INVESTIGATION OF PYGMY SPERM WHALE (*Kogia breviceps*) POPULATIONS IN THE SOUTHEASTERN UNITED STATES USING STABLE ISOTOPES OF CARBON, NITROGEN, AND OXYGEN IN TEETH

A thesis submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

in

ENVIRONMENTAL STUDIES

by

NICOLE R. MONTEY
APRIL 2015

at

THE GRADUATE SCHOOL OF THE UNIVERSITY OF CHARLESTON,
SOUTH CAROLINA AT THE COLLEGE OF CHARLESTON

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ABSTRACT

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The pygmy sperm whale *(Kogia breviceps)* is currently the second-most commonly stranded cetacean in the Southeastern United States (SEUS), but information concerning their population structure is severely limited. This study utilized stable isotope analysis to investigate the possible migratory patterns and population structure of *K. breviceps* among six different regions in the SEUS. Combined growth layers from different regions of the teeth were subsampled via dental drill and analyzed representing four different age classes: calf, juvenile, sub-adult, and adult, as well as four yearlings that had stranded with their mothers. Stable isotope ratios of carbon and nitrogen were measured in the organic component of 46 teeth, and oxygen isotope ratios were measured in the inorganic (hydroxyapatite) component of 21 teeth obtained from stranded individuals. There was a high degree of individual variability in $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ resulting in no significant differences between the six different regions: South Carolina, Georgia, Northern, Central, and Southern Florida, and the Gulf of Mexico. Differences between the age classes were significant for $\delta^{13}C$ and $\delta^{15}N$. Adults exhibited significantly more negative $\delta^{13}C$ than subadults. These results support a previously hypothesized inshore-offshore migration for *Kogia breviceps.* Yearlings displayed significantly higher $\delta^{15}N$ values than all other age classes due to nursing. A slight increase in $\delta^{15}N$ from juvenile to adult supports a possible ontogenetic shift in the trophic level of prey. Results from this study provide the first carbon and nitrogen isotope values from different age classes of pygmy sperm whales as well as the first reported oxygen isotopes values for this species.

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Table of contents

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

INTRODUCTION

Pygmy sperm whale life history

The pygmy sperm whale (Figure 1) has a cosmopolitan distribution and can be found in tropical and temperate waters of the Atlantic, Pacific, and Indian Oceans. From analysis of prey, it is believed these animals live beyond the edge of the continental shelf and feed on deep-sea cephalopods (McAlpine 2009). The pygmy sperm whale is the second-most common cetacean to strand in the Southeast United States (SEUS) with the highest frequency of strandings in the Atlantic occurring in Charleston County, SC, Chatham County, GA, and Brevard County, FL (Berini 2009, Figure 2). Although there is a high occurrence of strandings in these areas, little information about the ecology and population trends of these animals is available. This lack of information can be attributed to many factors including the inconspicuous behavior of the species, general deep-water distribution, and the inability of the species to survive in captivity (Bloodworth and Odell 2008; McAlpine 2009). Individuals held in captivity are prone to stress-induced cardiomyopathy, dehydration, and severe dietary reactions (Manire *et al.* 2004). Furthermore, the presence of pygmy sperm whales in their native habitat is usually only detected in ideal conditions (Baird 2005) and they often dive to avoid approaching ships (Mullin and Fulling 2004) making it extremely difficult to obtain population data. To add to the already difficult task of population studies, *Kogia breviceps* has a sister species, the dwarf sperm whale (*Kogia sima*), and the two are very difficult to distinguish in the wild.

Abundance estimates for *Kogia breviceps* are available from aerial and shipboard surveys conducted by the National Marine Fisheries Service, reported by Waring *et al.* (2013). These surveys include estimates from the Western North Atlantic Ocean (WNA), extending from North Carolina to the Bay of Fundy, and the Gulf of Mexico. Surveys were also conducted in the Western South Atlantic (WSA), extending from North Carolina to Florida, but these estimates are not currently available. The WNA abundance estimate is 741 individuals. The best available estimate for the Gulf of Mexico is 186 individuals. However, this estimate is a combination of both *Kogia* species and not specifically *Kogia breviceps*. Although there is no information to differentiate the Atlantic stock from the Gulf of Mexico stock, they are considered separate for management purposes (Waring *et al.* 2013).

The diet of *Kogia breviceps* has been explored through stomach content analysis (Pauly *et al.* 1998; Walker and Macko 1999; Santos *et al.* 2006; Staudinger *et al.* 2013), but there are limited studies available researching the behavior and populations of this species. Only a few geographical areas such as the Bahamas and the Hawaiian Islands are suitable areas for boat-based surveys on this species. A study by Baird (2005) is one of a few studies to document at sea sightings using observations of *Kogia* species around the Hawaiian Islands between 2000-2003. *Kogia* were spotted on 18 occasions. Of these 18 sightings, 13 were *Kogia sima*, one was *Kogia breviceps*, and four were only identified to genus.

Based on stranding records it is believed that this species does not make long-range latitudinal migrations. Walker *et al.* (2005) examined the effects of coastal current patterns in relation to strandings and found a correlation between strandings and winds associated with downwelling. *K. breviceps* strandings from the state of Florida were more common on the east coast and Panhandle during winter, while the Southwest coast and Florida Keys had a higher number of strandings during the summer. These high-stranding seasons on each coast occur in downwelling-favorable conditions, which is believed to influence cetacean movements (Walker *et al.* 2005). As cetaceans are known to track frontal convergences, it is hypothesized that a change from upwelling favorable winds to downwelling favorable winds causes cetaceans to follow the front as it moves inshore (Walker *et al.* 2005). When this front disappears, it is hypothesized that the animals become disoriented and strand trying to navigate. It is also speculated that mature individuals move inshore to mate during the winter and spring and that birthing occurs in the summer through fall (Berini 2009). This is consistent with stranding records in which larger individuals strand in the winter and spring and a higher number of mother and calf pairs strand in the summer and autumn (Berini 2009).

The reproductive biology of this species is only known from stranded individuals. Aging *K. breviceps* is difficult, but this species is believed to mature very rapidly and have a relatively short lifespan, reaching a maximum of only 30 years. Males reach sexual maturity when they are 2.7 to 3.0 m long, usually around 5.5 years old, while females reach maturity between 2.6 to 2.8 m long, around 3.5 years old (Ross 1979; Smar 2006). When fully mature, this species does not exhibit any evidence of sexual dimorphism (Smar 2006).

Stable isotopes

In order to effectively conserve a species, understanding the ecology, behavior, and movements of that species is essential. Tracking a species' movements can be done directly, by tag-recapture methods of satellite, radio, or sonic telemetry, or indirectly, by inferring locations from biogeochemical markers such as stable isotopes and trace elements (Rubenstein & Hobson 2004). Due to the difficultly in sighting or tracking *Kogia breviceps*, biogeochemical markers are a more practical means to establish patterns of movement as they do not require marking and recapturing individuals.

Stable isotope analysis has become a well-established technique for diet exploration of marine mammals, including studies on elephant seals (Aurioles *et al.* 2006), sea lions (Hobson and Sease 1998), bottlenose dolphins (Walker *et al.* 1999; Owen *et. al* 2011), long-finned pilot whales (Abend and Smith 1997), and a comprehensive study of marine mammals by Walker and Macko (1999). Stable isotopes have also been used to characterize ontogenetic shifts of Odontoceti species including killer whales (Newsome *et al.* 2009) and sperm whales (Mendes *et al.* 2007). Recently, there has been an increase in utilizing isotopes to identify movements of animals between geographic locations and habitats (Mendes *et al.* 2007; Owen *et al.* 2011). Studies on phytoplankton and zooplankton demonstrate that stable isotopes of carbon ($\delta^{13}C$) differ latitudinally due to higher primary production in temperate waters as compared to high-latitude regions in coastal areas (Newsome *et al*. 2009). Takai *et al.* (2000) states that the phytoplankton $\delta^{13}C$ decrease is attributed to a change in temperature and CO_2 concentrations in the water, which causes a change of -0.015‰ per 1^0 latitude in the northern hemisphere when moving from the equatorial plane to the pole. The region east of Florida, which is an open-ocean, mid-latitude region, has low phytoplankton densities due to downwelling (Figure 3). North of this region, wind is from west to east, and the wind pushes surface waters to the south. South of this region, the wind is from east to west, pushing water northward. The convergence of surface water causes downwelling (Stewart 2009). Therefore, carbon isotopes could reflect differences between animals feeding in different geographical locations.

Nitrogen directly relates to the foraging habits of an organism, with $\delta^{15}N$ increasing by 3-5‰ for each trophic level. It is suggested to use the same tissue type for nitrogen analysis because fractionation occurs differently among tissues (Clementz and Koch 2001). Kelly (2000) states that muscle tissues more closely represent those of the body, while tissues found in the bone and skin are more enriched in $\delta^{15}N$. It is important to note that enrichment occurs in mammals during the first years when calves are still nursing (Mendes *et al.* 2007; Newsome *et al.* 2009.) The milk produced by lactating females is isotopically the same as their tissues. As such, a nursing calf will display higher $\delta^{15}N$ values because they are "consuming" tissues of an adult (Knoff *et al.* 2008). Interestingly, a recent study by Staudinger *et al.* (2013) found no increase in $\delta^{15}N$ values as growth increased in *Kogia breviceps*. The study by Staudinger et al. (2013) contained a small sample size (n=14)

Oxygen isotopic values are an indicator of aquatic habitats and are correlated with the body of water an organism is living in (Thewissen *et al.* 1996; Clementz & Koch 2001; Clementz *et al.* 2006). Oxygen isotopes can be used to discriminate between freshwater, marine, and terrestrial animals as it is correlated with water salinity and temperature (Clementz *et al.* 2006, Vighl *et al.* 2014). Terrestrial animals can have large variations of $\delta^{18}O$ because the oxygen sources are diet and drinking water (Clementz *et al*. 2006), which can vary widely. Fully aquatic species, such as cetaceans, however show very small differences in $\delta^{18}O$ values among individuals due to living in isotopically homogeneous waters. Although cetaceans do not continually ingest water, it is taken in from prey (Yoshida & Miyazaki 1991) and is also constantly diffused across the skin; 98% of the oxygen flux into and out of marine mammals comes from diffusion across the skin (Clementz & Koch 2001, Clementz *et al.* 2006). Cetaceans consume prey that has $\delta^{18}O$ similar to their environmental water, as such the $\delta^{18}O$ from cetacean teeth should be correlated with the environmental water of its prey. As oxygen is not fractionated during uptake, the oxygen values should be correlated with those of the environmental water, both the water the animal is located in as well as that of prey consumed (Yoshida & Miyazaki 1991, Clementz & Koch 2001). As an organism moves between bodies of water with different isotopic compositions, the isotopic signature is recorded into their tissues. As teeth are inert after synthesis, the isotopic ratios can be analyzed to give a historical account of movements. Cetaceans are homoeothermic and have a nearly constant body temperature; therefore a variation in the isotopic composition in teeth is due to a change in the isotopic composition of ingested and diffused water and not a change in temperature (Thewissen *et al.* 1996; Clementz *et al.* 2006). Additionally, the fractionation of oxygen isotopes during respiration is not considered significant as the air they inhale is saturated with water vapor (Yoshida & Miyazaki 1991). Although the composition of water in the SEUS does not have a high variability for oxygen (Figure 4), the $\delta^{18}O$ values can be used to determine whether there is a migration inshore to more estuarine environment or north to colder water; both would result in a decrease in $\delta^{18}O$

(Yoshida & Miyazaki 1991; Clementz & Koch 2001; Clementz *et al.* 2006; Borell *et al.* 2013). A study by Clementz & Koch (2001) found oxygen isotopes are valuable for identifying habitat preference in four different ecosystems: terrestrial, freshwater, marine, and estuarine. Analysis of nine different aquatic species as well as two terrestrial species found that terrestrial individuals have the highest $\delta^{18}O$ as well as the largest variability due to variable oxygen sources and physiological responses to the environment (sweating/panting, waste excretion, and respiration) (Clementz *et al*. 2006). For the aquatic animals, freshwater individuals had the highest $\delta^{18}O$, intermediate in marine environments, and lowest in estuarine habitats. Changes in $\delta^{18}O$ due to changes in latitude and water temperature have been seen in male sperm whales in the eastern north Atlantic (Borrell *et al.* 2013). As males separate from breeding groups and migrate north toward Artic waters, the $\delta^{18}O$ values decrease.

Analysis of oxygen isotopes, combined with the analysis of the carbon and nitrogen isotopes, can aid in determining the habitat an animal has lived in and whether migration has occurred. Tracking by use of stable isotopes has been successful in studies of migrant birds and insects. These species have summer and wintering grounds that are separated by thousands of miles and differences in the isotope composition in each area can be detected through stable isotope forensics (Bowen *et al.* 2005).

Significance of teeth

Teeth are extremely valuable tools for ecological and dietary studies. As they grow throughout an individual's lifetime, new layers are continually added to the older layers through the interior of the tooth until the pulp cavity is filled (Walker *et al.* 1999; Owen *et al.* 2011). Every year as the teeth grow, the proteins and calcified tissues become metabolically inert providing historical dietary and foraging information relating to each animal's behavior and movements. This would imply that every year, organic matter exposed to individuals through prey consumption is represented in their teeth. Abend and Smith (1997) and Tieszen *et al.* (1983) describe this as an "isotopic memory". As the carbon and nitrogen are incorporated into the tissues isotopic fractionation occurs, enriching the heavier isotopes of each element in the tissues relative to prey. This process is called isotope fractionation. It has been demonstrated that there is approximately 1-2% carbon enrichment and 3-5% nitrogen enrichment in cetaceans from prey to predator (Kelly 2000; Newsome *et al.* 2009). In tissues such as muscle, this isotopic signature represents more recently assimilated nutrients, while teeth can provide a chronological record that spans the entire lifetime (Walker and Macko 1999). Teeth are better indicators of long-term isotopic history because they are less metabolically active and have a slower turnover rate resulting in organic material becoming well preserved (Tieszen *et al.* 1983; Owen *et al.* 2011). Teeth also demonstrate a direct correlation to dietary intake, and provide a sufficient amount of organic material for analysis (Krueger *et al.* 1984; Hobson & Sease 1998; Walker & Macko 1999; Mendes *et al.* 2007; Newsome *et al.* 2009).

Mammalian teeth are composed of enamel, dentin, and cementum (Figure 5). The dentin is the collagenous matrix which most of the tooth is comprised of. It is composed of inorganic hydroxyapatite and organic collagen. The cementum is the thin layer of tissue that surrounds the portion of dentine known as the root. The enamel forms the hard outer layer of the tooth, except in the *Kogiid* family, which lacks enamel (McAlpine 2009). *Kogia breviceps* lack teeth in the upper jaw but instead have pockets in which the 10-16 pairs of teeth located in the lower jaw fit into.

Aims and Significance

The objective of this study is to investigate if *Kogia breviceps* populations in the SEUS have distinct geography, habitat, or foraging patterns based on stable isotopes of carbon nitrogen, and oxygen. This project will provide the groundwork for future studies of this species by presenting results of stable isotopes ($\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$) from teeth of stranded pygmy sperm whales along the SEUS. The hypothesis and goals of this study are as follows:

Hypotheses

H1. *Kogia breviceps* do not exhibit long-range latitudinal migration patterns or utilization of distinct environments at different age classes based on carbon, nitrogen, and oxygen isotope signatures.

- The $\delta^{13}C$ values at the four drill sites for each individual will not be significantly different.

H2. The $\delta^{15}N$ for each individual will increase with age due to feeding at higher trophic levels.

- It is expected each animal will show an increased $\delta^{15}N$ value during the first year as a calf. The mothers are producing milk by catabolizing their own tissues and the nursing offspring will display enriched $\delta^{15}N$ values. After weaning occurs, the $\delta^{15}N$ value will drop as the calf/juvenile preys on smaller squid. As the individual matures and grows, an increase in $\delta^{15}N$ is expected due to consuming larger prey and feeding at a higher trophic level.

H3. The $\delta^{18}O$ results will show a low variability among individuals due to homogeneity of offshore oceanic habitat.

- It is believed that *Kogia breviceps* feed and live off the continental shelf where there are no coastal influences and the composition of the water is similar along the coast.

Goals

1. Create a baseline study that can be used for further research to identify possible distinct stocks of *Kogia breviceps*
2. Develop a method for stable isotope analysis of *Kogia breviceps* teeth
3. Determine whether isotopic differences exist at different age classes within individuals
4. Determine whether isotopic differences exist among individual animals at the same age classes from different regions in the SEUS

This study is the only of its kind to explore the population structure and movements of *Kogia breviceps* by use of stable isotopes. There are relatively few studies concerning the pygmy sperm whale but a large interest in this species exists due to the frequency of strandings. A study by Walker and Macko (1999) offers the only stable isotope data from teeth available and the sample size was very small (n=12). The dietary studies performed by Staudinger *et al.* (2013) represent only a short-term diet whereas analysis of teeth can provide a long-term dietary record. A much larger sample size (n=46) and also a comprehensive analysis of the entirety of the SEUS, spanning from South Carolina to the Gulf of Mexico, will provide substantial knowledge related to the ecology of this species. Although abundance estimates are available for *Kogia breviceps*, there is still insufficient data to determine population trends for this species (Waring *et al.* 2013) and the IUCN lists this species as “data deficient”. Under the Marine Mammal Protection Act of 1972, all marine mammals are not to fall below their optimum sustainable population levels (Marine Mammal Protection Act of 1972). In order to achieve a sustainable population for *Kogia breviceps*, the population structure and behavior is essential for preservation of this species. Collection of these baseline data is also important for understanding, preserving, and managing the ecosystems in which they live.

