries stocks in this estuary.

Recent studies have shown that otolith microchemistry can be used as a spatially-explicit environmental record to address various difficult fishery recruitment issues, including stock identification, the determination of migration pathways, the reconstruction of previous habitat information, age validation, and especially, use as a natural tag of ambient conditions experienced during various life-history phases (Gunn et al., 1992; Campana et al., 1995, 1999; Thorrold et al., 1997, 1998a, b). Otoliths are already formed in newly-hatched fish larvae and continue to grow through concentric additions of alternating calcium carbonate and protein layers around a central nucleus. Also incorporated into the crystalline component of the otolith matrix are various trace elements, and the relative abundance of these elements in the otoliths is influenced by the chemical composition of the water in which the fish are growing. Approximately 90% of the calcium carbonate and trace elements of otoliths are derived from the water (Milton and Chenery, 2001). The elemental composition of otoliths is not, however, merely a passive reflection of the chemical composition of the water in which the fish are growing because of the metabolic and physiological pathways that elements follow to become incorporated into the otolith. Saltwater fish drink water to maintain their osmotic balance, and consequently many inorganic elements from this water first pass from the intestine into the blood plasma. From the blood plasma the elements then pass into the endolymph fluid that bathes the otoliths, and finally, some of the elements become part of the otolith during the otolith crystallization process (Campana 1999). Because the otoliths are not susceptible to dissolution or resorption, and because growth continues throughout life, these calcified structures provide a permanent record of the influence of exogenous factors on the otolith calcium-protein matrix.

In addition to the incorporation of trace elements into the otolith structure, environmental conditions during otolith growth can also be signified by particular carbon and oxygen stable isotope ratios within otoliths (Thorrold et al., 1998b). These stable isotope ratios also reflect the water chemistry during otolith growth, and are particularly sensitive to changes in salinity. By jointly considering trace element signatures and both carbon and oxygen stable isotope ratios, Thorrold et al. (1998b) were able to clearly distinguish juvenile weakfish, *Cynoscion regalis*, originating from three adjacent rivers within the Chesapeake Bay éstuarine system. It was anticipated that this methodology could also be used with the closely related spotted seatrout, *Cynoscion nebulosus*, in areas of the northcentral Gulf of Mexico (Gulf) that are influenced by different watersheds.

Spotted seatrout are one of the most highly prized game fish in inshore waters throughout the Gulf states (Perret et al., 1980; Hettler, 1989; Deegan, 1990). This is the only species of the drum family (Sciaenidae) that spawns primarily in shallow inshore waters (Johnson and Seaman, 1986; Peebles and Tolley, 1988), and remains in inshore waters throughout life. It is known that juveniles require shallow marsh-edge or seagrass habitat (McMichael and Peters, 1989), but in Mississippi we do not know where the most important nursery source areas for these young fish are located. If juveniles from different watersheds can be distinguished by the elemental "fingerprint" of otoliths, then the inner portion of adult otoliths can be analyzed to determine where these fish developed as young juveniles.

OBJECTIVES

(Year 1):

1) Collect young juvenile spotted seatrout from nine potential sub-regions extending from Grand Bay, Alabama to the Louisiana marshes east of the Mississippi River.
2) Remove sagittal otoliths from juveniles and determine if the sub-regions where these fish were collected can be distinguished by "elemental fingerprinting" of the otoliths. These analyses will involve assays of whole dissolved otoliths.
3) Determine how precisely juveniles can be categorized based on spatial patterns of otolith microchemistry.

(Year 2):

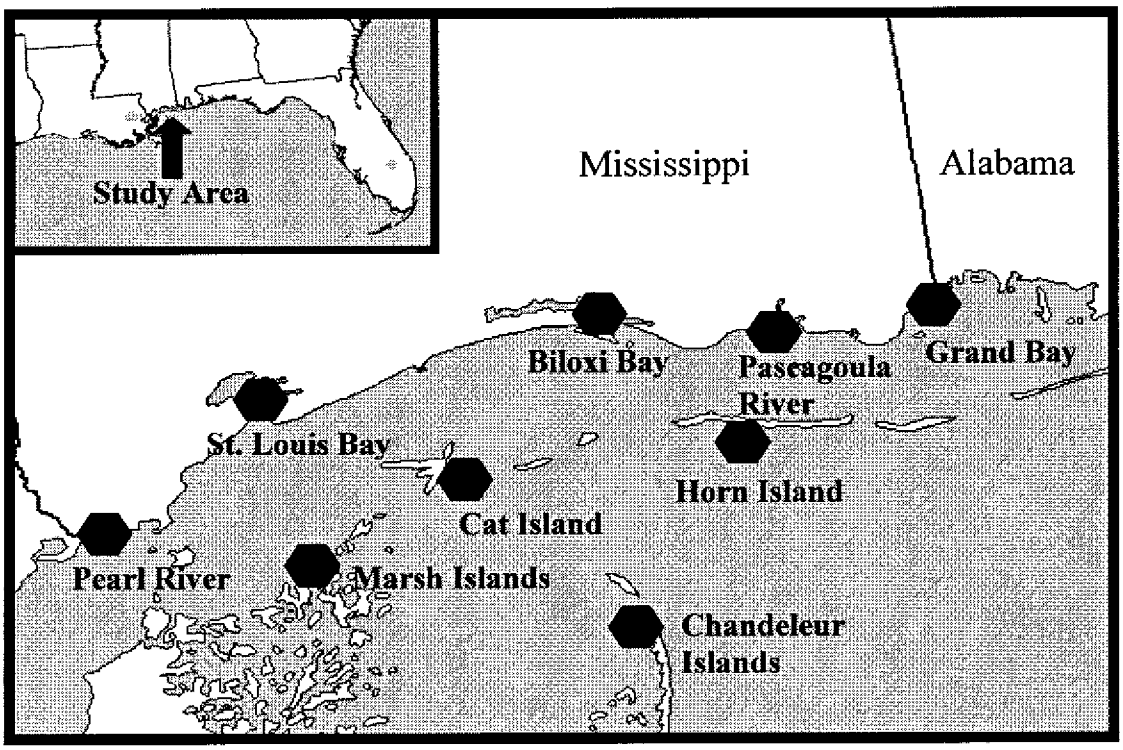
1) Collect age 1+ spotted seatrout from throughout the study region.
2) Remove sagittal otoliths from adults and determine the elemental composition and stable isotope ratios ($\delta^{13}C$ and $\delta^{18}O$) of the inner portion (formed during the juvenile stage) of these otoliths.
3) Classify the source areas from chemical "fingerprints" of the inner portion of adult otoliths through the application of the discriminant function analyses based on juvenile otoliths processed during year 1, in order to determine which nursery sub-regions the adults were using as young juveniles.
4) Assess the relative potential importance of different nursery sub-regions through the integration of information on the relative amounts of nursery habitats known to occur within the sub-regions, along with monitoring data on spotted seatrout stock abundances within the geographic source areas. Required outside data will be acquired from regional monitoring programs.

METHODS

Collection of juveniles and adults.

Young juvenile spotted seatrout were collected during late summer 2001 from shoreline habitat in nine nursery sub-regions bordering Mississippi Sound from Grand Bay, Alabama to the Louisiana marshes east of the Mississippi River (Figure 1). These sub-regions were chosen to encompass the entire geographic range of source sub-regions potentially contributing to the stock structure of spotted seatrout in Mississippi. Collections were taken with a 15.2 m bag seine with a bag mesh size of 3.17 mm. Juveniles were stored on ice, returned to the laboratory and frozen.

Figure 1. Sampling locations for juvenile spotted seatrout collected in 2001 and adult spotted seatrout collected in 2002 and 2003.



Adult spotted seatrout were collected in 2002 and 2003 from the same regions as juveniles were collected (Figure 1) using a 91 m gill net with a 7 cm stretch mesh. The net was fished by anchoring one end to the shoreline and allowing a soak time of 30 min. Fish were stored on ice, returned to the laboratory and frozen. Of particular interest were age 1 fish collected in 2002 and age 2 fish collected in 2003 because these specimens belonged to the same year class as juveniles collected in 2001 for which regional otolith elemental signatures were determined.

Otolith analyses using solution-based elemental assays and isotope analyses of δ^{13}C *and* δ^{18}O.

Juvenile spotted seatrout were thawed and measured prior to the removal of otoliths. Sagittal otoliths were used because they are the largest of the three types of otoliths and are conventionally used for otolith microchemistry work. Otoliths were removed from both the left and right sides of juveniles with acid-washed teflon-coated forceps, rinsed with ultrapure (Milli-Q) water, and temporarily stored in sterile 24-well cell culture clusters. In a Class 100 clean room using a laminar flow bench, each otolith was placed into an acid-washed, pre-weighed (µg), micro centrifuge tube using acid-washed teflon forceps. Centrifuge tubes were then filled with 0.001 N re-distilled nitric acid using a metal-free polyetheylene pipette tip that had been triple-rinsed with 0.1 N re-distilled nitric acid and triple-rinsed with Milli-Q water. Otoliths were washed with the dilute acid to remove any remaining contaminants (metal ions) from the otolith surface. After one to two minutes, the acid was removed from the centrifuge tubes with a clean pipette tip, and then the otoliths were triple-rinsed while in the centrifuge tubes with Milli-Q water, and air-dried in the laminar flow bench for 24 h. Centrifuge tubes containing cleaned otoliths were then re-weighed to obtain otolith weights (µg).

Cleaned otoliths that were removed from the left side of juveniles were dissolved in a measured quantity of 0.1 N re-distilled nitric acid, and otolith solutions were assayed with a magnetic sector ICP mass spectrometer (ThermoFinnigan Element 2) located at the Stennis Space Center (USM Department of Marine Science). Calibration was by external standards which were 4 mM in Ca, about the same Ca concentration as the otolith samples. All elements were measured at medium resolution on the ICP-MS and In was used as an internal standard to correct for instrument drift. In addition, selection of samples for analysis was random which precluded the confounding effects of instrument drift (Campana and Gagné, 1995). The molar concentrations of different elements in the otoliths were standardized to the number of calcium ions in the otoliths and expressed as ratios to the molar concentration of Ca.

Cleaned otoliths from the right side of juveniles were powdered and analyzed for stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$. Otoliths were powdered with an agate mortar and pestle which was rinsed with Milli-Q water. Two mortars and pestles were used so that one could be dried under a heat lamp while the other was in use. Powdered otoliths were transferred to acid-washed micro centrifuge tubes. Samples were pretreated by heating in vacuo at 75 °C for 0.5 h, and analyzed on a Micromass Optima isotope ratio mass spectrometer. Carbon dioxide from each sample was generated by acidification with phosphoric acid in a heated (90°C) common acid bath. The resultant gas was purified and introduced into the mass spectrometer inlet system and compared against a standard reference gas of known isotopic value. Values of $\delta^{13}C$ and $\delta^{18}O$ were calculated against V-PDB. Mean precision was (one sigma) +/- 0.04 per mille for $\delta^{13}C$ and +/- 0.06 per mille for $\delta^{18}O$.

Adult spotted seatrout were thawed, measured and sexed prior to the removal of sagittal otoliths. Otoliths were removed from both the left and right sides of fish and embedded in epoxy-resin molds. The inner portion of otoliths that formed during the early juvenile life-stage was extracted with six precision cuts from each otolith using a low-speed Buehler Isomet saw. Extraction accuracy was enhanced by observing otoliths using a large mounted magnifying-lens while making the cuts. The size of extracted cores, i.e. length, width and depth, was determined by comparison with otoliths from juveniles used in the first portion of this study. Juvenile otoliths ranged in weight from 2 mg to 48 mg (n=240, $\bar{x}$ = 8.9 mg). Otolith lengths, widths and depths (maximum thickness) were measured for 17 otoliths that ranged in weight from 4.7 to 20.9 mg (Table 1).

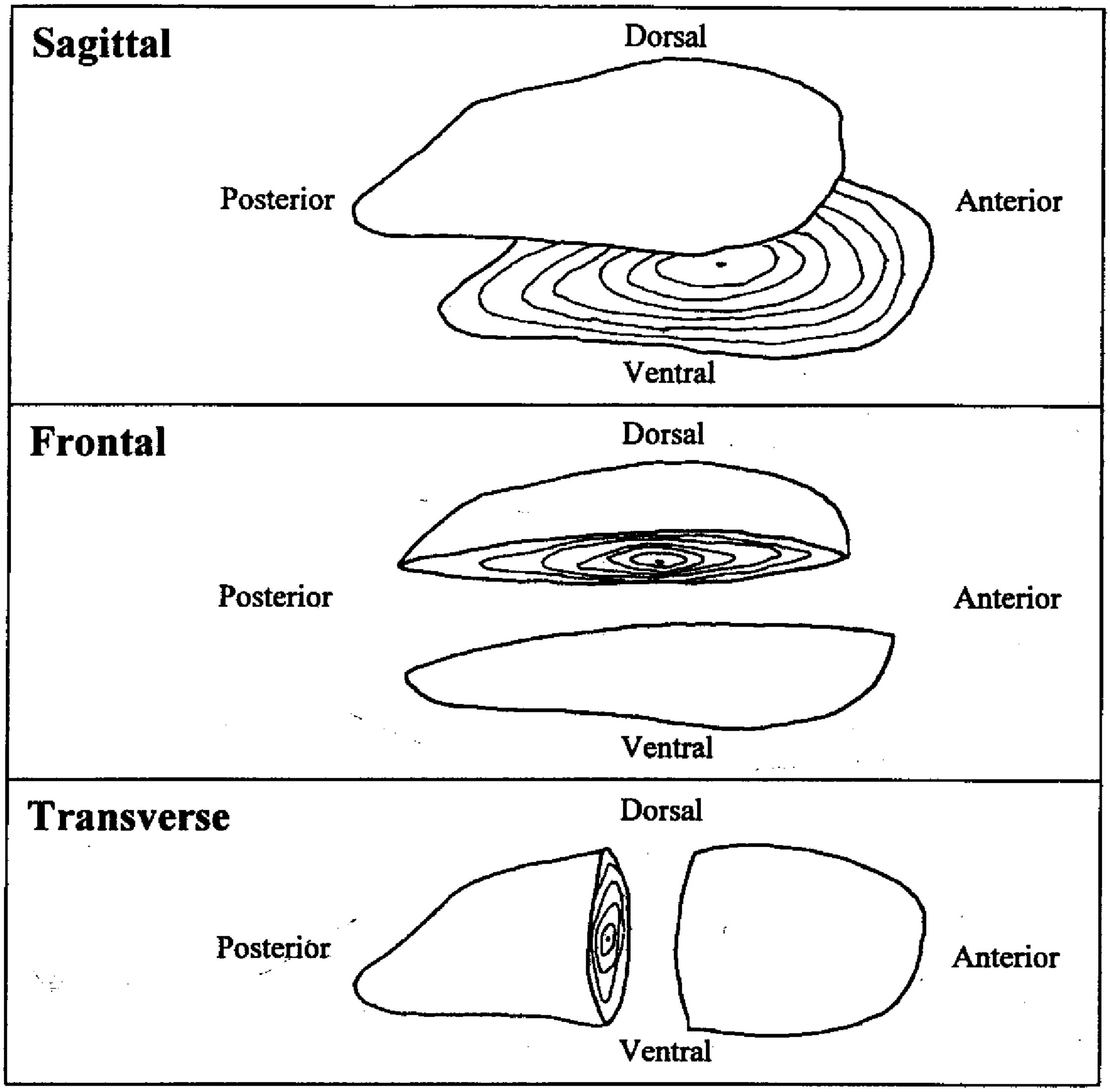
Table 1. Morphometric measurements of juvenile spotted seatrout otoliths used to determine dimensions of core to be extracted from adult otoliths.

Otolith Weight (mg)	Otolith Length (mm)	Otolith Width (mm)	Otolith Depth (mm) (maximum thickness)
4.7	3.60	1.70	0.72
4.8	3.68	1.60	0.64
5.4	3.76	1.76	0.72
5.6	3.60	1.76	0.80
5.8	3.84	1.76	0.64
5.8	4.00	1.92	0.64
6.1	3.92	1.68	0.72
6.2	3.76	1.76	0.80
11.6	4.80	2.32	0.96
15.3	5.28	2.16	1.04
18.0	5.68	2.40	1.04
18.2	5.68	2.88	1.04
18.3	5.84	2.48	1.12
20.4	5.92	2.80	1.12
20.7	5.92	2.64	1.12
20.9	5.76	2.48	1.20
20.9	6.00	2.48	1.04

Otolith width averaged 45.5% of otolith length, and otolith depth averaged 19.0% of otolith length. Because the edges of otoliths are tapered, as opposed to the thicker edges of a rectangular block that is cut from the center of an adult otolith, the extracted portion was chosen to be shorter (3.6 mm) than the mean juvenile otolith length. Based on the otolith length/width/depth relationships of spotted seatrout otoliths, an otolith with a length of 3.6 mm would have a width of about 1.6 mm and a maximum depth of 0.7 mm. This pre-determined otolith length of 3.6 mm also provided a mean weight of 10.7 mg for the rectangular cores that were extracted from adult otoliths. This was similar to the mean weight of juvenile otoliths ($\bar{x}$ = 8.9 mg).

