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Connectivity of Reef Fishes Between Mangroves and Coral Reefs in Broward County, Florida

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NOVA SOUTHEASTERN UNIVERSITY
HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

CONNECTIVTY OF REEF FISHES BETWEEN MANGROVES AND CORAL REEFS IN BROWARD COUNTY, FLORIDA

By

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Abstract

Many marine fishes use the mangrove ecosystem for foraging, protection, spawning, and as a nursery habitat. To develop a better understanding of energy flow between the coastal mangrove and coral reef ecosystems, the ontogentic migration and trophic connectivity of reef fishes were examined through the use of carbon (C), nitrogen (N), and oxygen (O) stable isotope ratios. Juvenile and adult gray snapper *Lutjanus griseus,* lane snapper *L. synagris*, bluestriped grunt *Haemulon sciurus,* French grunt *H. flavolineatum*, sailor's choice *H. parra*, yellowfin mojarra *Gerres cinereus*, and great barracuda *Sphyraena barracuda* were collected from both mangrove and coral reef sites located near Port Everglades, Broward County, Florida. All species were analyzed for δ^{13}C and δ^{15}N of muscle tissues and δ ^{18}O and δ ^{13}C of otoliths to evaluate ontogenetic migrations, foraging, and occupation within both the mangrove and reef sites. The δ^{13}C and δ^{15}N in muscle tissue were more depleted in juvenile fish from the mangroves than their adult forms caught on the adjacent reef. The δ^{18}O and δ^{13}C otolith data were significantly different between species, age class, and habitat, with lower δ^{18}O values for juvenile fish caught in the mangroves. A general trend of increasing δ^{13}C in otoliths corresponded to increasing total length, also suggesting juvenile movements from mangrove to nearshore reefs with age. Overall, the findings of this study further confirm that several commercially and recreationally important reef-associated fishes utilize mangrove ecosystems during juvenile life stages.

Keywords: stable isotopes; otoliths; mangroves; reef fishes

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Introduction

Many ecological and recreationally important species of tropical fishes are thought to use the mangrove ecosystem for foraging, protection, and as a nursery habitat before an ontogenetic shift to nearshore coral reefs. The community structure of Broward County reefs is highly variable according to location and physical factors. Development has considerably modified Port Everglades, a commercial port located just south of Fort Lauderdale, affecting the amount and quality of the available adjacent mangrove habitat. Due to human activity, both mangroves and coral reefs are now under threat. Identifying these essential habitats and preserving the linkages between them is crucial to foster ecosystem health and sustainable fisheries on coral reefs (Kathiresan and Bingham 2001, Serafy et al. 2003, McMahon 2011).

Mangrove forests dominate the low-energy intertidal zones of river deltas, lagoons, estuaries, and coastal systems in the tropics, subtropics, and along some temperate coasts. This ecosystem captures and cycles various organic materials, chemical elements, and important nutrients. Along with acting as a physical trap and providing attachment surfaces for various marine organisms, mangroves also provide protected nursery areas for reef-associated fishes. Therefore, the current rate of mangrove deforestation will likely have severe consequences for ecosystem function, fish productivity, and the resilience of coral reefs (Mumby et al. 2004, Blaber 2007).

Managers approach fishery management from either a single species approach or an ecological perspective, depending on such factors as agency mandate and governing statute (Link 2002). Fisheries managers, conservationists, and the general public all widely hold views that mangroves are important for the maintenance of fish populations

(Mumby et al. 2004, McMahon, 2011). Ecosystem-based fishery management is a more holistic approach to resource allocation and management, where fishery managers take into consideration the interactions among multiple components of an ecosystem to achieve sustainability. An ecosystem management approach requires the integration of information from a wide range of disciplines, levels of ecological organization, and temporal and spatial scales (Botsford et al. 1997). Ecosystem-based management takes all major ecosystem components and services into account in managing fisheries.

Many studies have emphasized the importance of coral reef conservation for management of reef fishes (e.g., Bryant et al. 1998, Claudet et al. 2006, Almany et al. 2009, Carter et al. 2015). However, a need exists to demonstrate the importance of habitats essential for early life-history stages of reef fishes, such as mangroves. Deciphering the relationships between mangrove and reef habitats for reef-associated fishes is now more important than ever for the sustainability of fisheries and for managing the exploitation and conservation of mangrove forests.

Mangrove Communities

Mangroves are a diverse group of tropical, hydrophytic trees and shrubs that grow at the interface between land and sea where conditions are usually harsh and restrictive. Mangrove plants have a number of specialized adaptations to allow them to cope with tidal inundation of roots by salty waters, such as pneumatophores to allow oxygen exchange in anaerobic sediments, above ground roots to grow with shallow root systems, and foliage salt-excretion to remove excess salt (Duke et al. 1998, Kathiresan and Bingham 2001). These plants, and their associated microbes, fungi, plants, and animals, establish a mangrove forest community or "mangal;" the mangal and its associated abiotic factors create the mangrove ecosystem (Odum 1982, Kathiresan and Bingham 2001).

Mangroves are distributed circumtropically along coastlines between 25° north and 25° south latitude, occurring in 112 known countries and territories (Kathiresan and Bingham 2001). More than 80 species of mangroves form forests worldwide and the present worldwide area of mangroves is estimated to be less than 150,000 km^2, which represents 40% of original mangrove coverage worldwide (Blaber 2007). Only three species of mangrove are found along western North Atlantic Ocean coastlines: red mangrove *Rhizophora mangle,* black mangrove *Avicennia germinans*, and white mangrove *Languncularia racemosa.* The buttonwood *Conocarpus erectus* is often considered a fourth species, but it is not a true mangrove. However, it is considered an associated species due to its common presence in the coastal habitat where mangroves are found (Odum and Heald 1972, Odum 1982, Thayer et al. 1987, Carter et al. 2015). Mangrove forests are one of the world's most threatened tropical ecosystems, with deforestation occurring due to aquaculture, timber, and industrial developments (Valiela 2001, Blaber 2007, Carter et al 2015).

Mangrove Community Benefits

A mangrove ecosystem provides numerous benefits to the coastline, including sediment stabilization, runoff filtration, and protection of the coast from storm-induced erosion; research has shown mangrove ecosystems are more effective in these functions than man-made concrete barriers (Odum 1982, Pearce 2001). Although mangroves themselves are susceptible to hurricane damage, they provide considerable protection to areas on their landward side by trapping, holding, and stabilizing intertidal sediments (Thayer et al. 1987, Carter et al. 2015).

Mangrove leaves are a primary source of plant detritus in subtropical-tropical ecosystems. Carbon derived from mangrove detritus supports mangal communities along both coasts of Florida. Many consumers depend primarily on mangrove-derived detrital carbon from dead vegetation, as an energy source (Zieman et al. 1984). Dissolved organic matter (DOM), results from detritus material remaining in the mangal where it decomposes. Litterfall is usually heavier during the summer months when thinning of the canopy reduces transpiration. The efflux of detritus and nutrients enrich primary production in neighboring ecosystems and, therefore, enhance adult fish biomass (Laegdsgaard and Johnson 2001).

Nursery Habitat

Along with enriching primary production, mangrove ecosystems also provide a nursery habitat for fishes and invertebrates. A nursery habitat can be broadly defined as a habitat for a particular species that contributes a greater than average number of individuals to the adult population than production from other habitats in which juveniles occur (Beck et al. 2001, Sheridan and Hays 2003, Nagelkerken and van der Velde 2004). Many commercially and recreationally important species of marine fishes and invertebrates use the mangrove ecosystem for foraging, protection, spawning, and as a nursery habitat (Nagelkerken et al. 2000, Kathiresan and Bingham 2001).

Shallow, coastal areas containing mangroves and seagrass beds are considered important nurseries for juvenile fishes (Roberson and Blaber 1992, Dorenbosch et al. 2003). Some coastal, pelagic fish larvae, such as great barracuda, settle into shallow coastal habitats where they grow from juveniles to subadults or adults (Blaber 2000). Red mangroves, which dominate the outer perimeter of protected shorelines and islands, have a well-developed prop root system that is flooded semi-diurnally by tides and can serve as habitat for fishes (Odum 1982, Thayer et al. 1987). The submerged prop roots of red mangroves provide conditions that are favorable for growth and survival of young reef fishes. Reduced visibility in the turbid mangrove waters may reduce predation by large fishes; and structural complexity of the mangroves provides excellent shelter and production for the juvenile fishes (Odum and Heald 1972, Parrish 1989, Shulman and Ogden 1987, Nagelkerken et al. 2000, Kathiresan and Bingham 2001, Mumby et al. 2004). Mumby et al. (2004) demonstrated that mangroves were an important intermediate nursery habitat for reef fishes and strongly influenced the fish community structure on neighboring coral reefs by showing that the biomass of four commercially important species more than doubled when the adult habitat was connected to mangroves.

Broward County Coral Reefs

Both natural and artificial coral reefs and their associated sea life are important natural resources for the recreational fishing and diving industries in Broward County. Community structure on the reefs of Broward County is highly variable according to location and physical factors (Moyer et al. 2003). To create a functional ecosystem, a balance must exist between the abundance of corals, sponges, and fishes, which are all dependent upon the structure of the reef, the water quality, and the abiotic conditions around the reefs (Broward County Board of County Commissioners 2010).

Natural Coral Reefs

The coastal region of southeast Florida is highly developed, containing one-third of Florida’s population, while many southeast Florida reefs are located just 1.5 km from the urbanized shoreline (Collier et al. 2008). In Broward County, three reefs run nearly parallel to the shoreline at various depths. These reef tracts are found at depths ranging from 3 to 30 meters and are locally referred to as inshore, middle, and offshore reefs (Ferro et al. 2005). The ridge complex is approximately 600 m wide and the middle and inner reefs are estimated to be 6-7 and 5-6 ky in age, respectively (Baron et al. 2002, Lightly 1977). Community structure on the reefs is highly variable according to location and associated physical factors. Generally, the proportion of living coral cover increases seaward, with the outer reef typically having the highest value of coral cover (Moyer et al. 2003).

The inshore reef tract is located approximately 0.3 km offshore and ranges in depth from 1.8 to 9.1 m. The average depth north of Port Everglades (Fort Lauderdale) was 4.4 m, whereas it was 5.3 m south of the port. South of the port, the inshore reef was also characterized by hardbottom substrate, with little or no coral growth. North of the port, the inshore reef was characterized by slightly more coral, but remained one of the least complex areas (Ferro et al. 2005). Baron et al. (2002) found that the inshore, hardbottom reef was important juvenile habitat; however, it did not appear to provide unique or obligatory habitat for any of the fish species that were observed.