MATERIALS AND METHODS

Sample Collection

The samples used in this study were obtained from stranded *Kogia breviceps* along the Southeast United States coast (Figure 6). All teeth collected were from animals that stranded in the past 20 years, except two mother and calf pairs and two males in the Gulf of Mexico. The National Centers for Coastal Ocean Science (NCCOS), Coastal Marine Mammal Assessments Program (Charleston, SC) provided the teeth from South Carolina (*n*=9) and Georgia (*n*=10). Hubbs-Sea World Research Institute from Orlando, Florida provided the teeth samples for the Florida regions, both Atlantic and Gulf. Florida has been divided into four regions to investigate if there are differences in the isotopic values of animals along this coastline. The Atlantic coast of Florida has been divided into the Northern (*n*=4), Central (*n*=7), and Southern (*n*=8) regions (Figure 7). The other region is the Gulf of Mexico (*n*=4). Within the Central Florida region, there are four yearlings as well. For the purposes of this study, yearlings are individuals less than 140 cm that stranded with their mothers.

The stranding networks in all areas collect teeth from the middle of the lower left jaw. These teeth are less worn and provide a better specimen for analysis. For the purpose of this study, all teeth collected were stored dry with no chemical treatment (Walker and Macko 1999; Owen *et al.* 2011).

Dentin Extraction

One tooth from each animal was sectioned longitudinally using a water-cooled Buehler 100 diamond-edged saw blade (Buehler, Lake Bluff, IL) following as closely to the midline as possible. Powdered dentin for isotopic analysis was collected at the Dental Facility of the Medical University of South Carolina, Charleston, SC using a dental micro-drill and carbide bur attachment. One half of each tooth was placed in a large tin capsule, in order to collect the powdered dentin, and 5-10 mg of powdered dentin was extracted at four separate locations to be used for stable isotope analysis. At each separate drill site per tooth, a new tin capsule and clean carbide bur was used to prevent cross contamination between sites. Each of the four drill sites spanned multiple annual growth layers and therefore represent life-history stages during the animals' lifespan: calf, juvenile, sub-adult, and adult (Figure 8). The site adjacent to the pulp cavity represents the final years before the animal died. Ages were not available for all animals in this study, for simplicity, this site is referred to as the adult. Moving away from the pulp cavity, sub-adult and juvenile drill sites were taken to provide more isotopic references. The fourth site was near the tip of the tooth representing the first years as a calf. It would be beneficial to extract dentin samples for each growth layer, however, due to the small size of growth layer groups in *Kogia breviceps* teeth, as compared with larger whale teeth; each growth layer cannot be drilled separately and yield sufficient sample for analysis. Studies analyzing the ontogenetic shifts of killer whales (Newsome *et al.* 2009) and sperm whales (Mendes *et al.* 2007) have utilized the larger size of these cetaceans' teeth and have been able to drill each growth layer individually to provide isotopic values for each year of life. Due to the small size of the yearling teeth, they were crushed using a mortar and pestle and analysis is based on whole tooth content

Carbon and Nitrogen Stable Isotope Analysis

Once extracted, ~5 mg of the powdered dentin was transferred to 0.5 mL eppendorf tubes. For carbon and nitrogen analysis, a subsample of the dentin was soaked in chilled 0.5 M HCl to dissolve the hydroxylapatite and isolate the remaining collagen content of the teeth. In order to determine the appropriate acid soaking time, a small experiment was conducted prior to acid treatment. Separate trial samples of dentin (5mg) were soaked for increasing lengths of time: 4-32 hours in multiples of 4 hours, rinsed 5x with de-ionized water, and then lyophilized to remove the supernatant and leave the isolated collagen powder from the tooth. The mass of each sample was taken in order to optimize the time required to dissolve the inorganic carbon in the hydroxyapatite without degradation and loss of the organic collagen. It is suggested that 12-15 hours is the time in which the dentin becomes demineralized using 0.5 M HCl in killer whale teeth (Newsome *et al.* 2009). Based on the observed changes in $\delta^{13}C$ and $\delta^{15}N$ from the present study, it was determined that between 15-18 hours was the optimal time in which dentin becomes demineralized without degradation of the collagen.

All samples were soaked in 0.5M HCl for 18 hours, rinsed with milli-Q water, and then centrifuged. The rinsing and centrifuge process was repeated 5 times. Samples were then frozen and lyophilized overnight. Approximately, 0.2-0.3 mg of dentin collagen was weighed into tin boats for isotopic analysis. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic values were determined using a Delta V plus (2007) elemental analysis coupled with isotope ratio mass spectrometry (EA-IRMS) (Grassineau 2006) at Skidaway Institute of Oceanography in Savannah, GA.

Oxygen Stable Isotope Analysis

Oxygen samples (n=21) were treated with 0.5 mL 30% H_2O_2 for 24 hours to remove organic contaminants then rinsed 5 times with Milli-Q water. The samples were then soaked for 24 hours in 0.5 mL of 1 M calcium acetate/acetic acid buffer (pH of ~5) to remove any diagenetic carbonate, rinsed 5 times with Milli-Q water, frozen, and lyophilized according to protocols from the University of California at Santa Cruz (Andreasen 2008). Stable oxygen isotopic determinations ($\delta^{18}O$) were analyzed using a Thermo Fisher Delta Plus V with a Kiel device (Borrell *et al.* 2013) in Kim M. Cobb's laboratory at the Georgia Institute of Technology, Atlanta, GA. Approximately 2.0 g of each sample was determined to produce the optimal amount of CO_2 gas for analysis.

Isotopic values of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and oxygen ($\delta^{18}O$) are expressed in delta (δ) notation as parts per thousand determined from:

$$\delta = [(R_{sample}/R_{standard})-1] \text{ x } 1000$$

δ thus represents the isotope ratio of the sample relative to the standard. R is the heavy-to-light isotope ratio ($^{13}C/^{12}C$; $^{15}N/^{14}N$; $^{18}O/^{16}O$) in the sample and the reference standard. The standard for carbon and oxygen is the Vienna Peedee Belemnite (vPDB) marine calcium carbonate shell from South Carolina (Craig 1957). Nitrogen isotope ratios are relative to atmospheric nitrogen. For carbon, most mammalian tissues are negative in relation to vPDB and thus have a negative isotopic $^{13}C/^{12}C$ ratio (Krueger *et al.* 1984). Most mammalian tissues have a positive isotopic $^{15}N/^{14}N$ ratio. The oxygen standard most commonly used in zoology is the Vienna Standard Mean Ocean Water (VSMOW) (Borrell *et al.* 2013; Vighi *et al.* 2014); thus the $\delta^{18}O$ values were converted from vPDB to VSMOW using the following equation:

$$\delta^{18}O_{SMOW}=1.03086x\ \delta^{18}O_{vPDB}+30.86$$

In relation to this standard, mammalian tissues have a positive $^{18}O/^{16}O$ ratio (Clementz and Koch 2001, Clementz *et al.* 2006).

Statistical analysis

Data were tested for normality using the Shapiro-Wilk's goodness-of-fit test. Nitrogen displayed a normal distribution and was not transformed. Oxygen did not show a normal distribution initially. An outlier was removed from the sample analysis, HUBB-0339 drill site 3 (juvenile). After this removal, the residuals were tested for normality again and the distribution was normal. The carbon data were not normally distributed and no transformation was able to correct for non-normality. The log-transformed data best fit the assumptions of normality and these data were used in the analysis.

A univariate mixed effects multi-way ANOVA was performed using JMP 11.0.0 (SAS Institute, Inc., Cary, NC) to test whether sex, region, age class, the interaction between age class and sex, and region and sex nested in individuals as a random effect had a significant effect on each isotopic value. The statistical analyses were considered significant at $P < 0.05$. Tables 1-4 detail the biological information available as well as the stable isotope values for each individual analyzed.

RESULTS

Upon initial analysis of the data, the yearlings that were originally categorized as calves (4) were shown to be significantly different than the calf sites of the drilled teeth (Figure 9). For this reason, these four animals were changed to be categorized as yearlings to test for differences between them and the calf site of the adult teeth sampled.

There were 46 individuals sampled for carbon and nitrogen analysis, four of which were yearlings where the whole tooth was used as one sample. Together, this produced a total of 176 samples. Successful analysis was conducted on 169 samples for nitrogen and carbon stable isotopes. There were seven samples that did not produce enough mass for stable isotope analysis after sample processing and had to be discarded. Four of the discarded samples were from one individual in central Florida.

For oxygen analysis, 28 individuals were selected between the six regions. Of these individuals, four were the yearlings, which comprised only one sample each. A total of 99 samples were prepared for oxygen analysis; however only 66 returned values that could be used. Samples that were discarded did not produce enough carbon dioxide for analysis due to an early release of phosphoric acid, which dissolved the samples too soon. This resulted in data for 21 individuals. Fewer samples were analyzed for oxygen than carbon and nitrogen due to budget constraints.

Carbon

Regional Differences

The $\delta^{13}C$ values among the geographical regions in this study were not significantly different (p=0.99) (Figure 10). The regional comparison was a combination of all age classes for each animal as well as the whole tooth for the yearlings. South Carolina values ranged from -16.9‰ to -12.8‰ (mean: -14.1‰; std dev ± 0.9). Individuals from Georgia had $\delta^{13}C$ values ranging from -17.4‰ to -12.6‰ (mean: -14.0‰; std dev ± 1.1). The results from Florida regions had values ranging from -17.2‰ to -12.8‰ (mean: -13.9; std dev ± 1.2), -19.9‰ to -12.0‰ (mean: -14.0; std dev ± 1.6), and -17.5‰ to -12.7‰ (mean: -13.9; std dev ± 1.3) for Northern, Central, and Southern Florida, respectively. Central Florida had the two highest and two lowest $\delta^{13}C$ values. The two highest values were from HUBB-0339 while the lowest values were from SWF-8860. The Gulf of Mexico showed a range of -14.7‰ to -12.6‰ (mean: -13.5; std dev ± 0.6).

Age Class and Gender Differences

Significant differences were found in $\delta^{13}C$ (p=0.0081) among the different age classes (Figure 11). Yearlings had the highest $\delta^{13}C$, but showed a large degree of variability that did not allow for any significant differences between them and the other age classes. Values were relatively low in samples taken at the calf site, and progressively increased until the sub-adult age class, which was followed by a significant decrease in adult $\delta^{13}C$ values. Male and female $\delta^{13}C$ did not differ overall (p=0.79), or within each age class based on the interaction term between sex and age classes (p=0.66) (Figure 12).

Individual Differences

Individual variability was shown to be the most important factor in each isotope model. Figure 13 displays the mean $\delta^{13}C$ values for each individual in this study. Carbon presented the largest range of individual variability at 12.6-16.4‰. A Tukey test revealed that only one individual was significantly different than the others; HUBB-0339. This individual had the lowest $\delta^{13}C$ at -19.9‰ and showed the largest standard deviation (3.1‰) as can be seen in the graph. A one-way ANOVA was performed to attempt to reveal any trends within individuals in each region. A difference among individuals was only significant in Georgia.

Nitrogen

Regional Differences

Isotopic values of $\delta^{15}N$ were determined for 46 individuals in six regions. Overall, Georgia had the highest $\delta^{15}N$ value at 14.5‰ and Central Florida had the lowest at 10.5‰. Individuals from South Carolina ranged from 11.1‰ to 13.6‰ (mean: 12.2‰; std dev ± 0.5) and individuals from Georgia showed values ranging from 10.7‰ to 14.5‰ (mean: 12.2‰; std dev ± 0.7). Florida was divided into three Atlantic regions: Northern, Central, and Southern. These regions had $\delta^{15}N$ ranges of 10.8‰ to 13‰ (mean: 11.8‰; std dev ± 0.5), 10.5‰ to 14.4‰ (mean: 12.1‰; std dev ± 0.9), and 11.4‰ to 13.5‰ (mean: 12.1‰; std dev ± 0.5) respectively. Animals stranded in the Gulf of Mexico had a range of 10.6‰ to 12.8‰ (mean: 11.9‰; std dev ± 0.7). As a combination of all age classes for each individual, significant differences were not detected ($p=0.57$) in $\delta^{15}N$ values between the regions (Figure 14).

Age Class and Gender Differences

$\delta^{15}N$ values were significantly different among age classes ($p<0.0001$) (Figure 15). Yearlings, individuals less than 140 cm that had stranded with their mother, had the highest $\delta^{15}N$ values compared to the other age classes. A one-way ANOVA was performed to test if age class would still be significant with the yearling removed. Excluding the yearlings from the samples, the age class is still significant ($p=0.03$). An increasing trend can be seen through the transition from juvenile, sub-adult, and adult stages. Sex ($p=0.33$) and the interaction between sex and age class ($p=0.65$) (Figure 16) were not significant factors in the nitrogen model indicating no unique trends among different combinations of gender and age class.

Individual Differences

Individual variability was shown again to be the largest factor in the model. The high degree of variability each individual displayed caused regional differences to be insignificant due to the large degree of overlap. Figure 17 displays the mean $\delta^{15}N$ values for each individual. The $\delta^{15}N$ values ranged from 10.7-13.1‰. There were 7 individuals that were significantly different from the overall mean: GA0816, HUBB-0339, S-94-37, SWF-8420, S-95-20, SC9806, and HBOI-0709. A one-way ANOVA was performed to attempt to reveal any trends within individuals in each region. Individual differences showed to be significant in each region.

Oxygen

The oxygen model did not include any interactions. The model included sex, age class, region, and region and sex nested in individuals as a random effect. The model also excluded the juvenile drill site from HUBB-0339 as it was an outlier and caused a non-normal distribution. Isotopic values of oxygen were determined for 21 individuals. None of the effects tested were found to be significant.

Regional Differences

Georgia (n=1) had $\delta^{18}O$ values ranging from 30.1‰ to 30.5‰ (mean: 30. 3‰; std dev ± 0.2). Only two of four samples from this individual ran successfully. South Carolina (n=3) ranged from 30.3‰ to 31.1‰ (mean: 30.6‰; std dev ± 0.3). Northern Florida (n=4) ranged from 30.0‰ to 31.5‰ (mean: 30.6‰; std dev ± 0.5). Central Florida had the highest and lowest $\delta^{18}O$ values, 28.7‰ to 31.7‰ (mean: 30.5‰; std dev ± 0.7). Southern Florida (n=3) had a range of 30.0‰ to 31.3‰ (mean: 30.6‰; std dev ± 0.4). The Gulf of Mexico (n=2) resulted in a range of 30.3‰ to 31.2‰ (mean: 30.8‰; std dev ± 0.3). Significant differences were not detected (p=0.73) in $\delta^{18}O$ values among regions (Figure 18).

Age Class Differences

No significant differences in $\delta^{18}O$ were found among age classes (p=0.22). The four yearling teeth showed a large standard error (Figure 19) leading to no significant differences between any of the age classes. There was also no significant difference between the sexes (p=0.14). The interaction between the sexes at each age class was not present in the oxygen model.

Individual Differences

The individual differences are harder to detect in the oxygen isotopes compared to the nitrogen and carbon. There were less samples run, 66 compared to 169, and there was a high degree of standard deviation for each individual. This large degree of standard deviation caused a lot of overlap between individuals and there were no differences determined according to a Tukey test. Figure 20 displays the mean $\delta^{18}O$ values for each individual. The $\delta^{18}O$ values displayed the smallest range; 29.9- 31.2‰. The individuals within Central Florida had the largest degree of variability with HUBB-0339 having the greatest standard deviation (1.1‰).

DISCUSSION

Regional differences and migration patterns

The results from the stable isotope analysis demonstrate that there were no regional differences among individuals. This suggests that populations of *Kogia breviceps* in the SEUS are not highly segregated. It is believed that *Kogia breviceps* feed and live off of the continental shelf but it is unknown to what degree they utilize more coastal environments. Coastal water chemistry is expected to be more variable due to varying terrestrial influences and higher seasonal temperature fluctuations that occur in these shallower waters. Considering the more homogeneous nature of oceanic waters off of the shelf, the lack of observable differences in stable isotope signatures of carbon, nitrogen, and oxygen suggest pygmy sperm whales in the SEUS are not heavily utilizing coastal habitats supporting H1 and H3. Additionally, an absence of large variation in the carbon values from the present study suggests no long-range latitudinal migration for *Kogia breviceps*. A study by Mendes *et al.* (2007) discusses the application of carbon stable isotopes to detect migrations into northern latitudes by male sperm whales. In this study, males showed decreasing $\delta^{13}C$ values around the age of nine, when segregating from natal groups and move to higher latitudes. This change is not detected for *Kogia breviceps* analyzed in this study supporting H1 that they do not make large latitudinal movements throughout their lifetime.

The continental shelf of the southeastern Atlantic coast is a wide and shallow shelf. The width of this shelf varies from 30 km off of Cape Hatteras, 145 km off

Savannah, GA, and 2 km off West Palm Beach, FL (Atkinson *et al.* 1983). The shelf is characterized as a "live bottom" and is distinguished by rocky reefs with benthic biota that comprise 20% of the shelf bottom. This is a higher percentage of hard shelf bottom than is found in regions to the north and in the Gulf of Mexico (Shepard 2012). Compared to the Gulf of Mexico shelf, the Atlantic shelf is a higher energy shelf due to the Gulf Stream, which flows along the shelf break until Cape Hatteras where it deflects to the open ocean (Harlan 2014). Although the shelf varies in distance from the coast, the presence of oceanic and benthic squid beaks found in pygmy sperm whale diets demonstrate that this species hunts in open waters as well as near the bottom of the outer continental shelf. In a study by Staudinger *et al.* (2013), squid beaks were found from families that are typically found at depths ranging from 200 to 1,800 meters. The continental shelf off the coast of South Carolina and Georgia extends 145 km offshore and has a maximum depth of 100 m. Extending past the shelf in this area is the Blake Plateau which drops to 1000 meters at its deepest edge (Sautter 2012).