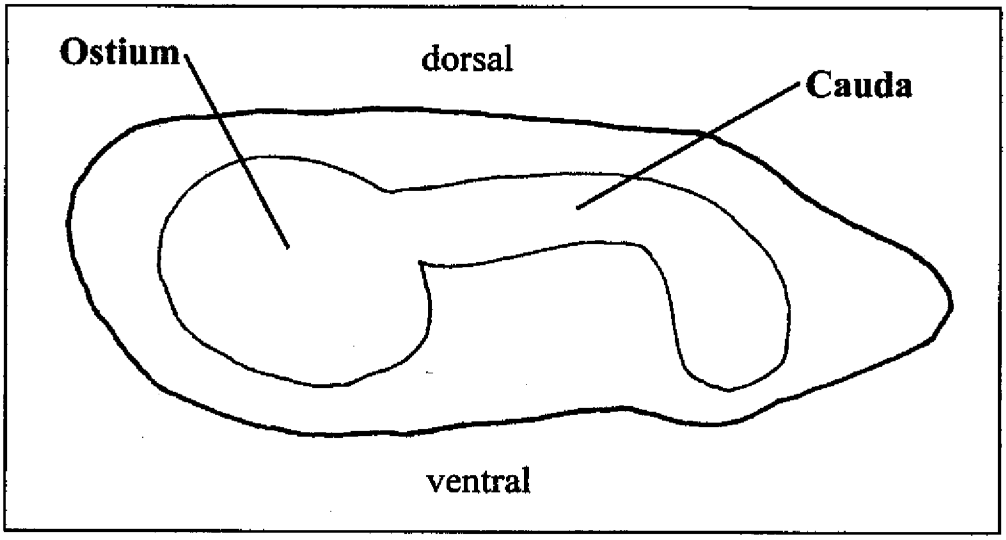
Embedded adult otoliths were first observed in the sagittal plane (Figure 2).

Figure 2. Orientation of cross section through otolith taken in the sagittal, frontal and transverse planes.



The saw blade was aligned over the otolith at the junction between the ostium portion of the sulcus acousticus, and the ventral edge of the cauda (Figure 3). This reference point was positioned over the otolith primordium.

Figure 3. Surface of spotted seatrout otolith showing the ostium and cauda portions of the sulcus acousticus.



A core length of 3.6 mm was obtained by making a transverse cut at 1.8 mm to each side of the primordium. The embedded otolith was re-positioned to expose a transverse cross section. The center of this section, which was positioned over the primordium and which was referenced by the base of a cross section of the sulcal groove, was lightly marked with an ultra fine-point pencil mark. This mark was needed to reposition the saw blade, and a frontal cut was then made at 0.8 mm on each side of the mark to establish the width of the removed core (1.6 mm). Finally, the depth of the core to be extracted was first determined by again re-positioning the otolith to expose a frontal cross section, and marking the center of this section across the width of the otolith with several fine pencil marks. A core depth of 0.7 mm was obtained by making a sagittal cut at 0.35 mm to each side of the marked center.

Prior to cutting the core from an otolith, a thin transverse slice was cut at the edge of the block to be extracted in order to age the adults. Annuli were counted following Bedee et al. (2003).

To initially clean otolith cores of the ultra-fine pencil marks, marked sides of the cores were lightly sanded using 1000 grit wet-or-dry sandpaper and cores were rinsed with Milli-Q water. Otolith cores were then placed into acid-washed micro centrifuge tubes, and during the second stage of cleaning, the outer layer of the core was dissolved using 0.3 N re-distilled nitric acid. Acid was added to centrifuge tubes using a metal-free polyetheylene pipette tip that had been triple-rinsed with 0.1 N re-distilled nitric acid and triple-rinsed with Milli-Q water. After five minutes, the acid was removed from the centrifuge tubes with a clean pipette tip, and then the otolith cores were triple-rinsed while in the centrifuge tubes with Milli-Q water, and air-dried for 24 h. The weight of otolith cores was reduced by about 9% by this acid treatment. After the treatment, otolith cores remained as sharp-edged rectangular blocks without any visible pitting of the otolith surface. Final cleaning was conducted in a Class 100 clean room using a laminar flow bench. Secor et al. (2001) also used a more rigorous approach to remove surface contamination of otoliths than in most studies; otoliths were immersed for 5 min in 1% nitric acid, resulting in a mass loss of four to five percent. In studying the effect of such an acid treatment on the chemical composition of otoliths, Secor et al. (2001) found only small changes in the concentration of elements, and the effect of the acid treatment was consistent among elements. Campana et al. (2000) found no significant differences for concentrations of elements between acid rinsed and un-rinsed cod otoliths; elements examined were Li, Mg, Mn, Sr and Ba.

Otolith cores were treated the same way as juvenile otoliths. Each otolith core was placed into an acid-washed, pre-weighed, micro centrifuge tube using acid-washed teflon forceps. Centrifuge tubes were then filled with 0.001 N re-distilled nitric acid using a metal-free polyetheylene pipette tip that had been triple-rinsed with 0.1 N re-distilled nitric acid and triple-rinsed with Milli-Q water. Otoliths cores were washed with the dilute acid to remove any remaining contaminants (metal ions) from the otolith surface. After one to two minutes the acid was removed from the centrifuge tubes with a clean pipette tip, and then the otolith cores were triple-rinsed while in the centrifuge tubes with Milli-Q water, and air-dried in the laminar flow bench for 24 h. Centrifuge tubes containing cleaned otolith cores were then re-weighed to obtain core weights. Cleaned cores from left and right otoliths were analyzed for trace elements and both $\delta^{13}C$ and $\delta^{18}O$ in the same way as for juvenile otoliths.

Data analyses

Otolith microchemical variables included concentrations of both the six trace elements and the stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$. Molar concentrations of otolith microchemical variables were standardized by molar calcium concentrations before any analyses. Variables that were heterogeneous among regions or that did not conform to a normal distribution were transformed ($\log_{10}$ transformed or Box Cox transformed). Subsequently, Kolmorgorov-Smirnov one-sample tests were performed against the normal distribution using three forms of the calcium-standardized otolith variables: untransformed, $\log_{10}$ transformed, and Box Cox transformed values. Because calcium-standardized lithium values were so small, they were multiplied by 100 to scale them up to retain the proper precision for SPSS. Using SPSS 11.0, Levene's tests were run on all forms of the otolith variables within a One-Way ANOVA context in order to test for homogeneity of variance across the nine *a priori* subregions. Raw untransformed data were used in subsequent analyses when both Levene's and overall K-S tests were nonsignificant ($P > 0.05$). If either of these assumptions were violated ($P < 0.05$) when using the raw data, the data transformation was used for which heterogeneity of variance across regions was minimized. As a result, raw values were used for both isotopes, as well as for Mg, SR and Li (multipled by 100), Log_{10} transformed values of Ba and Mn were used, and Box-Cox transformed values were used for Sodium.

An initial Principal Components Analysis (PCA) was performed to (1) reduce the dimensionality representing the number of otolith variables into fewer composite axes, (2) examine how and which otolith variables were interrelated; and (3) examine how juveniles from different sub-regions were separated within the PCA ordination space. Subsequent regressions of initial PCA scores on fish weight showed a strong ontogenetic relationship with PCA 2. The PCA was performed with the correlation matrix and the axes were rotated using the Varimax option. Regressions of PCA scores on log otolith weight (proxy to body size) revealed strong ontogenetic relationships in otolith microchemistry. Thus, all otolith variables from the PCA were standardized with respect to otolith weight prior to subsequent analysis. Standardized residuals from regressions on $\log_{10}$ otolith weight also served to scale all otolith variables the same.

A second PCA analysis performed for the same purposes stated above used the standardized residuals. Subsequent regressions on log otolith weight showed that ontogenetic effects were removed. Finally, a Canonical Discriminant Function Analysis (CDFA) used the standardized ototlith data to develop a set of eight significant discriminant functions for classifying the sub-regional groups. All eight possible Canonical discriminant functions were included in the analysis, based on the stepwise evaluation of increased significance for each function using the Wilk's lambda selection procedure. Discriminant analysis is useful for predicting group membership based on values of the input variables for each unknown case. Selected CDFA options included: (1) the within-groups covariance matrix; (2) prior probabilities of group membership were considered equal across groups; and (3) all otolith variables were entered together into the analysis. Classification success was tested using the "Leave one out" classification method. This procedure entails the classification of each case within the analysis through the use of discriminant functions derived from all cases other than that case.

A computer program was developed to predict original sub-regions for adult spotted seatrout based on their otolith microchemistry using the CDFA parameters. The program accepts input for each specimen: the sub-region where it was collected, $\log_{10}$ otolith weight, and raw values for the eight otolith variables. The raw values for the otolith variables were transformed as in the original CDFA, and standardized residuals were calculated with respect to predicted values based on otolith weight using parameters from the otolith weight regressions. Using classification functions from the CDFA for each of the nine sub-regions, function values were calculated based on subregion-specific constants and weights applied to each otolith variable for each individual. The individual was subsequently assigned to the sub-region for which the highest classification function value was obtained. A preliminary run of the classification program using the original specimens from which the CDFA was derived showed complete agreement with the results of the "Leave one out" procedure, except for the correct classification of one individual by the program that was misclassified by :Leave one out". Subsequently the classification program was run on the otolith cores extracted from samples of adult spotted seatrout described above.

RESULTS

Juvenile spotted seatrout

One hundred and ninety nine juvenile spotted seatrout were collected from the nine sub-regions of coastal Mississippi. Otolith microchemical variables included stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$, and molar concentrations of Ba, Li, Mg, Mn, Na and Sr, standardized by molar Ca concentrations (Table 2, Appendix 1). The eight major otolith microchemistry variables were reduced to three components with eigenvalues that were greater than one by the Varimax rotated PCA. The first three PCA dimensions effectively summarized the otolith variables by describing 85% (i.e., 49%, 20 %, and 16%, respectively) of their total variation. PC1 mainly reflected increasing concentrations of Li, $\delta^{13}C$ and $\delta^{18}O$, as well as an inverse relationship with Sr and Ba. PC2 mainly reflected correlated concentrations of Na and Mg. PC3 mainly reflected a high correlation with Mn (Table 3).

Table 2. Mean (±SD) molar concentrations of otolith microchemical variables (standardized by molar calcium concentrations), and stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$ in otoliths of juvenile *Cynoscion nebulosus* collected in the northcentral Gulf of Mexico.

Site	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	Li ($\mu g\ g^{-1}$)	Na ($mg\ g^{-1}$)	Mg ($mg\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Sr ($mg\ g^{-1}$)	Ba ($\mu g\ g^{-1}$)
Biloxi Bay	-6.59 (0.71)	-3.84 (0.39)	1.60 (0.68)	12.6 (0.93)	0.172 (0.021)	44.4 (12)	2.51 (0.18)	18.7 (5.7)
St. Louis Bay	-7.80 (1.2)	-3.96 (0.35)	1.01 (0.59)	12.6 (0.71)	0.186 (0.023)	52.8 (16)	2.70 (0.22)	33.9 (8.0)
Cat Island	-3.82 (0.35)	-2.30 (0.087)	3.00 (0.61)	13.1 (0.82)	0.193 (0.027)	31.2 (4.8)	2.25 (0.17)	23.6 (6.0)
Chandeleur Islands	-1.73 (0.56)	-0.657 (0.28)	4.19 (0.53)	13.8 (1.2)	0.155 (0.019)	53.6 (10)	2.05 (0.18)	8.72 (2.5)
Grand Bay	-5.12 (0.55)	-2.39 (0.070)	2.88 (0.47)	12.8 (0.83)	0.173 (0.029)	42.8 (9.2)	2.20 (0.17)	12.2 (4.5)
Horn Island	-3.03 (0.49)	-2.30 (0.053)	3.17 (0.55)	13.6 (0.65)	0.185 (0.023)	17.3 (2.3)	2.20 (0.14)	20.6 (3.8)
LA Marshes	-5.15 (0.39)	-2.69 (0.16)	2.27 (0.56)	14.3 (1.5)	0.208 (0.031)	39.9 (6.9)	2.35 (0.20)	30.0 (8.7)
Pascagoula River	-7.89 (0.99)	-4.39 (0.23)	1.18 (0.35)	12.2 (0.99)	0.147 (0.019)	45.9 (8.1)	2.61 (0.27)	27.3 (12)
Pearl River	-8.21 (0.80)	-3.27 (0.33)	1.19 (0.37)	15.3 (1.3)	0.175 (0.017)	86.2 (28)	2.57 (0.21)	42.9 (11)

Table 3. Principal Components Analysis loadings (with Varimax rotation) on otolith variables that were not adjusted for otolith weight.

	Component 1	**Component 2**	**Component 3**
D13C	**.863**	-.027	-.372
D18O	**.943**	.115	.026
Lithium	**.914**	.180	-.178
Sodium	.201	**.838**	.358
Magnesium	-.076	**.865**	-.193
Manganese	-.221	.025	**.942**
Strontium	**-.866**	-.072	.144
Barium	**-.776**	.375	-.044

A bivariate plot of means of PCA scores ± 1 standard error showed separation of the nine subregions within the first two dimensions of the PCA (Figure 4). However, both PC2 and PC3 reflected an ontogenetic trend, as shown by strong relationships between these composite variables and $\log_{10}$ otolith weight ($F = 137.05$ and 35.9, respectively; $P < 0.001$) (Figure 5).

Figure 4. Bivariate plot of means (± 1 standard error) of unadjusted Factor scores within the first two PCA dimensions..

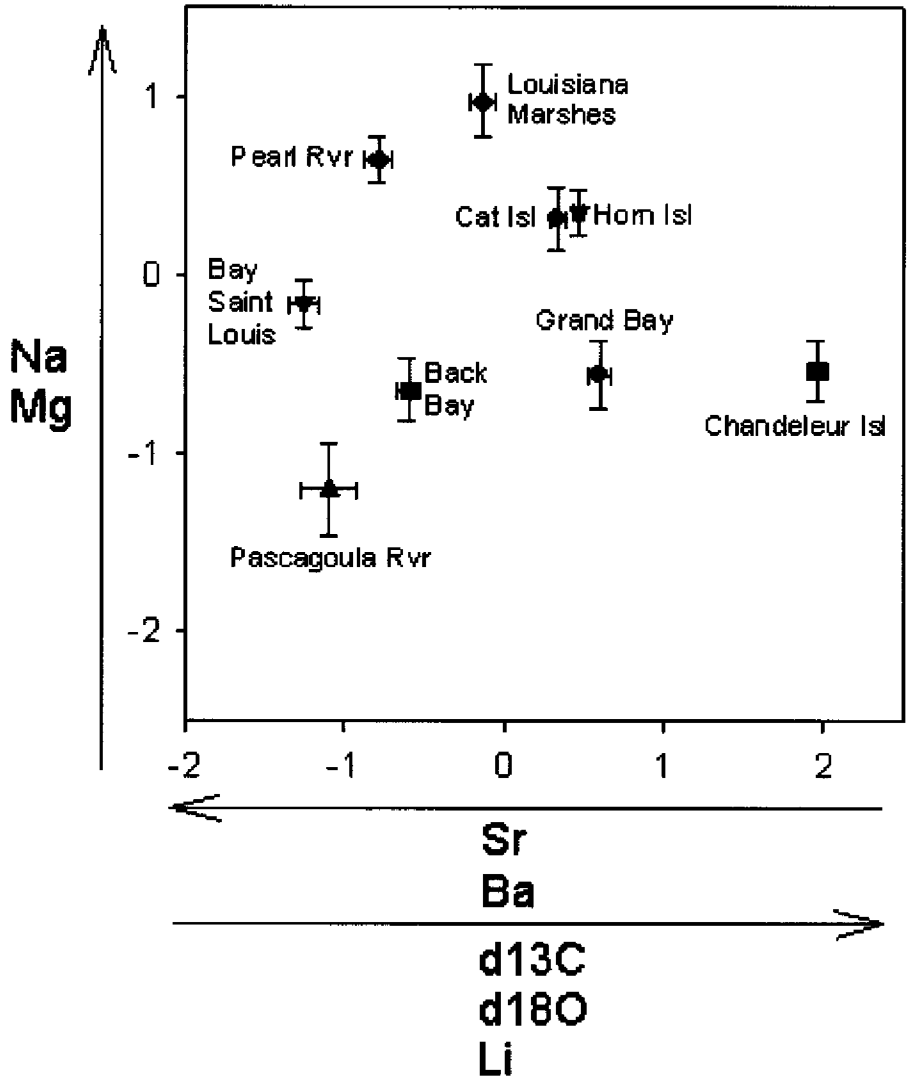
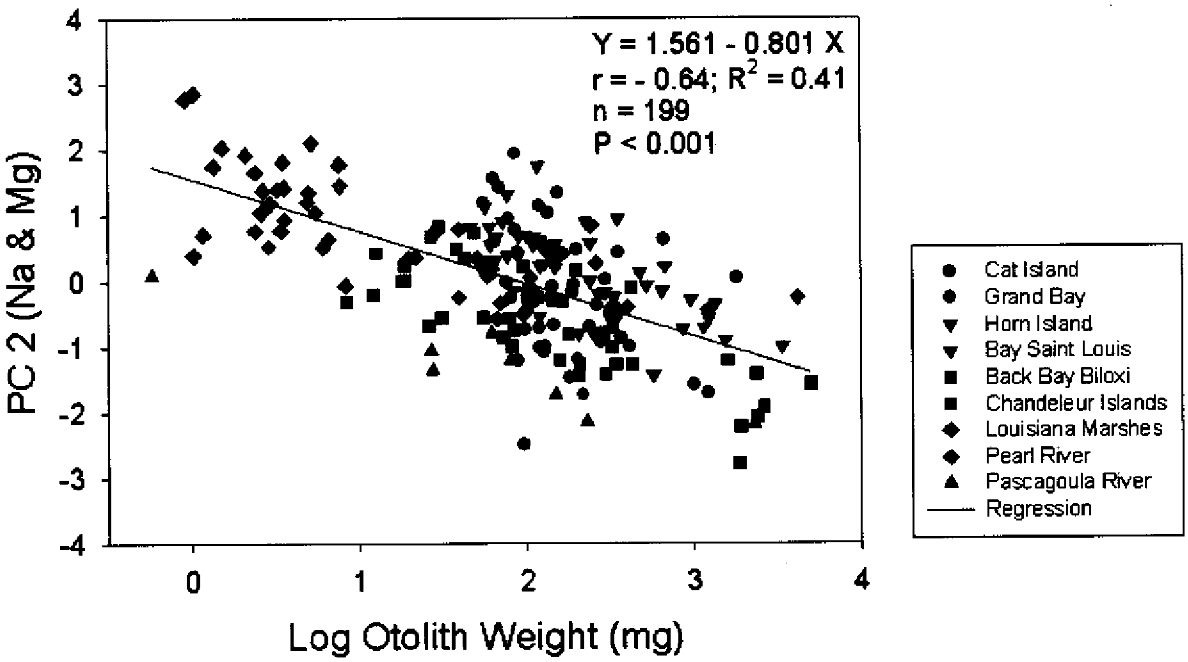


Figure 5. Relationship between the 2nd PCA axis from the unadjusted PCA and $\log_{10}$ otolith weight.