Ferro et al. (2005) discovered that the middle reef tract had the most substantial north/south change in depth, with a range of 1.8 to 22.1 m. South of Port Everglades, the crest was significantly deeper, with a depth of 10.7 m versus a depth of 5.7 m north of the port. The crest of the middle reef was found to be low in complexity, composed mostly of platform type substrate, with substantial algal cover and little coral or sponge growth.

The outer reef was one continuous structure, ranging in depth from 12.1 to 32.4 m, with the seafloor being deeper south of the port. The western edge was usually found at a depth of approximately 24.0 m. This edge also had less complexity compared to the crest and eastern edge. The eastern edge was found to have the most complexity, characterized by a well-defined reef border with coral patches and some spur-and-groove formations (Moyer et al. 2003, Ferro et al. 2005).

Species composition generally resembled other Caribbean and tropical Atlantic Ocean sites. Increased fish abundance and species richness were found from inshore to offshore reefs. The nearshore, hard bottom habitat is important for many juvenile fishes, especially haemulid grunts (Baron et al. 2002). Recruitment and evasion of predators by recently settled fishes are facilitated by availability of cryptic and size-scaled shelter; therefore, speciose fish assemblage, by mostly juveniles, is associated with the hard bottom. Many consider the inshore reef (Ault et al. 2001, Baron et al. 2002, Moyer et al. 2003) to be an important nursery area for reef fishes. The summer months were observed to typically be the period of highest fish abundance and species richness, as well as the period of highest population densities of juvenile grunts (Gilliam, 1999, Sherman et al. 2001, Baron et al. 2002). On the deeper reefs, labrid wrasses, acanthurid surgeonfishes and doctorfish, and pomacentrid damselfishes were more abundant (Ferro et al. 2005). In contrast, serranid groupers and lutjanid snappers were found to be relatively rare throughout the southeast Florida reefs, probably due to high fishing pressures (Gilliam 1999, Ault et al. 2001, Sherman et al. 2001, Baron et al. 2002).

Artificial Reefs

Several artificial reefs have been deployed in southeast Florida waters. These artificial reefs can consist of ships, limestone boulders, and prefabricated structures. Artificial reefs are deployed as habitat and fishery enhancement and for experimental studies (Sherman et al. 1999, Sherman et al. 2001, Arena et al. 2002, Arena et al. 2007). Ships that were intentionally sunk in 50 -120 m depths for artificial reefs had different assemblages of fishes than shallower, vessel reefs (Bryan 2006). Specifically, the abundance of herbivorous species was higher on shallower, sunken artificial reefs, while the presence of planktivorous species was greater on deeper reefs (Arena et al. 2002, Bryan 2006). Fish assemblages were found to cluster into groups based primarily on depth (<9 m versus >18 m) and secondarily on structural substrate (Arena et al. 2007).

South Florida Reef Fish Fisheries

Both recreational and commercial fishing activities occur heavily in southeast Florida waters. Recreational anglers in the southeast Florida counties of Broward, Miami-Dade, and Monroe land more than 200 fish species, and these anglers account for roughly 20% of the statewide recreational fishing licenses, indicating a significant local contribution to fishing pressure. The targeted species along the natural reef tract for recreational fishing are members of the snapper-grouper complex, including snappers, groupers, grunts, and sparid porgies (Johnson et al. 2007). Johnson et al. (2007) reported recreational fishery landings from 1990 through 2000 included 27% reef fishes, 23% coastal migratory fishes, and 50% offshore pelagic fishes. Total landings of reef fishes in southeast Florida during that time were 4.8 million pounds a year, with 68% by recreational anglers, 27% by commercial fishers, and 5% by headboat (for-hire fishing vessels).

Study species

The seven fish species collected for this project included gray snapper *Lutjanus griseus*, lane snapper *L. synagris*, bluestriped grunt *Haemulon sciurus*, French grunt *H. flavolineatum*, sailor's choice *H. parra*, yellowfin mojarra *Gerres cinereus*, and great barracuda *Sphyraena barracuda*. These species of reef fishes are known to inhabit both the mangrove ecosystems and the reef habitats in South Florida. Though some studies have been conducted on the connectivity of reef fish between mangroves and coral reefs (e.g., Nagelkerken et al. 2000, Serafy et al. 2003, Mumby et al. 2004), few studies have incorporated stable oxygen and carbon isotope ratios to determine the contribution of mangroves as nursery habitats for coral reef fishes (Cocheret de la Morinière et al. 2003, Huxham et al. 2007, McMahon 2011).

Snappers (Lutjanidae)

Snappers consist of 16 genera and 105 species worldwide. Lutjanids represent five genera and 18 species in the western central Atlantic Ocean. Snappers are distinguished from other reef fish species by their one or two enlarged canine teeth.

Snappers are characterized as periodic strategists and they include high fecundity, small egg size, delayed maturity, and synchronized spawning. In the tropical latitudes, spawning generally peaks during the spring and fall and usually occurs in the evening or early night. Snappers are batch spawners, meaning individual females generally spawn several times throughout the year (Martinez-Andrade 2003). Snappers are an important source of food, revenue, and recreational fishing globally throughout the tropical latitudes (Clarke et al. 1997).

Gray snapper (*Lutjanus griseus*)

The gray snapper (colloquially, the mangrove snapper) is a recreationally important fish found throughout the western Atlantic Ocean and Gulf of Mexico from Bermuda and North Carolina to Brazil (Wuenschel et al. 2005). It is found along the mid-Atlantic and southeast coast of the United States and is abundant around the coastline of southeast Florida.

Gray snapper individuals often have no distinguishing characteristics to differentiate them from other snappers, such as the cubera snapper *Lutjanus cyanopterus*. However, the gray snapper will occasionally have a dark band that runs from the upper jaw across the eye. The coloration of the gray snapper varies from pale to dark gray or reddish brown. It has a rounded anal fin and a dark margin may occur on the caudal fin (Humann and Deloach 2002).

The gray snapper rarely exceeds 45 cm and usually weighs less than 4.5 kg. Sexual maturity occurs after about two years and its maximum age is thought to be 25 years (Richards and Saksena 1980, Chester and Thayer 1990). Length at maturity ($_{Lcm}$) is 18 to 33 cm (Table 1). Age at maturity (t_{cm}) is four years and the natural mortality rate (M) is 0.52 (Martinez-Andrade 1997).

The gray snapper occupies a variety of habitats. The juveniles are usually associated with nearshore grass beds and mangrove edges, while the adults tend to be found toward deeper channels and offshore reefs (Rutherford et al. 1989, Chester and Thayer, 1990). Before the adults move to offshore reef habitats, individuals tend to settle in habitats within estuarine and nearshore environments that include mangroves, seagrass, macroalgae, and nearshore reef habitats. Nearshore habitats, especially mangroves, are used as juvenile habitats while adults spawn on outer reefs. Juveniles are strongly association with structured habitats and have a wide tolerance to temperature and salinity ranges that imply structure may be an overriding determinant of habitat selection (Chester and Thayer 1990, Faunce et al. 2002, Tzeng et al. 2003, Faunce and Serafy, 2007).

Table 1: The length of maturity (cm) for each fish species in Total Length (TL) or Fork Length (FL)

Species	Length of Maturity	References
Gray Snapper	18.0-33.0 cm TL	Martinez-Andrade 2003
Lane Snapper	29.4-41.9 cm FL	Martinez-Andrade 2003
Bluestriped Grunt	30.0-35.0 cm TL	Buchon-Navaro et al. 2006
French Grunt	11.0-17.0 cm TL	Jones et al. 2006
Sailor's Choice	30.0-35.0 cm TL	Serafy et al. 2003, Buchon-Navaro et al. 2006
Yellowfin Mojarra	19.0-30.0 cm TL	Halpern 2004
Great Barracuda	44.2 cm FL	Jones et al. 2010

Table 2. Prey items for all fish species

Species	Prey Items	References
Gray Snapper	Mainly crustaceans and fishes. Also, smaller non-decapod crustaceans.	Harrigan et al. 1989, Hettler 1989
Lane Snapper	Mainly fishes. Other prey include crustacean, gatropds, cephalopods, polychaetes, planktonic organisms	Martinez-Andrade 2003
Bluestriped Grunt	Crustaceans, decapods, fishes	Coceret de la Morinière et al. 2003
French Grunt	Molluscs, forminferia, bivalves, gastropods, decopods	Layman and Silliman 2002, Cochert de la Morinière et al. 2003
Sailor's Choice	Molluscs, bivalves, crustaceans, amphipods	Layman and Silliman 2002
Yellowfin Mojarra	Mainly benthic invertebrates, molluscs, bivalves, crustacean, amphipods, forminifera	Kerschner et al. 1985, Layman and Silliman 2002
Great Barracuda	Almost exclusively piscivorous. Juvenilles feed on small epibenthic fishes	Schmidt 1989

Lane snapper (*Lutjanus synagris*)

The lane snapper is another recreationally important snapper in the Family Lutjanidae. They are an important component of the recreational and commercial fisheries in the Caribbean basin and often account for a significant portion of overall commercial catch in areas such as Puerto Rico and Cuba. Despite their commercial and recreational importance, the early life history of the lane snapper is poorly understood. More information is needed on the biology, habitat requirements, and spatial distributions to better effectively manage the valuable snapper fisheries (Clarke et al. 1997, Mikulous Jr and Rooker 2007,). They are commonly found throughout the east coast of the United States from North Carolina through the Gulf of Mexico and the Caribbean Sea to the southeastern coast of Brazil (Human and Deloach 2002, Karlsson et al. 2009).

Lane snappers are distinguished from other snappers by several faint yellow to pink body stripes and a black spot just below the rear dorsal fin. Their pectoral, ventral and anal fins are often yellow and their dorsal tail fins are often reddish (Human and Deloach 2002).

The maximum size length of the lane snapper is 38.1 cm, but they are typically 20-30.5 cm in length. Manickhand-Dass (1987) found that the size at maturity was achieved at one year for males and two years for females, or around 29.4-41.9 cm Total Length (TL) (Luckhurst et al. 2000). The length of maturity for males is 25-31 cm and for females 37-41 cm TL (Manichahand-Dass 1987, Luckhurst et al. 2000). Males grew slightly faster and also achieved a greater size than females (Randall 1967) (Table 1).