The Gulf of Mexico continental shelf is a very wide shelf that extends 900 km in length from the Panhandle to the Florida Keys. Pygmy sperm whales have been sighted in the Gulf of Mexico in a range of depths: from 200m to 2000m. Baumgartner *et al*. (2000) conducted surveys in the Gulf of Mexico and found both *Kogia* species to be most often associated in water over the upper continental slope. The results from the Gulf of Mexico did not show a significant difference for carbon, nitrogen, or oxygen compared to the other regions. There was a slight increase in the mean δ^{13}C and δ^{18}O in this region, but due to individual variability, they were not significantly different.

Harlan (2014) created backcast simulations to determine the origin of drift from stranded *Kogia breviceps* along the South Atlantic Blight, which extends from Cape Hatteras, NC to West Palm Beach, FL. It was discovered that individuals that had stranded in North Carolina remained isolated from animals in South Carolina and Georgia. Findings from Harlan (2014) suggest there is a population separation between North and South Carolina. Individuals from North Carolina were not included in this study but Staudinger *et al.* (2013) presented carbon and nitrogen values from epaxial muscle of pygmy and dwarf sperm whales stranded in North Carolina and Virginia. The pygmy sperm whale carbon and nitrogen means from that study are -17.1‰ ± 0.6‰ and 10.8‰ ± 0.5‰, respectively. The overall carbon mean from this study was -14.0‰ ± 1.2‰ and nitrogen is 12.1‰ ± 0.7‰. The results from the study by Staudinger *et al.* (2013) are the most recent stable isotope data available for *Kogia breviceps* in the Western North Atlantic to compare results from the present study.

Although it is not believed that *Kogia breviceps* have a latitudinal migration, it has been hypothesized that there is an inshore-offshore migration that occurs. A study by Santos and Pierce (2006) documented a seasonal occurrence of *Kogia breviceps* strandings in the northeastern Atlantic Ocean. In this area, which includes Spain, France, and Scotland, 20 of the 22 specimens observed were found to strand during the autumn and winter months; possibly indicating a seasonal inshore-offshore migration. Berini (2009) also found a seasonal pattern in the size of stranded individuals. Mature individuals were found to strand during the winter and spring, possibly indicating that mature individuals move inshore to mate during these seasons. Berini (2009) also stated that these findings could be in agreement with Ross (1979) who found that mating and calving occur in the fall and spring in South Africa; where the seasons are opposite of those in the northern hemisphere. Additionally, Mullin *et al*. (2004) found *Kogiids* in the Gulf of Mexico to be twice as abundant during the spring and summer than in the fall and winter.

Carbon isotopes are capable of identifying movements between offshore, inshore, benthic, and pelagic habitats (Owen *et al*. 2011). Coastal environments have more negative $\delta^{13}C$ values as compared to offshore environments. The carbon values presented, although not different among the age classes, do show an upward trend from calf to sub-adult (Figure 11). This supports the theory of an inshore migration. As the calves have lower $\delta^{13}C$ values compared with the juvenile and sub-adults, they could be further inshore as calves where the water is more depleted in $\delta^{13}C$. As the calves are weaned and move further offshore, the $\delta^{13}C$ increases as the waters become more enriched. The decrease from sub-adult to adult is more difficult to explain. It is possible it is due to a movement inshore either due to sickness or for reproductive purposes. The animals used in this study were all stranded animals that washed ashore or were along the coastlines before they died. Marine mammals strand when they are sick or have become disoriented and move too far inshore. However, the adult drill site is a combination of growth layers, not just the last year before the animal died. Even if the individuals would have moved closer to the coast when sick, it most likely would have been for a few weeks, not years, which would not result in lowered $\delta^{13}C$ values. Another possibility for the lower $\delta^{13}C$ values as adults is feeding at deeper, more benthic depths. As the pygmy sperm whales reached the adult age class, they could begin diving to greater depths to feed than as sub-adults, causing a lower $\delta^{13}C$ signature.

An absence of large variation in the carbon values from the present study suggests no long-range latitudinal migration for *Kogia breviceps*. A study by Mendes *et al.* (2007) discusses the application of carbon stable isotopes to detect migrations into northern latitudes by male sperm whales. In this study, males showed decreasing $\delta^{13}C$ values around the age of nine, when segregating from natal groups and move to higher latitudes. This change is not detected for *Kogia breviceps* analyzed in this study supporting the hypothesis that they do not make large latitudinal movements throughout their lifetime.

Additionally, *Kogia breviceps,* along with their sister species, *Kogia sima* were found to be the only marine mammals in the SEUS to show any appreciable susceptibility to domoic acid produced by the dinoflagellate *Pseudo-nitzchia*. A study done by Fire *et al.* (2009) analyzed urine and fecal samples from stranded *Kogia breviceps* and *Kogia sima* from 1997-2008. Of the 41 animals analyzed, 59% tested positive for domoic acid (DA), however prior to November 2006, the SEUS was a region that had not experienced domoic acid-producing harmful algal blooms (HABs). Blooms occurring in 2006 and 2007 displayed very low DA concentrations and neither was spatially (within 100 miles) and temporarily (within 1 month) correlated with *Kogia* strandings in the study. The only animal that stranded nearby to a bloom was a *T. truncatus* that tested negative for DA exposure. As these blooms were found within the continental shelf, it can be speculated that *Kogia* moved inshore, also within the shelf, and have a unique feeding behavior or habitat utilization that is not yet fully understood that allows this species to be affected by DA.

Age Class and Gender Effects

While Staudinger *et al.* (2013) reported no increase in nitrogen values with an increase in size for *Kogia breviceps*, the $\delta^{15}N$ results of this study show that there is a slight increase in values as individuals age and increase in size. However, this difference represents a fraction of a trophic level, suggesting that pygmy sperm whales are stenophagic across these regions. This supports published stomach content studies indicating pygmy sperm whales as cephalopod specialists. The mean $\delta^{15}N$ value in the whole tooth samples from the four yearlings (13.9 ± 0.3‰) was significantly higher than all other age classes. The yearlings in this study were all less than 140 cm and had stranded with their mothers so it is assumed they were still nursing. These four individuals had very high $\delta^{15}N$ values compared to those of the calf, juvenile, sub-adult, and adult drill sites (12.1‰, 11.9‰, 12.0‰, and 12.2‰). Young mammals, in this study the yearlings, that are still nursing exhibit a heavier nitrogen isotope ($\delta^{15}N$) due to isotopic fractionation during milk production. Higher $\delta^{15}N$ values in nursing offspring compared to their mothers has been reported in teeth and muscle of killer whales (Newsome *et al.* 2009; Endo *et al.* 2014), the teeth of sperm whales (Mendes *et al.* 2007), the skin of bottlenose dolphins (Knoff *et al.* 2008), and the fingernails of humans (Fuller *et al.* 2006). This $\delta^{15}N$ enrichment due to nursing was the largest difference among age classes, but adults also had significantly higher $\delta^{15}N$ than juveniles, with sub-adults intermediate, suggesting a slight ontogenetic increase in trophic level may occur. The calf drill site was slightly higher than juveniles, but we speculate that this could have been due to partial inclusion of the enriched yearling region of the tooth that is immediately adjacent to the calf region. Pygmy sperm whales grow very rapidly; females are mature by age 3 and males at 5 (Smar 2006). Due to this rapid growth, once a calf is weaned and begins a diet of solid food; they are of a size that would allow the consumption of prey of a similar size as an adult pygmy sperm whale, explaining the modest increase.

Differences between the sexes were not found to be significant for carbon, nitrogen, or oxygen. The carbon results indicate that if there is an inshore-offshore movement of this species, both sexes make that migration, not just females into a calving ground. Berini (2009) states that males could be moving inshore for mating purposes, as 70% of single stranding individuals are male. The $\delta^{15}N$ for the interaction between sex and age class demonstrated that there was no feeding difference between the sexes for *K. breviceps*. Figure 16 displays the $\delta^{15}N$ values for both sexes throughout the lifetime of *K. breviceps*. Males and females appear to feed on the same size prey throughout their lives, as there are no differences between $\delta^{15}N$ values. A difference of 3-5‰ indicates feeding at a full trophic level difference. Males have slightly higher $\delta^{15}N$ values for the juvenile-adult stages, however the difference is only 0.3‰ suggesting a modest shift in diet.

Individual Variability

Variability among and within individuals was very large for this study. Carbon values among individuals showed the greatest variability. Southern Florida had large fluctuations in $\delta^{13}C$ signatures. This is the only region that had all animals reaching lengths over 300 cm; with the largest being 351 cm. In Southern Florida, these animals could be displaying a large variability due to lack of a wide continental shelf in this region. The shelf only extends ~2 km compared with the 147 km off the coast of South Carolina and Georgia. The animals in Southern Florida could be moving on and off the shelf more frequently or diving to deeper depths for prey. Within individuals, some had remarkably consistent $\delta^{13}C$ values from calf to adult: GA1128 (male), GA1001 (male), GA0801 (male), FLBL (female), S-95-17 (female), ACS-9810 (male), and SC1119 (male). This suggests these individuals have utilized a similar environment and prey their whole life. Interestingly, of these seven individuals with consistent $\delta^{13}C$ signatures, five were males. Other individuals have extremely variable results: HUBB-0339 (female), GA0816 (female), HUBB-0635 (female), S-95-20 (male), MMRF-03 (male), SC9634 (female), and MARS-9905 (female), suggesting their environment may have changed during their lifetime. Of these animals, five were female. Although the comparison between sexes at all age classes did not show a significant difference; individual males display lower variability within $\delta^{13}C$ signatures compared to females. The individual with the large deviation, HUBB-0339, was a nursing female that stranded with a yearling in central Florida. This individual displayed values of -19.9, -13.8, -13.7, and -18.1 for calf, juvenile, sub-adult, and adult drill sites, respectively. The extremely negative carbon values were the highest for this study. The values from this individual support an inshore movement, as the more negative values are when this animal was the youngest and oldest. HUBB-0339 was the only individual with a large deviation in carbon values that also had oxygen values associated. For oxygen as well, this individual showed large variability suggesting movement between different habitats during its lifetime. Even though the mean $\delta^{18}O$ for this individual was similar to other individual's sampled, the mean $\delta^{13}C$ signature was very different.

Nitrogen signatures showed less variability. As pygmy sperm whales mature at young ages, the prey consumed as a juvenile is similar in size to that an adult would feed on. This explains the smaller deviations for all individuals compared to the carbon values. There are no differences between the sexes as they both mature early and can reach similar lengths, presumably feeding on similar sized prey. The two individuals that have lower δ^{15}N mean values of 10.7 are SWF-8420B and S-94-37 from the Gulf of Mexico and Central Florida respectively. SWF-8420B is a 251 cm male that stranded in 1984 while S-94-37 is a 279 cm female that stranded in 1994. Consumption of different prey types back in 1984 could be attributed to the lower δ^{15}N values for SWF-8420B however without other individuals from this far back it is difficult to make any conclusions concerning the reduced δ^{15}N. It is also difficult to make any conclusion about S-94-37 because there is no biological data associated with this animal that would lead to a reduced δ^{15}N.

Oxygen values showed to be highly variable as well, especially in the Central Florida region. Within each region, the standard deviation for the individuals was similar, leading to a small degree of variability within the regions, as was seen. Essentially, there was a high degree of variability within each individual but not within each region. The individuals analyzed resulted in standard deviations <0.5% except for three individuals, ACS-9843, HUBB-0339, and HUBB-1126, which is typical for aquatic animals living in homogenous waters (Clementz *et al.* 2006).

The individuals that had means significantly different from the average were investigated and no conclusions could be made about the deviation from the mean. Of these individuals, four were males and three were females and each from a different region so the region was not a factor. Due to a lack of sample, these individuals could not be analyzed again.

Oxygen values

The animals in this study displayed low variability within and among regions, suggesting they are integrating a relatively homogeneous body of seawater with respect to $\delta^{18}O$ (Figure 18). Due to the uniformity of the ocean in the SEUS, the oxygen values for each animal should not have varied greatly compared to animals in other regions (Clementz & Koch 2001; Clementz et al. 2006). Figure 19 shows a slight decrease in $\delta^{18}O$ values as individuals become older. Decreasing oxygen values may be associated with an increase in trophic levels. Endo *et al.* (2012) reported negative correlations between $\delta^{18}O$ and $\delta^{15}N$ values in muscle from baleen whales. In the most recent paper, Endo *et al.* (2014) discusses the $\delta^{18}O$ values between killer whales and baleen whales. Killer whales, which feed at higher trophic levels than baleen whales, showed $\delta^{18}O$ values lower than baleen whales; providing support for a decrease in $\delta^{18}O$ with an increase in trophic level. This is also supported through the yearlings used in this study. The yearlings, who display enriched $\delta^{15}N$ values compared to the other age classes (Figure 15), exhibited lower $\delta^{18}O$ values (Figure 19). However, caution must be taken due to the limited number of samples available for analysis.

Also, as with the carbon isotope signatures, a lack of large variability within the regions and age classes suggests pygmy sperm whales do not make latitudinal migrations, as oxygen stable isotopes are capable of detecting these changes to higher northern latitudes. A study on sperm whales in the eastern North Atlantic shows as males migrate to higher latitudes and colder waters around Denmark, the $\delta^{18}O$ is depleted compared to waters in their natal groups around Northwest Spain (Borrell *et al*. 2013).

The original intent of the oxygen analysis was to compare mother and yearling isotope values against each other. The intent was that the yearlings, who were recently born and had not traveled great distances, would have oxygen values similar to their surrounding water that they were born into. The mothers, who were analyzed at four different life stages, could have been moving between different bodies of water throughout their lives. If the isotopic ratios between the calf and the mother were different, a migration during the mothers' life is possible. The comparison was not possible due to machine error resulting in only 2 mother calf pairs available for analysis, HUBB-1126/HUBB-1127 and SWF-8860/SWF-8861. For these two pairs, there were no significant differences of $\delta^{18}O$ values between the means of the mothers' and the yearling whole tooth.

CONCLUSION

Kogia breviceps are considered a rare species due to the lack of sightings at sea. However, with the high occurrence of strandings, particularly in the Southeastern United States, it is believed this species has a larger population size than has been reported in Stock Assessment Reports. With such a large geographic range, *K. breviceps* have been documented around the world: from South Africa (Ross 1979) to New Zealand (Beatson 2007) and Canada (Baird 1996). They have also frequently been documented around the Hawaiian Islands (Baird 2005) and multiple locations in the Caribbean Ocean including Cuba, Colombia, and Puerto Rico (Cardona-Maldonado and Migucci-Giannoni (1999).

The goal of the current study was to explore the utility of stable isotopes to investigate the populations of pygmy sperm whales in the Southeastern United States. This was the first study to analyze pygmy sperm whale populations through carbon, nitrogen, and oxygen stable isotopes in teeth across multiple regions and decades.

Results from this study suggest *Kogia breviceps* do not make long latitudinal migrations, but there is a possible small-scale inshore migration. The animals in this study show no detectable regional differences across South Carolina, Georgia, and the Atlantic and Gulf coasts of Florida. This could indicate that *Kogia breviceps* have a large home range or migrate regularly among these different regions. However, due to the relative uniformity of the open ocean waters in which these animals are thought to live, stable isotope values may not be sensitive enough to separate populations in the Southeastern United States, south of South Carolina, if they do exist. As stable isotopes of carbon and oxygen are capable of detecting northern migrations into colder waters, the lack of large changes within the stable isotopes of pygmy sperm whales in this study suggest they do not migrate into northern cold waters. For comparison, male sperm whales are known to make large migrations to northern latitudes either solo or move between different groups. They return back to tropical waters for breeding purposes. Females and calves remain in the tropical and subtropical waters yearlong forming pods of 15-20 individuals. This is similar to pygmy sperm whales in which males tend to strand alone while mother and calf strand together (Smar 2006). However, due to the lack of variability within carbon and oxygen isotopes, it is not believed that pygmy sperm whales make latitudinal migrations like their relative the sperm whale. Carbon values from this study support a small-scale inshore-offshore migration hypothesis as well as displaying lower $\delta^{13}C$ values as calves and gradually increasing as the animals' age. Adult drill sites displayed lower carbon signatures, which are representative of a coastal or benthic environment. These lower values are due to a change in environment. As pygmy sperm whales mature, they could begin feeding at deeper depths or move inshore for breeding purposes, both causing lower carbon values. These results are correlated with results found by Santos and Pierce (2006) and Berini (2009). Santos and Pierce (2006) found that strandings of pygmy sperm whales occurred seasonally in the Northeastern Atlantic Ocean with a higher frequency of strandings occurring in the autumn and winter months. Berini (2009) also found mature animals were more likely to strand during the winter and spring in the SEUS, possibly due to moving inshore for a mating season. In the Gulf of Mexico, *Kogiids,* both pygmy and dwarf sperm whales, were found to be twice as abundant on the shelf during the spring and summer (Mullin *et al.* 2004).

With the observance of large deviations for individuals, it is still unknown whether these large changes in isotope values are caused by migrations inland or a change in water chemistry. It is possible that individual pygmy sperm whales can develop different migrational tendencies. Based on the individual stable isotope values, some individuals show very tight ranges of carbon values, indicating that they do not migrate and stay in relatively the same area their entire lives. Other individuals have large ranges of carbon values and possibly make migrations out to deeper water or along the coastlines. The ranges for each individual vary greatly, leading to the possibility that some animals are "homebodies" and stay in the same area while others venture out and migrate to other waters.

Results from Harlan (2014) indicate that a separate population of *Kogia breviceps* may exist north of Cape Fear, North Carolina. Harlan (2014) assessed stranding records and created backcast simulations to determine that individuals who strand in North Carolina have 'points of origin north of South Carolina, and may be separate from individuals in South Carolina and Georgia. Stable carbon isotope values from Staudinger *et al.* (2013) also suggest a possible population separation between North and South Carolina. Specimens from North Carolina and Virginia resulted in a carbon mean of -17.1‰ ± 0.6‰ while the mean from the present study is -14.0‰ ± 1.2‰. However, due to utilization of different samples; (teeth versus muscle), results from the two studies should not be compared, although this raises speculation of different populations that need further investigation.. A larger study needs to be conducted which not only includes repeated samples, but also North Carolina and Virginia specimens, and similar tissue samples from all regions. Additionally, a genetic component to test for differences between animals in the SEUS would further aid in distinguishing the population(s) in this area.