Such ontogenetic variation could potentially confound the geographic pattern of the otolith chemical signature and collection locations. Five of the eight otolith variables were significantly related to $\log_{10}$ otolith weight ($F = 7.5$ to 397.0; $P = 0.007$ to < 0.001), including $\delta^{13}C$, Na, Mg, Mn, and Ba. Interestingly, $\delta^{13}C$ was also significantly related to otolith weight ($F = 7.5$; $P = 0.007$) despite the fact that it loaded best on PC1 along with $\delta^{18}O$, which, overall, was unrelated to otolith weight ($F = 1.63$; $P = 0.20$). Further, because different forms of the variables were used on various transformation scales, all eight otolith variables were standardized with respect to otolith weight. In order to derive a set of otolith variables that were unrelated with body size and on a similar scale, the standardized residuals from regressions of otolith variables on $\log_{10}$ otolith weight were used for subsequent multivariate analyses. These standardized variables are termed size-adjusted otolith variables.

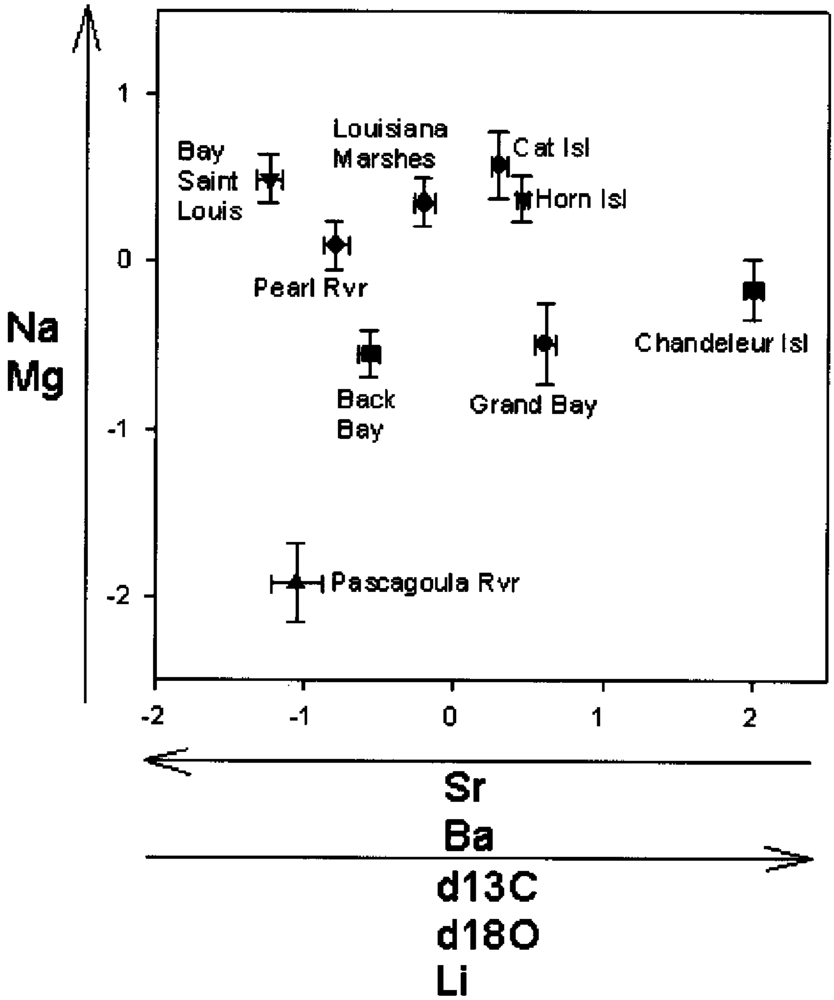
A second Varimax rotated PCA of the eight size-adjusted otolith variables was performed with the 199 individual juvenile speckled trout. Again, the eigenvalues for the first three PCA axes were each greater than one, and collectively accounted for 84% of the total variation in the size-adjusted otolith variables (50%, 19%, and 15%, respectively). Generally, loadings by the size-adjusted otolith variables contributed to the same PC axes and were of similar magnitudes and directions of influence compared to the unadjusted PCA (Table 4).

Table 4. Principal Components Analysis loadings (with Varimax rotation) on otolith variables that were adjusted for otolith weight.

	Component 1	**Component 2**	**Component 3**
D13C	**.877**	.123	-.315
D18O	**.940**	.142	.004
Lithium	**.903**	.195	-.206
Sodium	.286	**.848**	.203
Magnesium	-.140	**.809**	-.280
Manganese	-.225	-.046	**.941**
Strontium	**-.858**	-.037	.209
Barium	**-.812**	.247	-.093

Again, PC1 mainly reflected increasing concentrations of Li, $\delta^{13}C$ and $\delta^{18}O$, as well as an inverse relationship with Sr and Ba. PC2 mainly reflected correlated concentrations of Na and Mg. Principal component 3 mainly reflected a high correlation with Mn (Table 4). In the size-adjusted PCA, PC axes 2 and 3 were now completely uncorrelated with otolith weight. Although the general regional pattern was similar between the two PCA runs, relative positions of the nine *a priori* regions were shifted within the first two PCA dimensions (Figure 6).

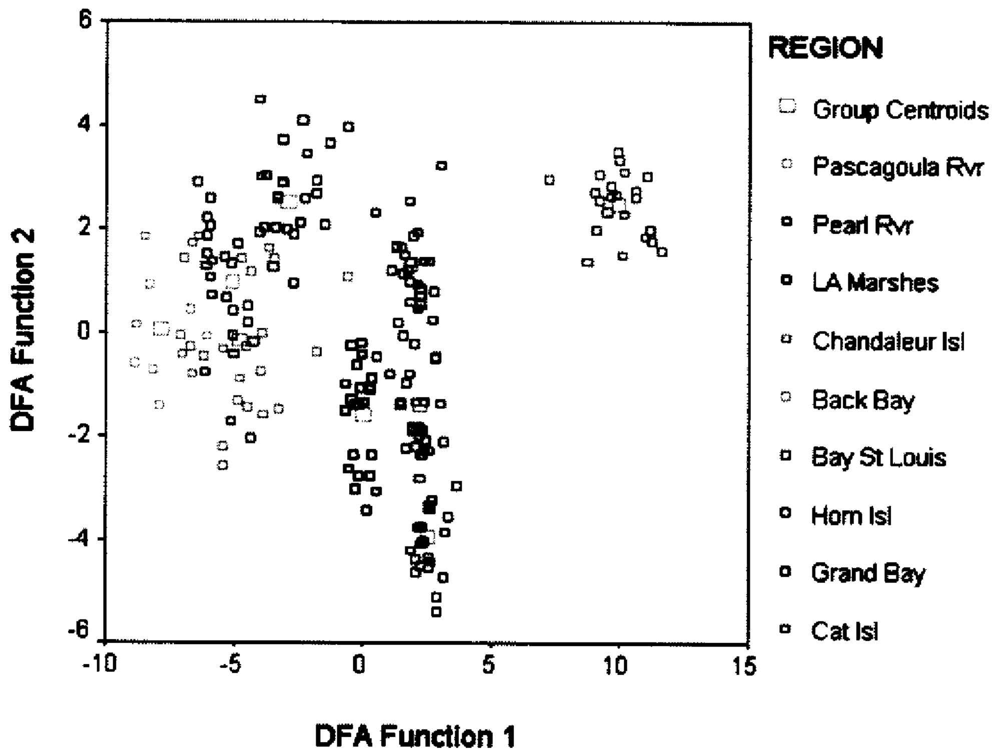
Figure 6. Bivariate plot of means (± 1 standard error) of size-adjusted Factor scores.



This difference in the dispersion of regional coordinates in PC space reflected the effects of size-related variation in the otolith chemistry variables, which had been factored out of the second PCA.

Thus, the size-adjusted otolith variables were used to develop a Canonical Discriminant Function which was not confounded by fish size. All eight possible canonical discriminant functions were included in the analysis, based on the stepwise evaluation of increased significance for each function using the Wilk's lambda selection procedure. The first three discriminant functions accounted for 96.4% of the cumulative variance in the eight otolith variables: 76.2% for CDF1, 14.2% for CDF2, and 6.0% for CDF3. Variance explained by subsequent discriminant functions accounted for progressively diminishing amounts of variation. A plot of the199 juvenile spotted seatrout along with group centroids within the space defined by the first two canonical discriminant functions showed considerable separation of the nine regional groups (Figure 7).

Figure 7. A plot of 199 juvenile spotted seatrout collected within nine regions along the Mississippi coastline along with group centroids within the space defined by the first two canonical discriminant functions.



Using the "Leave-one out" classification procedure, each case in the CDFA was classified by functions derived from all other cases. Based on this procedure, 93.5% of the 199 juvenile speckled trout originally included in the CDFA were correctly classified

(Table 5). Classification success among regions ranged between 89 and 100%. The lowest success of 89% resulted because one of nine specimens from the Pascagoula River region was misclassified as a Biloxi Bay specimen. All 24 Grand Bay and all 24 Chandaleur Island specimens were classified correctly.

Adult spotted seatrout

Two hundred and six adult spotted seatrout were collected from the nine areas of coastal Mississippi in 2002 and 2003. Otolith microchemical variables were the same as those measured for otoliths from juveniles and included stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$, and molar concentrations of Ba, Li, Mg, Mn, Na and Sr, standardized by molar Ca concentrations (Table 6, Appendix 2).

Adult spotted seatrout ranged in age from one to five years old (Table 7). Eighty two of the 206 specimens belonged to the 2001 year class for which patterns of juvenile otolith microchemistry were determined. Sixty-six of these specimens were collected in 2002 and 16 were collected in 2003. The following description considers results for adult spotted seatrout for each sub-region of concern.

Table 5. Canonical discriminant function analysis of size-adjusted otolith microchemistry variables from 199 juvenile spotted seatrout collected during 2001 from nine coastal regions in Mississippi.

	REGION	Cat Island	Grand Bay	Horn Island	St Louis Bay	Biloxi Bay	Chandeleur Islands	LA Marsh	Pearl River	Pascagoula River	Total
Count	**Cat Island**	**22**	1	0	0	0	0	1	0	0	24
	Grand Bay	0	**24**	0	0	0	0	0	0	0	24
	Horn Island	2	0	**22**	0	0	0	0	0	0	24
	St Louis Bay	1	0	0	**22**	0	0	0	1	0	24
	Biloxi Bay	0	0	0	0	**22**	0	1	0	1	24
	Chandeleur Islands	0	0	0	0	0	**22**	0	0	0	22
	LA Marsh	1	0	1	0	0	0	**22**	0	0	24
	Pearl River	0	0	0	2	0	0	0	**22**	0	24
	Pascagoula River	0	0	0	0	1	0	0	0	**8**	9
Percent	**Cat Island**	**91.7**	4.2	0	0	0	0	4.2	0	0	100.0
	Grand Bay	0	**100.0**	0	0	0	0	0	0	0	100.0
	Horn Island	8.3	0	**91.7**	0	0	0	0	0	0	100.0
	St Louis Bay	4.2	0	0	**91.7**	0	0	0	4.2	0	100.0
	Biloxi Bay	0	0	0	0	**91.7**	0	4.2	0	4.2	100.0
	Chandeleur Islands	0	0	0	0	0	**100.0**	0	0	0	100.0
	LA Marsh	4.2	0	4.2	0	0	0	**91.7**	0	0	100.0
	Pearl River	0	0	0	8.3	0	0	0	**91.7**	0	100.0
	Pascagoula River	0	0	0	0	11.1	0	0	0	**88.9**	100.0

Table 6. Mean (±SD) molar concentrations of otolith microchemical variables (standardized by molar calcium concentrations), and stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$ in otolith cores of *Cynoscion nebulosus* from the 2001 and 2002 year-class collected in the northcentral Gulf of Mexico.

Collection Location	$\delta^{13}C$ (‰)		$\delta^{18}O$ (‰)		Li ($\mu g\ g^{-1}$)		Na ($mg\ g^{-1}$)		Mg ($mg\ g^{-1}$)		Mn ($\mu g\ g^{-1}$)		Sr ($mg\ g^{-1}$)		Ba ($\mu g\ g^{-1}$)	
	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class	2001 year class	2002 year class
Biloxi Bay	-5.81 (1.7)		-2.76 (1.1)		1.79 (0.71)		11.4 (0.64)		0.138 (0.019)		36.9 (14.9)		2.25 (0.27)		16.8 (7.5)	
St. Louis Bay	-5.12 (2.3)		-2.64 (0.88)		1.46 (0.76)		11.3 (0.63)		0.141 (0.020)		43.4 (16.0)		2.28 (0.32)		28.1 (13.0)	
Cat Island	-4.24 (1.7)	-2.62 (0.55)	-2.41 (1.0)	2.00 (0.24)	2.03 (0.90)	2.70 (0.70)	11.1 (0.52)	10.8 0.64	0.145 (0.019)	0.146 (0.020)	36.2 (11.0)	36.4 (11)	2.34 (0.41)	2.04 (0.15)	24.9 (16.0)	9.68 (2.6)
Chandeleur Islands	-3.91 (2.0)	-3.26 (0.62)	-2.47 (1.2)	2.36 (0.63)	2.04 (0.82)	2.79 (0.63)	10.7 (0.95)	11.1 0.49	0.138 (0.032)	0.157 (0.020)	47.8 (21.0)	54.3 (24)	2.00 (0.33)	1.97 (0.14)	27.1 (24.0)	10.7 (5.5)
Grand Bay	-5.49 (1.2)	-4.86 (n=1)	-2.13 (0.72)	1.88 (n=1)	2.62 (0.52)	3.29 (n=1)	11.5 (0.76)	11.6 (n=1)	0.136 (0.022)	0.165 (n=1)	34.9 (14.0)	101 (n=1)	2.08 (0.20)	2.13 (n=1)	8.51 (2.4)	8.67 (n=1)
LA marshes	-4.04 (0.91)	-3.23 (0.97)	-2.64 (0.65)	2.27 (0.43)	1.34 (0.47)	1.79 (0.49)	11.0 (0.75)	11.0 0.66	0.149 (0.030)	0.148 (0.017)	36.6 (5.1)	44.8 (17)	2.34 (0.28)	2.04 (0.16)	39.3 (11.0)	17.5 (6.3)
Pascagoula River	-4.23 (3.0)	-5.39 (1.4)	-2.87 (0.65)	2.98 (0.71)	2.43 (0.65)	1.93 (0.61)	11.0 (0.47)	10.9 0.44	0.147 (0.019)	0.149 (0.025)	66.0 (33)	39.2 (23)	2.10 (0.28)	2.24 (0.20)	10.0 (5.7)	12.8 (7.9)
Pearl River	-8.65 (n=1)		-5.01 (n=1)		0.879 (n=1)		12.4 (n=1)		0.151 (n=1)		66.8 (n=1)		2.69 (n=1)		58.0 (n=1)	

Table 7. Capture location and predicted location during juvenile life-stage for adult spotted seatrout collected in 2002 and 2003.

Capture Location	Year Collected	Age	Predicted Location During Juvenile Life-Stage (number of fish)								
			Grand Bay	Pasc Riv	Biloxi Bay	St. Louis Bay	Pearl River	Horn Island	Cat Island	LA Marsh	Chand Islands
Grand Bay	2002	1	4								1
	2003	1	2								
		2	4								
		3	1								
		5				1					
Pascaloula River	2003	1	6	2	3				1	2	
		2	1		2						
		3	1								
Biloxi Bay	2002	1	7	5	3				1	3	2
	2003	2	2								
St. Louis Bay	2002	1	4			4	1		5	3	1
Pearl River	2002	1		1							
		2							1		
Horn Island	2002	2				1					2
		3	2								
		4						1			
Cat Island	2002	1			1						
		2							1		3
		3	1								
	2003	1	3						1	1	
		2	1	1					3	2	1
		3									1
Louisiana Marshes	2002	1			1						
		2									8
	2003	1	4	1				2	10	9	
		2							1	3	
		3									1
Chandeleur Islands	2003	1	7	1	3				3		
		2	5	1						3	1

Grand Bay – Based on the microchemistry of otolith cores, eleven of 13 adult fish collected in Grand Bay were predicted to have developed as young juveniles in Grand Bay (Table 7). For the 2001 year class, four of the five fish collected in 2002 ostensibly originated from Grand Bay, and one specimen had otolith-core characteristics similar to juveniles collected in the Chandeleur Islands (Table 7). All four specimens of the 2001 year class collected in 2003 from Grand Bay were ostensibly come from this source area. One five-year-old specimen, the oldest fish collected in this study, was apparently originally from St. Louis Bay, but it must be emphasized that this was not the year class for which elemental signatures were determined.