Lane snapper occupy a variety of habitats from natural and artificial coral reefs to soft bottom habitats and muddy brackish water. Post-settlement information is limited, but studies have shown that juvenile lane snapper use a variety of habitats, including seagrass, mangrove prop roots, shelf ridges and soft bottoms (Mikulous and Rooker 2007). Adult lane snapper are typically thought to be sedentary and to occupy offshore coral reefs or other hard bottom habitats (Karlsson et al. 2009, Bortone and Williams 1986). Lane snapper mainly feed on fishes; however, other prey includes crutaceans crabs, gastropods, cephalopods, polychaetes, and planktonic orgranisms (Martinez-Andrade 1997).

Grunts (Haemulidae)

The Family Haemulidae, commonly called grunts, represents a dominant member of tropical reef fish communities. The family Haemulidae consists of 136 species around the world, although only 18 species are found in the Greater Caribbean area. The common family name of grunt is derived from the “grunting” sounds produced when grinding teeth deep within the throat are amplified by the air bladder (Humann &and Deloach 2002). Adults have distinctive features and are usually easy to distinguish; however, identifying juveniles to species levels can be challenging.

Fishes of this family dominate shallow tropical reefs in the Caribbean basin. Due to their abundance, fishery value and trophic importance, they are one of the most important reef fishes (Lindeman and Toxey 2002). *Haemulon* spp. play an important ecological and social role in schooling associations where they are involved in mixed species schooling behavior protective mimicry and foraging facilitation behavior with several reef fish species (Lindeman and Toxey 2002, Trott et al. 2010).

Bluestriped grunt (*Haemulon sciurus*)

The bluestriped grunt is associated with tropical and subtropical reefs in the western Atlantic Ocean. They are abundant to occasional from South Carolina through Florida into the Gulf of Mexico, as well as in Bermuda and the Greater Caribbean Sea (Humann and Deloach, 2002, Trott et al. 2010).

Haemulon sciurus closely resembles the French grunt *H. flavolineatum*, although the bluestriped grunt is much larger and its blue stripes are broader and run horizontally rather than diagonally. Bluestriped grunts have a dark caudal fin, dark rear dorsal fin, and the remaining fins are yellow. They have blue stripes over a yellow-gold body. Juvenile bluestriped grunts have a long, parallel upper eye stripe, and parallel yellow stripes below the lateral line (Humann and Deloach 2002).

Cocheret de la Morinière et al. (2003) found that the average size at which the bluestriped grunt becomes sexually mature (23.5 cm) was also the size at which the major dietary change occurred; this change corresponded to the average size of individuals found on the adjacent reef. Grunts usually form aggregations when they are 18-35 cm in length (Table 1) (Trott 2010).

Common habitats for the bluestriped grunt include mangroves, reefs, and seagrass beds. The juveniles are common in shallow areas, whereas the adults form small groups over coral and rocky substrates (Kendall et al. 2003). Bluestriped grunts remain closely associated with the mangrove habitat for protective measures. When small juveniles reach sufficient size (4-6 cm total length, per Mumby 2004), they may migrate into the mangroves, which then serve as an intermediate life stage habitat.

Bluestriped grunts forage primarily in seagrass and mangrove habitats and as they increase in size, a diet shift occurs with decreasing importance of small crustaceans and increasing importance on decapods and fishes (Table 2). They are typically nocturnal feeders that generally form large, inactive schools at their daytime resting site and at night migrate into seagrass beds to feed. Expansion of foraging distance could enable the subadults to find the coral reef and could, therefore, drive nursery-to-reef ontogenetic shifts (Cocheret de la Moriniere et al. 2003).

French Grunt (*Haemulon flavolineatum*)

The French grunt is abundant to the Florida Keys and common to Florida, Bahamas, the Caribbean Sea and also the Gulf of Mexico and north to South Carolina. The French grunt has yellow stripes on white yellowish or silver background that are diagonal below the lateral line. Stripes above the later line are horizontal and their fins are yellow (Humann and Deloach 2002). Typical sizes range from 15 to 25.4 cm total length, with a maximum reported total length of 30.5 cm (Human & Deloach 2002). Sexual maturity is achieved at 11.0-17.0 cm TL (Jones et al. 2006)(Table 1).

Juveniles and sub-adults typically use the mangroves and seagrass beds for shelter habitats during the daytime (Cocheret de la Morniere et al. 2004, Verweij et al. 2006). They are abundant in shallow reef communities and typically form schools associated with natural and artificial structures. During the day they often congregate in small to large schools under bottom formations on the reef, while at dusk they leave their daytime shelter and migrate to adjacent seagrass beds to feed (Burke 1995). French grunts feed on macrobenthic organisms after migrations from reef to soft bottom and macroalgae in seagrass beds (Parrish 1989, Nagelkerken et al. 2002, Lindeman and Toxey 2002, Hitt et al. 2011) (Table 2).

Sailor's Choice (*Haemulon parra*)

The sailor's choice is common in waters around Florida, the Bahamas, and continental coasts of Central and South America. Black spots on scales, which form numerous oblique stripes on the body, are used to distinguish the sailor's choice from other grunts. They are also silvery to pearly gray, with dusky to dark fins (Humann and Deloach 2002).

Time of settlement usually occurs from 4-6 cm (Cocheret de la Morinere et al. 2004) and like other grunts, they form aggregations, typically around 18-35 cm TL. Length at maturity is obtained around 30-35 cm TL (Table 1). Similar to other grunts (i.e. bluestriped grunts), they inhabit mangrove habitats for protection and move offshore to reefs and open areas in schools; however, they can occasionally be solitary (Humann and Deloach 2002). Sailor's choice feed on mollucs, bivalves, crustaceans, and amphipods (Layman and Silliman 2002).

Mojarras (Gerridae)

The family Gerreidae consists of eight genera and forty-four species. Mojarras are reflective silver fishes with laterally compressed bodies and extremely protrusible mouths for catching benthic invertebrates. Mojarras mostly feed during daylight hours and are typically found over sand or mud bottoms.

Yellowfin mojarra (*Gerres cinereus*)

The yellowfin mojarra is common in the waters surrounding Florida, the Bahamas, Caribbean Sea and the Gulf of Mexico and south to Brazil, including the Antilles (McEachran and Fechhelm 1998; Humann and Deloach 2002).

The yellowfin is among the largest mojarra with a deeply compressed and elongated body, which typically is bright silver with yellow pelvic fins. Usually there are seven or eight broken, bluish vertical bars along their sides (Evermann and Meek 1883, Humann and Deloach 2002). Maturity is reached at a length of 20 cm. Average size adults range from 20 to 30.5 cm. The maximum length recorded was 41 cm with the common length of 30 cm, and the maximum mass was 530 g (McEachran and Fechhelm 1998) (Table 1).

The species is associated with open sandy beach, mud bottom, seagrass beds, mangrove habitats, and coral reefs. They enter brackish water and sometimes occur in small aggregations. The average depth at which the yellowfin mojarra can be found is 1.5 to 12 m deep (McEachran and Fechhelm 1998). The yellowfin mojarra has been observed to use the mangroves as their primary juvenile habitat, but they are also commonly found in high densities as juveniles on mud flats. Only a portion of the adult population makes an ontogenetic shift to adjacent coral reefs (Jones et al. 2010).

Mojarras feed mainly on benthic invertebrates, such as polychaetes, tunicates, and bivalves, in the sand patches among reefs. Yellowfin mojarras will swim and hover over sand near reefs and stop occasionally to dig for small invertebrates. They feed by prodding their mouth into the sediment and expelling sand through their gill openings after filtering out benthic infauna (Evermann and Meek 1883) (Table 2).

Barracuda (Sphyridae)

As an economically, ecologically, and culturally important top-level predator, barracudas play a key role in the ecology of coral reefs. Twenty-one species form a single genus and they are found throughout most of the tropical and subtropical seas of the world. Many recreational anglers and subsistence fishers often target barracuda, for consumption (O'Toole et al. 2011).

Great barracuda (*Sphyraena barracuda*)

Barracuda are in the family Sphyraenidae. The great barracuda *Sphyraena barracuda* ranges in the western Atlantic waters from Cape Cod, Massachusetts to southeastern Brazil. However, it is particularly abundant off South Florida and throughout the Caribbean Sea (Schmidt 1989).

The great barracuda is a large fish with a long, cylindrical, powerful body. It has an elongate, fusiform body with a tapered head and a terminal mouth. The wedge-shaped head is large, about one-quarter of the total length of the fish, with the lower jaw projecting beyond the upper jaw. Both jaws have conical, canine teeth. The external color of the fish readily adjusts itself to its surroundings; for example, a barracuda lying near the bottom over coral sand will alter its pigmentation to be almost unnoticeable. It is grey or silver in color with a greenish cast dorsally and whitish ventrally. Many irregular, small black blotches occur along the lower sides of the fish (Humann and Deloach 2002, Porter and Motta 2004, O'Toole et al. 2011).

Barracuda larvae are presumed to develop offshore, and after settlement in nearshore mangrove and seagrass habitats, individuals grow rapidly. They attain an average size of 37.8 cmm fork length (FL) in the first year. Females often reach sexual maturity as early as 3-4 years of age and grow to 58 cm FL, while males mature at 1-2 years of age and reach 46 cm FL (Schmidt 1989) (Table 1).

Large adult barracudas are found mostly offshore around reefs, rock outcroppings, and artificial structures, whereas smaller adults and juveniles prefer nearshore mangrove and seagrass environments. Barracuda abundance is enhanced by the presence of adjacent, shallow water habitats, such as seagrass and mangroves. Some young appear to mimic blades of sea grass and floating debris. Barracuda inhabit shallow embayments during their juvenile and subadult stages before migrating to offshore habitats to spawn at maturity (Eggleston et al. 2004).

Great barracuda are generally solitary individuals and are frequently found swimming slowly or hovering in place. Barracuda are ambush predators that lie in wait and burst at high speeds, around 12.2 m s^{-1}, to capture a prey item (O'Toole et al. 2011). They strike their prey as rapidly as possible, sever its prey with its sharp teeth, and swallow the large fragments whole. *S. barracuda* are almost exclusively piscivorous throughout their life history. Schmidt (1989) found that juvenile barracuda less than 33.3 cm fed on small epibenthic fishes, such as the goldspotted killifish *Floridichthys carpio* and rainwater killifish *Lucania parva*. The diet of juveniles most likely reflects both the prey availability and some selectivity based on the size of the fish that can be easily ingested by the barracuda. As the barracuda grows, the selection of prey organisms grows to those of progressively larger size due to the increase in mouth size. Based on stomach content analyses, barracuda are regarded as diurnal foragers, feeding in shallower habitats during the early morning and early evening, and spending time in surface waters over deeper habitats when not feeding (Table 2) (Kadison et al. 2010).