Carbon and nitrogen models were only significantly different for the age class portion of this study. The age class data also presents new ontogenetic information for pygmy sperm whales. Males and females mature at a rapid rate and there is no sexual dimorphism between mature individuals. Due to this, there were no observed ontogenetic differences between the sexes at each age class. Although not large, a slight increase in $\delta^{15}N$ values can be observed. However, it is speculated that because pygmy sperm whales mature so early in life, they feed on similar prey the majority of their lives, creating small ontogenetic changes across age classes. The $\delta^{18}O$ values correlated with results found by Endo *et al.* (2014), who found that cetaceans at higher trophic levels resulted in lower $\delta^{18}O$ values.

There is still much uncertainty concerning the ecology of *Kogia breviceps.* However, the findings from this study provide baseline information that can be used to assess the populations of pygmy sperm whales in the Western North Atlantic and can aid in determining a population structure in this area. In order to further preserve this species in the future, the basic ecology and structure is necessary.

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Table 1. Data for pygmy sperm whales (*Kogia breviceps*) stranded in the Southeastern United States and included in the stable isotope analysis (n=46). Individuals are sorted by region.

Field Number	County	Region	Size (cm)	Sex	Mature	Date Stranded	Code	Latitude	Longitude
Ga-1128	Camden	Georgia	295	M	Yes	5/20/11	3	30.826	-81.436
GA0911	Glynn	Georgia	282	F	Yes	5/27/09	1	31.096	-81.403
GA0816	Chatham	Georgia	285	F	Unk	6/30/08	3	31.742	-81.103
GA1107	Camden	Georgia	310	M	Yes	2/15/11	3	30.810	-81.446
GA0801	Camden	Georgia	328	M	Yes	1/19/08	3	30.847	-81.425
GA1219	Chatham	Georgia	309	F	Yes	7/10/12	1	31.865	-80.985
GA1001	Camden	Georgia	288	M	Yes	1/24/10	3	30.900	-81.406
GA1028	McIntosh	Georgia	315	M	Yes	8/9/10	1	31.436	-81.236
GA1220	McIntosh	Georgia	302	F	Yes	7/26/12	2	31.508	-81.300
GA1142	McIntosh	Georgia	298	M	Yes	8/16/11	5	31.515	-81.178
FLBL	Escambia	Gulf of Mexico	283	F	Yes	2/13/03	1	30.327	-87.350
SWF-8420B	Lee	Gulf of Mexico	251	M	Unk	1/25/84	1	26.550	-82.202
FLGM-02	Okaloosa	Gulf of Mexico	329	M	Yes	3/29/03	2	30.396	-86.631
SWF-9220B	Pinellas	Gulf of Mexico	312	M	Yes	8/31/92	1	27.705	-82.739
S-94-37	Brevard	Central Florida	279	F	Yes	11/12/94	1	28.097	-80.567
HUBB-0635	Volusia	Central Florida	292	F	Yes	6/27/06	2	29.228	-81.000
acs-9810	Volusia	Central Florida	327	M	Unk	2/4/98	3	28.856	-80.775
acs-9843	Brevard	Central Florida	302	M	Unk	10/4/98	1	28.408	-80.590
HUBB-0339	Brevard	Central Florida	323	F	Yes	8/15/03	1	28.050	-80.551
*hubb-0340	Brevard	Central Florida	127	F	No	8/15/03	1	28.050	-80.551
hubb-1126	Brevard	Central Florida	271	F	Yes	7/1/11	2	25.559	-80.567
*hubb-1127	Brevard	Central Florida	138	M	No	7/1/11	2	28.564	-80.568
swf-8860	Brevard	Central Florida	327	F	Yes	6/14/88	2	28.230	-80.599
*swf-8861	Brevard	Central Florida	132	M	No	6/14/88	1-2	28.230	-80.599

Table 1. *(Continued)*

Field Number	**County**	**Region**	**Size (cm)**	**Sex**	**Mature**	**Date Stranded**	**Code**	**Latitude**	**Longitude**
*S-95-27	Volusia	Central Florida	122	M	No	1995			
HUBBS-0344	Flagler	Northern Florida	303	M	Yes	9/23/03	2	29.525	-81.150
S-94-25	Flagler	Northern Florida	272	F	Unk	5/21/94	1	29.458	-81.116
S-97-20	St. Johns	Northern Florida	Unk	F	Unk	7/27/97	1	30.229	-81.374
S-95-20	St. Johns	Northern Florida	310	M	Yes	7/23/95	2	29.837	-81.264
SC0404	Charleston	South Carolina	313	M	Yes	2/2/04	2	32.685	-79.886
SC9801	Horry	South Carolina	318	M	Yes	1/6/98	1	33.732	-78.825
SC1150	Charleston	South Carolina	311	M	Yes	6/21/11	2	32.610	-80.021
SC9806		South Carolina	Unk	M	Unk	1/19/98	2	33.003	-79.488
SC0220	Horry	South Carolina	298	F	Yes	8/10/02	1	33.746	-78.810
SC1369	Beaufort	South Carolina	285	M	Unk	11/3/13	1	32.342	-80.462
SC9634	Charleston	South Carolina	312	F	Yes	9/11/96	2	32.776	-79.803
SC1119	Charleston	South Carolina	350	M	Yes	3/18/11	3	32.694	-79.888
SC1359	Beaufort	South Carolina	304	M	Yes	10/26/13	1	32.218	-80.667
S-95-17	St. Lucie	Southern Florida	320	F	Yes	7/15/11	1	27.436	-80.278
EAI-9808	Martin	Southern Florida	323	F	Yes	10/15/98	1	27.186	-80.159
HBOI-0709	Indian River	Southern Florida	302	M	Yes	10/30/07	2	27.646	-80.353
MMRF-02	Monroe	Southern Florida	351	M	Yes	2/28/03	2	24.929	-80.583
MMRF-03	Monroe	Southern Florida	322	M	Yes	3/1/03	1	24.917	-80.650
FKMMRT	Monroe	Southern Florida	304	M	Yes	8/10/02	1	33.746	-78.810
hboi-9904	St. Lucie	Southern Florida	305	M	Yes	10/11/99	1	27.465	-80.289
MARS-9905	Dade	Southern Florida	Unk	F	Yes	10/14/99	1	25.953	-80.119

Table 2. Carbon data for pygmy sperm whales (*Kogia breviceps*) stranded in the Southeastern United States and included in the stable isotope analysis (n=46). Individuals are sorted by region and include the average of all drill sites per individual. Drill site numbering follows: (1) adult, (2) sub-adult, (3) juvenile, (4) calf, and (5) yearlings.
*There are four yearlings; each stranded with mother.

Field Number	**County**	**Region**	**Size**	**Sex**	**$\delta^{13}C$ (1)**	**$\delta^{13}C$ (2)**	**$\delta^{13}C$ (3)**	**$\delta^{13}C$ (4)**	**$\delta^{13}C$ (5)**	**$\delta^{13}C$(avg)**
GA1128	Camden	Georgia	295	M	-13.6	-13.5	-13.4	-13.4		-13.5
GA0911	Glynn	Georgia	282	F	-14.3	-13.9	-14.1	-14.5		-14.2
GA0816	Chatham	Georgia	285	F	-13.9	-14.1	-13.9	-17.4		-14.8
GA1107	Camden	Georgia	310	M	-16	-13.8	-13.4	-12.8		-14
GA0801	Camden	Georgia	328	M	-13	-12.8	-12.6	-12.9		-12.8
GA1219	Chatham	Georgia	309	F	-13.8	-13.1	-12.9	-14.2		-13.5
GA1001	Camden	Georgia	288	M	-13.2	-13.4	-13.4	-13.4		-13.4
GA1028	McIntosh	Georgia	315	M	-15.2	-13.3	-13.2	-13.9		-13.9
GA1220	McIntosh	Georgia	302	F	-13.3	-13.5	-13.4	-15		-13.8
GA1142	McIntosh	Georgia	298	M	-16.9	-14.2	-15.2	-16.3		-15.7
FLBL	Escambia	Gulf of Mexico	283	F	-13.6	-13.2	-13.3	-13.5		-13.4
SWF-8420B	Lee	Gulf of Mexico	251	M		-13.2	-13.3	-14.2		-13.6
FLGM-02	Okaloosa	Gulf of Mexico	329	M	-13	-13.3	-14.4	-13.6		-13.6
SWF-9220B	Pinellas	Gulf of Mexico	312	M	-14.7	-12.6	-12.9	-12.9		-13.3
S-94-37	Brevard	Central Florida	279	F	-14.7	-13.4	-14			-14
HUBB-0635	Volusia	Central Florida	292	F	-14.4	-13.3	-16.8	-14.4		-14.7
acs-9810	Volusia	Central Florida	327	M	-13.2	-13	-13.1	-12.9		-13.1
acs-9843	Brevard	Central Florida	302	M	-15	-13.1	-13.2	-13.6		-13.7
HUBB-0339	Brevard	Central Florida	323	F	-18.1	-13.7	-13.8	-19.9		-16.4
*hubb-0340	Brevard	Central Florida	127	F					-13.4	-13.4
hubb-1126	Brevard	Central Florida	271	F	-13.5	-13.7	-13.8			-13.7
*hubb-1127	Brevard	Central Florida	138	M					-14.0	-14.0
swf-8860	Brevard	Central Florida	327	F	-12.8	-12.6	-12.4	-12.4		-12.6

Table 2. (Continued)

Field Number	**County**	**Region**	**Size**	**Sex**	**$\delta^{13}C$ (1)**	**$\delta^{13}C$ (2)**	**$\delta^{13}C$ (3)**	**$\delta^{13}C$ (4)**	**$\delta^{13}C$ (5)**	**$\delta^{13}C$(avg)**
*swf-8861	Brevard	Central Florida	132	M					-12.9	-12.9
*S-95-27	Volusia	Central Florida	122	M					-13.5	-13.5
HUBBS-0344	Flagler	Northern Florida	303	M	-15	-14	-14.9	-13.7		-14.4
S-94-25	Flagler	Northern Florida	272	F	-14.8	-12.9	-12.8	-12.8		-13.3
S-97-20	St. Johns	Northern Florida	Unk	F	-12.9	-13.4	-12.9	-13.5		-13.2
S-95-20	St. Johns	Northern Florida	310	M	-14.2	-13.1	-14.9	-17.2		-14.9
SC0404	Charleston	South Carolina	313	M	-13.1	-13.2	-14.3	-13.4		-13.5
SC9801	Horry	South Carolina	318	M	-12.8	-12.8	-14	-13.2		-13.2
SC1150	Charleston	South Carolina	311	M	-13.9	-13.4	-14.3	-13.5		-13.8
SC9806		South Carolina	Unk	M	-15.9	-13.9	-14.6	-13		-14.4
SC0220	Horry	South Carolina	298	F	-14.5	-14.2	-14	-14.3		-14.3
SC1369	Beaufort	South Carolina	285	M	-15.2	-14.4	-14.2	-14.9		-14.7
SC9634	Charleston	South Carolina	312	F	-13.5	-16.9	-14.4	-14		-14.7
SC1119	Charleston	South Carolina	350	M	-14	-13.8	-13.4	-13.8		-13.8
SC1359	Beaufort	South Carolina	304	M	-13.9	-13.7	-13.9	-15.6		-14.3
S-95-17	St. Lucie	Southern Florida	320	F	-13.5	-13.4	-13.3	-13.4		-13.4
EAI-9808	Martin	Southern Florida	323	F	-13.5	-13.7	-13.3	-13.3		-13.5
HBOI-0709	Indian River	Southern Florida	302	M	-15.3	-12.9	-13.7	-12.9		-13.7
MMRF-02	Monroe	Southern Florida	351	M	-14.8	-16.7	-14.3	-14.2		-15
MMRF-03	Monroe	Southern Florida	322	M	-12.7	-12.8	-13.8	-17.3		-14.2
FKMMRT	Monroe	Southern Florida	304	M	-15	-13.3	-13.3	-13.2		-13.7
hboi-9904	St. Lucie	Southern Florida	305	M	-15.2	-13.1	-13.1	-13.6		-13.8
MARS-9905	Dade	Southern Florida	Unk	F	-17.5	-15	-13.5	-13.9		-15

Table 3. Nitrogen data for pygmy sperm whales (*Kogia breviceps*) stranded in the Southeastern United States and included in the stable isotope analysis (n=46). Individuals are sorted by region and include the average of all drill sites per individual. Drill site numbering follows: (1) adult, (2) sub-adult, (3) juvenile, (4) calf, and (5) yearlings.
*There are four yearlings; each stranded with mother.

Field Number	**County**	**Region**	**Size**	**Sex**	**δ^{15}N (1)**	**δ^{15}N (2)**	**δ^{15}N (3)**	**δ^{15}N (4)**	**δ^{15}N (5)**	**δ^{15}N(avg)**
Ga-1128	Camden	Georgia	295	M	11.4	11.6	12.2	12.2		11.9
GA0911	Glynn	Georgia	282	F	12.3	12	12.1	13.3		12.4
GA0816	Chatham	Georgia	285	F	11.1	10.7	11.5	11.7		11.3
GA1107	Camden	Georgia	310	M	12.4	12.6	12.8	12.8		12.7
GA0801	Camden	Georgia	328	M	12.3	13.7	13	12.3		12.8
GA1219	Chatham	Georgia	309	F	12.1	11.5	11.4	12.1		11.8
GA1001	Camden	Georgia	288	M	12.1	12.5	12.4	12.6		12.4
GA1028	McIntosh	Georgia	315	M	14.5	13.2	12.2	11.5		12.9
GA1220	McIntosh	Georgia	302	F	12.5	12.4	12.1	12		12.3
GA1142	McIntosh	Georgia	298	M	11.6	12	12	12.3		12
FLBL	Escambia	Gulf of Mexico	283	F	11.9	11.6	11.9	11.1		11.6
SWF-8420B	Lee	Gulf of Mexico	251	M		10.7	10.6	10.7		10.7
FLGM-02	Okaloosa	Gulf of Mexico	329	M	12.8	12.2	12	12.2		12.3
SWF-9220B	Pinellas	Gulf of Mexico	312	M	12.5	12.6	12.3	12.6		12.5
S-94-37	Brevard	Central Florida	279	F	10.8	10.7	10.5			10.7
HUBB-0635	Volusia	Central Florida	292	F	12.1	12.4	11.9	11.8		12.1
acs-9810	Volusia	Central Florida	327	M	12.1	12	11.4	11.4		11.7
acs-9843	Brevard	Central Florida	302	M	12.1	11.9	12	11.5		11.9
HUBB-0339	Brevard	Central Florida	323	F	12.5	11.9	12.3	12.7		12.4
*hubb-0340	Brevard	Central Florida	127	F					13.7	13.7
hubb-1126	Brevard	Central Florida	271	F	11.4	11.5	11.2			11.4
*hubb-1127	Brevard	Central Florida	138	M					13.9	13.9

Table 3. (Continued)

Field Number	**County**	**Region**	**Size**	**Sex**	**$\delta^{15}N$ (1)**	**$\delta^{15}N$ (2)**	**$\delta^{15}N$ (3)**	**$\delta^{15}N$ (4)**	**$\delta^{15}N$ (5)**	**$\delta^{15}N$(avg)**
*S-95-27	Volusia	Central Florida	122	M					14.4	14.4
*swf-8861	Brevard	Central Florida	132	M					13.5	13.5
swf-8860	Brevard	Central Florida	327	F	12.6	12.2	12.2	12.3		12.3
HUBBS-0344	Flagler	Northern Florida	303	M	12.2	13	12.3	12		12.4
S-94-25	Flagler	Northern Florida	272	F	11.5	11.5	12.3	12		11.8
S-97-20	St. Johns	Northern Florida	Unk	F	12.2	12.1	11.8	11.7		12
S-95-20	St. Johns	Northern Florida	310	M	11.5	10.8	11.3	11.2		11.2
SC0404	Charleston	South Carolina	313	M	13	12.6	12.4	12.5		12.6
SC9801	Horry	South Carolina	318	M	12.7	11.8	12.1	12.1		12.2
SC1150	Charleston	South Carolina	311	M	12.3	12.2	11.7	12.2		12.1
SC9806		South Carolina	Unk	M	13.3	13.2	12.2	13.2		13
SC0220	Horry	South Carolina	298	F	11.7	12	11.7	11.9		11.8
SC1369	Beaufort	South Carolina	285	M	12.2	11.1	12.3	13.6		12.3
SC9634	Charleston	South Carolina	312	F	12.4	12.2	11.9	12.6		12.3
SC1119	Charleston	South Carolina	350	M	12	12.1	11.5	11.6		11.8
SC1359	Beaufort	South Carolina	304	M	12.2	12.4	11.9	11.4		12
S-95-17	St. Lucie	Southern Florida	320	F	12.3	11.8	11.4	11.5		11.8
EAI-9808	Martin	Southern Florida	323	F	12.5	12.1	11.8	12.2		12.2
HBOI-0709	Indian River	Southern Florida	302	M	13.5	13.3	13.1	12.4		13.1
MMRF-02	Monroe	Southern Florida	351	M	12.1	11.9	11.8	11.9		11.9
MMRF-03	Monroe	Southern Florida	322	M	11.9	11.9	11.4	11.5		11.7
FKMMRT	Monroe	Southern Florida	304	M	12.5	12.1	12.1	12.6		12.3
hboi-9904	St. Lucie	Southern Florida	305	M	11.8	11.7	11.8	11.4		11.7
MARS-9905	Dade	Southern Florida	Unk	F	12.8	12.1	12.1	12		12.3

Table 4. Oxygen data for pygmy sperm whales (*Kogia breviceps*) stranded in the Southeastern United States and included in the stable isotope analysis (n=21). Individuals are sorted by region and include the average of all drill sites per individual. Drill site numbering follows: (1) adult, (2) sub-adult, (3) juvenile, (4) calf, and (5) yearlings.
*There are four yearlings; each stranded with mother.