Pascagoula River - All 18 adult spotted seatrout were collected in 2003. Thirteen of these 18 specimens ostensibly originated from Grand Bay or Biloxi Bay, the two sub-regions adjacent to the Pascagoula River. Only three adults collected in 2003 were from the 2001 year class; one of these fish was predicted to originate from Grand Bay, and two were predicted to have originated from Biloxi Bay.

Biloxi Bay – Twenty-one of 23 fish from Biloxi Bay were one-year-old fish collected in 2002, ie. belonged to the 2001 year class. Fifty percent of these fish ostensibly came from the Pascagoula River (n=5) or Grand Bay (n=7), and only three of these fish were ostensibly from Biloxi Bay. Six fish ostensibly came from the barrier islands or Louisiana marshes south of the Mississippi coast; one of these was ostensibly from Cat Island, three from the Louisiana marsh, and two from the Chandeleur Islands.

St. Louis Bay – All adult fish from St. Louis Bay were collected in 2002 (n=18) and thus belonged to the 2001 year class. Thirteen of these fish were predicted to have come from either St. Louis Bay (n=4) or nearby Cat Island (n=5) or the neighboring Louisiana marsh (n=3). However, four specimens had the elemental signature characteristics of juveniles collected in the more distant Grand Bay.

Pearl River – Only two specimens were collected in the vicinity of the Pearl River; a single one-year-old that ostensibly originated from the Pascagoula River, and one two-year-old ostensibly from Cat Island.

Cat Island – Of the eight two-year-old fish collected in 2003 (2001 year class), three ostensibly originated from Cat Island, and two had the otolith signature of the nearby Louisiana marsh. Five one-year-olds were collected in 2003; one ostensibly came from Cat Island, one from the Louisiana marsh, and three from Grand Bay.

Louisiana marshes (south of the Mississippi coast) – Three of the four two-year-olds collected in 2003 from the Louisiana marshes (2001 year class) ostensibly originated from the Louisiana marshes, and one ostensibly came from nearby Cat Island. Nineteen of the 26 one-year-olds collected in 2003 had elemental signatures similar to juveniles collected in either the Louisiana marsh (n=9) or nearby Cat Island (n=10). Four of these one-year-olds ostensibly came from Grand Bay. Eight of the 9 fish collected in 2002 were two-years-old, and all eight of those ostensibly came from the Chandeleur Islands.

Horn Island – Of the six fish collected from Horn Island in 2002, one four-year-old ostensibly originated from Horn Island, and two three-year-olds had the otolith elemental signature characteristic of Grand Bay. Of the three two-year-olds collected here, one was ostensibly from St. Louis Bay, and two were from the Chandeleur Islands.

Chandeleur Islands – Five of the ten specimens from the 2001 year-class collected in 2003 from the Chandeleur Islands ostensibly originated from Grand Bay, and seven of the 14 one-year-olds collected in 2003 had otolith chemical signatures similar to juveniles from this disparate location. As explained in the discussion, this may be an artifact that resulted from adult spotted seatrout being collected from outside the juvenile range at the southern end of the Chandeleur Islands. In contrast, juveniles from this sub-region were collected at the northern end of the island chain. Seven of the remaining12 specimens ostensibly came from either the Chandeleur Islands (n=1) or neighboring Cat Island and the Louisiana marshes.

Relative amounts of nursery habitats within the geographic source areas

Of five major geographic source areas recognized along the Mississippi mainland, the one containing the most extensive area of nursery habitat for juvenile spotted seatrout extends along the shoreline of Grand Bay, which includes a section of the Alabama coastline (Figure 8). The shoreline in this area is fringed primarily with the marsh grass *Spartina alterniflora*. Extensive marsh habitat in this area extends all the way from just east of the Pascagoula river to the westernmost shoreline of Alabama. In addition, large areas of submerged aquatic vegetation (SAV) (*Ruppia maritime*) occur in Grand Bay. The second most extensive area of habitat along the Mississippi mainland are the marshes of Hancock County which extend eastward from the Mississippi border (Pearl River) to midway between the Pearl River and St. Louis Bay (Figure 8). Third in linear extent of shoreline habitat is the lower reaches of the Pascagoula River system. The remaining two major geographic source areas recognized along the mainland, St. Louis Bay and Biloxi Bay, contain diminished amounts of natural shoreline habitat because of the shorter linear extent of shoreline, as well as increased habitat loss caused by shoreline development.

Of the four major source areas located south of the Mississippi mainland, the Louisiana marshes have the most extensive sections of natural shoreline fringed with *Spartina alterniflora*. The western side of the Chandeleur Islands has both extensive shoreline habitat, and large areas of SAV in the form of several species of seagrasses. The remaining two locations, Cat Island and Horn Island, have limited amounts of shoreline habitat due to their smaller areas, but do have some SAV.

Historical monitoring data for spotted seatrout used to assess stock abundances within the geographic source areas.

Historical data were obtained from gill-net monitoring programs conducted by both the Mississippi Department of Marine Resources (DMR) and the Gulf Coast Research Laboratory (GCRL). The GCRL data set extended from 1993 to 2004 (Table 8), and the DMR data were collected more recently (2002-2004; Table 9). The same gear was used for both monitoring programs: a 750 ft gill net with 5 panels (2-4" mesh at ½" increments). Gill nets were set from the shore in the same manner for both monitoring programs, and nets were consistently fished for 30 min. Both monitoring programs sampled four of the areas that were assessed in the present study: the lower Pascagoula River system, Biloxi Bay, St. Louis Bay, and marshes east of the Pearl River.

Figure 8. Stations sampled using gill nets by the Mississippi Department of Marine Resources (station prefix D) and the Gulf Coast Research Laboratory (station prefix G).

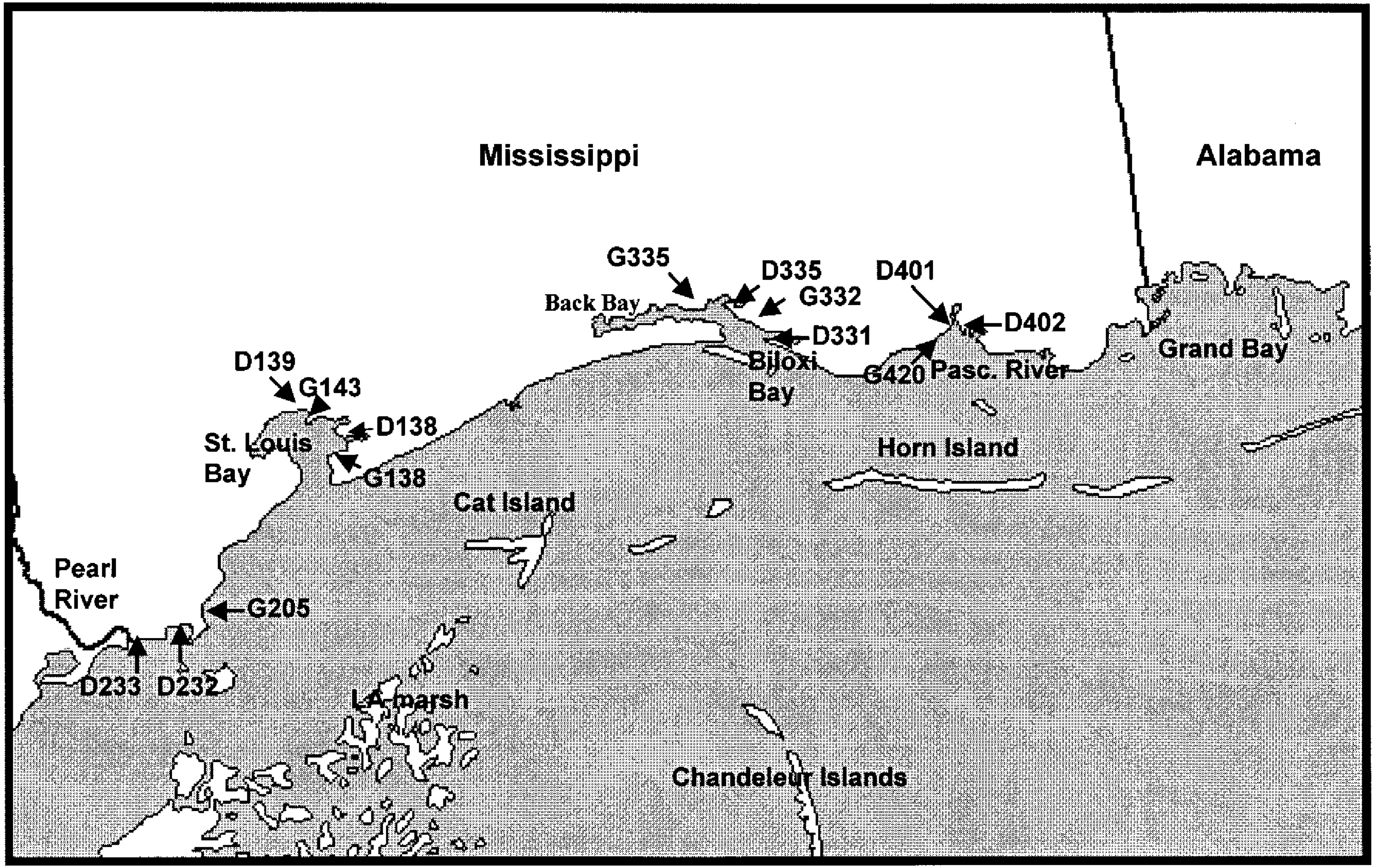


Table 8. Mean number of spotted seatrout collected each month per 30 minute gill-net set (n=2 at each station) by the Gulf Coast Research Laboratory during 1993 to 2004 (no data after July 2004). Station locations are shown in Figure 8.

	Months											
Stations (West to East)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
205	0.09	0.50	1.05	3.14	3.18	1.87	5.14	1.66	3.60	1.70	1.85	1.35
143	0.13	0.14	2.55	2.23	2.18	1.09	0.73	1.10	1.15	1.37	0.40	1.25
138	0.32	1.05	2.68	4.05	1.82	1.14	1.41	1.40	2.15	2.20	3.10	1.50
335	0.05	0.18	0.37	1.14	0.37	0.64	1.23	1.40	1.70	2.40	0.45	0.05
332	0.73	0.64	3.14	4.27	2.68	3.55	1.77	0.95	1.00	2.40	1.50	0.40
420	-	0.09	0.18	1.00	3.14	1.82	0.50	0.80	0.35	0.09	0.30	-

Table 9. Mean number of spotted seatrout collected each month per 30 minute gill-net set (n=2 at each station) by the Mississippi Department of Marine Resources from 2002 to 2004 (no data after August 2004). Station locations are shown in Figure 8.

	Months											
Stations (West to East)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
233	0.50	0.67	1.67	2.84	5.00	5.84	1.50	0.84	-	5.67	-	-
232	-	0.34	2.17	2.84	3.50	0.67	0.50	0.34	1.00	1.84	0.34	0.17
139	2.75	2.17	4.50	2.84	1.00	-	0.17	-	0.17	3.25	1.25	-
138	-	1.50	0.50	1.15	-	0.17	-	0.17	-	-	-	-
335	-	0.50	-	0.34	0.17	0.17	-	-	0.34	0.50	0.67	0.67
331	-	-	0.17	0.17	0.67	0.34	1.00	0.84	0.50	-	-	-
401	-	0.17	0.17	-	-	-	-	0.34	-	-	0.34	-
402	-	1.17	0.34	-	-	-	-	-	-	-	-	-

Catch per unit effort (CPUE; 30 minute gill-net set) was lowest in winter months, particularly during January. The highest CPUE for stations sampled by the Mississippi DMR occurred at station D233 just east of the Pearl River (Table 10). Between March and October, the mean CPUE at this location (two net-sets per month) was 3.3 spotted seatrout. The marshes east of the Pearl River also produced the highest catches during the GCRL survey: at station G205 a mean CPUE of 2.7 fish were collected. Lowest abundances of spotted seatrout were found near the mouth of the Pascagoula River and in the Back Bay of Biloxi. The mean CPUE at both stations sampled by the Mississippi DMR in the Pascagoula River (D401 and D402) was only 0.25 and 0.34 fish, respectively. Catches by the GCRL monitoring program were also low in the lower

Table 10. Mean number of spotted seatrout collected per 30 minute gill-net set from March through October. Stations were sampled twice monthly. Station prefix D refers to stations sampled by the Mississippi Department of Marine Resources (2002 to 2004), and station prefix G refers to stations sampled by the Gulf Coast Research Laboratory (1993 to 2004).

	Station Number	**Catch per unit effort**
Marshes east of the Pearl River	D233	3.34
	D232	1.61
	G205	2.67
St. Louis Bay	D139	1.99
	D138	0.50
	G143	1.55
	G138	2.11
Back Bay of Biloxi	D335	0.30
	G335	0.97
Biloxi Bay	D331	0.53
	G332	2.47
Pascagoula River	D401	0.25
	D402	0.34
	G420	0.99

Pascagoula River, with a mean CPUE of only 0.99 fish at station G420 (Table 10). Catches at the two stations sampled in the Back Bay of Biloxi were also low: at station G335 the mean CPUE was 0.97 fish, and at station D331 sampled by the Mississippi DMR, only 0.53 fish were collected per net set. In adjacent Biloxi Bay, the mean CPUE increased to 2.47 fish for collections taken by GCRL at station G332. Catches at nearby station D331 by the Mississippi DMR remained low, perhaps because of sampling variability; DMR collections extended only from 2002 to August 2004. Spotted seatrout collected in St. Louis Bay were intermediate in abundance. Mean CPUE at the two stations sampled by GCRL (G138 and G143) were 2.11 and 1.55 fish, respectively. At the two stations sampled by Mississippi DMR, mean CPUE was relatively high at station D139 (1.99 fish), but was lower at station D138 (0.50 fish).

DISCUSSION

The utilization of otolith microchemistry as a natural marker was preceded by studies to identify fish stocks using chemical differences in other hard body parts, including scales (Lapi and Mulligan, 1981) and vertebrae (Mulligan et al., 1983). Prior to this, stock identification had been based on tagging experiments, meristic and/or morphometric indices, and electrophoretic techniques. It is necessary to identify the spatial extent of fish stocks for management purposes, and this need continues to increase as populations of many species have declined significantly with increased fishing pressure and habitat loss.

Mulligan et al. (1987) first used a suite of otolith trace elements to define patterns that could be used to identify fish stocks; >70% of adult striped bass, *Morone saxatilis*, collected in four tributaries of the Chesapeake Bay could be correctly assigned to riverine groups based on otolith microchemistry. Striped bass otoliths studied by Mulligan et al. (1987) were examined in cross-section using a scanning electron microscope equipped with an energy-dispersive X-ray analyzer to identify chemical signatures. Using solution-based inductively coupled plasma-mass spectrometry (ICP-MS), Secor et al. (2001) were able to define resident, estuarine, and ocean migratory subpopulations of Hudson River striped bass. Edmonds et al. (1988; 1991; 1992), also using solution-based ICP-MS, were able to distinguish stocks of pink snapper (*Chrysophrys auratus*), orange roughy (*Hoplostethus atlanticus*), and yellow-eye mullet (*Aldrichetta forsteri*), respectively, in western Australian waters. In additional studies conducted to delineate stocks using patterns of otolith microchemistry, Campana and Gagné (1995) found they could distinguish various source areas of Atlantic cod stocks with 83-94% accuracy.

Many questions about migration patterns of coastal and marine fishes that have previously been almost impossible to answer can now be addressed using otolith microchemistry. However, the use of this approach has yielded mixed results in oceanic systems. Campana et al. (1995) showed that the annual winter migration of Atlantic cod out of the Gulf of Saint Lawrence is greater than previously believed. Elemental fingerprints for this study were comprised of relative concentrations of Li, Mg, Zn, Sr, Ba and Pb. However, Proctor et al. (1995) were unable to differentiate different migration routes for southern bluefin tuna (*Thunnus maccoyii*) using otolith composition data. Rooker et al. (2001), studying the closely related northern bluefin tuna (*Thunnus orientalis*), were able to discriminate juveniles collected from three nurseries in the western Pacific Ocean. Numerous studies of anadromous behavior in fishes have focused on concentrations of Sr in otoliths because Sr is substituted for Ca into the lattice of aragonite calcium carbonate (Kinsman and Holland, 1969; Secor, 1992), and the concentration of Sr in marine waters is far greater than in freshwater (Rosenthal et al., 1970; Bruland, 1980; Kalilsh, 1990). In addition, the quantity of Sr incorporated into an otolith is directly proportional to the quantity of Sr present in the endolymph (Kalish, 1989). The application of variability in Sr/Ca ratios in otoliths has been used to study anadromy in numerous taxa, including salmonids (Kalish, 1990), striped bass (Secor, 1992) and American shad (*Alosa sapidissima*) (Limburg, 1995). This methodology has also been used to study up-estuary movement in bay anchovy (*Anchoa mitchilli*) (Kimura et al. 2000), and offshore-inshore migration of larval and juvenile Atlantic croaker (*Micropogonias undulatus*) (Thorrold et al. 1997).