Stable Isotope Ratios

Stable isotopes are non-radioactive variants of an element whose relative uptake can be modified by the environment or biological activity due to their slightly different atomic mass (DeNiro and Epstein 1978, 1981, Campana 1999). Stable isotope ratios have a long history of use as biological tracer recorders of temperature, salinity, pH, and indicators of feeding history, trophic level, and metabolic rate (Peterson and Fry 1987, Hobson 1999, Huxham et al. 2007). Carbon and nitrogen are the two elements most commonly used for trophic analyses, although there has been an increase in the use of oxygen, sulfur, lead, strontium and boron stable isotope ratios for other uses (e.g., oxygen for reconstructing ocean temperature and sulfur for determining the dietary contribution of estuarine-sourced detritus) (Post 2002, Shepard et al. 2007).

Carbon Isotope Ratios

Two naturally occurring stable forms (isotopes) of carbon exist – ^{12}C and ^{13}C – while the radioactive isotope ^{14}C decays over time and can be used for dating purposes. The normal ratio of $^{13}C:^{12}C$ is 1.1‰ worldwide, while on average animals are enriched in $\delta^{13}C$ from 0.5-1‰ relative to the ratio in their diet. Large differences in $\delta^{13}C$ values are characteristic of plants bioenergetically processing carbon through either the C_3,C_4, or CAM photosynthetic pathways (DeNiro and Epstein 1978, O'Leary 1981). Analyses of

^{13}C:^{12}C in faunal tissues have been used to both investigate marine food web dynamics and also to infer migration and habitat connectivity (Radkte et al. 1996, Dufour et al. 1998, Hobson 1999, Huxham 2007).

Animals that move between isotopically distinct food webs retain information of previous feeding location and diet for periods of time, dependent on the turnover rate of the tissue of interest (Hobson 1999). Within marine and freshwater aquatic systems, $\delta^{13}C$ gradients in food webs may be related to inshore or benthic linked food webs versus offshore or pelagic food webs. France (1995) found seagrass-associated fishes with a $\delta^{13}C$ more negative than -15‰ were components of the planktonic foodweb, while fish with $\delta^{13}C$ more positive than -14‰ derived their carbon from benthic algae.

Nitrogen Isotope Ratios

Two naturally occurring forms of stable nitrogen isotopes, ^{14}N and ^{15}N, exist. As ^{14}N is the far more common isotope, ^{15}N: ^{14}N can be used as a tool for estimating trophic position. Numerous studies have used $\delta^{15}N$ because trophic levels are simple to define, characterize the functional role of organisms, and enable estimates of energy or mass flow through ecological communities (Post 2002). DeNiro and Epstein (1981) found that the $\delta^{15}N$ of an animal's diet could be estimated from the $\delta^{15}N$ of its individual tissues. Therefore, isotopic analysis of animal nitrogen can be used to reconstruct aspects of diet.

The trophic level concept is limited in its ability to capture the complex interactions and tropic omnivory that are prevalent in many ecosystems (Paine 1988, Polis and Strong 1996, Persson 1999, Vander Zanden and Rasmussen 1999, Post 2002). However, $\delta^{15}N$ can still be used to estimate trophic position because the ratio of the heavier to lighter nitrogen isotopes of a consumer is typically enriched by 3-4 ‰ relative to its diet (DeNiro and Epstein 1981, Minagawa &Wada 1984, Peterson and Fry 1987, Post 2002, Fry 2006). Natural abundance levels of $\delta^{15}N$ range from -20 to + 20‰. Animal tissues are almost always enriched in $\delta^{15}N$ relative to values measured for plants and enrichment increases along with advancing trophic levels (Minagawa and Wada 1984).

Oxygen Isotope Ratios

The stable isotope ratios of oxygen in the calcium carbonate ($CaCO_3$) matrix of otoliths have been used to determine temperature histories of fish to reconstruct geographic locations at various times throughout the life of the individual animal. When thermodynamic relationships are the only factors affecting the fractionation of carbon and oxygen isotopes during precipitation of $CaCO_3$ from solution, the stable isotopes are precipitated in equilibrium (Kalish 1991). Carbonates precipitated under such equilibrium conditions are often used to estimate past temperature and water composition (Campana 1999).

Oxygen has three common stable isotopes, ^{16}O, ^{17}O, and ^{18}O, with ^{16}O being the most abundant in nature. Only the ^{18}O:^{16}O ratios need to experimentally assessed for each locale because the ratios of ^{18}O:^{17}O are functionally constant worldwide. The changes in oxygen isotopes result from fractionations caused by phase transitions of oxygen in water, chemical or biological reactions, and transport process. In the global water cycle, the most significant process of fractionation is that of phase changes, from vapor to liquid to solid and vice versa (Gat 1996). The oxygen and hydrogen isotope ratios in precipitation are a function of isotopic fractionation resulting from the evaporation of seawater and condensation of cloud moisture. Stable isotopic composition of precipitation depends on latitude, altitude, and temperature. Therefore, oxygen isotopic composition in organisms differs among geographic locations (Yapp and Epstein 1982, Rundel et al. 1989).

Stable Isotopes in Muscle Tissue

Animals that move between isotopically distinct foodwebs are able to retain information from previous food type and trophic levels for certain periods of time, depending on the elemental turnover rates of the tissue of interest (DeNiro and Epstein 1978, 1981, Hobson 1999, Fry 2006). Some keratinous tissues like hair and nails are metabolically inert, and they maintain an isotopic record reflecting the location of where the tissue was synthesized. Other tissues are metabolically active, and the dietary information obtained will be temporal, ranging from a few days (e.g., blood plasma) to several weeks (e.g., muscle), depending on regeneration ("turnover") rates (DeNiro and Epstein 1978, 1981, Hobson 1999).

Stable isotope "clocks" based on tissue turnover rates can be used to help estimate animal migration routes and which foods support consumers as they switch diets. However, otoliths are not regenerated, but accrete layers over time. Thus, while muscle tissues reflect short-term records (generally <90 days) of averaged source carbon and dietary contribution, otoliths provide a permanent, long-term record of habitat and carbon resources (DeNiro and Epstein 1978, Dufour et al. 1998, Gillanders and Kingsford 2000).

Stable Isotopes in Otoliths

Otoliths are accretionary structures located within the inner ear and are composed primarily of calcium carbonate ($CaCO_3$) embedded within a gelatinous matrix (Thorrold et al. 1997, Campana 1999). Teleost fishes have three pairs of otoliths: the sagittae, lapilli, and asterisci. These paired, calcified structures are used in teleost fishes for balance and orientation, as well as for hearing. When a sound wave passes through the fish, the otoliths vibrate at different frequency than that of the surrounding tissue. The sagittae are the largest of the three pairs and are typically the best choice for aging and stable isotope studies (Thorrold et al. 1997). The lapillus in particular gives the fish a gravitational orientation by acting as an "ear stone" (Campana 1999).

Since otoliths are acellular, and therefore metabolically inert after deposition, they have the potential to preserve chemical and abiotic signals specific to particular periods in a fish's life (Huxham et al. 2007). The elemental composition of the calcium carbonate matrix is dominated mainly by calcium, oxygen, and carbon, followed by minor elements such as sodium, strontium, potassium, sulfur, nitrogen, chloride, and phosphorus (Campana 1999).

Otoliths can contain a complete record of temperature composition of the ambient water to which the fish was exposed. A change in temperature alters the balance between the organic matrix and the inorganic calcium carbonate formation and, is, therefore, expected to change the ratio of elements that are incorporated (Campana 1999). Salinity, pH, dissolved oxygen concentrations, and other factors such as depth can also influence elemental uptake into the fish's otolith. With known (or estimated) geographic variations in water chemistry, environmental availability, and the incorporation rate into the otolith, it is possible to retrospectively determine the physical and chemical characteristics of the water in which a fish has resided (Thorrold et al. 1997, Campana 1999).

The $\delta^{13}C$ in muscle reflects the main source of carbon to consumers. However, the relationship in $\delta^{13}C$ between carbon isotope signatures in food and those found in otoliths is complex. Campana (1999) estimated that only 10-30% of the carbon in otoliths is derived from metabolic sources, with the remainder coming from dissolved inorganic carbon (DIC); therefore, diet is not a dominant controlling factor in otolith $\delta^{13}C$. Carbon isotope ratios in otoliths are influenced by nutrient sources depending upon the carbon-fixing pathway of primary producers, the level of fractionation to higher trophic levels, and the metabolic rate of the consumer (Radtke et al. 1996). As a result of these qualifiers, $\delta^{13}C$ has only a limited value as a migration marker. However, it may be useful at sites with a steep $\delta^{13}C$ gradient, such as mangroves versus reefs (DeNiro and Epstein 1978; Huxham et al. 2007, Sluis 2011).

Objectives and Hypotheses

Port Everglades, a commercial port located just south of Fort Lauderdale at an artificially maintained inlet, accommodates high traffic in recreational vessels, commercial ships, and cruise ships. Development has considerably modified Port Everglades, affecting the amount and quality of the available adjacent mangrove habitat. This study expanded the knowledge of the connectivity between the mangrove and offshore reef fish populations through stable isotope analyses of otolith and muscle tissue. The goal was to collect reef fishes both from mangrove sites located adjacent to Port

Everglades and coral reef sites located offshore in the vicinity of Port Everglades in Broward County, Florida. All fish species were analyzed using stable isotope ratios of otoliths and muscle to evaluate ontogenetic migrations, foraging, and occupation within the mangrove and reef sites. This study will help provide a better understanding of importance and utilization of mangrove and reef sites by multiple age classes of fishes. This study will help provide a better understanding of importance and utilization of mangrove ecosystems by reef site assemblages. Studying the ontogenetic movements of reef fishes in this area will clarify the relative importance of the various habitats essential for early life-history stages of reef fishes.