Field Number	**County**	**Region**	**Size**	**Sex**	**$\delta^{18}O$ (1)**	**$\delta^{18}O$ (2)**	**$\delta^{18}O$ (3)**	**$\delta^{18}O$ (4)**	**$\delta^{18}O$ (5)**	**$\delta^{18}O$ (avg)**
Ga-1128	Camden	Georgia	295	M	30.44	30.11				30.28
FLBL	Escambia	Gulf of Mexico	283	F				31.18		31.18
FLGM-02	Okaloosa	Gulf of Mexico	329	M	30.70	30.31	31.04	30.86		30.73
acs-9810	Volusia	Central Florida	327	M	30.44	30.65	30.27	29.64		30.25
acs-9843	Brevard	Central Florida	302	M	30.52	30.03	30.46	31.38		30.60
HUBB-0339	Brevard	Central Florida	323	F	30.53	30.81	28.69	31.18		30.30
hubb-1126	Brevard	Central Florida	271	F	31.42	30.57	31.70			31.23
*hubb-1127	Brevard	Central Florida	138	M					29.94	29.94
swf-8860	Brevard	Central Florida	327	F	30.64		31.03	30.33		30.67
*swf-8861	Brevard	Central Florida	132	M					30.34	30.34
HUBBS-0344	Flagler	Northern Florida	303	M	30.58		31.50	30.58		30.89
S-94-25	Flagler	Northern Florida	272	F	30.02	31.23	30.29	30.56		30.52
S-97-20	St. Johns	Northern Florida	Unk	F	30.30	29.98	30.74	30.62		30.41
S-95-20	St. Johns	Northern Florida	310	M	30.00	30.26	31.10	30.89		30.56
SC0404	Charleston	South Carolina	313	M	30.56	31.05	30.33	30.61		30.64
SC9801	Horry	South Carolina	318	M	30.41	30.55	30.28	30.49		30.43
SC9634	Charleston	South Carolina	312	F				31.09		31.09
SC1119	Charleston	South Carolina	350	M	30.84	30.68	30.81	30.24		30.64
S-95-17	St. Lucie	Southern Florida	320	F	30.71	30.91	31.31	30.87		30.95
EAI-9808	Martin	Southern Florida	323	F	30.16	30.32	30.11	30.54		30.28
FKMMRT	Monroe	Southern Florida	304	M	29.96	30.67	30.44			30.35

Figure 1. Stranded Kogia breviceps

Figure 2. Stranding distribution of *Kogia breviceps* from 1992-2001 showing a higher occurrence of strandings in Charleston, Chatham, and Brevard counties (Berini 2009).

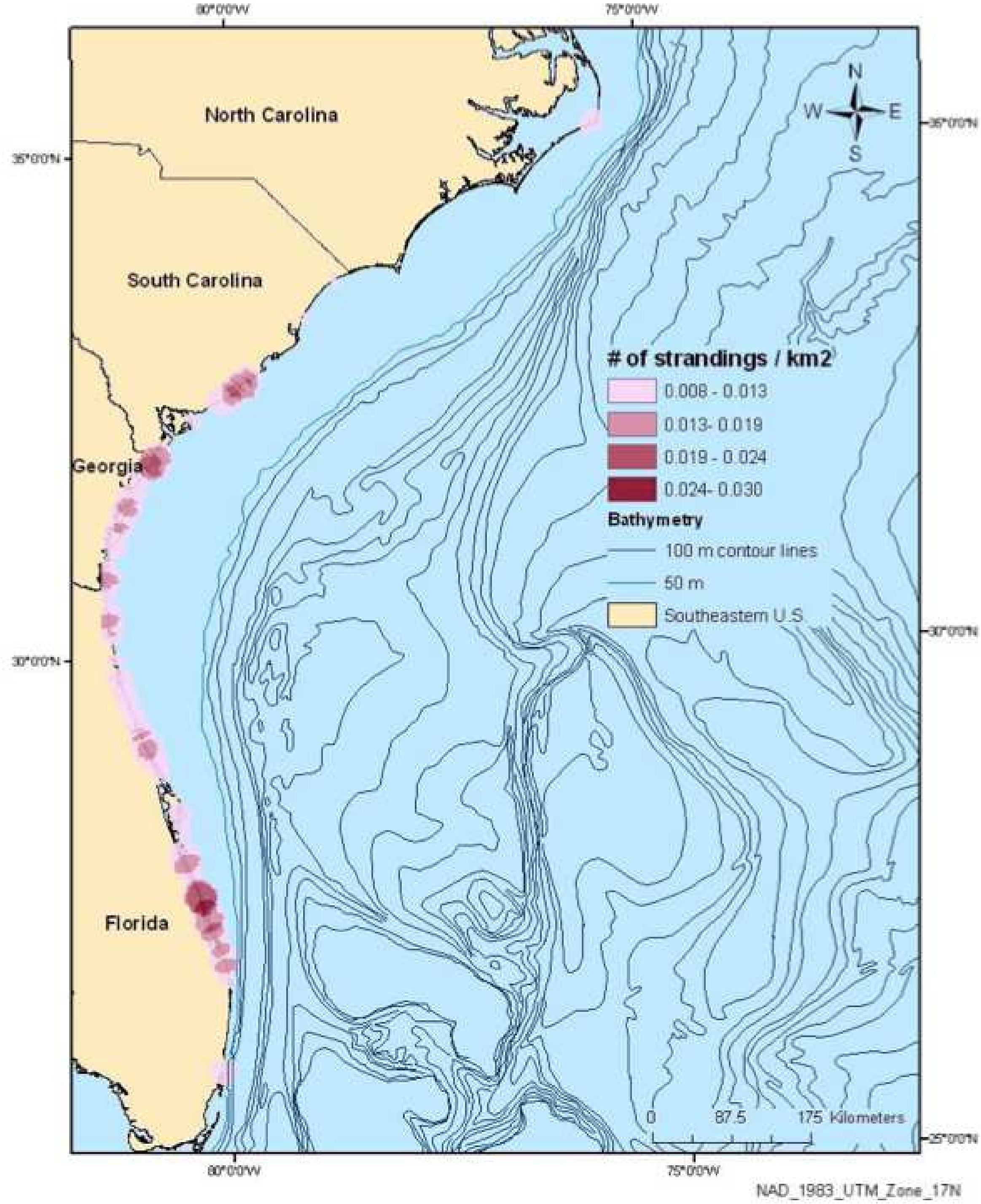

80°0'0"W
75°0'0"W
35°0'0"N
30°0'0"N
25°0'0"N
N
W
E
S
North Carolina
South Carolina
Georgia
Florida
# of strandings / km2
0.008 - 0.013
0.013- 0.019
0.019 - 0.024
0.024- 0.030
Bathymetry
100 m contour lines
50 m
Southeastern U.S
0
87.5
175 Kilometers
NAD_1983_UTM_Zone_17N

Figure 3. Averaged phytoplankton concentrations in the Southeastern United States from 2002-2008 (Stewart 2009). Phytoplankton concentrations are used to differentiate habitats. Along the SEUS, concentrations are similar making it difficult to utilize carbon signatures to differentiate populations of *Kogia breviceps*.

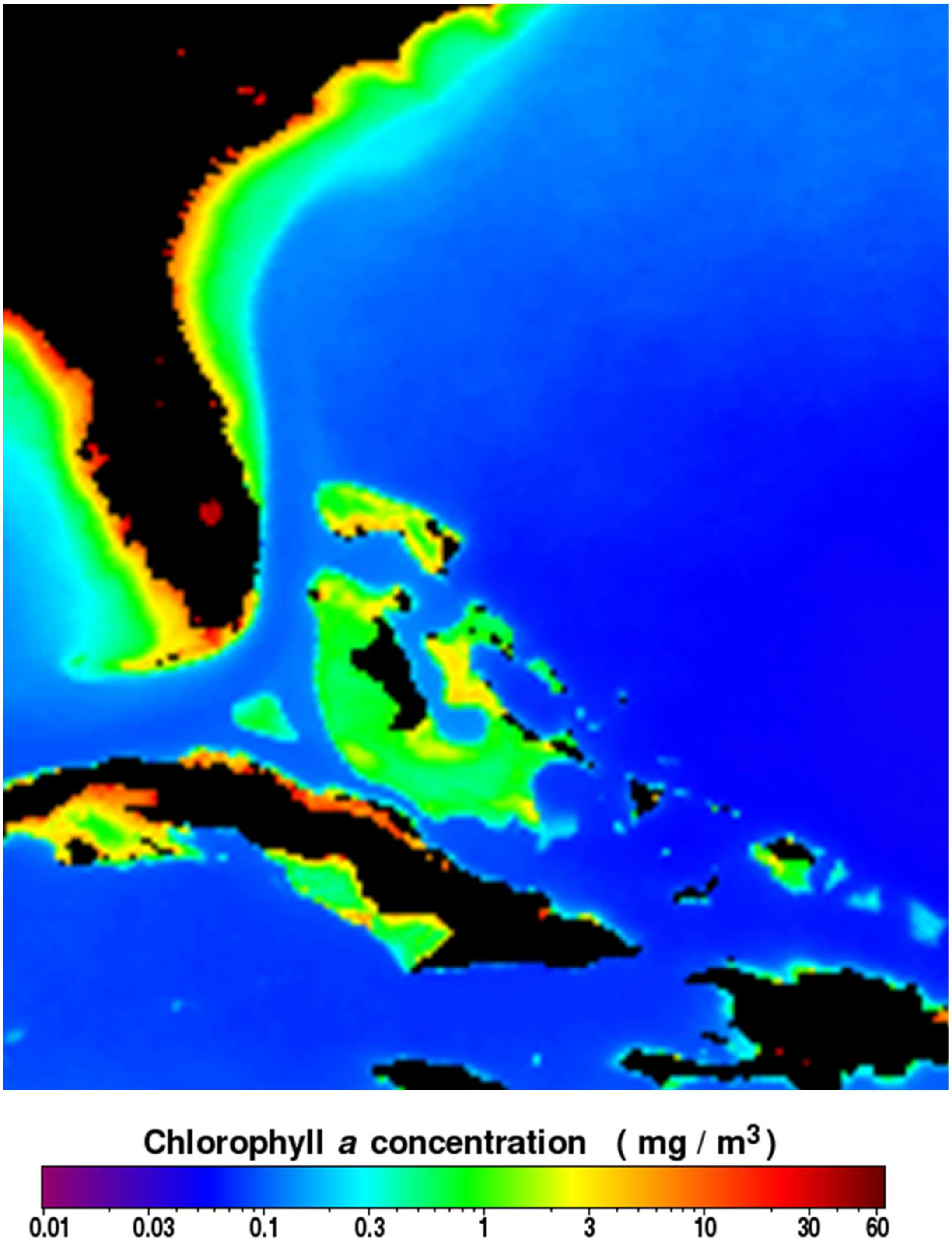

Chlorophyll a concentration (mg / m^3)
0.01
0.03
0.1
0.3
1
3
10
30
60

Figure 4. Remote sensing image displaying sea surface temperatures along Eastern United States. The Southeastern United States exhibits similar temperatures along the coast and into the Gulf of Mexico (Williams 2012).

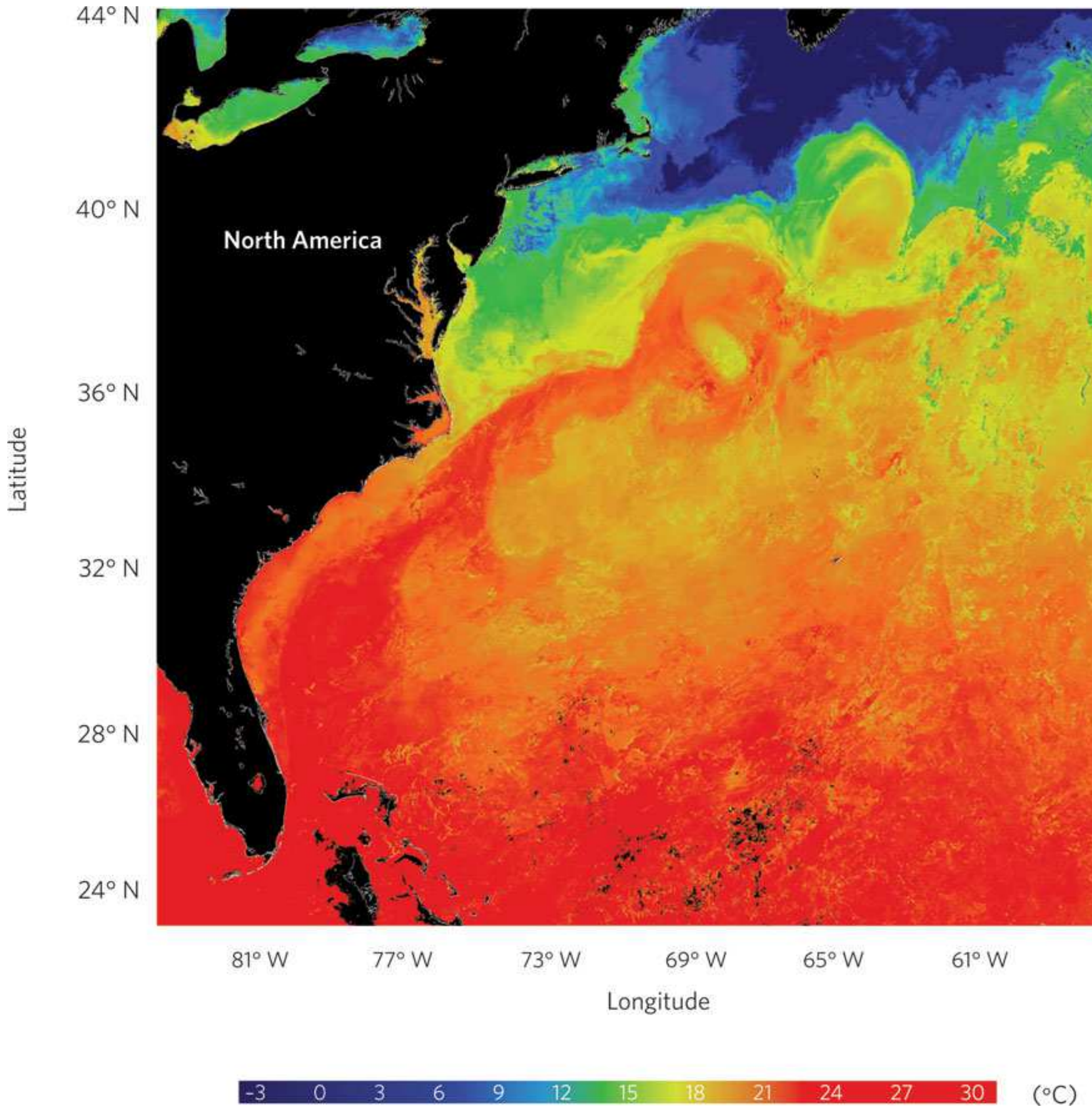

44° N
40° N
36° N
32° N
28° N
24° N
Latitude
North America
81° W
77° W
73° W
69° W
65° W
61° W
57° W
Longitude
-3
0
3
6
9
12
15
18
21
24
27
30
(°C)

Figure 5. Decalcified thin section of a *Kogia breviceps* tooth showing the dentine, cementum, and pulp cavity (Smar 2006). *K. breviceps* teeth do not possess enamel.

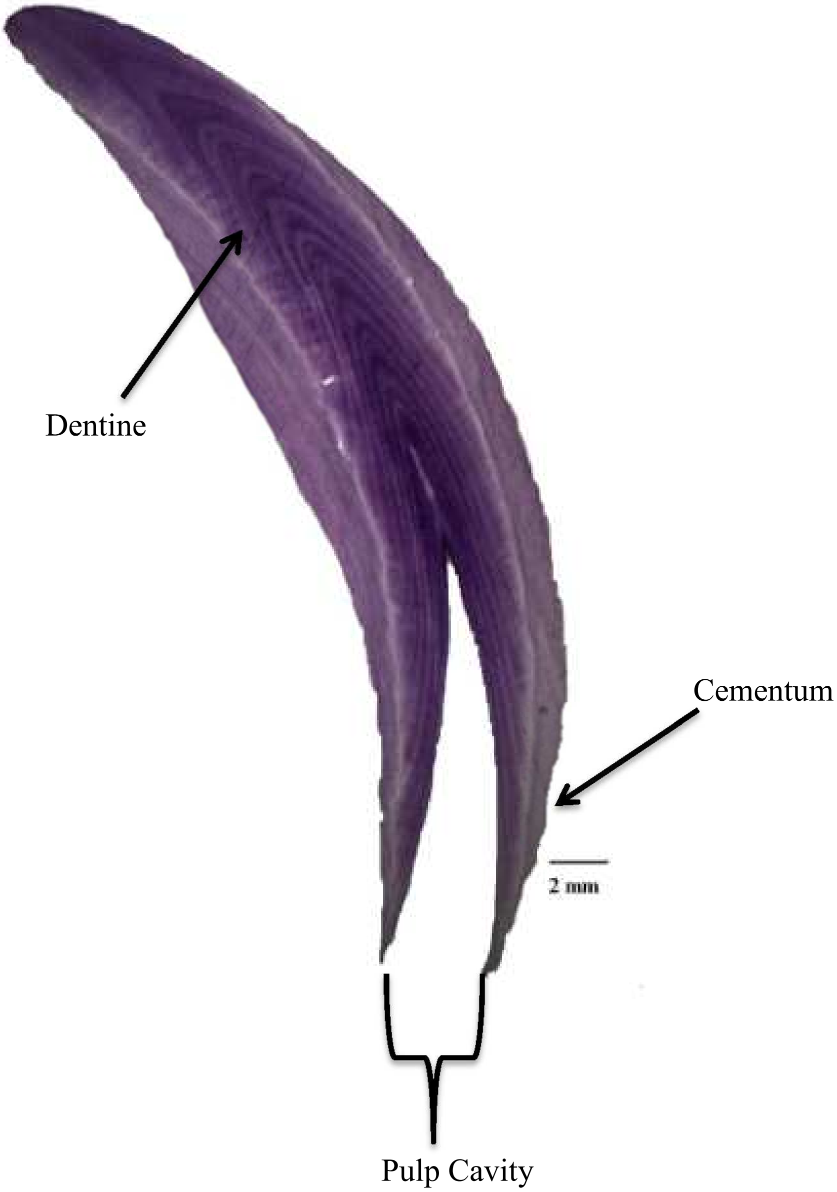

Dentine
Cementum
2 mm
Pulp Cavity

Figure 6. Locations of stranded *Kogia breviceps* specimens from South Carolina and Georgia used in this study.