Many questions requiring knowledge about changes in habitat use can now be addressed by considering ontogenetic changes and variation in otolith microchemistry as natural tags reflective of ambient conditions experienced during earlier life-history stages. For example, Fowler et al. (1995) showed how the effects of different salinity and temperature regimes experienced by Atlantic croaker could be deciphered from the otolith microchemistry of different portions of the otolith. Indeed, Edmonds et al. (1992) successfully distinguished populations of yellow-eye mullet from four estuarine locations along the southwestern Australian coast based on otolith microchemistry. In Australia, Gillanders and Kingsford (1996) were actually able to show that the otolith fingerprints of adult wrasses reflected 41% recruitment from local estuaries and 59% from nearby reefs. In contrast, Edmonds et al. (1991), showed little previous movement of adult orange roughy captured from three areas off the eastern and western coasts of Tasmania, since the elemental composition of their otoliths matched the expected signatures of the areas in which they were captured. Thorrold et al. (1998b) used otolith microchemistry to classify juvenile weakfish (*Cynoscion regalis*) to estuarine nursery areas in the South

Atlantic Bight and Middle Atlantic Bight, and subsequently showed that a large percentage of weakfish show natal homing behavior (Thorrold et al. 2001). In the northcentral Gulf, Patterson et al. (1999) reported that they could correctly classify the nursery locations of age-0 red snapper based on their otolith core microchemistry with greater than 85 to 90 % accuracy. Patterson et al. (2004) found significant differences between elemental signatures in otoliths of red drum collected from five different estuaries in the Gulf. In addition, red drum from the Gulf could be distinguished from those collected from the Atlantic with 99% accuracy.

Although many studies have shown that otolith microchemistry can often be used to differentiate fish that have grown in different geographic regions, our study revealed a spatial separation of fish over a smaller scale than has previously been found. It is likely that this is partly because the Mississippi coastline is influenced by freshwater discharge from eight rivers, and also because other studies have focused on larger geographic scales. Juvenile spotted seatrout collected in nine regions bordering Mississippi Sound could be differentiated with over 90% accuracy, and the mean distance among regions was only 25 km. In a previous study using scale and otolith morphologies, Colura and King (1989) were able to separate spotted seatrout collected in the northeastern and southwestern areas of Galveston Bay with an accuracy of 72% and 79%, respectively.

In our study of juvenile spotted seatrout otoliths, it was necessary to make adjustments to account for ontogenetic influences on the elemental composition of otoliths. The need for such adjustments was shown by the strong relationship between the second axis of the Principal Components Analysis and body size ($\log_{10}$ otolith weight). Several other studies have made similar adjustments, including Mulligan et al. (1987), Campana et al. (2000), Rooker et al. (2001), and Hanson et al. (2004). After the ontogenetic effect on otolith microchemistry was factored out of these analyses, a second Principal Components Analysis showed separation of the nine sub-regions within the first two components. An inspection of the mean regional coordinates with respect to PC1 (horizontal axis) suggested an underlying riverine discharge gradient associated with this axis (Figure 6). Regions were arrayed better along this axis with respect to presumed freshwater discharge than to geographical proximity. For example, the Pearl River, St.

Louis Bay, Biloxi Bay, and Pascagoula River regions are characteristically more influenced by riverine input than the remaining five locations, and these regions had relatively low values with respect to PC1. Variability in otolith Sr concentrations contributed to the composite variable forming PC1, and it is perplexing that otoliths from juveniles collected in regions where salinity levels would be expected to be relatively low, i.e. Pearl River, St. Louis Bay, Biloxi Bay and Pascagoula River, contained comparatively high concentrations of Sr. Previous studies have used the direct relationship between otolith Sr concentrations and salinity to study anadromous behavior in fishes (Kalish, 1990; Secor, 1992; Limburg, 1995). It should be noted that Sr was only one of five variables that contributed strongly to PC1, and ranges in salinity were much less than experienced by an anadromous species.

A Canonical Discriminant Function Analysis (CDFA) that classified the data into nine multiple *a priori* sub-regional groups showed considerable separation of those groups. Juveniles were plotted within the space defined by the first two canonical discriminant functions. Again, a discharge related pattern was evident within the CDFA plot when juveniles were plotted within the space defined by the first two discriminant functions. St. Louis Bay, Biloxi Bay, and Pascagoula River groups were least well separated by the first two canonical discriminant functions. However, all nine *a priori* regions were clearly differentiated within the context of all eight CDFA functions, and were classified with respect to their region (n=9) with over 90% accuracy. In most cases, misclassified specimens were assigned to regions geographically related to their source regions. For example, two Horn Island specimens were misclassified as Cat Island specimens; of the two Louisiana Marsh specimens, one was assigned to nearby Cat Island and the other to Horn Island; and two of 24 Pearl River specimens were misclassified as coming from St. Louis Bay. If several source sub-regions that were in close proximity were combined, the accuracy of classification of juveniles with respect to their source areas would be extremely high. These data indicate that small juvenile spotted seatrout remain generally within a particular estuarine system or sub-region.

Both tagging and genetic studies have shown that movement of adult spotted seatrout is limited. Baker et al. (1986) tagged 2040 spotted seatrout during five years in

Bastrop bayou, Texas. Of the 176 recaptured fish, none came from adjacent tributaries in the Galveston Bay system, suggesting the possibility of subpopulations within Galveston Bay. Gold et al. (1999), found genetic divergence among subpopulations of spotted seatrout in the northern Gulf, and attributed this to behavioral factors that limit female dispersal from a natal bay or estuary. Gold et al. (2003), found genetic evidence suggesting that the population structure of spotted seatrout along the Texas coast may be comprised of a series of overlapping subpopulations distributed along the coast. These subpopulations were proposed to each be centered in individual estuaries with enough mixing between neighboring estuaries to prevent genetic divergence.

Hendon et al. (2003) tagged 15,206 spotted seatrout along the Mississippi coast from 1995 through 1999. Most fish (84%) were shorter than 356 mm, which was the state's legal size limit of 14 inches, and 3% of tagged fish were recaptured (n=408). Ninety percent of recaptured fish moved less than 10 km from the site of tagging, and 82% of fish moved <3 km. One tagged fish moved 60 km over a period of 200 d, and three fish (0.7 %) moved at least 50 km. Our study indicated more movement of spotted seatrout between regions of the Mississippi coast. This may be because our study extended over a two-year period, whereas 81% of recaptures in the study by Hendon et al. (2003) occurred within eight weeks of tagging. Brown-Peterson and Warren (2001) found regional differences in the spawning frequency of spotted seatrout in coastal Mississippi; fish from the barrier islands and St. Louis Bay areas spawned more frequently than fish from Biloxi Bay. The extent to which these differences were mediated by environmental conditions is not known. These regional differences in spawning frequency were not reflected in the present study by the predicted relative contribution of these regions to stocks of spotted seatrout across the Mississippi coast based on otolith microchemistry.

A useful product of the CDFA used in our analysis of juvenile spotted seatrout otoliths was a set of function coefficients that were used to estimate in which sub-regions adults developed as juveniles based on the elemental composition of the inner portion of their otoliths. Of the 206 adult spotted seatrout that were collected from the nine areas of coastal Mississippi in 2002 and 2003, 82 specimens belonged to the 2001 year class for which patterns of juvenile otolith microchemistry were determined. Previous studies have examined the inner portion of adult otoliths by using various types of micro-probe analyses of otolith cross-sections (eg. Mulligan et al., 1987; Thorrold et al., 1997; Secor, 1992; Limburg, 1995; Proctor et al., 1995; Yamashita et al., 2000). Our study differed in that the inner portion of adult otoliths was extracted with six precision cuts, and after extensive cleaning the removed core was dissolved and analyzed using ICP-MS.

One indication that this methodology could be used to determine the source area of adult fish was indicated by the high proportion of adults collected in Grand Bay that were predicted to have come from Grand Bay as juveniles. Eleven of 13 adult fish (85%) collected in Grand Bay were predicted, based on the microchemistry of otolith cores, to have developed as young juveniles in Grand Bay. Of the 2001 year class, four of the five fish collected in 2002 were predicted to have come from Grand Bay, and one specimen had otolith-core characteristics similar to juveniles collected in the Chandeleur Islands. All four specimens of the 2001 year class collected in 2003 from Grand Bay were predicted to have come from this area. Grand Bay, which now comprises the Grand Bay National Estuarine Research Reserve, is the most extensive area of habitat for juvenile spotted seatrout along the Mississippi and western Alabama shoreline.

Many adults from other regions of the Mississippi coastline ostensibly came from the Grand Bay region, indicating that this is an important source area for spotted seatrout. The number of adults predicted to have developed as juveniles in Grand Bay decreased along the Mississippi shoreline with increased distance from Grand Bay. In the neighboring Pascagoula River sub-region, otolith cores of eight of 18 adults (44%) had elemental signatures similar to the elemental composition of juveniles from Grand Bay. In the Biloxi Bay sub-region, located immediately west of the Pascagoula River, nine of 23 adults (39%) were predicted to have come from Grand Bay. Progressing westward, only 4 of 18 adults collected in St. Louis Bay were predicted to have come from Grand Bay, and none of the few adults collected in the Pearl River sub-region were predicted to have come from this sub-region. Many of the fish collected in the Pascagoula River sub-region belonged to the 2002 year class, but all specimens from Biloxi Bay and St. Louis Bay were from the 2001 year class, i.e. the same year class for which juvenile otolith signatures were determined. It is possible that this westward movement of fish was facilitated by the prevailing westerly water currents in Mississippi Sound.

Although the strongest regional affinity between elemental signatures of adult otolith cores and juvenile otoliths was found for spotted seatrout from Grand Bay, many of the other sub-regions showed a strong regional affinity when neighboring sub-regions were combined. For instance: 72% of adults from the Pascagoula River sub-region (n=18) were ostensibly from either this area, or neighboring Grand Bay and Biloxi Bay; 50% of adults from Biloxi Bay were ostensibly from the neighboring Pascagoula River sub-region or Grand Bay; 72% of adults from St. Louis Bay (n=18) were ostensibly from either this sub-region, or either neighboring Cat Island and the Louisiana marsh; 54% of adults from Cat Island (n=13) were apparently from either this island or the neighboring Louisiana marsh; and 80% of adults from the Louisiana marsh (n=40) were ostensibly from either this area, or neighboring Chandeleur Islands and Cat Island. Surprisingly, 50% of adults collected from the Chandeleur Islands (n=24) had otolith core signatures similar to juveniles collected in Grand Bay. This is likely an artifact because adult spotted seatrout were caught at the southern end of the Chandeleur Island chain, but juveniles were collected near the northern end of the islands. It is quite possible that the southern end of the Chandeleur Islands chain that borders Breton Sound has water chemistry with similar characteristics to Grand Bay. A plot of juvenile spotted seatrout within the space defined by the first two canonical discriminant functions in the CDFA showed fish collected in Grand Bay and the northern end of Chandeleur Islands to be grouped closely together, even though there was no overlap between the two groups. This similarity may be in part because Grand Bay is the only mainland sub-region that was not strongly influenced by riverine input.

Site fidelity could not be assessed for adults from the Pearl River sub-region because only two adults were collected from this area. However, the influence of this sub-region as a source area, based on the otolith elemental signature of juveniles collected in this sub-region, was negligible. Only one adult from another sub-region, neighboring St. Louis Bay, was predicted to have come from the Pearl River area. Juveniles from the Pearl River sub-region were collected in the Hancock County marshes, which are bordered on their western edge by the Pearl River. These marshes constitute the second most extensive area of habitat along the Mississippi mainland. Based on the strong apparent influence of Grand Bay in eastern Mississippi as a source area for spotted seatrout, it is surprising that no influence was detected in the western portion of the coastline for the Pearl River sub-region as a source area. Hendon et al. (2003), in assessing longshore movement of adult spotted seatrout, also found no easterly movement of fish along the Mississippi coastline. However, a general pattern of westerly movement was found in the eight recaptures that moved a significant distance along the coastline (Hendon et al., 2003).

The Pearl River sub-region, although apparently not an important source area of spotted seatrout for other regions of the Mississippi coast, supports a large population of spotted seatrout as evidenced by historical monitoring data. This historical information includes gill-net catch data collected by both the Mississippi Department of Marine Resources (MDMR) and the Gulf Coast Research Laboratory (GCRL) in four of the sub-regions included in our spotted seatrout study (Pearl River, St. Louis Bay, Biloxi Bay and Pascagoula River). The highest mean catch per unit effort (CPUE) from March through October occurred in the Pearl River sub-region for both MDMR and GCRL collections. Lowest CPUE was found in the Pascagoula River. It is likely that gill-net catches of spotted seatrout in the Grand Bay sub-region would be relatively high, but no data exist for this area. The fact that no evidence was found to support the idea that the Pearl River sub-region is an important source area of spotted seatrout for other areas of the Mississippi coast in no way diminishes the importance of this region as a habitat for juveniles, as evidenced by the significant population of fish that it supports. In addition, it is quite possible that Pearl River sub-region is an important source area of fish for more westerly sections of the coast.

The Louisiana marshes, located south of St. Louis Bay, provide extensive habitat for juvenile spotted seatrout, and this area is well known by anglers for the population of spotted seatrout that it supports. However, the influence of this sub-region as a source area of spotted seatrout for Mississippi was limited. Approximately one third of adults from the 2001 year class collected at neighboring Cat Island (n=6) or the nearby

Chandeleur Islands (n=10) ostensibly came from the Louisiana marshes based on otolith microchemistry. This influence decreased with distance away from the Louisiana marshes. Seventeen percent of adults from the 2001 year class collected in St. Louis Bay (n=18) and 13% of adults from Biloxi Bay (n=23) had otolith elemental characteristics of juveniles from the Louisiana marshes

IMPLICATIONS

Knowledge of spotted seatrout population structure, including movements between sub-regions and utilization of nursery areas by juveniles, will provide fisheries managers with important life history information needed for management decisions. Contrary to our expectations, results of this study failed to confirm that the extensive salt marsh habitat in the eastern areas of Louisiana or the large areas of submerged aquatic vegetation bordering the western side of the Chandeleur Islands serve as major source areas for the spotted seatrout stock structure along the Mississippi coast. Surprisingly, otolith microchemistry indicated that the Grand Bay region in eastern Mississippi probably functions as an important source area of spotted seatrout for sections of the Mississippi coastline. Differences in the movement of young fish between regions likely provides heterogeneous gene-flow for the population; and as we learn more about the source-sink biology of spotted seatrout, the relative importance of all coastal shorelines must be emphasized. Loss of habitat connecting sub-regions could impede the movement of fish between these areas.

Elemental signatures of adult otolith cores also showed more mixing of fish between adjacent estuarine sub-regions during the first two years of life than has been shown with tagging studies. However, one and two-year-old spotted seatrout did show strong regional affinities, particularly when neighboring sub-regions were combined. Considering the current strong interest in stock-enhancement of spotted seatrout in Mississippi, regional influences would need to be taken into consideration for determining release locations for hatchery-reared young juveniles. Additional comparative studies of sub-regional differences in vital rates such as settlement, early growth, and mortality are needed to fully understand stock-recruitment dynamics of this fish in Mississippi. Additionally, monitoring studies of spotted seatrout populations along the Mississippi coast need to include all sub-regions in sampling designs.

Based on otolith microchemistry, our study showed a spatial separation of juvenile spotted seatrout over a smaller geographic scale than has previously been found for other fishes. Juveniles collected in nine regions bordering Mississippi Sound could be differentiated with over 90% accuracy, and the mean distance among regions was only 25 km. This distinction between fish collected in different sub-regions was likely possible because the Mississippi coastline is influenced by freshwater discharge from eight rivers. It is therefore likely that these techniques can be applied to other estuarine-dependent species in this area.

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Appendix 1. Molar concentrations of otolith microchemical variables (standardized by molar calcium concentrations), and stable isotope ratios of δ13C and δ18O in otoliths of juvenile *Cynoscion nebulosus* collected in the northcentral Gulf of Mexico.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
1	Cat Isl	-4.01772	-2.28330	0.0000040145	0.0148724729	0.0002378123	0.0000319012	0.0023166856	0.0000279469
2	Cat Isl	-3.79025	-2.44011	0.0000033441	0.0130556545	0.0001503910	0.0000286061	0.0024774773	0.0000287779
3	Cat Isl	-3.66943	-2.30246	0.0000022487	0.0132133536	0.0002054509	0.0000344570	0.0023947025	0.0000311475
4	Cat Isl	-3.30669	-2.19597	0.0000035884	0.0146576621	0.0002207279	0.0000332309	0.0022634139	0.0000304442
5	Cat Isl	-3.77339	-2.19345	0.0000037469	0.0134062413	0.0001639589	0.0000291563	0.0024031301	0.0000275140
6	Cat Isl	-3.90470	-2.30356	0.0000039278	0.0134711840	0.0002134116	0.0000339596	0.0022243538	0.0000297017
7	Cat Isl	-3.53307	-2.25326	0.0000027806	0.0127951000	0.0002082504	0.0000326343	0.0025314805	0.0000344347
8	Cat Isl	-3.88452	-2.14719	0.0000026195	0.0141056171	0.0002131172	0.0000287186	0.0022540897	0.0000288341
9	Cat Isl	-3.57432	-2.20806	0.0000032724	0.0128008155	0.0002043274	0.0000269886	0.0019421498	0.0000211788
10	Cat Isl	-3.31232	-2.17477	0.0000034795	0.0139486083	0.0002001451	0.0000340670	0.0023016298	0.0000334764
11	Cat Isl	-3.91658	-2.23850	0.0000029979	0.0136070238	0.0001988667	0.0000305482	0.0021351356	0.0000219529
12	Cat Isl	-3.53501	-2.29648	0.0000032052	0.0125677271	0.0001657720	0.0000278114	0.0021889941	0.0000238082
13	Cat Isl	-4.14031	-2.49114	0.0000026828	0.0113879736	0.0001327943	0.0000244711	0.0023656934	0.0000185139
14	Cat Isl	-3.93778	-2.26187	0.0000033827	0.0132816907	0.0001964143	0.0000330596	0.0024572462	0.0000214372
15	Cat Isl	-4.07237	-2.32428	0.0000033929	0.0137117461	0.0002351138	0.0000274934	0.0019641195	0.0000189794
17	Cat Isl	-2.93000	-2.26000	0.0000027622	0.0115657459	0.0001444258	0.0000375736	0.0022340710	0.0000128489
16	Cat Isl	-4.07000	-2.32000	0.0000020903	0.0133825779	0.0001959935	0.0000274512	0.0022990981	0.0000240222
18	Cat Isl	-3.37767	-2.30209	0.0000030468	0.0126854961	0.0001956003	0.0000485749	0.0024573179	0.0000183041
19	Cat Isl	-3.99882	-2.37965	0.0000030527	0.0125580365	0.0001778862	0.0000286350	0.0020529275	0.0000217124
20	Cat Isl	-4.26562	-2.38710	0.0000034090	0.0132076977	0.0002028118	0.0000290781	0.0020966320	0.0000189579
21	Cat Isl	-4.37773	-2.45114	0.0000019092	0.0134178285	0.0002239510	0.0000329916	0.0023416186	0.0000168682
22	Cat Isl	-4.08397	-2.33778	0.0000018650	0.0124540292	0.0001969107	0.0000286217	0.0022399617	0.0000195079
23	Cat Isl	-4.19342	-2.30087	0.0000029722	0.0127945517	0.0001724303	0.0000292159	0.0018957545	0.0000152286
24	Cat Isl	-4.00186	-2.32736	0.0000021411	0.0125896731	0.0001793851	0.0000295739	0.0020847573	0.0000198458
25	Grand Bay	-4.60268	-2.34750	0.0000027735	0.0126918958	0.0001696944	0.0000583479	0.0019259779	0.0000068250
26	Grand Bay	-5.08518	-2.36962	0.0000035194	0.0132700219	0.0002038303	0.0000340032	0.0019522006	0.0000132781
27	Grand Bay	-4.08751	-2.28694	0.0000031943	0.0129025370	0.0001772286	0.0000480588	0.0023130798	0.0000109047