The objectives of this study were to: 1) collect seven species of fishes – gray snapper *Lutjanus griseus*, lane snapper *L. synagris*, bluestriped grunt *Haemulon sciurus*, French grunt *H. flavolineatum*, sailor's choice *H. parra*, yellowfin mojarra *Gerres cinereus* and great barracuda *Sphyraena barracuda* – at different age classes, within both mangrove and reef habitats, and during different seasons, 2) analyze both muscle and otolith tissue samples, 3) use statistical analysis to determine whether differences exist among carbon and nitrogen stable isotopes in muscle tissue among species, capture habitat, age-class and season, and 4) use statistical analysis to determine whether differences exist among oxygen and carbon stable isotopes in fish otolith samples among species, capture habitat, age-class and season.

Hypotheses

The three questions being asked during this study are: 1) Does a difference exist between δ^{18}O and δ^{13}C signatures in reef fish otoliths between coastal mangrove habitats and offshore reef habitats? 2) Do juvenile reef fishes utilize the mangrove habitat as nurseries and then become established in nearby coral reef communities? 3) Will fish trophic dynamics vary between the mangrove and reef habitats?

It is expected that the $\delta^{18}O$ and $\delta^{13}C$ signatures in reef fish otoliths will differ between mangrove and reef habitats. Juvenile fish will utilize the mangroves more than the adults; this will be observed through the use of oxygen and carbon isotope ratios in fish otoliths. Freshwater input, in addition to surface precipitation, is likely to have a greater influence on nearshore sites, compared to offshore sites, thus affecting $\delta^{18}O$. It is also expected that there will be a difference in fish diet between juvenile and reef habitats. This will be assessed through the analyses of the $\delta^{13}C$ and $\delta^{15}N$ in muscle tissue.

Materials and Methods

Study Sites

The study was carried out at three mangrove habitat sites along the Intracoastal Waterway as well as on the first and second reef tracts and associated artificial reefs located in Broward County, Florida (Figure 1). All sites had a minimum of three of the fish species present at each sampling period throughout the study period. All mangrove sites were shallow, brackish, accessible by land, and populated by all of the identified reef fish species in this study. Mangrove Site 1 (M1) is located along the Intracoastal Waterway at the Loggerhead Fishing Pier in Hollywood State Park. It is approximately 5 km south of the Nova Southeastern University (NSU) Oceanographic Center and the Port Everglades Entrance Channel. The site had no restriction of access to the Intracoastal

Waterway. Mangrove Site 2 (M2) is located at the Anne Kolb Nature Center in West Lake Park, about 1 km south of M1 and 144 m from the Intracoastal Waterway. Even though this site is not found directly on the Intracoastal Waterway, it is connected and accessible to organisms from the waterway. Mangrove Site 3 (M3) is Whiskey Creek, located within John U. Lloyd State Park, 2.4 km north of M1 and 2.5 km south of the NSU Oceanographic Center. This site is also accessible to organisms from the Intracoastal Waterway.

All these inshore sites are accessible to moving organisms, but there are slight differences among these sites. M1 has the most direct offshore water accessibility, followed by M2, and then M3. Accessibility is based on the amount of the mangle available to the organisms moving into the site as well as the distance from the Intracoastal Waterway.

The reef sites were located on the first and second reef tracts and artificial reefs offshore Broward County, Florida in close proximity to Port Everglades. The nearshore area of Broward County is characterized by three coral reef/hard bottom tracts, separated by sand substrate, which run parallel to the coast in sequentially deeper water. These reef tracts, locally referred to as the First, Second, and Third reefs, are found at depths ranging from 3 to 30 m. The first reef tract is generally located approximately 0.5 nm offshore, while the second reef tract is approximately 1.0 nm offshore (Ferro et al. 2005). Seven sites were located on the first reef tract and eight sites were located on the second reef tract.

Permits

The Nova Southeastern University (NSU) Institutional Animal Care and Use Committee (IACUC) granted approval for this project (#040-468-12-0919). A State of Florida Fish and Wildlife Conservation Commission Special Activity License (SAL #12-1420B-SR), a Florida Department of Environmental Protection research permit for John U Lloyd State Park (#04091315) and a Broward County research permit for Anne Kolb Nature Center (#ES090612-007) were obtained. In accordance with University scientific diving protocols, a dive log was filed with the NSU Oceanographic Center Dive Safety Officer (DSO). The DSO approved in advance the participation of the volunteer divers associated with this project, all of whom were certified by the American Academy of Underwater Sciences (AAUS), per NSU protocols.

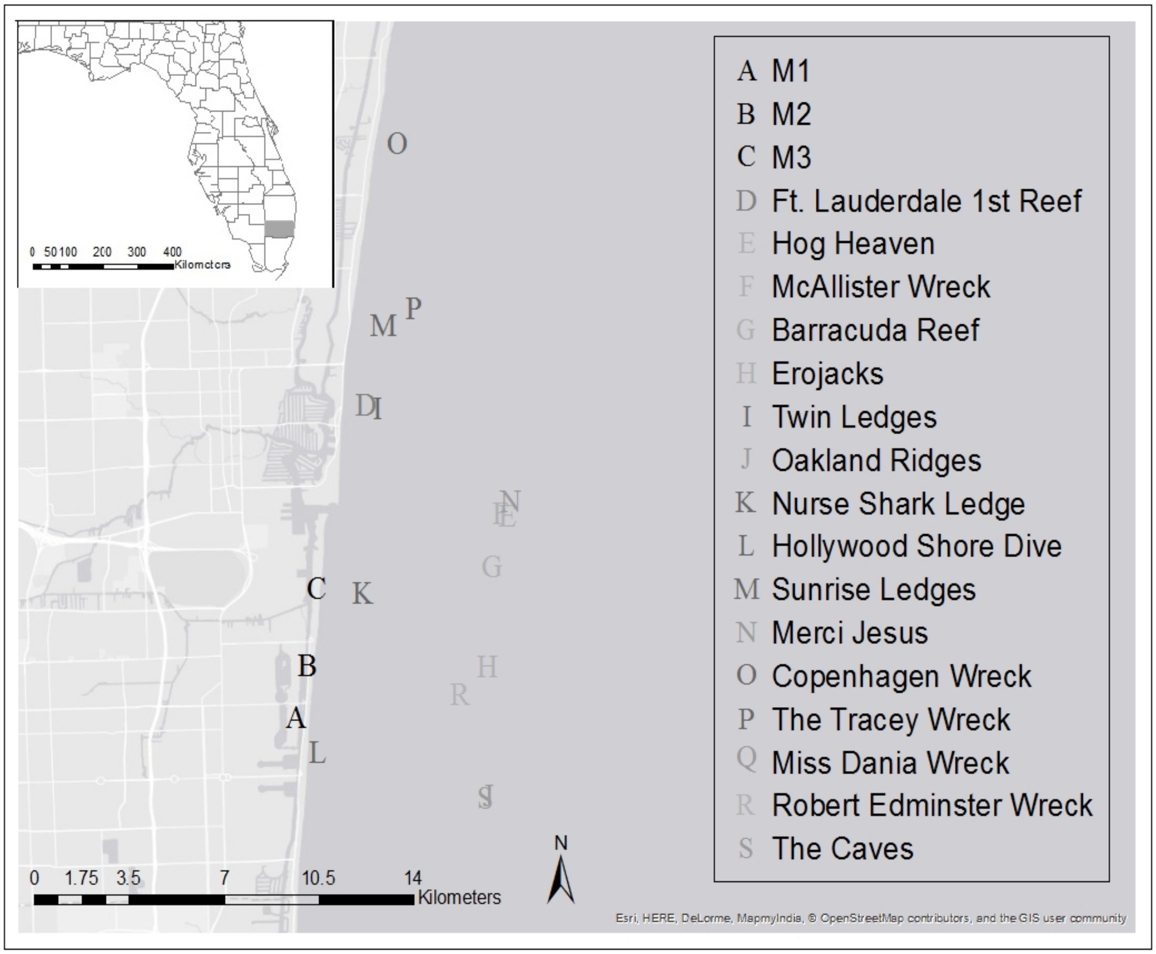

Figure 1. Sampling locations of the reef sites in proximity to the three mangrove sites in Broward County, Florida. M1 (Mangrove Site One), M2 (Mangrove Site Two), M3 (Mangrove Site 3). Other sites included for reference indicate common recreational dive sites (first reef tract = dark gray, second reef tract = light gray) in the area.

Field Sampling Methods

Field sampling began in March 2013 and continued every other week at all sites for one year to capture seasonal variations. Seasons consist of two seasons, dry (December-April) and wet (May – November) seasons. A total of 656 fish were collected and analyzed: 36 gray snapper, 21 lane snapper, 90 bluestriped grunt, 145 French grunt, 22 sailor's choice, 126 yellowfin mojarra, and 216 great barracuda. Surface water temperature and salinity were recorded at each site using an YSI environmental meter. Juvenile versus adult maturity status was determined from a literature review of Von Bertalanffy growth models and size at maturity (Martinez-Andrade 2003, Halpern 2004, Buchon-Navaro et al. 2006, Jones et al. 2006, Jones et al. 2010) (Table 1).

Fish collection in the mangrove sites was attempted during a flood to slack high tide. A combination of 30-ft (9.1 -m), 40-ft (12.2-m), and 50-ft (15.24-m) seine nets was used to collect fishes from the mangrove sites with the intent to capture juvenile specimens. The seine net was used by two persons who walked the seine net in front of the mangle and then swept it in an arch shape to the other side of the seine. All fish specimens were placed in plastic bags, labeled with site and date, and placed in a cooler filled with ice. Since hypothermia is a generally accepted and humane method for fish euthanization (Schaffer, 1997), captured fishes were transferred and stored in a -20°C freezer until processed in the laboratory.

Volunteer scientific divers collected fish specimens at the reef sites using a speargun and Hawaiian sling. A dive team of two was in the water at a time, one diver using a spear gun and the second diver acting as safety diver and usingd a Hawaiian sling. Dives were performed using a local dive charter (M/V *Sea Experience*; Fort

Lauderdale, Florida) and occurred every two weeks for one year. Supplementary shore dives were done off Hollywood Beach and Dania Beach. All shore diving took place in the morning before peak beach traffic times.

Dive teams carried a stringer and safety sausage. Once the fish was harvested, it was strung onto the stringer. If necessary, the stringer full of fish was floated to the surface by the safety sausage where the boat captain would pick up the harvested fish, protecting the divers from any potential predators. Water samples for salinity were also collected during this time. Dive computers recorded the bottom water temperature at each collection site.