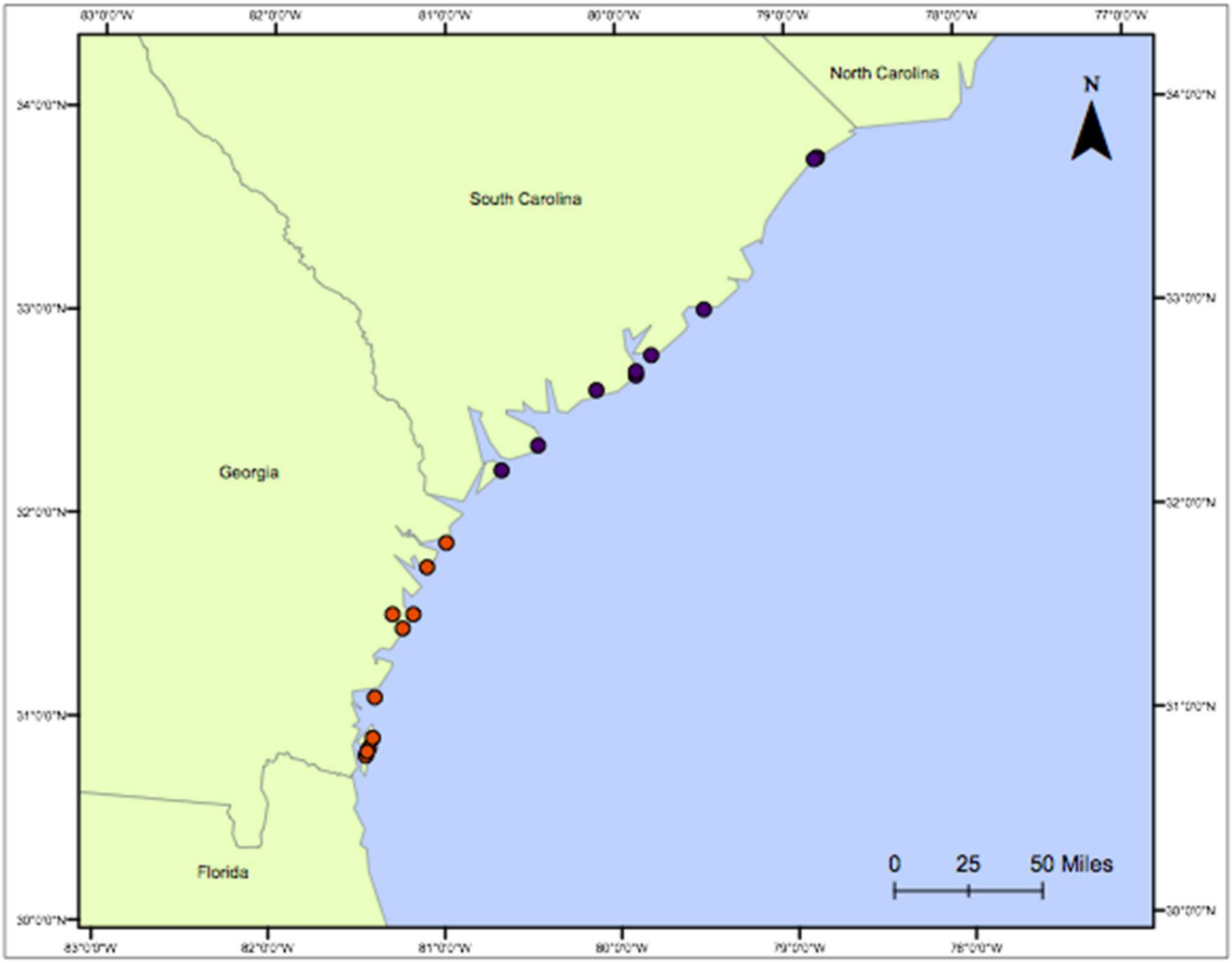

83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
79°0'0"W
78°0'0"W
77°0'0"W
34°0'0"N
33°0'0"N
32°0'0"N
31°0'0"N
30°0'0"N
North Carolina
N
South Carolina
Georgia
Florida
0
25
50 Miles

Figure 7. Locations of stranded *Kogia breviceps* specimens located in the 4 different Florida regions. Red symbols are animals from the Gulf of Mexico, dark blue are Southern Florida, yellow are Central Florida, and green are Northern Florida. The mother calf pairs in Central Florida are represented as a yellow circle with a black dot.

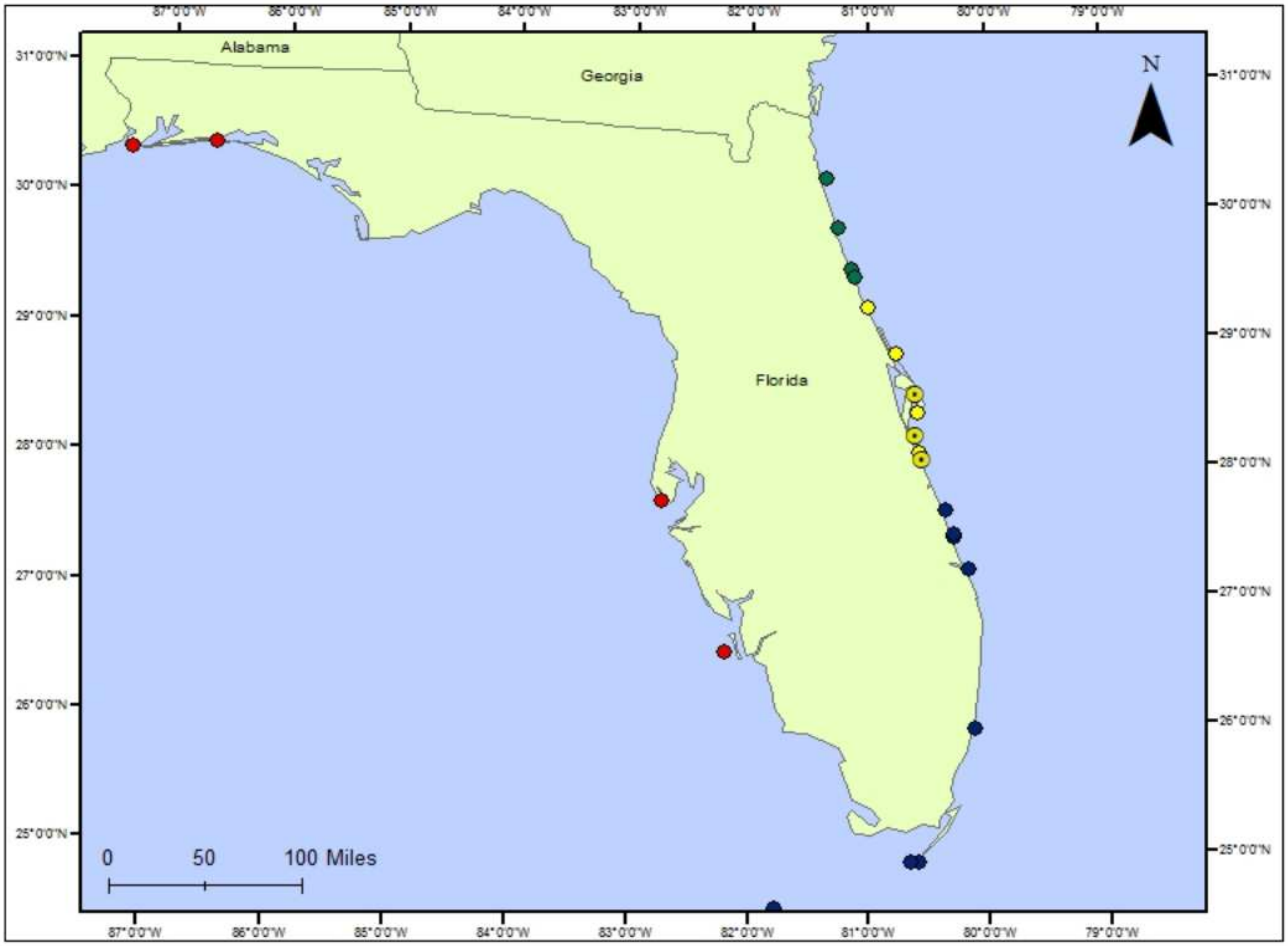

Alabama
Georgia
Florida
N
0
50
100 Miles
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
79°0'0"W
31°0'0"N
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
25°0'0"N

Figure 8. Locations of the 4 separate drill sites. Each site is a combination of growth layers as the teeth are too small to drill into individual growth layers.

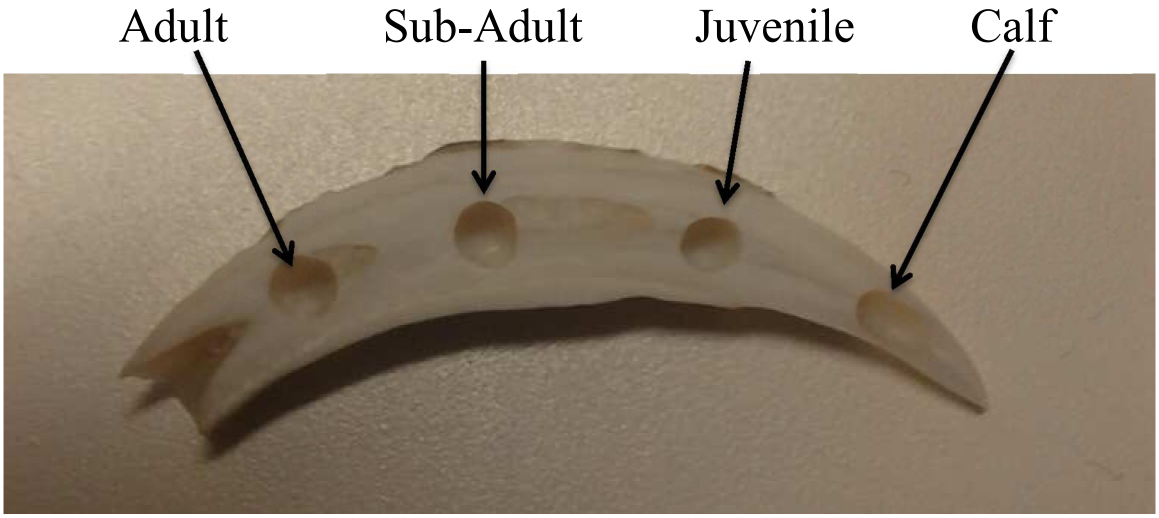

Adult
Sub-Adult
Juvenile
Calf

Figure 9. Nitrogen and carbon isotope ratios (mean‰ ± standard error) in dentin of pygmy sperm whale teeth. Colors: pink= yearlings, orange= Georgia, red= Gulf of Mexico, yellow= Central Florida, green= Northern Florida, purple= South Carolina, and blue= Southern Florida.

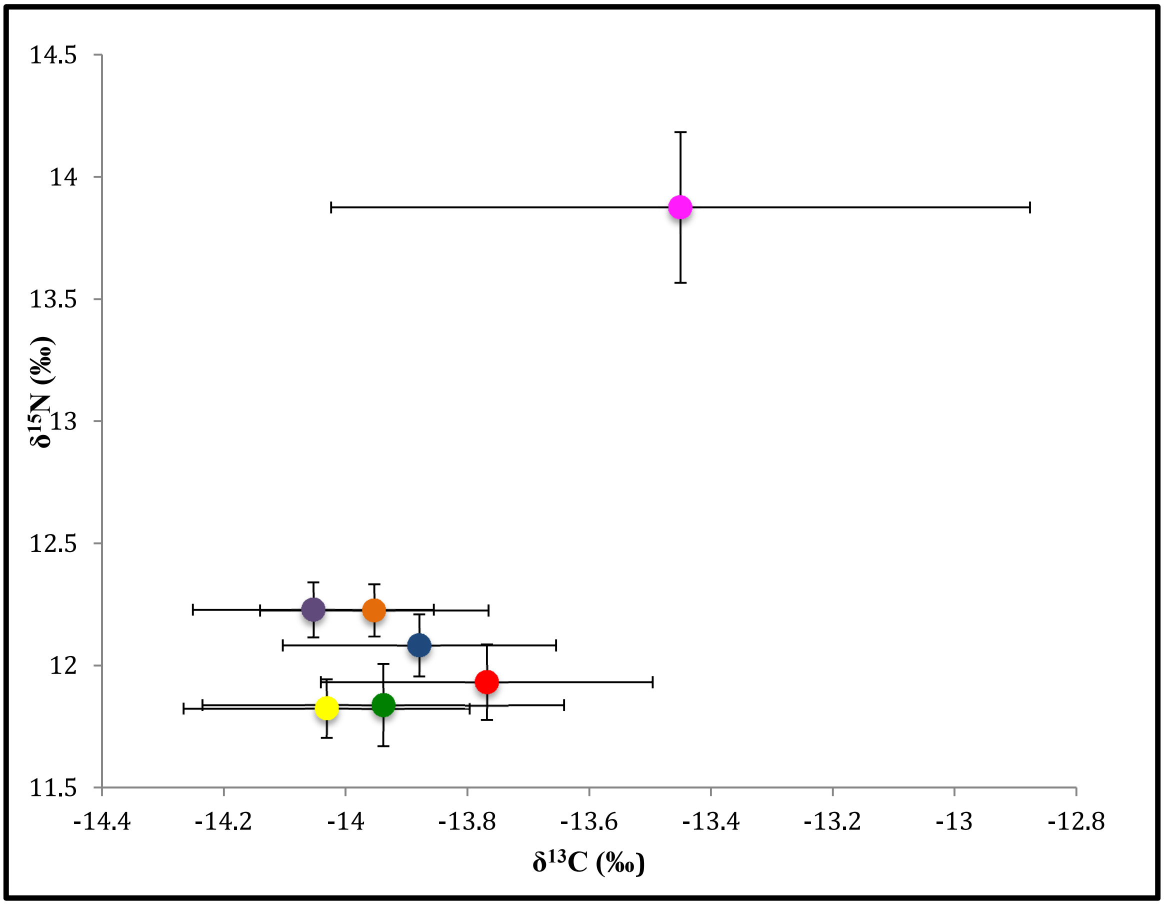

14.5
14
13.5
13
12.5
12
11.5
δ15N (‰)
-14.4
-14.2
-14
-13.8
-13.6
-13.4
-13.2
-13
-12.8
δ13C (‰)

Figure 10. Carbon ($\delta^{13}C$) isotope values (mean‰ ± standard error) for pygmy sperm whales in six regions in the Southeastern United States. A Tukey test indicated that there were no differences among the regions.

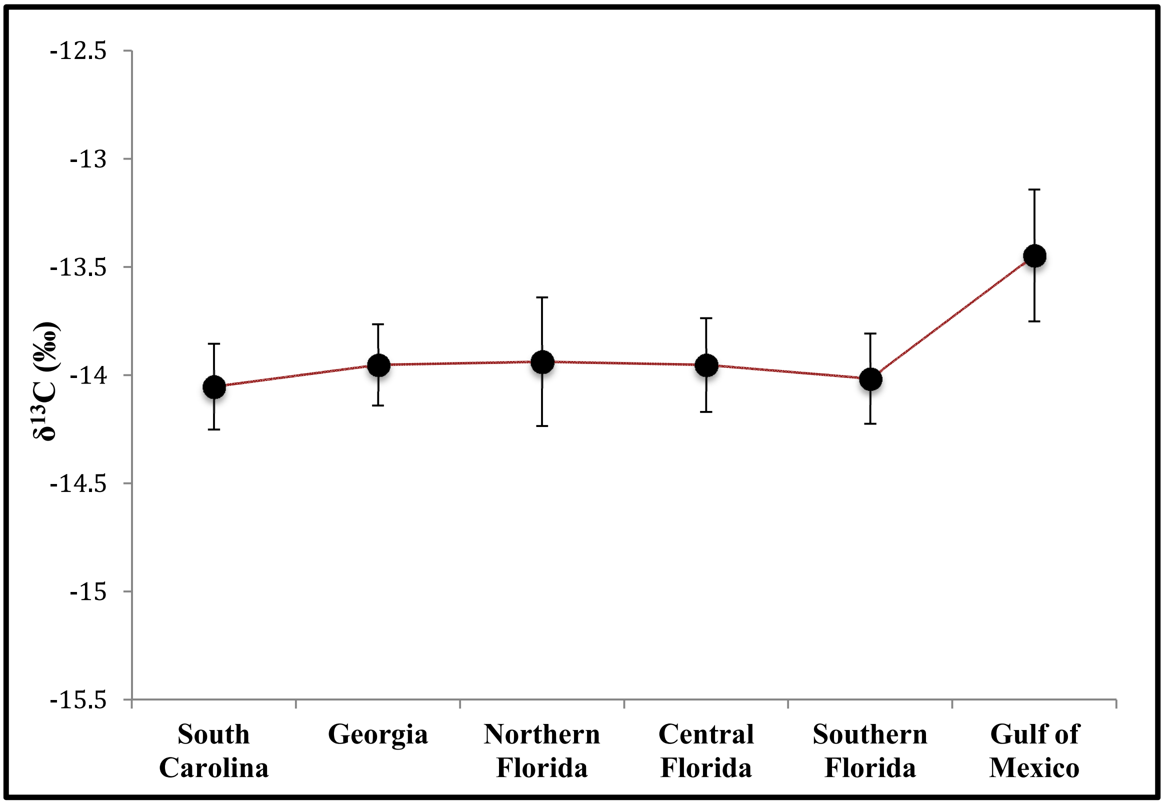

-12.5
-13
-13.5
-14
-14.5
-15
-15.5
δ13C (‰)
South Carolina
Georgia
Northern Florida
Central Florida
Southern Florida
Gulf of Mexico

Figure 11. Carbon ($\delta^{13}C$) isotope values (mean‰ ± standard error) for pygmy sperm whales for all age classes. Different letters indicate differences based on Tukey test. Sub adults (A) and adults (B) were significantly different, as they do not share the same letter.