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
28	Grand Bay	-5.20823	-2.41513	0.0000027310	0.0131307187	0.0001598232	0.0000386923	0.0019457693	0.0000058393
29	Grand Bay	-5.13390	-2.39310	0.0000025510	0.0133617976	0.0001871468	0.0000366474	0.0019715707	0.0000105233
30	Grand Bay	-4.60083	-2.44809	0.0000024005	0.0130928591	0.0001716915	0.0000531712	0.0021001830	0.0000077077
31	Grand Bay	-4.52931	-2.31957	0.0000029107	0.0125347119	0.0001523128	0.0000383285	0.0021932434	0.0000118570
32	Grand Bay	-4.89210	-2.33322	0.0000019235	0.0117905669	0.0001534369	0.0000425709	0.0023694849	0.0000186565
33	Grand Bay	-4.87050	-2.41160	0.0000027799	0.0130457112	0.0001606571	0.0000308623	0.0021971939	0.0000100736
34	Grand Bay	-5.17096	-2.41792	0.0000030025	0.0117381422	0.0001488729	0.0000337479	0.0021824825	0.0000099069
35	Grand Bay	-4.97558	-2.42802	0.0000030028	0.0127216424	0.0001534739	0.0000331707	0.0023981896	0.0000097587
36	Grand Bay	-5.79727	-2.43004	0.0000031504	0.0143360989	0.0002060017	0.0000339742	0.0022678542	0.0000146723
37	Grand Bay	-4.09278	-2.35411	0.0000033140	0.0127286954	0.0001652515	0.0000588727	0.0021027369	0.0000108086
38	Grand Bay	-5.59268	-2.49228	0.0000034138	0.0131298788	0.0001749242	0.0000527447	0.0020092376	0.0000129862
39	Grand Bay	-4.95711	-2.44245	0.0000026680	0.0120819788	0.0001450167	0.0000307428	0.0024707973	0.0000171559
40	Grand Bay	-5.92661	-2.49660	0.0000027186	0.0117267622	0.0001239333	0.0000304437	0.0023266836	0.0000171942
41	Grand Bay	-5.59006	-2.42840	0.0000030847	0.0133713213	0.0001772212	0.0000389381	0.0023515833	0.0000150724
42	Grand Bay	-5.99224	-2.41811	0.0000027484	0.0137133949	0.0002340801	0.0000548892	0.0023916657	0.0000197048
43	Grand Bay	-5.66785	-2.28656	0.0000033387	0.0125057757	0.0001932053	0.0000485997	0.0021168230	0.0000018611
44	Grand Bay	-6.03626	-2.52039	0.0000031879	0.0147390026	0.0002281844	0.0000511743	0.0024195301	0.0000194258
45	Grand Bay	-5.40717	-2.44500	0.0000031266	0.0122152045	0.0001538343	0.0000402693	0.0021968216	0.0000118509
46	Grand Bay	-4.69582	-2.24998	0.0000035426	0.0127858268	0.0002181450	0.0000490470	0.0020244777	0.0000134563
47	Grand Bay	-4.99898	-2.40791	0.0000016177	0.0109481171	0.0001319487	0.0000493776	0.0023087179	0.0000078127
48	Grand Bay	-4.89898	-2.31053	0.0000024917	0.0126760078	0.0001591183	0.0000414361	0.0022119959	0.0000150896
49	Horn Isl	-3.00943	-2.22228	0.0000034876	0.0137230872	0.0001945202	0.0000185905	0.0025513172	0.0000250817
50	Horn Isl	-4.43843	-2.43361	0.0000020248	0.0130900771	0.0001722936	0.0000190704	0.0022300789	0.0000206825
51	Horn Isl	-2.86330	-2.32969	0.0000036947	0.0145477261	0.0002035770	0.0000173680	0.0021928394	0.0000228453
52	Horn Isl	-2.55942	-2.21532	0.0000023444	0.0132575557	0.0001625543	0.0000148954	0.0021192550	0.0000218756
53	Horn Isl	-2.59556	-2.29886	0.0000036885	0.0131939429	0.0001821887	0.0000173382	0.0020551602	0.0000228658
54	Horn Isl	-3.76511	-2.28650	0.0000028541	0.0142322790	0.0001927803	0.0000181005	0.0020840031	0.0000192580
55	Horn Isl	-3.27301	-2.24017	0.0000037339	0.0132199597	0.0002052627	0.0000179025	0.0019737520	0.0000196488

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
56	Horn Isl	-3.10587	-2.34228	0.0000034367	0.0147846360	0.0001813055	0.0000182008	0.0023772447	0.0000279239
57	Horn Isl	-2.85715	-2.29915	0.0000022646	0.0121477667	0.0001717745	0.0000179030	0.0023585585	0.0000140368
58	Horn Isl	-3.00391	-2.19916	0.0000027720	0.0126054118	0.0001472007	0.0000143532	0.0021507260	0.0000175225
59	Horn Isl	-2.90109	-2.27968	0.0000036600	0.0133887763	0.0001670089	0.0000217288	0.0022567650	0.0000302734
60	Horn Isl	-2.77175	-2.33292	0.0000031558	0.0133181027	0.0001590446	0.0000176149	0.0022064894	0.0000195575
61	Horn Isl	-2.44395	-2.24260	0.0000038030	0.0132243034	0.0001853786	0.0000187990	0.0020618476	0.0000167106
62	Horn Isl	-2.80298	-2.25933	0.0000038513	0.0136282776	0.0002591791	0.0000209719	0.0020744479	0.0000162608
63	Horn Isl	-3.02053	-2.30513	0.0000026025	0.0139539298	0.0001851087	0.0000129393	0.0020765855	0.0000167730
64	Horn Isl	-2.98934	-2.31113	0.0000034843	0.0134613296	0.0001923206	0.0000157884	0.0023315850	0.0000239325
65	Horn Isl	-2.92425	-2.27749	0.0000033974	0.0136648500	0.0001826558	0.0000152318	0.0022413886	0.0000207404
66	Horn Isl	-3.01981	-2.32570	0.0000035188	0.0143973596	0.0001759022	0.0000170842	0.0023454647	0.0000244415
67	Horn Isl	-2.16502	-2.28569	0.0000028087	0.0140517580	0.0001897927	0.0000143978	0.0020877903	0.0000183918
68	Horn Isl	-2.68519	-2.33092	0.0000037616	0.0146916071	0.0002135818	0.0000183012	0.0024255319	0.0000220499
69	Horn Isl	-3.45473	-2.31373	0.0000026660	0.0138947577	0.0001927229	0.0000199446	0.0021623595	0.0000188740
70	Horn Isl	-2.84408	-2.37045	0.0000034823	0.0128653891	0.0001526580	0.0000129539	0.0021003989	0.0000170484
71	Horn Isl	-3.16492	-2.36273	0.0000025883	0.0136690816	0.0001796365	0.0000169843	0.0021018721	0.0000193062
72	Horn Isl	-3.97755	-2.29303	0.0000030380	0.0133902756	0.0001901187	0.0000177174	0.0022732986	0.0000185272
73	St. louis Bay	-7.56656	-3.80365	0.0000012003	0.0128205252	0.0001790033	0.0000426191	0.0025667199	0.0000301483
74	St. louis Bay	-3.73847	-2.56715	0.0000032743	0.0124210832	0.0001531749	0.0000376906	0.0024387778	0.0000380628
75	St. louis Bay	-6.72604	-3.64344	0.0000015433	0.0138560380	0.0002044408	0.0000584760	0.0026532349	0.0000404711
76	St. louis Bay	-7.27416	-3.96201	0.0000012622	0.0122549784	0.0001704378	0.0000347211	0.0026751271	0.0000306756
77	St. louis Bay	-8.21470	-4.09311	0.0000010356	0.0127776976	0.0001766148	0.0000650842	0.0027610576	0.0000354261
78	St. louis Bay	-6.93174	-3.59684	0.0000014463	0.0128792235	0.0001882479	0.0000532495	0.0025270461	0.0000241057
79	St. louis Bay	-7.10705	-3.97373	0.0000014481	0.0121223420	0.0001933967	0.0000538499	0.0027856098	0.0000358670
80	St. louis Bay	-7.12931	-3.64988	0.0000011190	0.0129474033	0.0001810789	0.0000703416	0.0025271616	0.0000259956
81	St. louis Bay	-8.67925	-4.16337	0.0000006725	0.0126183369	0.0001737420	0.0000544774	0.0026012120	0.0000233006
82	St. louis Bay	-8.39115	-4.11889	0.0000000208	0.0116186761	0.0001402478	0.0000437241	0.0029641225	0.0000435927
83	St. louis Bay	-8.58048	-4.13452	0.0000008676	0.0136946288	0.0002315973	0.0000640602	0.0024960935	0.0000203447

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
84	St. louis Bay	-8.26617	-4.20676	0.0000007609	0.0129096007	0.0002018882	0.0000528322	0.0027598144	0.0000310528
85	St. louis Bay	-9.21660	-4.09141	0.0000007384	0.0129237332	0.0002155999	0.0000791730	0.0028103282	0.0000411352
86	St. louis Bay	-8.95651	-4.19703	0.0000007493	0.0131547448	0.0002314936	0.0000654459	0.0028419052	0.0000375458
87	St. louis Bay	-8.51954	-4.13161	0.0000004940	0.0125021315	0.0001529253	0.0000487461	0.0027187289	0.0000388058
89	St. louis Bay	-9.61030	-4.24967	0.0000009598	0.0128751421	0.0002042817	0.0000887941	0.0032291832	0.0000425289
90	St. louis Bay	-9.75535	-4.27525	0.0000007578	0.0140725393	0.0002055652	0.0000714658	0.0033192255	0.0000553379
91	St. louis Bay	-7.33751	-4.07087	0.0000010815	0.0118063280	0.0001606362	0.0000457073	0.0026558320	0.0000300756
92	St. louis Bay	-8.32414	-4.22384	0.0000007227	0.0113996653	0.0001687671	0.0000239271	0.0024774213	0.0000376647
93	St. louis Bay	-7.67093	-3.89280	0.0000010645	0.0118841270	0.0001801336	0.0000537437	0.0026273628	0.0000332308
94	St. louis Bay	-7.40105	-3.98642	0.0000007654	0.0119167711	0.0001968774	0.0000474461	0.0026337583	0.0000301143
95	St. louis Bay	-6.23016	-3.93154	0.0000009675	0.0115710546	0.0001766805	0.0000263136	0.0027284277	0.0000354158
96	St. louis Bay	-7.73079	-4.11297	0.0000007931	0.0121346356	0.0001929796	0.0000459160	0.0023875814	0.0000232595
97	Back Bay	-7.48614	-4.42542	0.0000007324	0.0123189703	0.0001930243	0.0000375684	0.0023520954	0.0000139315
98	Back Bay	-7.67388	-4.48041	0.0000010522	0.0117725881	0.0001407863	0.0000432082	0.0028902469	0.0000221070
99	Back Bay	-7.83495	-4.42731	0.0000008877	0.0123770900	0.0001545752	0.0000305121	0.0025361356	0.0000117403
100	Back Bay	-7.46624	-4.17815	0.0000011727	0.0126526711	0.0001714284	0.0000643417	0.0022271121	0.0000121059
101	Back Bay	-7.52533	-4.26611	0.0000011952	0.0128652016	0.0001816227	0.0000403579	0.0026960564	0.0000240282
102	Back Bay	-7.12424	-4.04692	0.0000018951	0.0128053084	0.0001683525	0.0000438727	0.0026170259	0.0000193414
103	Back Bay	-6.22788	-3.76788	0.0000018156	0.0131126827	0.0001778957	0.0000325273	0.0024166051	0.0000172279
104	Back Bay	-5.82689	-3.10307	0.0000030336	0.0127480309	0.0001619757	0.0000308285	0.0023483496	0.0000171920
105	Back Bay	-5.03983	-2.83582	0.0000027687	0.0135732261	0.0002112277	0.0000688011	0.0024114603	0.0000173746
106	Back Bay	-5.93778	-3.70863	0.0000017946	0.0124935004	0.0001478892	0.0000411099	0.0024918957	0.0000305624
107	Back Bay	-5.69752	-3.46111	0.0000022147	0.0125899925	0.0001634337	0.0000292617	0.0022845610	0.0000143490
108	Back Bay	-6.07016	-3.86067	0.0000020070	0.0140642006	0.0002060305	0.0000339486	0.0023008546	0.0000210575
109	Back Bay	-6.18937	-3.54109	0.0000027127	0.0140111156	0.0002068317	0.0000373965	0.0025488524	0.0000238922
110	Back Bay	-6.52811	-3.73457	0.0000020731	0.0139046961	0.0001897566	0.0000450028	0.0026560119	0.0000268238
111	Back Bay	-6.32477	-3.59464	0.0000013077	0.0121955006	0.0001503406	0.0000548523	0.0025403420	0.0000165042
112	Back Bay	-6.30602	-3.84648	0.0000009896	0.0111785060	0.0001734368	0.0000355928	0.0025024417	0.0000133294

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
113	Back Bay	-6.55371	-3.90460	0.0000011960	0.0109576526	0.0001542792	0.0000421007	0.0025564893	0.0000127185
114	Back Bay	-6.17223	-3.71097	0.0000008061	0.0107811616	0.0001453500	0.0000520004	0.0024874988	0.0000129314
115	Back Bay	-6.82799	-4.09754	0.0000013568	0.0125117367	0.0001559390	0.0000757949	0.0024786042	0.0000122829
116	Back Bay	-6.98793	-3.92014	0.0000012296	0.0128023376	0.0001747781	0.0000448131	0.0028855394	0.0000177404
117	Back Bay	-6.67218	-3.94928	0.0000004801	0.0109693445	0.0001461516	0.0000491948	0.0024571960	0.0000147900
118	Back Bay	-7.23488	-3.92428	0.0000015175	0.0131870990	0.0002024390	0.0000569450	0.0027493488	0.0000215969
119	Back Bay	-6.30310	-3.86740	0.0000019869	0.0132391609	0.0001811513	0.0000357911	0.0025713043	0.0000248542
120	Back Bay	-6.03390	-3.49522	0.0000021308	0.0127868304	0.0001718304	0.0000396617	0.0023004483	0.0000296433
121	Chandeleur Isl	-2.55852	-0.50302	0.0000051009	0.0153806434	0.0001887149	0.0000597876	0.0019992748	0.0000076841
122	Chandeleur Isl	-2.44319	-0.46476	0.0000042918	0.0148265649	0.0001740917	0.0000478731	0.0017226083	0.0000076166
123	Chandeleur Isl	-3.23103	-0.42307	0.0000045489	0.0150627137	0.0001433883	0.0000386972	0.0017906911	0.0000066206
124	Chandeleur Isl	-2.08319	-0.87819	0.0000039462	0.0134467450	0.0001504314	0.0000468776	0.0020051248	0.0000070260
125	Chandeleur Isl	-2.63376	-0.29449	0.0000045454	0.0148511574	0.0001557529	0.0000342043	0.0017534491	0.0000087200
126	Chandeleur Isl	-1.65137	-0.81998	0.0000037711	0.0133815024	0.0001432321	0.0000505147	0.0020580031	0.0000066450
127	Chandeleur Isl	-1.14901	-0.76929	0.0000037093	0.0125277247	0.0001383301	0.0000619715	0.0021140518	0.0000074294
128	Chandeleur Isl	-0.99804	-0.55173	0.0000042462	0.0138101833	0.0001732863	0.0000535417	0.0020190166	0.0000160793
129	Chandeleur Isl	-1.72691	-0.70669	0.0000040595	0.0133965671	0.0001502423	0.0000618843	0.0021874368	0.0000095744
130	Chandeleur Isl	-1.76247	-0.86047	0.0000038261	0.0126635232	0.0001371521	0.0000609543	0.0022537853	0.0000094363
131	Chandeleur Isl	-1.70562	-0.66827	0.0000047930	0.0133468856	0.0001327252	0.0000449911	0.0020088141	0.0000089201
132	Chandeleur Isl	-1.34832	-0.36289	0.0000046229	0.0152934096	0.0001771948	0.0000519108	0.0019186090	0.0000067691
133	Chandeleur Isl	-1.47592	-0.84112	0.0000042615	0.0136937981	0.0001627871	0.0000555542	0.0021890406	0.0000106689
134	Chandeleur Isl	-1.45635	-0.88572	0.0000036572	0.0124246991	0.0001399909	0.0000618260	0.0021353187	0.0000074822
135	Chandeleur Isl	-1.14338	-0.64861	0.0000043103	0.0136578552	0.0001808088	0.0000556653	0.0019906810	0.0000072759
136	Chandeleur Isl	-1.77291	-0.68057	0.0000041396	0.0139480132	0.0001628042	0.0000557588	0.0019728176	0.0000078040
137	Chandeleur Isl	-1.46573	-0.65692	0.0000046912	0.0141305869	0.0001665137	0.0000792321	0.0023456471	0.0000093054
138	Chandeleur Isl	-1.47824	-0.33416	0.0000043294	0.0144263017	0.0001320844	0.0000613461	0.0020056849	0.0000088348
139	Chandeleur Isl	-1.23847	-1.15336	0.0000033449	0.0121778077	0.0001428803	0.0000430470	0.0025088965	0.0000149562
140	Chandeleur Isl	-1.27681	-1.31893	0.0000027656	0.0107705976	0.0001202360	0.0000647393	0.0021173603	0.0000065241