Observational Data Collection

Observational data were recorded before specimens were collected. Tidal phase, wind direction and air temperature were collected prior to sampling (NOAA, 2015). Weather observations and precipitation were recorded upon arrival at each site. The start time and time of collection were also recorded. At the mangrove sites, water temperature (°C) and salinity (‰) measurements were taken using an YSI meter. The active divers recorded bottom water temperature from Sherwood dive computers. Water samples were collected at each dive site in a sealed 50-ml tube and labeled with site, date, and time. These samples were later analyzed in the laboratory for salinity using an YSI meter. Weather conditions (e.g., rainfall amounts) were collected from NOAA and South Florida Water Management District websites (NOAA 2015, SFWMD 2015).

Laboratory Analyses

All fishes were thawed, identified, and assigned individual identification numbers. Fish samples were weighed and measured for standard, fork, and total length (SL, FL, TL, respectively). Maturity status (juvenile versus adult) was determined from a literature review of Von Bertalanffy growth models and size at reproductive maturity (Martinez-Andrade 2003, Serafy et al. 2003, Halpern 2004, Bouchon-Navaro et al. 2006, Jones et al. 2010) (Table 1). The majority of fishes sampled could not be gender- identified, as they were reproductively immature, so gender was removed as a variable in this study.

Approximately 1 g of white muscle tissue was excised from above the lateral line of each. All tissues were placed in individual aluminum tins and dried in an oven at 60° C for 48-72 hours until dessicated. Each sample was than placed in a stainless steel capsule and homogenized using a Wig-L-Bug MSD model amalgamator (DENTSPLY Rinn; Elgin, IL). Samples were stored in clean, dry glass shell vials.

Excised sagittal otoliths were cleaned with a 2% hypochlorite solution and then thoroughly rinsed with deionized water to remove any adhering tissue. Otoliths were dried overnight in a fume hood and stored as a pair in 1.5-mL centrifuge vials. Campana (2000) found no compositional difference between the left and right otolith of a fish; therefore, either sagittal otolith can be used. However, the right otolith was used in this study whenever possible for standardization, allowing the left otolith to be archived for future aging studies.

One hundred thirty-eight otolith samples were used for biochemical analysis. A minimum of 10 fish for each species had both the core and edge sampled from the right otolith. Fishes were selected based on similarity of age class, habitat, and season. Otoliths were sanded flat to their maximum diameter using 400-grit sandpaper. A Dremel 9100 Fortiflex heavy duty flex shaft, with a diamond micro-drill bit (3/32”), was used to grind the core and edge samples. The drill bit was wiped cleaned with distilled water after each sample. For otoliths 5 mm and larger, approximately 50 µg of fine powder from each core and edge sample was placed in a glass vial; otoliths from juvenile fishes (< 5 mm) were crushed whole with a mortar and pestle.

Stable Isotope Analysis

All sample processing was conducted at the NSU Oceanographic Center. Each muscle tissue sample was weighed (0.5-0.8 mg) and placed into tins. Samples were analyzed using a Finnigan Delta Plus continuous flow isotope ratio mass spectrometer (CF-IRMS) at the Smithsonian OUSS/MCI Stable Isotope Mass Spectrometry Laboratory, Suitland, MD. All samples were linearly corrected with a two-point linear correction to acetanilide and urea standards calibrated to a Vienna Pee Dee Belemnite (VPDB) standard (Peterson and Fry 1989, Fry 2006). Vienna Pee Dee Belemnite was the standard used for $^{13}C/^{12}C$ and atmospheric air was used for $^{15}N/^{14}N$. Reproducibility was 0.2 ppt.

Otolith samples were processed at the Stable Isotope Lab at the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami. 0.5 µL of methanol was pipetted into each vial to transfer samples to glass vials used with the isotope ratio mass spectrometer ThermoQuest Finnigan Delta Plus. All data were corrected for the isobaric inferences with an internal machine CO_2 standard at mass 45 and 46, as well as an external carbonate standard OCC (Optically Clear Calcite). Values were reported relative to VPDB (Devereux 1967, Gerard and Muhling 2009, Huxham et al. 2007, Sluis 2011). The precision of the $\delta^{13}C$ and $\delta^{18}O$ values was less than 0.1‰, determined by repeated measurement of a standard. These values were expressed as parts per thousand (‰):

$$\delta X = [R_{sample} / R_{Standard} - 1] * 1000$$

Statistical Analysis

Data were separated into binary categories of species, age class, habitat, and season. Age classes consisted of juvenile and adult. Habitats were categorized as mangrove and reef. Dry season included data from March through April 2013 and December 2013 through April 2014. Wet season included data from May 2013 through November 2013. Historical rainfall data from South Florida Water Management District were used to determine the period of wet and dry seasons (SFWMD, 2015).

Descriptive statistics were generated for all data. The Shapiro-Wilk test was used to test for normality. Parametric tests included one-way ANOVA (analysis of variance), which was used to compare more than two independent samples. The Wilk's lambda test was used in multivariate analysis of variance (MANOVA) to test for differences between the means of identified groups of subjects on a combination of dependent variables. The non-parametric Kruskal-Wallis test, a version of the one-way ANOVA, was used to compare more than two independent samples. The mean $\delta^{18}O$ and $\delta^{13}C$ values for larval and adult stages of each fish were compared using paired t-tests, pairing within individuals. The mean $\delta^{18}O$ and $\delta^{13}C$ values for larval and adult stages of each fish were compared using the Mann-Whitney U test, a non-parametric version of a paired Student's t-test. Tukey's honestly significant difference (HSD) and Bonferonni post-hoc tests were used to test for comparisons among species, habitat, age class, and season. IBM SPSS Statistics version 23 was used.

Results

Collection Data

Sampling occurred from July 2012 through April 2014, main sampling occurred regularly every two weeks, weather permitting. A total of 656 fish specimens were collected during the sampling effort. Great barracuda had the highest number of total individuals collected, followed by French grunt, yellowfin mojarra, bluestriped grunt, gray snapper, sailor's choice, and lane snapper (Table 3).

Overall, more juvenile fish (60.2%) were collected than adults (39.45%) for all seven species. Great barracuda had the most juveniles collected, followed by yellowfin mojarra, sailor's choice, lane snapper, bluestriped grunt, and gray snapper and French grunt. The most adults collected were French grunt followed by bluestriped grunt, gray snapper, yellowfin mojarra, lane snapper, sailor's choice and great barracuda (Table 3).

More samples were collected in the mangroves (59.6%) compared to the reef (40.4%). Fish most often caught in the mangroves, from most to least, included great barracuda, yellowfin mojarra, sailor's choice, lane snapper, gray snapper, bluestriped grunt, and French grunt. French grunts were collected most often on the reef, followed by bluestriped grunt, gray snapper, lane snapper, sailor's choice, yellowfin mojarra, and, lastly, great barracuda (Table 3).

More samples were collected during the wet (55.9%) season compared to the dry (45.6%) season. In the dry season, more great barracuda were collected, followed by French grunt, yellowfin mojarra, bluestriped grunt, gray snapper, sailor's choice, and gray snapper. Great barracuda was also collected the most in the wet season, followed by French grunt, yellowfin mojarra, bluestriped grunt, gray snapper, lane snapper, and sailor's choice (Table 3).

Ecological Data

The Kruskal-Wallis test detected significant salinity differences between the mangrove and reef habitats (DF = 1, F = 39.949, $p \leq 0.001$). Salinity values in the mangrove environments ranged from 32.9 to 34‰ during the dry season and 18.8 to 32.9‰ during the wet season. Mean salinity in the mangroves was 33.5‰ ± 0.50 during the dry season (December-April) and 27.5‰ ± 5.03 during the wet season (May-November). Salinity values in the reef environments ranged from 33.9 to 35.9‰ during the dry season and 34.7 to 37.2‰ during the wet season. Mean salinity over the reef was 35.4‰ ± 0.47 during the dry season compared to 35.3‰ during the wet season (Figure 2). Mangrove salinity was significantly different between seasons (DF = 1, F = 7.149, $p = 0.016$) but was not over the reef (DF = 1, F = 1.952, $p = 0.335$). The Wilcoxon test showed a significant difference between both habitats and seasons ($p \leq 0.001$). Salinity for Reef Tract One ranged from 34.3 to 35.8‰ with a mean of 35.2‰ ± 0.46. Reef Tract Two had a salinity range of 34.6 to 36.2‰ and a mean salinity of 35.28‰ ± 0.43. Salinity between Reef Tract One and Reef Tract Two was not significantly different ($p = 0.645$).

Reef Tract One and Reef Tract Two were also not significantly different between seasons ($p = 0.547$).

The Shapiro-Wilk test indicated normality for water temperatures at both habitats (Mangroves: DF = 20, $p = 0.259$; Reefs: DF = 51, $p = 0.082$). Water temperature was significantly different between the mangrove and reef habitats (DF = 1, F = 21.895, $p \leq 0.001$). Mean water temperature in the mangroves was 27.6° C ± 2.85 during the dry season and 28.4° C ± 2.61 during the wet season (Figure 3); whereas, mean water temperature on the reef was 23.3° C ± 1.70 during the dry season and 26.34° C ± 2.13 during the wet season. There was a significant difference in water temperature on the reef between seasons (DF = 1, F = 7.149, $p = 0.016$); however, there was no significant difference in seasonal water temperatures in the mangroves (DF = 1, F = 1.07, $p = 0.932$). A significant difference was found between seasons and among sites using a two-way ANOVA (DF = 2, F = 36.683, $p \leq 0.000$). The mean water temperature for reef tract one was 27.52° C ± 4.63 and the temperature range was 21.1° C to 33.5° C. Reef Tract Two had a mean water temperature of 25.03° C ± 3.93 and ranged from 18.9° C to 33.3° C. There was no significant difference in water temperature between reef tracts ($p = 0.068$).