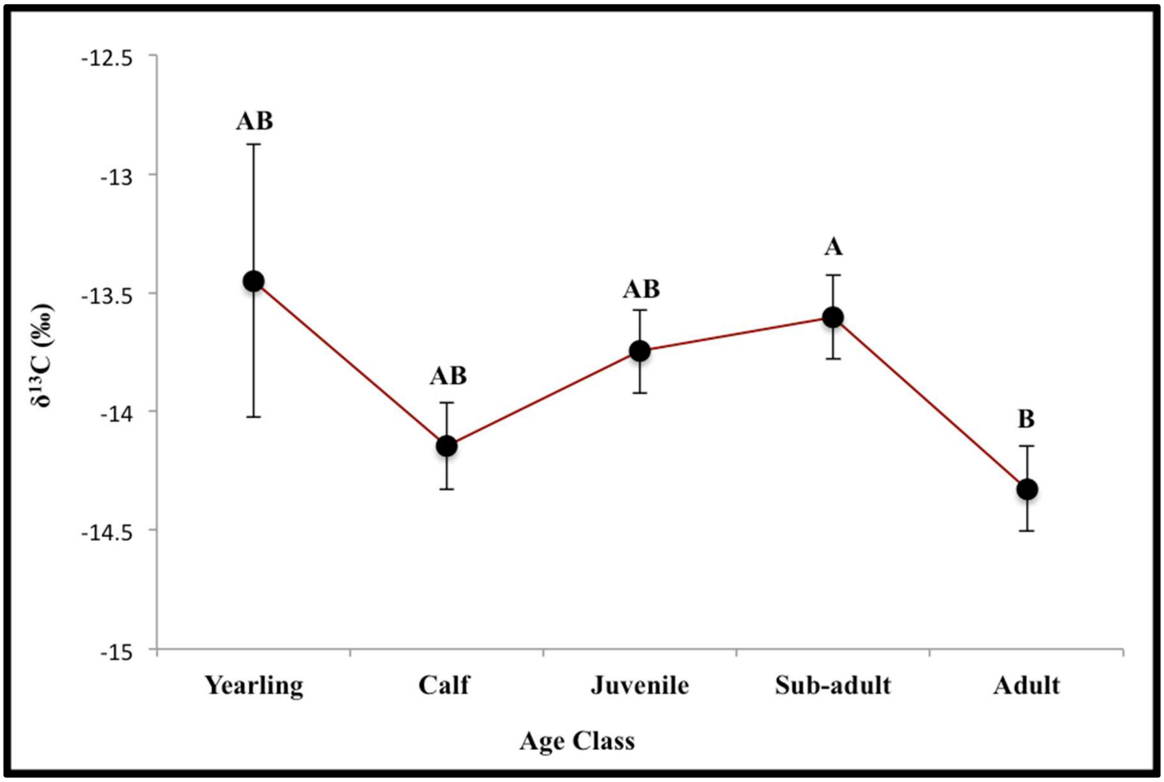

-12.5
-13
-13.5
-14
-14.5
-15
δ13C (‰)
AB
AB
AB
A
B
Yearling
Calf
Juvenile
Sub-adult
Adult
Age Class

Figure 12. Carbon (mean‰ ± standard error) differences between males and females through age classes. Tukey test results state that yearling male and females are not significantly different. Yearling males are significantly different than the other age classes for both sexes. However female yearlings are not significantly different than other age classes for both sexes.

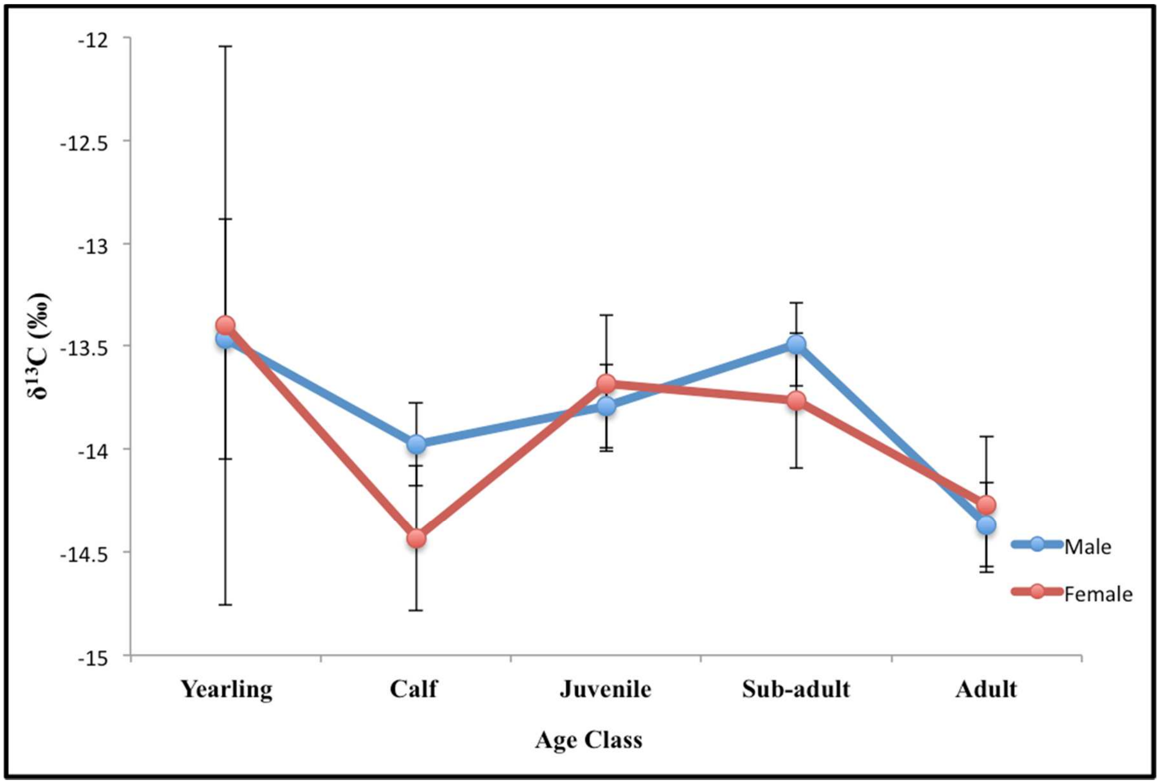
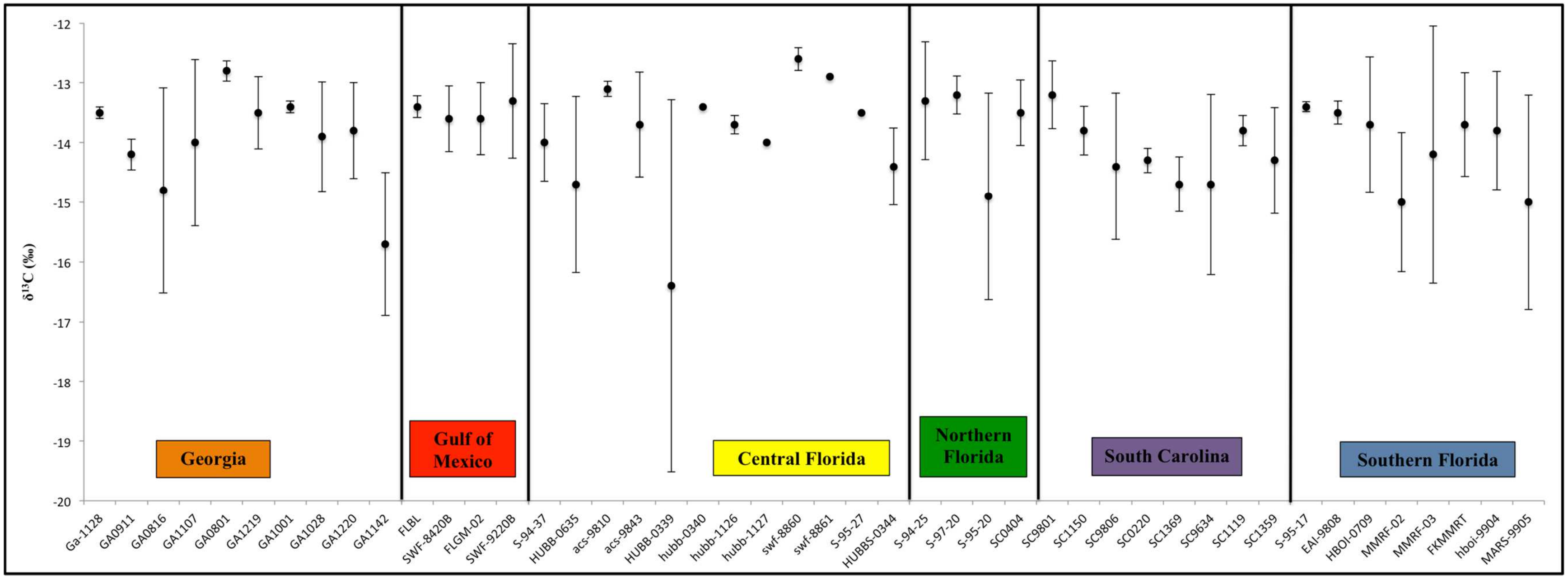

-12
-12.5
-13
-13.5
-14
-14.5
-15
δ13C (‰)
Yearling
Calf
Juvenile
Sub-adult
Adult
Age Class
Male
Female

Figure 13. Individual carbon values (mean‰ ± standard deviation) for all 46 individuals tested, divided by region.



$\delta^{13}C$ (‰)
-12
-13
-14
-15
-16
-17
-18
-19
-20
Georgia
Gulf of Mexico
Central Florida
Northern Florida
South Carolina
Southern Florida
Ga-1128
GA0911
GA0816
GA1107
GA0801
GA1219
GA1001
GA1028
GA1220
GA1142
FLBL
SWF-8420B
FLGM-02
SWF-9220B
S-94-37
HUBB-0635
acs-9810
acs-9843
HUBB-0339
hubb-0340
hubb-1126
hubb-1127
swf-8860
swf-8861
S-95-27
HUBBS-0344
S-94-25
S-97-20
S-95-20
SC0404
SC9801
SC1150
SC9806
SC0220
SC1369
SC9634
SC1119
SC1359
S-95-17
EAI-9808
HBOI-0709
MMRF-02
MMRF-03
FKMMRT
hboi-9904
MARS-9905

Figure 14. Nitrogen ($\delta^{15}N$) isotope values (mean‰ ± standard error) for pygmy sperm whales in six regions in the Southeastern United States. There were no significant differences between the regions as implied by a Tukey test.

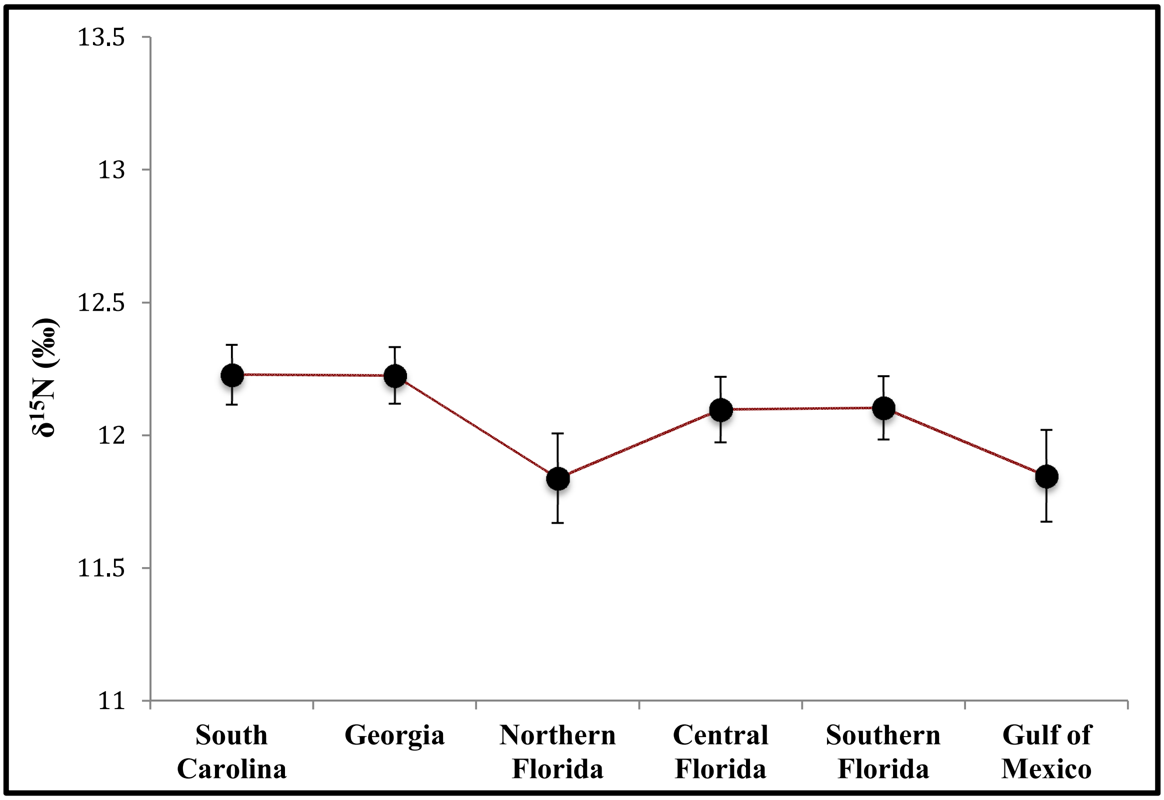

13.5
13
12.5
12
11.5
11
$\delta^{15}N$ (‰)
South Carolina
Georgia
Northern Florida
Central Florida
Southern Florida
Gulf of Mexico

Figure 15. Nitrogen ($\delta^{15}N$) isotope values (mean‰ ± standard error) for pygmy sperm whales for all age classes. Different letters indicate differences based on Tukey test. Yearlings (A) were significantly different than other age classes. Juveniles (C) were significantly different from adults (B).

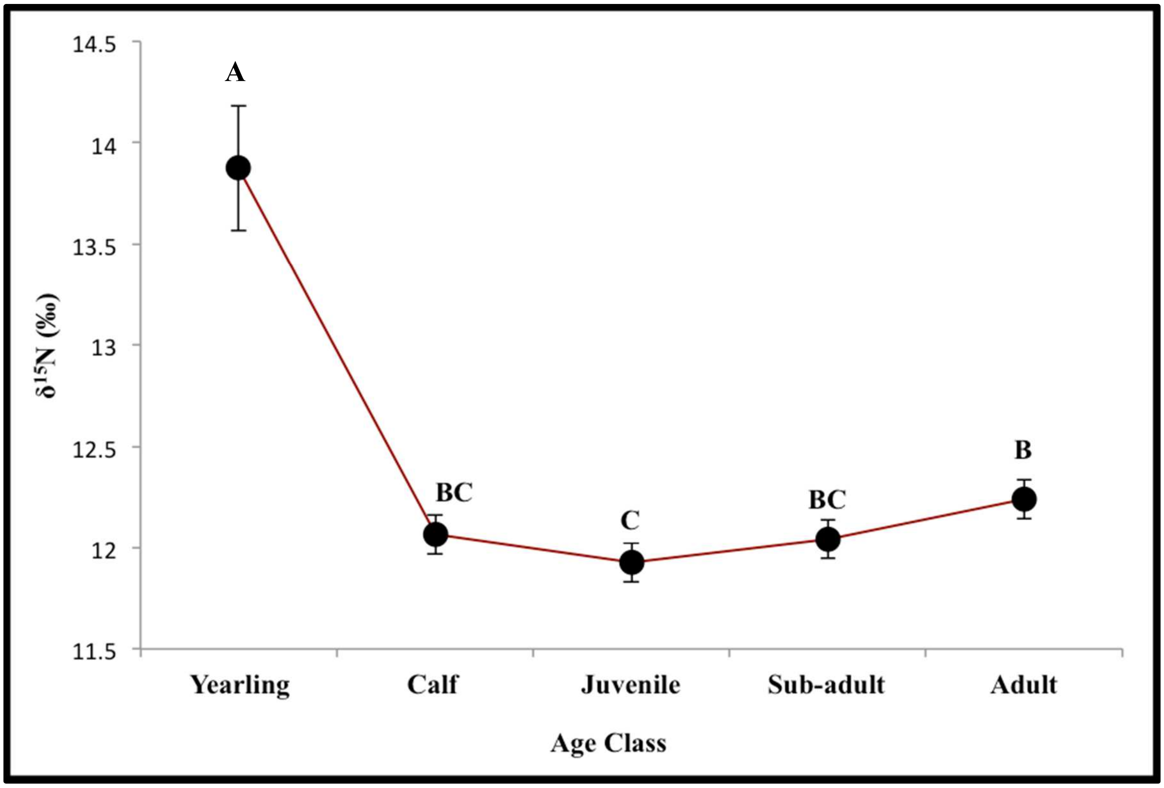

14.5
14
13.5
13
12.5
12
11.5
$\delta^{15}N$ (‰)
A
BC
C
BC
B
Yearling
Calf
Juvenile
Sub-adult
Adult
Age Class

Figure 16. Nitrogen (mean‰ ± standard error) differences between males and females through age classes. There were no differences between the sexes at any age class based on a Tukey test.