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
141	Chandeleur Isl	-1.78338	-0.39438	0.0000046718	0.0147433073	0.0001878659	0.0000488100	0.0019514132	0.0000078977
142	Chandeleur Isl	-1.78434	-0.24225	0.0000045351	0.0147902485	0.0001486879	0.0000401200	0.0019519083	0.0000085137
143	LA Marshes	-4.14147	-2.60432	0.0000019921	0.0132491486	0.0002002893	0.0000464227	0.0023683731	0.0000212714
144	LA Marshes	-5.04859	-2.57774	0.0000029126	0.0160073170	0.0002418371	0.0000275146	0.0019697535	0.0000190152
145	LA Marshes	-5.27942	-2.67108	0.0000022691	0.0142611661	0.0002090310	0.0000480566	0.0024386366	0.0000314253
146	LA Marshes	-4.68737	-2.56352	0.0000027019	0.0156012759	0.0002110577	0.0000287659	0.0021199765	0.0000178359
147	LA Marshes	-5.28990	-2.55260	0.0000024517	0.0155676219	0.0002063408	0.0000505017	0.0023902480	0.0000330698
148	LA Marshes	-5.70600	-2.23850	0.0000028504	0.0163918836	0.0002193879	0.0000299229	0.0021862257	0.0000195736
149	LA Marshes	-5.45947	-2.58036	0.0000028887	0.0156591645	0.0002236207	0.0000295421	0.0021834176	0.0000195732
150	LA Marshes	-5.27161	-2.61344	0.0000028350	0.0155884832	0.0002393721	0.0000335411	0.0020404473	0.0000192781
151	LA Marshes	-5.24337	-2.56670	0.0000025090	0.0153327672	0.0002364332	0.0000391003	0.0022627519	0.0000229967
152	LA Marshes	-5.44908	-2.54399	0.0000033953	0.0160474554	0.0002722177	0.0000490840	0.0022554814	0.0000244561
153	LA Marshes	-5.10080	-2.57486	0.0000032528	0.0162931352	0.0002757853	0.0000483421	0.0023544656	0.0000234043
154	LA Marshes	-5.60744	-2.62822	0.0000028111	0.0157831314	0.0002398493	0.0000372220	0.0020411748	0.0000220323
155	LA Marshes	-4.97854	-2.90098	0.0000017003	0.0127002474	0.0001838984	0.0000370509	0.0024173699	0.0000375359
156	LA Marshes	-5.04906	-2.83003	0.0000020038	0.0143433037	0.0001990479	0.0000410805	0.0022385482	0.0000286124
157	LA Marshes	-5.02300	-2.86920	0.0000018714	0.0131979857	0.0001826496	0.0000386624	0.0026180740	0.0000377656
158	LA Marshes	-5.19382	-2.76477	0.0000017816	0.0130708780	0.0001983940	0.0000380961	0.0024566375	0.0000348949
159	LA Marshes	-4.51291	-2.85092	0.0000015321	0.0121928166	0.0001710686	0.0000496351	0.0026265723	0.0000435797
160	LA Marshes	-4.49784	-2.76407	0.0000017352	0.0130020527	0.0001869987	0.0000435422	0.0025922261	0.0000438242
161	LA Marshes	-5.01302	-2.74619	0.0000018712	0.0130456356	0.0001792954	0.0000395928	0.0023637214	0.0000346400
162	LA Marshes	-5.30679	-2.81066	0.0000018002	0.0123974972	0.0001603239	0.0000426638	0.0024058753	0.0000332014
163	LA Marshes	-5.66467	-2.84436	0.0000017411	0.0123166714	0.0001629791	0.0000362257	0.0026297123	0.0000388019
164	LA Marshes	-5.15139	-2.84137	0.0000016129	0.0130793929	0.0001828738	0.0000378013	0.0026506352	0.0000395283
165	LA Marshes	-5.36252	-2.79230	0.0000019533	0.0137371178	0.0002035023	0.0000405230	0.0022971900	0.0000329266
166	LA Marshes	-5.67449	-2.82881	0.0000020385	0.0131539168	0.0002084022	0.0000450015	0.0025024635	0.0000411010
167	Pearl River	-5.94477	-4.09592	0.0000007589	0.0118119216	0.0001697067	0.0000377283	0.0031349869	0.0000822193
168	Pearl River	-8.80685	-3.43837	0.0000009360	0.0154581919	0.0001570646	0.0000634645	0.0024529704	0.0000366450

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
169	Pearl River	-8.79507	-3.55412	0.0000011958	0.0156055035	0.0001580925	0.0000711817	0.0024870958	0.0000333628
170	Pearl River	-8.93100	-3.59673	0.0000005729	0.0137380686	0.0001535962	0.0000715364	0.0027058553	0.0000437266
171	Pearl River	-9.31369	-3.40552	0.0000012250	0.0157583950	0.0001616836	0.0001128218	0.0024597794	0.0000392023
172	Pearl River	-9.20265	-3.05951	0.0000017060	0.0166648665	0.0002101994	0.0001321455	0.0027232009	0.0000461890
173	Pearl River	-8.70771	-3.44794	0.0000007224	0.0147143060	0.0001693750	0.0000693959	0.0025107959	0.0000380539
174	Pearl River	-9.03330	-3.32460	0.0000011912	0.0157423808	0.0001673321	0.0000941066	0.0026320573	0.0000410837
175	Pearl River	-8.90801	-3.66113	0.0000007217	0.0136277983	0.0001508978	0.0000474574	0.0026248152	0.0000383600
176	Pearl River	-7.05823	-3.97200	0.0000007838	0.0121262986	0.0001764499	0.0000392462	0.0028817705	0.0000625995
177	Pearl River	-7.18388	-3.18254	0.0000010653	0.0157177281	0.0001786388	0.0001111880	0.0025858887	0.0000543573
178	Pearl River	-7.55839	-3.33900	0.0000007364	0.0161895398	0.0001878351	0.0001198978	0.0027049982	0.0000523288
179	Pearl River	-8.02282	-3.31600	0.0000011528	0.0159127826	0.0001581983	0.0000963645	0.0026248947	0.0000441326
180	Pearl River	-8.06123	-3.25118	0.0000008506	0.0157800176	0.0001689017	0.0000689030	0.0026979788	0.0000452425
181	Pearl River	-7.57610	-3.05820	0.0000015881	0.0144283097	0.0001527717	0.0000753886	0.0023485517	0.0000305746
182	Pearl River	-8.60474	-3.07603	0.0000013661	0.0159930925	0.0001834014	0.0000708027	0.0022912097	0.0000368629
183	Pearl River	-8.90059	-3.25138	0.0000014779	0.0158567259	0.0001675215	0.0000830552	0.0026025037	0.0000463387
184	Pearl River	-8.50403	-3.04632	0.0000015772	0.0152353356	0.0001615785	0.0000652909	0.0022308551	0.0000322949
185	Pearl River	-7.87686	-2.92581	0.0000014286	0.0159788977	0.0001732055	0.0000708360	0.0023477767	0.0000318691
186	Pearl River	-7.87895	-2.77554	0.0000013022	0.0159700552	0.0001969394	0.0001293835	0.0026113865	0.0000360230
187	Pearl River	-7.96137	-3.05125	0.0000015213	0.0159666485	0.0002065431	0.0001242603	0.0025321225	0.0000403784
188	Pearl River	-8.11355	-2.96405	0.0000012483	0.0162713463	0.0001999378	0.0000997601	0.0024213349	0.0000385645
189	Pearl River	-7.58936	-2.83836	0.0000019808	0.0167287177	0.0001914243	0.0001065051	0.0022591215	0.0000361604
190	Pearl River	-8.41037	-2.95070	0.0000015395	0.0163034597	0.0001874127	0.0001088238	0.0027655214	0.0000422425
191	Pascagoula	-6.87864	-4.06389	0.0000014677	0.0126566791	0.0001678254	0.0000591228	0.0022604941	0.0000137016
192	Pascagoula	-7.03845	-4.15306	0.0000014372	0.0122700123	0.0001494386	0.0000501475	0.0023246155	0.0000124411
193	Pascagoula	-6.79818	-4.39428	0.0000013375	0.0120545353	0.0001568375	0.0000378636	0.0023696423	0.0000155608
194	Pascagoula	-7.37921	-4.12943	0.0000013018	0.0128260616	0.0001668460	0.0000464636	0.0028245887	0.0000326407
195	Pascagoula	-7.36917	-4.43196	0.0000012173	0.0122339435	0.0001529513	0.0000488147	0.0026879998	0.0000248932
203	Pascagoula	-8.45068	-4.54896	0.0000007771	0.0112008116	0.0001155712	0.0000421718	0.0027368640	0.0000353034

Appendix 1 continued.

Spec #	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
204	Pascagoula	-9.13050	-4.47121	0.0000016341	0.0141570441	0.0001608049	0.0000537379	0.0029723176	0.0000440328
205	Pascagoula	-9.10155	-4.73900	0.0000007629	0.0115914684	0.0001220565	0.0000334896	0.0029110797	0.0000423147
206	Pascagoula	-8.88678	-4.60778	0.0000006689	0.0107655354	0.0001324787	0.0000408906	0.0024093123	0.0000249994

Appendix 2. Molar concentrations of otolith microchemical variables (standardized by molar calcium concentrations), and stable isotope ratios of δ13C and δ18O in otolith cores of adult *Cynoscion nebulosus* collected in the northcentral Gulf of Mexico.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
1	1/02	Biloxi Bay	-5.70860	-1.69820	0.0000018100	0.01240	0.0001320	0.00003780	0.002110	0.00001250
2	1/02	Biloxi Bay	-9.48015	-4.53556	0.0000009426	0.01080	0.0001180	0.00001840	0.002920	0.00002110
3	1/02	Biloxi Bay	-6.76464	-2.35943	0.0000014200	0.01180	0.0001610	0.00003620	0.002260	0.00001560
4	1/02	Biloxi Bay	-6.18074	-4.06428	0.0000022100	0.01070	0.0001490	0.00003990	0.001780	0.00000916
5	1/02	Biloxi Bay	-5.06646	-3.60995	0.0000016280	0.01140	0.0001580	0.00003200	0.002410	0.00001230
6	1/02	Biloxi Bay	-8.83785	-4.20551	0.0000011600	0.01100	0.0001170	0.00003910	0.002680	0.00003060
7	1/02	Biloxi Bay	-1.13888	-2.38190	0.0000033312	0.01100	0.0001460	0.00007690	0.002010	0.00001470
8	1/02	Biloxi Bay	-6.86453	-3.79915	0.0000011892	0.01170	0.0001530	0.00003850	0.002260	0.00000893
9	1/02	Biloxi Bay	-7.52465	-4.15486	0.0000012300	0.01090	0.0001600	0.00002910	0.002320	0.00001690
10	1/02	Biloxi Bay	-4.42710	-2.60242	0.0000020100	0.01120	0.0001600	0.00005480	0.002140	0.00001830
11	1/02	Biloxi Bay	-3.91658	-1.87675	0.0000019444	0.01160	0.0001040	0.00002340	0.002130	0.00001010
12	1/02	Biloxi Bay	-3.53501	-1.41868	0.0000023000	0.01190	0.0001120	0.00003410	0.001860	0.00000987
13	1/02	Biloxi Bay	-4.14031	-3.64142	0.0000017600	0.01100	0.0001490	0.00002990	0.002510	0.00001550
14	1/02	Biloxi Bay	-3.93778	-2.15221	0.0000014200	0.01160	0.0001320	0.00003000	0.002150	0.00000928
15	1/02	Biloxi Bay	-4.07237	-1.66159	0.0000018900	0.01200	0.0001040	0.00001880	0.002110	0.00001770
17	2/02	Horn Isl	-2.93000	-0.93421	0.0000034700	0.01150	0.0001700	0.00003100	0.002200	0.00001980
18	2/02	Horn Isl	-4.07000	-1.27603	0.0000030358	0.01140	0.0001210	0.00002100	0.001990	0.00000682
19	3/02	Horn Isl	-3.37767	-2.43767	0.0000024000	0.01170	0.0001440	0.00002610	0.001850	0.00000643
20	2/02	Horn Isl	-3.99882	-4.25055	0.0000012060	0.01150	0.0001500	0.00008570	0.002590	0.00005940
21	3/02	Horn Isl	-4.26562	-2.36262	0.0000042000	0.01210	0.0001810	0.00005230	0.002350	0.00001790
22	4/02	Horn Isl	-4.37773	-1.68202	0.0000021500	0.01010	0.0000676	0.00000590	0.001800	0.00000292
23	1/02	Grand Bay	-4.08397	-2.15257	0.0000030800	0.01190	0.0001480	0.00005640	0.002260	0.00000800
24	1/02	Grand Bay	-4.19342	-2.89864	0.0000024315	0.01200	0.0001790	0.00004430	0.002380	0.00001160
25	1/02	Grand Bay	-4.00186	-1.60279	0.0000026400	0.01180	0.0001260	0.00001710	0.002070	0.00000683
26	1/02	Grand Bay	-4.60268	-3.07414	0.0000025300	0.01200	0.0001650	0.00003690	0.002090	0.00000601
28	1/02	Grand Bay	-5.08518	-0.92559	0.0000035300	0.01250	0.0001270	0.00002440	0.001880	0.00001070
32	2/02	LA Marshes a	-4.08751	-0.15344	0.0000027100	0.01140	0.0001000	0.00001630	0.001810	0.00000847
34	2/02	LA Marshes a	-5.20823	-0.28641	0.0000027700	0.01120	0.0001560	0.00004800	0.002170	0.00001970
36	1/02	LA Marshes a	-5.13390	-3.67267	0.0000009780	0.01160	0.0001700	0.00004430	0.002590	0.00005120
39	2/02	LA Marshes a	-4.60083	-1.24236	0.0000018100	0.01130	0.0001620	0.00004900	0.002410	0.00004530

Appendix 2 continued.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
40	2/02	LA Marshes a	-4.52931	-0.90686	0.0000017700	0.01030	0.0001100	0.00004800	0.001990	0.00003190
43	2/02	LA Marshes a	-4.89210	-0.23082	0.0000025900	0.01140	0.0001510	0.00002470	0.002190	0.00003150
45	2/02	LA Marshes a	-4.87050	-0.65826	0.0000032900	0.01180	0.0001490	0.00003230	0.001980	0.00001220
48	2/02	LA Marshes a	-5.17096	0.26668	0.0000017800	0.01240	0.0001890	0.00014400	0.002010	0.00002600
49	2/02	LA Marshes a	-4.97558	-0.23844	0.0000014200	0.01150	0.0001590	0.00004710	0.002330	0.00006490
51	1/02	St. Louis Bay	-5.79727	-2.79122	0.0000009881	0.01110	0.0001780	0.00007740	0.002000	0.00002500
52	1/02	St. Louis Bay	-4.09278	-2.39840	0.0000009560	0.01290	0.0001260	0.00004750	0.002460	0.00006010
53	1/02	St. Louis Bay	-5.59268	-1.66220	0.0000012300	0.01180	0.0001510	0.00004390	0.001980	0.00002380
54	1/02	St. Louis Bay	-4.95711	-3.06667	0.0000015800	0.01140	0.0001310	0.00003450	0.002470	0.00002400
55	1/02	St. Louis Bay	-5.92661	-2.85287	0.0000021231	0.01090	0.0001430	0.00004130	0.002250	0.00001920
56	1/02	St. Louis Bay	-5.59006	-2.38565	0.0000036020	0.01150	0.0001510	0.00007420	0.002020	0.00001420
57	1/02	St. Louis Bay	-5.99224	-2.11707	0.0000011100	0.01090	0.0001310	0.00002990	0.002050	0.00003000
58	1/02	St. Louis Bay	-5.66785	-2.46464	0.0000024900	0.01090	0.0001560	0.00003390	0.002050	0.00001620
59	1/02	St. Louis Bay	-6.03626	-3.34250	0.0000006100	0.01060	0.0001090	0.00004110	0.002660	0.00004800
60	1/02	St. Louis Bay	-5.40717	-2.14449	0.0000014500	0.01010	0.0001170	0.00004590	0.001930	0.00001460
61	1/02	St. Louis Bay	-4.69582	-4.00498	0.0000010100	0.01190	0.0001510	0.00002310	0.002530	0.00003030
62	1/02	St. Louis Bay	-4.99898	-1.81694	0.0000011238	0.01090	0.0001220	0.00003160	0.002200	0.00002920
63	1/02	St. Louis Bay	-4.89898	-1.23369	0.0000012754	0.01190	0.0001190	0.00002890	0.002340	0.00002020
64	1/02	St. Louis Bay	-3.00943	-1.98673	0.0000010900	0.01140	0.0001540	0.00006650	0.002220	0.00002420
65	1/02	St. Louis Bay	-4.43843	-4.29791	0.0000006260	0.01100	0.0001120	0.00004640	0.002990	0.00004740
66	1/02	St. Louis Bay	-2.86330	-3.46123	0.0000013600	0.01100	0.0001650	0.00003510	0.002630	0.00002920
67	1/02	St. Louis Bay	-2.55942	-2.01587	0.0000022000	0.01180	0.0001450	0.00002800	0.001870	0.00001350
70	1/02	St. Louis Bay	-2.59556	-3.88574	0.0000015853	0.01160	0.0001620	0.00004260	0.002630	0.00003290
71	1/02	Biloxi Bay	-3.76511	-2.84589	0.0000011200	0.01210	0.0001630	0.00005800	0.002310	0.00004060
72	1/02	Biloxi Bay	-3.27301	-1.48618	0.0000035827	0.01170	0.0001520	0.00001470	0.002040	0.00001390
73	1/02	Biloxi Bay	-3.10587	-2.05137	0.0000014619	0.01060	0.0001190	0.00003470	0.001960	0.00002050
74	1/02	Biloxi Bay	-2.85715	-4.36897	0.0000010500	0.01180	0.0001550	0.00006580	0.002430	0.00001390
75	1/02	Biloxi Bay	-3.00391	-2.71173	0.0000013631	0.01150	0.0001290	0.00003910	0.002540	0.00001480
76	1/02	Biloxi Bay	-2.90109	-1.31028	0.0000027200	0.01280	0.0001430	0.00003680	0.002100	0.00002380
79	3/02	Cat Isl	-2.77175	-1.91230	0.0000019000	0.01160	0.0001290	0.00005890	0.001710	0.00001090
81	2/02	Cat Isl	-2.44395	-0.08581	0.0000032100	0.01170	0.0000986	0.00003190	0.001980	0.00000808