Table 3. Total numbers of samples collected for each species, age class, habitat, and season. N_T = N Total, N_J = N Juvenile, N_A = N Adult, N_M = N Mangrove, N_R = N Reef, N_D = N Dry and N_W = N Wet

Species	Total (N_T)	Juvenile (N_J)	Adult (N_A)	Mangrove (N_M)	Reef (N_R)	Dry (N_D)	Wet (N_W)
Gray Snapper	36	10	26	10	26	19	17
Lane Snapper	21	16	5	15	6	6	15
Bluestriped Grunt	90	15	75	10	80	39	51
French Grunt	145	8	137	1	144	66	79
Sailor’s Choice	22	19	3	18	4	10	12
Yellowfin Mojarra	126	114	12	123	3	40	86
Great Barracuda	216	213	3	214	2	109	107
Total	**656**	**395**	**261**	**391**	**265**	**289**	**367**

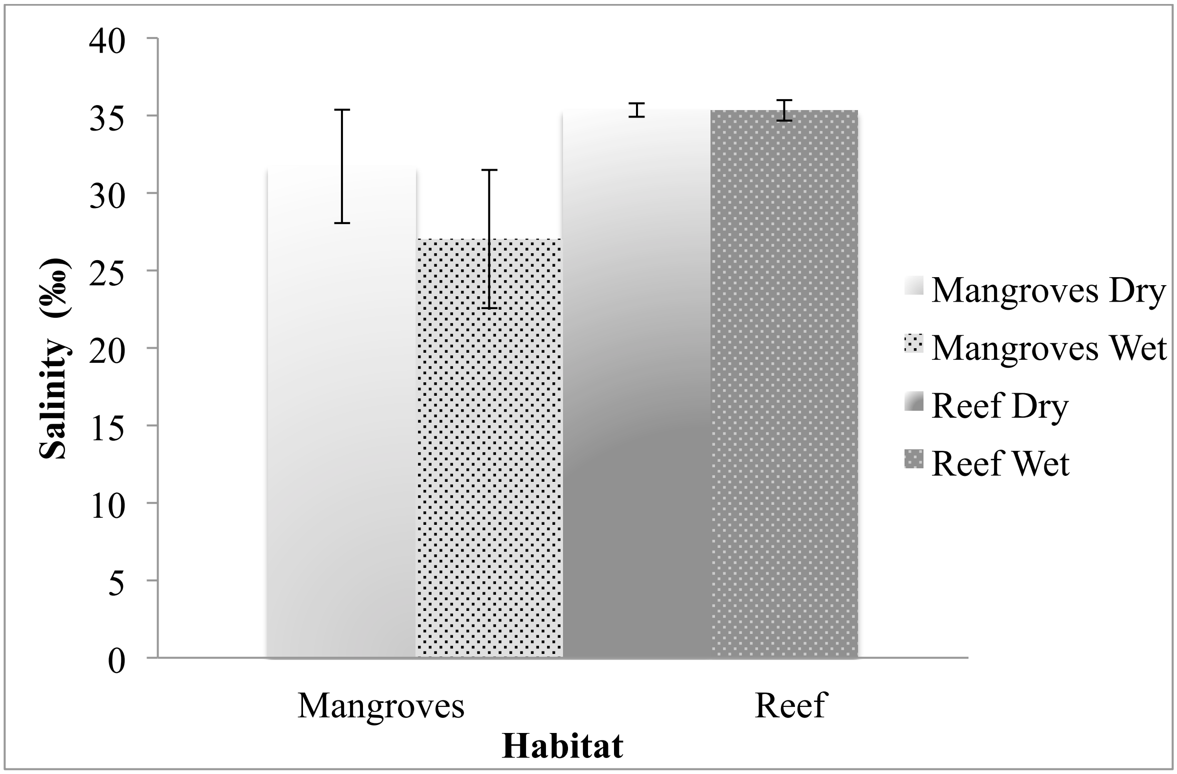

Figure 2. Mean salinity (‰) in the mangroves and on the reef during the dry (December-April) and wet (May-November) seasons.

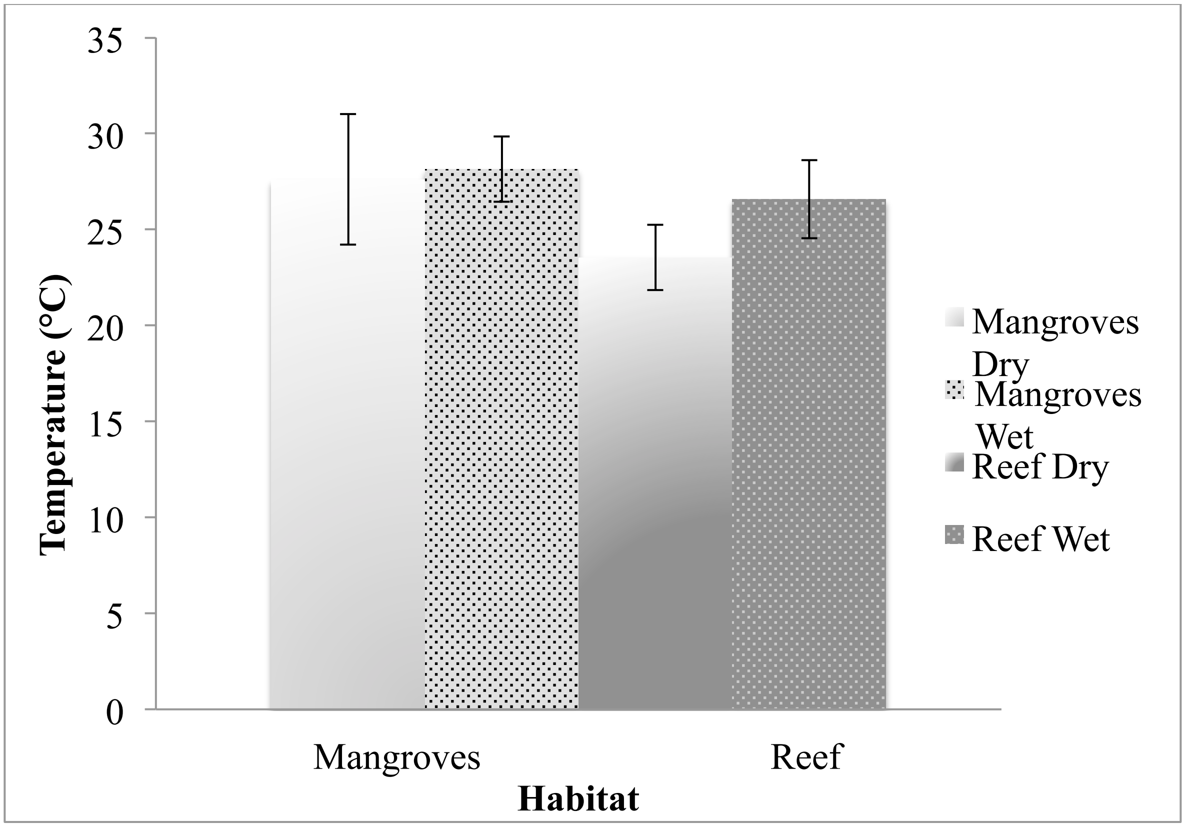

Figure 3. Mean water temperature (°C) in the mangroves and on the reef during the dry (December-April) and wet (May-November) seasons.

Muscle Stable Isotope Data

Muscle Species Data

A total of 263 muscle tissue samples from individual fish were analyzed for carbon and nitrogen stable isotope ratios. A Wilk's lambda test showed no significant difference for both $\delta^{13}C$ and $\delta^{15}N$ between habitat and season (DF =3, F = 1.056, p = 0.812; DF = 3, F = 1.195, p = 0.275), habitat and age class (DF = 3, F = 1.705, p = 0.402; DF = 3, F = 1.705, p =0.247), season and age class (DF = 3, F = 1.589, p = 0.443; DF = 3, F = 1.504, p = 0.221), and among habitat, season, and age class (DF = 5, F = 1.478, p = 0.490; DF = 5, F =1.09, p = 0.923).

The mean $\delta^{13}C$ for all fish samples was -17.01‰ ± 2.18 with a range from -22.13 to -12.40‰. A Kruskal-Wallis test revealed that $\delta^{13}C$ was significantly different among species, combined adults and juveniles (DF = 6, F = 128.932, $p \leq 0.001$). French grunts were the most enriched in $\delta^{13}C$ followed by bluestriped grunts, gray snapper, lane snapper, yellowfin mojarra, sailor's choice, and great barracuda.

The mean $\delta^{15}N$ was 11.91‰ ± 1.02 with a range from 8.68 to 16.02‰. Species were not significantly different between each other in $\delta^{15}N$ (DF = 6, F = 63.173, p = 0.283). Great barracuda were the most enriched in $\delta^{15}N$, followed by lane snapper, gray snapper, yellowfin mojarra, French grunt, sailor's choice, and bluestriped grunt (Table 4) (Figures 4 and 5).

Muscle Age Class Data

A total of 185 juvenile and 78 adult muscle samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$. The $\delta^{13}C$ ranged from -22.13 to -12.40‰ for the juvenile fish and averaged -17.90‰ ± 1.86, while the adults ranged from -18.57 to -12.44‰, with a mean of -14.89‰ ± 1.253. Adult samples were, on average, 1.88 ± 0.11‰ more enriched in $\delta^{13}C$ than juvenile samples (DF = 1, F = 97.991, $p \leq 0.001$). Age classes were not significantly different in $\delta^{13}C$ between reef tracts (DF = 1, p = 0.683). The bluestriped grunt was the most enriched juvenile of any species, followed by the great barracuda, French grunt, lane snapper, yellowfin mojarra, gray snapper, and sailor's choice. Lane snapper was the most enriched adult in $\delta^{13}C$, followed by sailor's choice, French grunt, gray snapper, bluestriped grunt, great barracuda, and yellowfin mojarra.

Juvenile fish muscle ranged from 8.68 to 14.17‰ in $\delta^{15}N$ and averaged 12.06‰ ± 0.97. The $\delta^{15}N$ in adult muscle ranged from 9.58 to 16.02‰ and averaged 11.57‰ ± 1.06. Adult fish muscle was significantly more enriched in nitrogen $\delta^{15}N$ than juvenile samples (DF = 1, F = 23.552, $p \leq 0.001$). The most enriched $\delta^{15}N$ in juvenile fish was lane snapper, followed by great barracuda, French grunt, yellowfin mojarra, gray snapper, bluestriped grunt, and sailor's choice. Adult great barracuda were the most enriched in $\delta^{15}N$, followed by gray snapper, yellowfin mojarra, French grunt, lane snapper, bluestriped grunt, and sailor's choice (Table 5) (Figure 6).

Muscle Habitat Data

A total of 162 fish were collected in the mangroves and 101 fish were collected on the reef. The mean $\delta^{13}C$ for all samples from the mangroves was -18.36‰ ± 1.43 and ranged from -24.58 to -14.57‰. On the reef, $\delta^{13}C$ ranged from -21.25 to -12.40‰, with a mean of -15.02‰ ± 1.47. Fish muscle collected in the mangroves was significantly more depleted in $\delta^{13}C$ than fish collected on the reef (DF = 1; F = 18.996, $p \leq 0.001$). Gray snapper was the most depleted in $\delta^{13}C$ in the mangroves followed by sailor's choice, French grunt, great barracuda, yellowfin mojarra, bluestriped grunt, and lane snapper. On the reef yellowfin mojarra were the most depleted in $\delta^{13}C$ followed by great barracuda, bluestriped grunt, gray snapper, French grunt, sailor's choice, and lane snapper (Table 6).