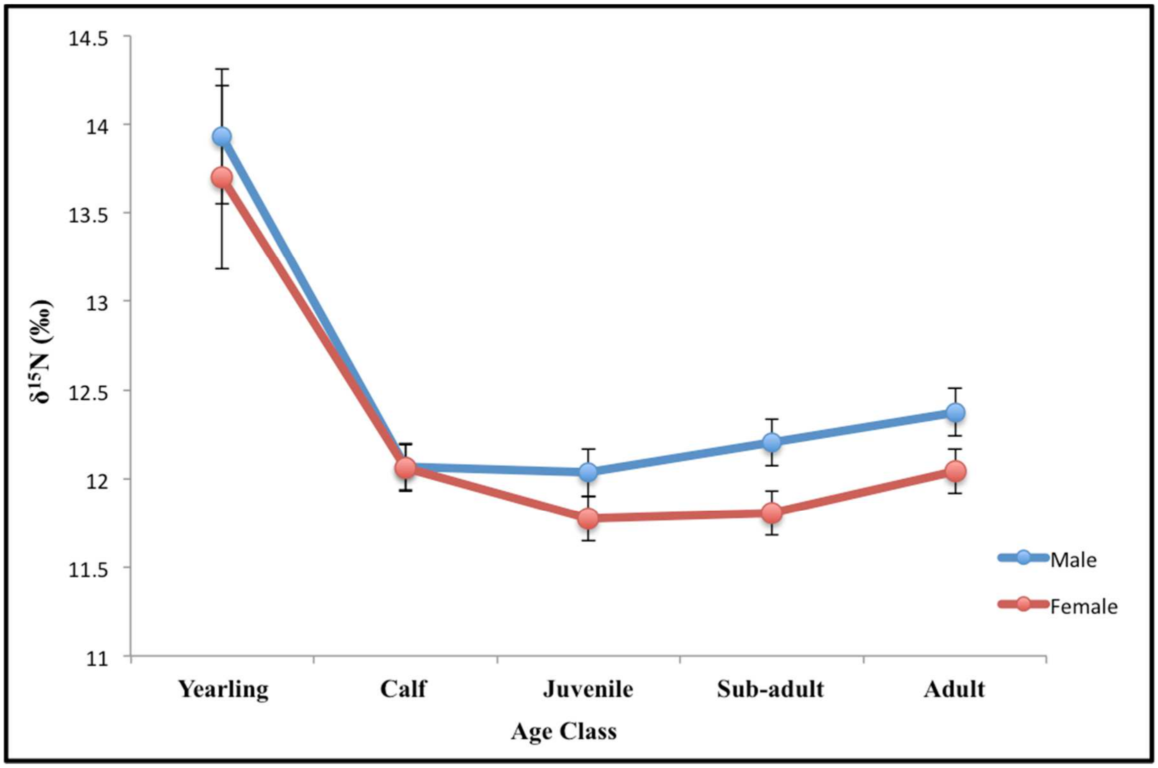

14.5
14
13.5
13
12.5
12
11.5
11
$\delta^{15}N$ (‰)
Yearling
Calf
Juvenile
Sub-adult
Adult
Age Class
Male
Female

Figure 17. Individual nitrogen values (mean‰ ± standard deviation) for all 46 individuals tested, divided by region. Box in the Central Florida region are the four yearlings. Each yearling was only one sample and there is no variability between different samples.

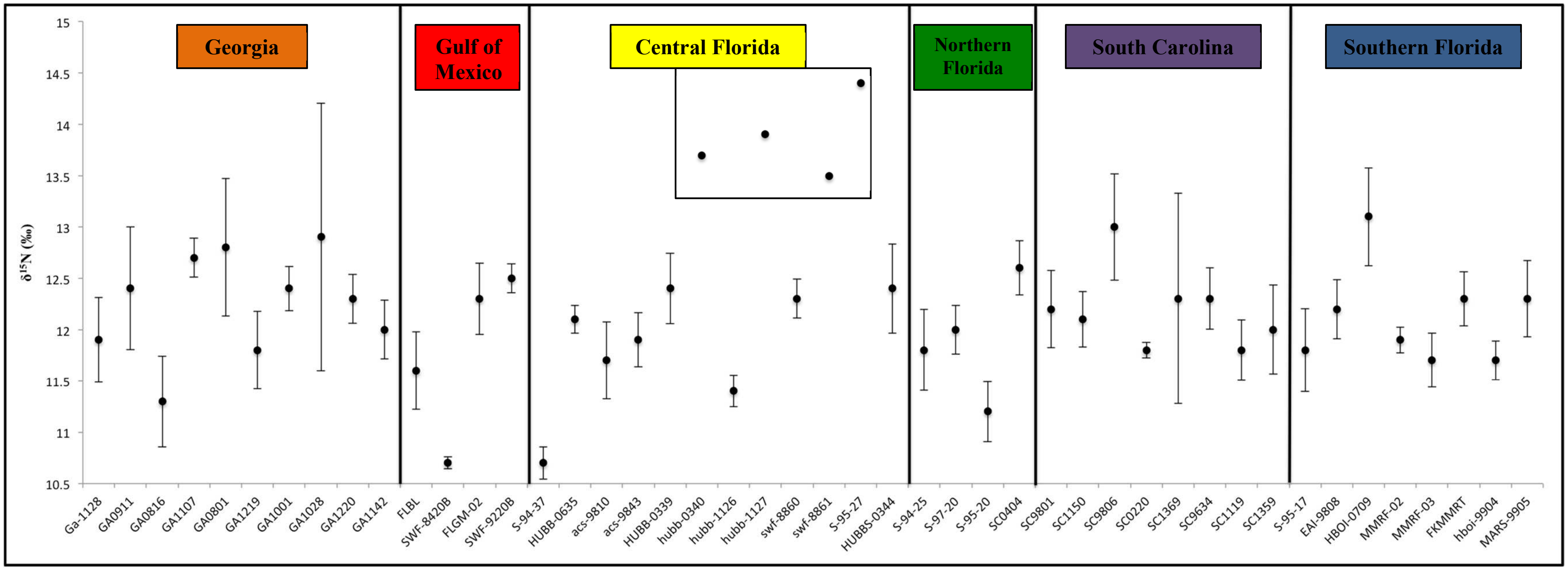
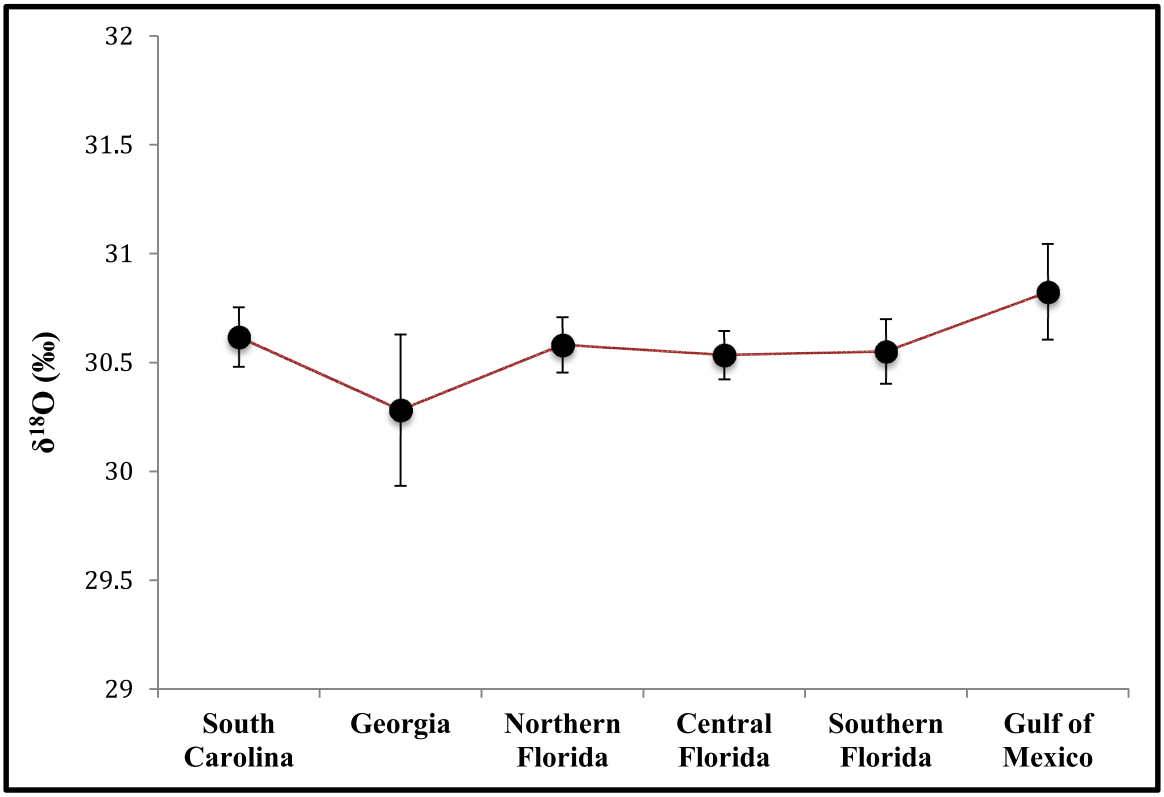
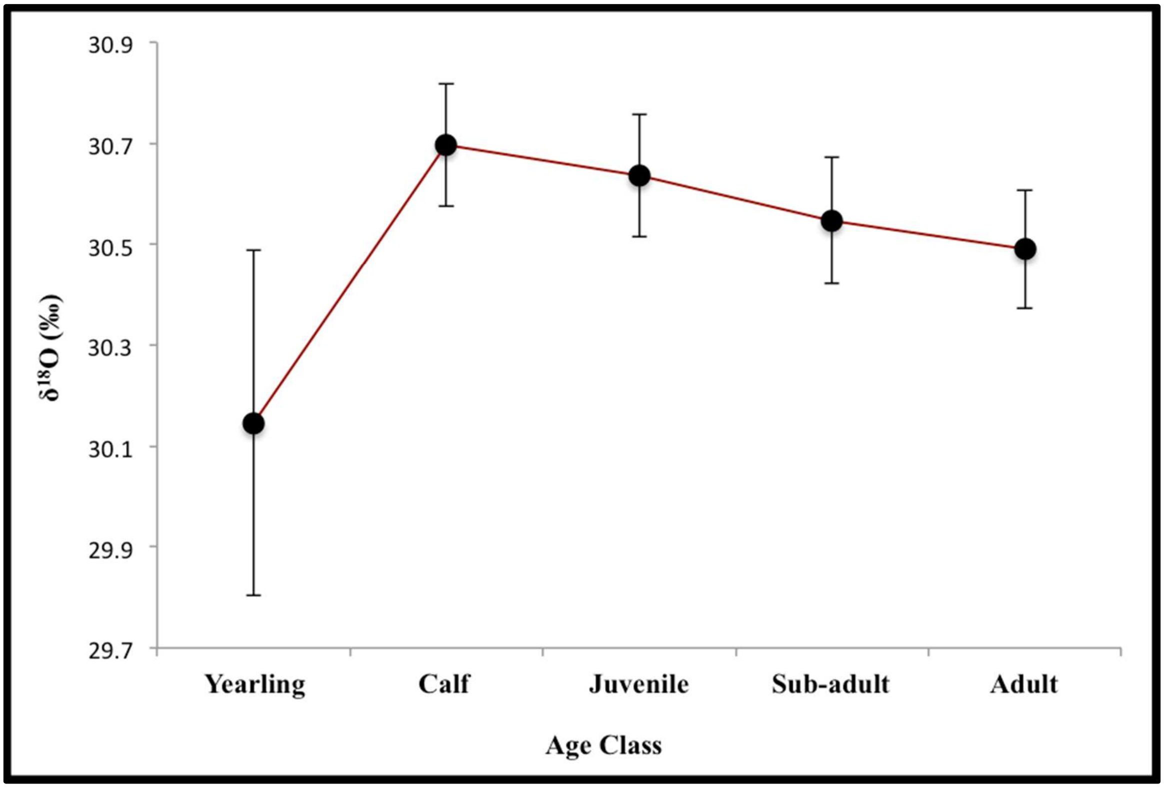

δ15N (‰)
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
Georgia
Gulf of Mexico
Central Florida
Northern Florida
South Carolina
Southern Florida
Ga-1128
GA0911
GA0816
GA1107
GA0801
GA1219
GA1001
GA1028
GA1220
GA1142
FLBL
SWF-8420B
FLGM-02
SWF-9220B
S-94-37
HUBB-0635
acs-9810
acs-9843
HUBB-0339
hubb-0340
hubb-1126
hubb-1127
swf-8860
swf-8861
S-95-27
HUBBS-0344
S-94-25
S-97-20
S-95-20
SC0404
SC9801
SC1150
SC9806
SC0220
SC1369
SC9634
SC1119
SC1359
S-95-17
EAI-9808
HBOI-0709
MMRF-02
MMRF-03
FKMMRT
hboi-9904
MARS-9905

Figure 18. Oxygen ($\delta^{18}O$) isotope values (mean‰ ± standard error) for pygmy sperm whales in six regions in the Southeastern United States. A Tukey test indicated that there were no differences between the regions.



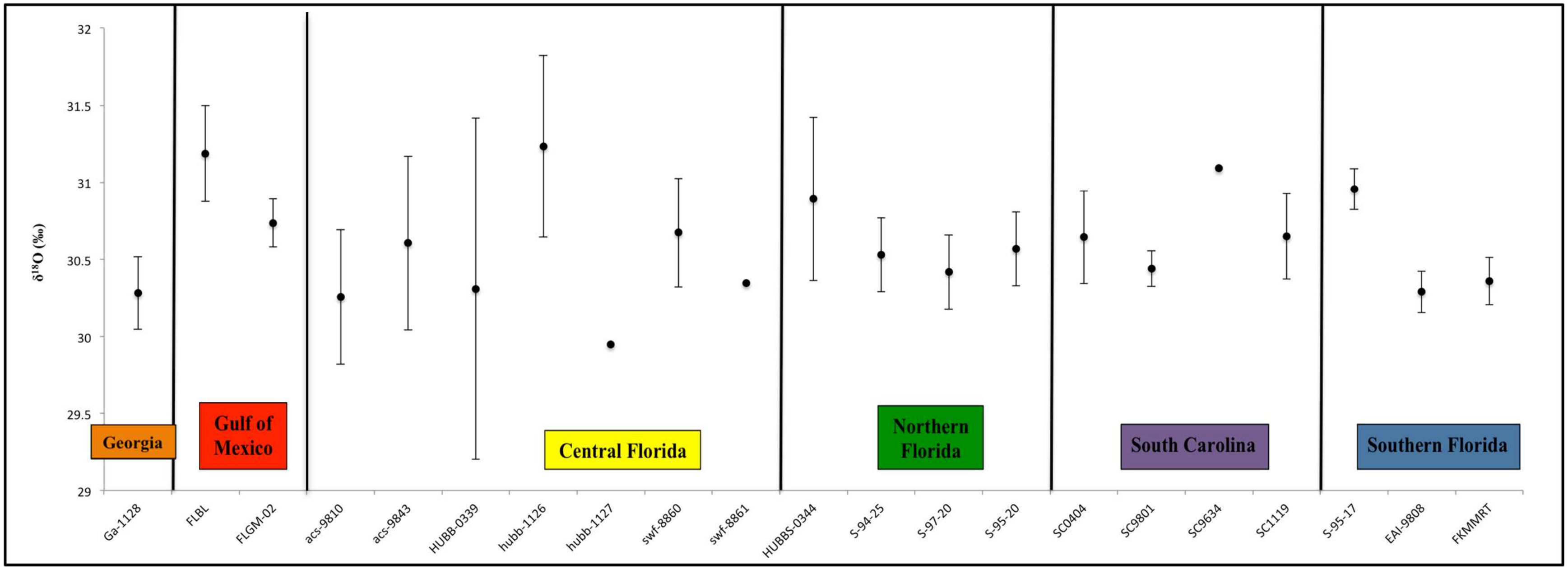
32
31.5
31
30.5
30
29.5
29
δ18O (‰)
South Carolina
Georgia
Northern Florida
Central Florida
Southern Florida
Gulf of Mexico

Figure 19. Oxygen ($\delta^{18}O$) isotope values (mean‰ ± standard error) for pygmy sperm whales for all age classes. There were no differences between the age classes based on a Tukey test.



30.9
30.7
30.5
30.3
30.1
29.9
29.7
δ18O (‰)
Yearling
Calf
Juvenile
Sub-adult
Adult
Age Class

Figure 20. Individual oxygen values (mean‰ ± standard deviation) for 21 individuals, divided by region.


δ18O (‰)
32
31.5
31
30.5
30
29.5
29
Georgia
Gulf of Mexico
Central Florida
Northern Florida
South Carolina
Southern Florida
Ga-1128
FLBL
FLGM-02
acs-9810
acs-9843
HUBB-0339
hubb-1126
hubb-1127
swf-8860
swf-8861
HUBBS-0344
S-94-25
S-97-20
S-95-20
SC0404
SC9801
SC9634
SC1119
S-95-17
EAI-9808
FKMMRT