Appendix 2 continued.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
82	2/02	Cat Isl	-2.80298	-2.42364	0.0000016600	0.01140	0.0001620	0.00005310	0.002580	0.00004280
86	2/02	Cat Isl	-3.02053	-1.33778	0.0000033400	0.01180	0.0001760	0.00002680	0.001970	0.00000518
87	1/02	Cat Isl	-2.98934	-3.32321	0.0000024397	0.01160	0.0001620	0.00003590	0.002410	0.00001110
90	2/02	Cat Isl	-2.92425	-1.13904	0.0000028100	0.01150	0.0001620	0.00003270	0.002570	0.00001610
93	2/02	Pearl River	-3.01981	-1.81816	0.0000018501	0.01090	0.0001260	0.00004530	0.002490	0.00004840
94	1/02	Pearl River	-2.16502	-5.00983	0.0000008790	0.01240	0.0001510	0.00006680	0.002690	0.00005800
95	3/03	Grand Bay	-2.68519	-3.73761	0.0000014600	0.01090	0.0001580	0.00004480	0.002520	0.00003930
96	3/03	Grand Bay	-3.45473	-2.10784	0.0000008820	0.00926	0.0000811	0.00002880	0.001920	0.00001970
97	1/03	Grand Bay	-2.84408	-2.34599	0.0000032477	0.01140	0.0001570	0.00002360	0.002150	0.00000442
98	1/03	Grand Bay	-3.16492	-1.87578	0.0000032900	0.01160	0.0001650	0.00010100	0.002130	0.00000867
99	2/03	Grand Bay	-3.97755	-2.56665	0.0000024000	0.01020	0.0001230	0.00005170	0.002190	0.00000722
100	2/03	Grand Bay	-7.56656	-2.56289	0.0000016800	0.01070	0.0001150	0.00003950	0.002080	0.00001130
101	5/03	Grand Bay	-3.73847	-3.28468	0.0000028100	0.01180	0.0001460	0.00001690	0.001840	0.00000723
102	2/03	Grand Bay	-6.72604	-1.46670	0.0000023200	0.01070	0.0001200	0.00001990	0.002080	0.00000964
103*	2/03	Grand Bay	-7.27416	-1.87634	0.0000029200	0.01160	0.0001220	0.00002360	0.001710	0.00000531
104	1/03	Cat Isl	-1.97985	-1.81080	0.0000031944	0.01090	0.0001530	0.00002820	0.001970	0.00000635
105	2/03	Cat Isl	-4.57176	-2.92493	0.0000011300	0.01110	0.0001600	0.00005900	0.002160	0.00005070
106	2/03	Cat Isl	-3.47845	-1.25688	0.0000021700	0.01060	0.0001310	0.00002010	0.002320	0.00002390
107	1/03	Cat Isl	-3.34059	-1.92611	0.0000023800	0.01020	0.0001240	0.00002610	0.001950	0.00000855
108	2/03	Cat Isl	-2.96659	-1.44445	0.0000026300	0.01100	0.0001460	0.00002940	0.002090	0.00001750
109	1/03	Cat Isl	-2.19061	-2.08728	0.0000033600	0.01170	0.0001740	0.00005070	0.002250	0.00001290
110	2/03	Cat Isl	-2.32283	-2.13294	0.0000032100	0.01220	0.0001740	0.00003900	0.002160	0.00001140
111	1/03	Cat Isl	-2.93248	-2.36113	0.0000016400	0.01090	0.0001480	0.00003250	0.001890	0.00001170
112	2/03	Cat Isl	-3.43654	-2.32803	0.0000018400	0.01050	0.0001490	0.00003000	0.002070	0.00001610
113	2/03	Cat Isl	-3.26592	-2.01344	0.0000030300	0.01130	0.0001390	0.00003560	0.002240	0.00002410
114	3/03	Cat Isl	-1.92005	-0.82178	0.0000030900	0.00995	0.0001430	0.00002220	0.001950	0.00000620
115	2/03	Cat Isl	-7.58035	-4.48164	0.0000006400	0.01080	0.0001380	0.00004170	0.003390	0.00005160
116	2/03	Cat Isl	-4.24013	-1.78120	0.0000011769	0.01080	0.0001110	0.00003540	0.002260	0.00001780
117	1/03	Cat Isl	-2.63956	-1.79183	0.0000029300	0.01020	0.0001300	0.00004450	0.002130	0.00000895
118	2/03	Chandeleur Isl	-3.71703	-2.33546	0.0000015912	0.01050	0.0001530	0.00004300	0.002130	0.00003540
119	1/03	Chandeleur Isl	-3.19767	-2.15408	0.0000022500	0.01070	0.0001270	0.00003070	0.001920	0.00001330

Appendix 2 continued.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
120	1/03	Chandeleur Isl	-3.48437	-1.95307	0.0000035415	0.01130	0.0001850	0.00006560	0.001970	0.00000732
121	2/03	Chandeleur Isl	-2.55434	-1.72038	0.0000033500	0.01100	0.0001430	0.00006210	0.001890	0.00000964
124	2/03	Chandeleur Isl	-3.38666	-3.25155	0.0000023900	0.01140	0.0001760	0.00008690	0.001890	0.00001100
125	1/03	Chandeleur Isl	-2.63990	-2.03069	0.0000024500	0.01130	0.0001630	0.00003440	0.002040	0.00001480
127	2/03	Chandeleur Isl	-3.62852	-2.47735	0.0000019862	0.01160	0.0001690	0.00004130	0.002070	0.00002020
128	1/03	Chandeleur Isl	-3.91346	-2.18093	0.0000017300	0.01080	0.0001430	0.00006610	0.002120	0.00002340
129	2/03	Chandeleur Isl	-8.98977	-5.71181	0.0000009660	0.01170	0.0001130	0.00004890	0.001300	0.00003440
130	1/03	Chandeleur Isl	-2.24808	-1.65388	0.0000031000	0.01070	0.0001470	0.00004710	0.001700	0.00000402
131	2/03	Chandeleur Isl	-2.60616	-0.93313	0.0000025400	0.01090	0.0001150	0.00002200	0.001780	0.00001140
132	1/03	Chandeleur Isl	-3.61439	-2.40226	0.0000031572	0.01100	0.0001620	0.00005120	0.001780	0.00000562
133	1/03	Chandeleur Isl	-3.26149	-1.95906	0.0000021900	0.01000	0.0001340	0.00003470	0.001930	0.00000890
134	2/03	Chandeleur Isl	-6.55328	-2.33097	0.0000014706	0.01070	0.0001390	0.00006610	0.002220	0.00004780
135	1/03	Chandeleur Isl	-3.87373	-3.40453	0.0000025600	0.01170	0.0001820	0.00003420	0.002180	0.00001640
136	2/03	Chandeleur Isl	-2.74107	-2.38631	0.0000029379	0.01030	0.0001330	0.00003550	0.001970	0.00000716
138	2/03	Chandeleur Isl	-1.43155	-1.40408	0.0000026500	0.00917	0.0001160	0.00006370	0.002350	0.00000699
139	1/03	Chandeleur Isl	-3.90533	-3.59724	0.0000020000	0.01130	0.0001510	0.00007870	0.002090	0.00001480
140	1/03	Chandeleur Isl	-2.02761	-1.48051	0.0000036427	0.01160	0.0001860	0.00009820	0.001900	0.00000517
141	2/03	Chandeleur Isl	-4.45325	-3.15790	0.0000008780	0.01200	0.0001870	0.00005490	0.002110	0.00007820
143	1/03	Chandeleur Isl	-3.04205	-2.87378	0.0000033200	0.01150	0.0001730	0.00009310	0.001950	0.00000783
144	1/03	Chandeleur Isl	-3.41540	-2.66031	0.0000032540	0.01060	0.0001450	0.00004440	0.002090	0.00000764
145	1/03	Chandeleur Isl	-3.75849	-2.34512	0.0000031400	0.01150	0.0001480	0.00002750	0.002000	0.00000944
147	1/03	LA Marshes a	-2.98149	-2.21878	0.0000025200	0.01150	0.0001660	0.00006060	0.001990	0.00001040
148	3/03	LA Marshes a	-3.29588	-1.13990	0.0000025600	0.01080	0.0001560	0.00003560	0.002120	0.00001810
149	2/03	LA Marshes a	-3.80032	-2.57497	0.0000012700	0.01130	0.0001670	0.00003740	0.002610	0.00004380
161	1/03	LA Marshes b	-2.73020	-2.36111	0.0000013100	0.01170	0.0001730	0.00002510	0.001910	0.00002050
162	1/03	LA Marshes b	-3.01123	-2.39380	0.0000022577	0.01140	0.0001530	0.00002240	0.001790	0.00001100
163	1/03	LA Marshes b	-3.11173	-2.49459	0.0000013827	0.01060	0.0001540	0.00003490	0.001940	0.00001340
164	1/03	LA Marshes b	-3.61292	-1.97566	0.0000015815	0.01120	0.0001730	0.00005110	0.002290	0.00003350
165	1/03	LA Marshes b	-3.47619	-2.12028	0.0000014300	0.01110	0.0001540	0.00002900	0.002280	0.00002520
166	1/03	LA Marshes b	-3.28884	-2.60659	0.0000020600	0.01170	0.0001310	0.00004350	0.001920	0.00001390
167	1/03	LA Marshes b	-3.49165	-1.88501	0.0000029991	0.01130	0.0001480	0.00003730	0.001850	0.00000771

Appendix 2 continued.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
168	2/03	LA Marshes b	-2.75159	-2.45533	0.0000013500	0.01170	0.0001680	0.00003020	0.002390	0.00004010
169	1/03	LA Marshes b	-3.89913	-2.35866	0.0000012600	0.01170	0.0001220	0.00003140	0.002200	0.00001380
170	1/03	LA Marshes b	-3.59636	-2.70839	0.0000015800	0.01160	0.0001370	0.00003370	0.001880	0.00001330
171	1/03	LA Marshes b	-2.76025	-1.62732	0.0000016500	0.01030	0.0001440	0.00006900	0.001960	0.00001480
172	1/03	LA Marshes b	-3.86785	-2.18200	0.0000018800	0.00986	0.0001290	0.00003520	0.002400	0.00002730
173	1/03	LA Marshes b	-2.69104	-2.28677	0.0000012900	0.01170	0.0001520	0.00003640	0.002300	0.00002140
174	1/03	LA Marshes b	-2.77798	-2.44894	0.0000017540	0.01150	0.0001630	0.00009630	0.002010	0.00002020
175	1/03	LA Marshes b	-2.35639	-2.43836	0.0000017200	0.01160	0.0001540	0.00002280	0.002110	0.00001770
176	1/03	LA Marshes b	-2.90653	-2.37499	0.0000020200	0.01130	0.0001520	0.00005960	0.001980	0.00001710
177	1/03	LA Marshes b	-1.79505	-1.92550	0.0000017100	0.01100	0.0001450	0.00004790	0.002000	0.00001950
178	1/03	LA Marshes b	-5.25993	-2.32829	0.0000013200	0.01080	0.0001300	0.00004150	0.002090	0.00001710
180	1/03	LA Marshes b	-1.45095	-2.26383	0.0000013200	0.01140	0.0001490	0.00002360	0.001780	0.00001300
181	1/03	LA Marshes b	-3.06646	-2.27606	0.0000015100	0.01030	0.0001510	0.00004850	0.002090	0.00001940
182	1/03	LA Marshes b	-3.71042	-1.97482	0.0000020200	0.01070	0.0001380	0.00004880	0.002030	0.00001950
183	1/03	LA Marshes b	-2.91168	-1.82042	0.0000022700	0.01120	0.0001620	0.00006820	0.002060	0.00001890
184	1/03	LA Marshes b	-2.26895	-1.83907	0.0000019100	0.01140	0.0001750	0.00005560	0.002130	0.00002410
185	1/03	LA Marshes b	-2.78539	-1.98570	0.0000027000	0.01090	0.0001540	0.00003350	0.002110	0.00001190
191	2/03	LA Marshes a	-4.33408	-2.61789	0.0000021200	0.01010	0.0001400	0.00003510	0.002000	0.00002260
192	2/03	LA Marshes a	-4.03174	-1.88575	0.0000009860	0.01030	0.0001000	0.00003600	0.002090	0.00003860
193	1/03	LA Marshes a	-6.21344	-3.96253	0.0000008836	0.00982	0.0001270	0.00005990	0.002040	0.00002450
194	1/03	LA Marshes a	-4.05006	-2.23760	0.0000021400	0.00926	0.0001030	0.00004950	0.001800	0.00000552
195	2/03	Biloxi Bay	-5.14645	-1.42377	0.0000024000	0.01060	0.0001310	0.00002810	0.002180	0.00002260
196	2/03	Biloxi Bay	-6.47468	-3.15624	0.0000012100	0.01010	0.0001270	0.00003220	0.002600	0.00001330
197	2/03	Pascagoula	-0.90209	-2.13724	0.0000030900	0.01050	0.0001330	0.00006030	0.001790	0.00000411
199	2/03	Pascagoula	-6.57220	-3.11918	0.0000017900	0.01110	0.0001410	0.00010100	0.002170	0.00001550
200	1/03	Pascagoula	-6.55059	-3.64205	0.0000016600	0.01100	0.0001440	0.00003490	0.002540	0.00001700
201	1/03	Pascagoula	-4.06849	-2.72171	0.0000014300	0.01180	0.0001870	0.00009920	0.002090	0.00001430
202	1/03	Pascagoula	-2.71438	-2.28111	0.0000009280	0.01040	0.0000986	0.00002340	0.002270	0.00001540
203	1/03	Pascagoula	-6.72811	-2.35549	0.0000023711	0.01090	0.0001500	0.00002460	0.002000	0.00000442
205	2/03	Pascagoula	-5.21238	-3.36092	0.0000024200	0.01140	0.0001680	0.00003620	0.002350	0.00001040
206	1/03	Pascagoula	-6.32744	-3.55871	0.0000022200	0.01070	0.0001560	0.00003070	0.002480	0.00001120

Appendix 2 continued.

Spec #	Age/Yr. Collected	Site	$\delta^{13}C$ (%)	$\delta^{18}O$ (%)	Li	Na	Mg	Mn	Sr	Ba
207	1/03	Pascagoula	-5.39865	-2.49428	0.0000028100	0.01130	0.0001480	0.00002880	0.002090	0.00000596
208	1/03	Pascagoula	-6.80337	-3.74697	0.0000016900	0.01090	0.0001200	0.00002550	0.002010	0.00001260
209	1/03	Pascagoula	-6.71678	-4.15966	0.0000013300	0.01160	0.0001810	0.00006290	0.002500	0.00003550
211	1/03	Pascagoula	-3.58140	-2.05542	0.0000024500	0.01040	0.0001430	0.00001620	0.002220	0.00001080
212	3/03	Pascagoula	-8.15257	-3.16918	0.0000012500	0.00997	0.0001250	0.00004110	0.002330	0.00001460
213	1/03	Pascagoula	-6.18531	-3.42071	0.0000022000	0.01090	0.0001650	0.00004070	0.002510	0.00000946
214	1/03	Pascagoula	-5.79312	-3.13793	0.0000019700	0.01080	0.0001490	0.00004190	0.002180	0.00000791
215	1/03	Pascagoula	-3.32289	-1.97342	0.0000028300	0.01050	0.0001240	0.00002400	0.002260	0.00000564
216	1/03	Pascagoula	-5.84404	-3.16059	0.0000012400	0.01090	0.0001750	0.00005700	0.002040	0.00001560

This publication was supported by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA Grant (R/SP-4)., the Mississippi-Alabama Sea Grant Consortium and the University of Southern Mississippi. The views expressed herein do not necessarily reflect the views of any of those organizations.