The $\delta^{15}N$ of fish from the mangroves ranged from 9.39 to 14.14‰, with a mean of 12.15‰ ± 0.92. On the reef the fish $\delta^{15}N$ ranged from 8.68 to 16.02‰, with a mean of 11.54‰ ± 1.06. Fish collected in the mangroves were also significantly different in $\delta^{15}N$ than fish collected on the reef (DF = 1, F = 5.959, $p \leq 0.001$). In the mangroves, sailor's choice was the most depleted in $\delta^{15}N$ followed by French grunt, gray snapper, yellowfin mojarra, great barracuda, lane snapper, and bluestriped grunt. On the reef, sailor's choices were the most depleted in $\delta^{15}N$ followed by bluestriped grunt, lane snapper, French grunt, gray snapper, yellowfin mojarra, and great barracuda (Table 6) (Figure 7).

Table 4. Total number, mean (x̄), standard deviation (SD), and range of muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for all fish species

	$\delta^{13}C$ Muscle Data			**$\delta^{15}N$ Muscle Data**		
	All Samples			**All Samples**		
Species	**N**	**Range (‰)**	**x̄ ± SD (‰)**	**N**	**Range (‰)**	**x̄ ± SD (‰)**
Gray Snapper	19	-22.13 to -12.44	-16.42 ± 3.1	19	9.30 to 16.02	12.14 ± 1.52
Lane Snapper	13	-20.06 to -13.84	-16.61 ± 1.6	13	11.25 to 12.98	12.33 ± 0.57
Bluestriped Grunt	32	-19.95 to -12.40	-15.3 ± 1.57	32	8.68 to 13.51	11.17 ± 1.01
French Grunt	49	-18.59 to -13.66	-14.75 ± 0.92	49	10.82 to 13.34	11.5 ± 0.63
Sailor's Choice	12	-21.15 to -14.11	-18.42 ± 2.23	12	9.62 to 12.43	11.19 ± 0.93
Yellowfin Mojarra	61	-21.25 to -14.57	-18.09 ± 1.41	61	9.39 to 14.14	12.05 ± 1.06
Great Barracuda	77	-21.58 to -15.65	-18.54 ± 1.27	77	9.88 to 15.13	12.42 ± 0.73

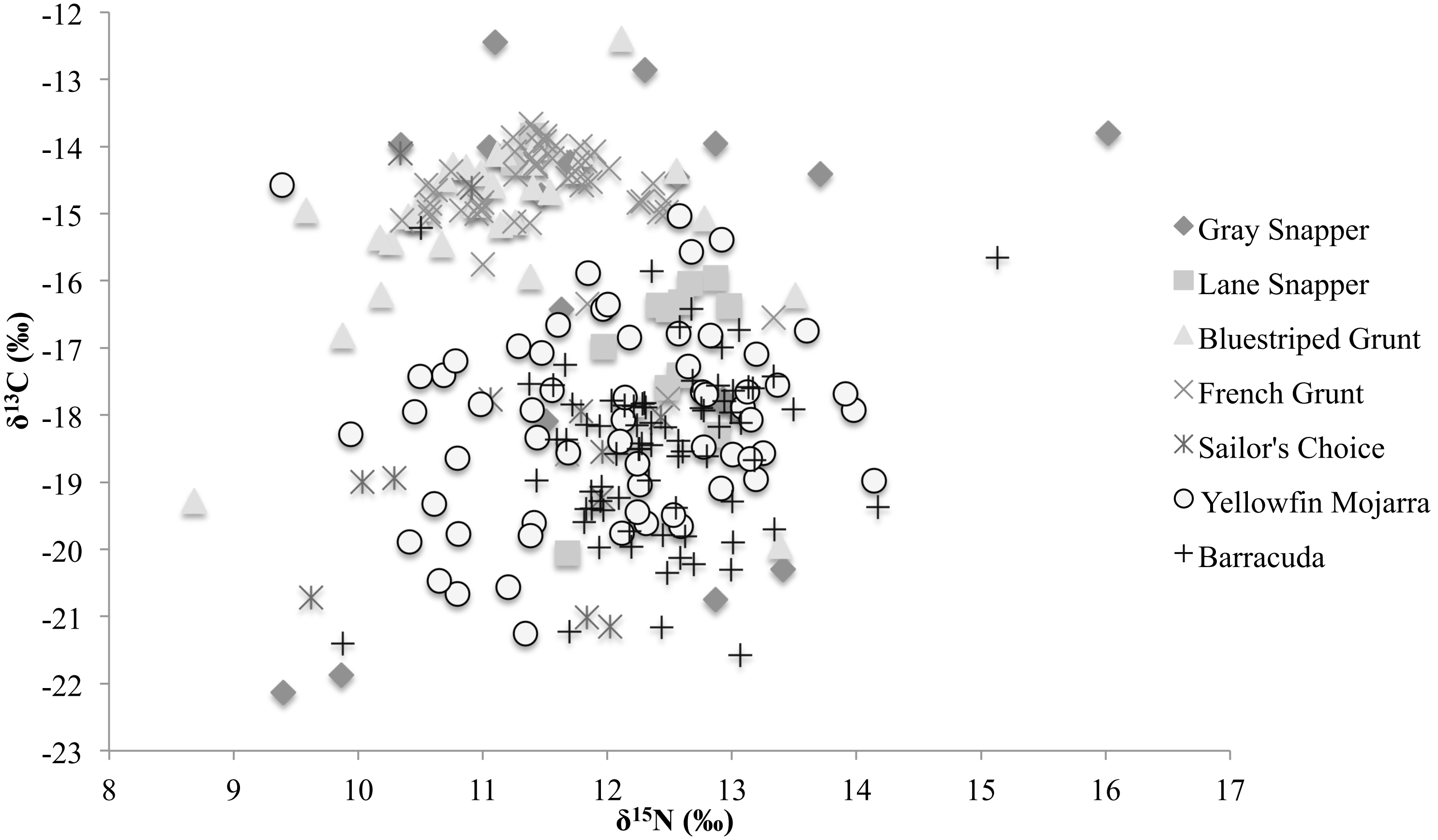

Figure 4. Muscle δ^{13}C (‰) and δ^{15}N (‰) values by species for specimens of seven teleost fish species caught in Broward County, Florida. All sizes have been included.

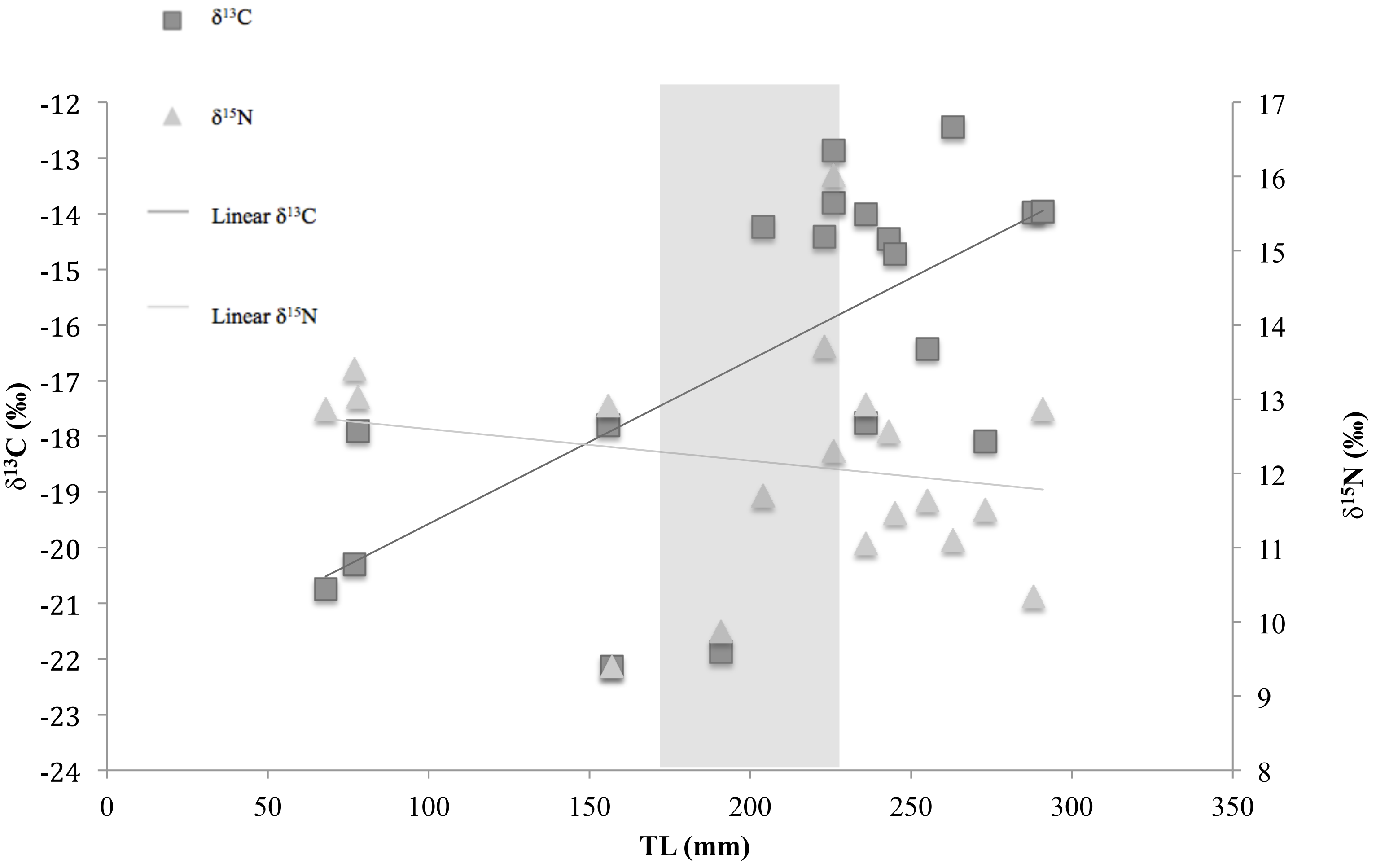

Figure 5a. Muscle δ^{13}C (‰) and δ^{15}N (‰) compared to TL for gray snapper. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

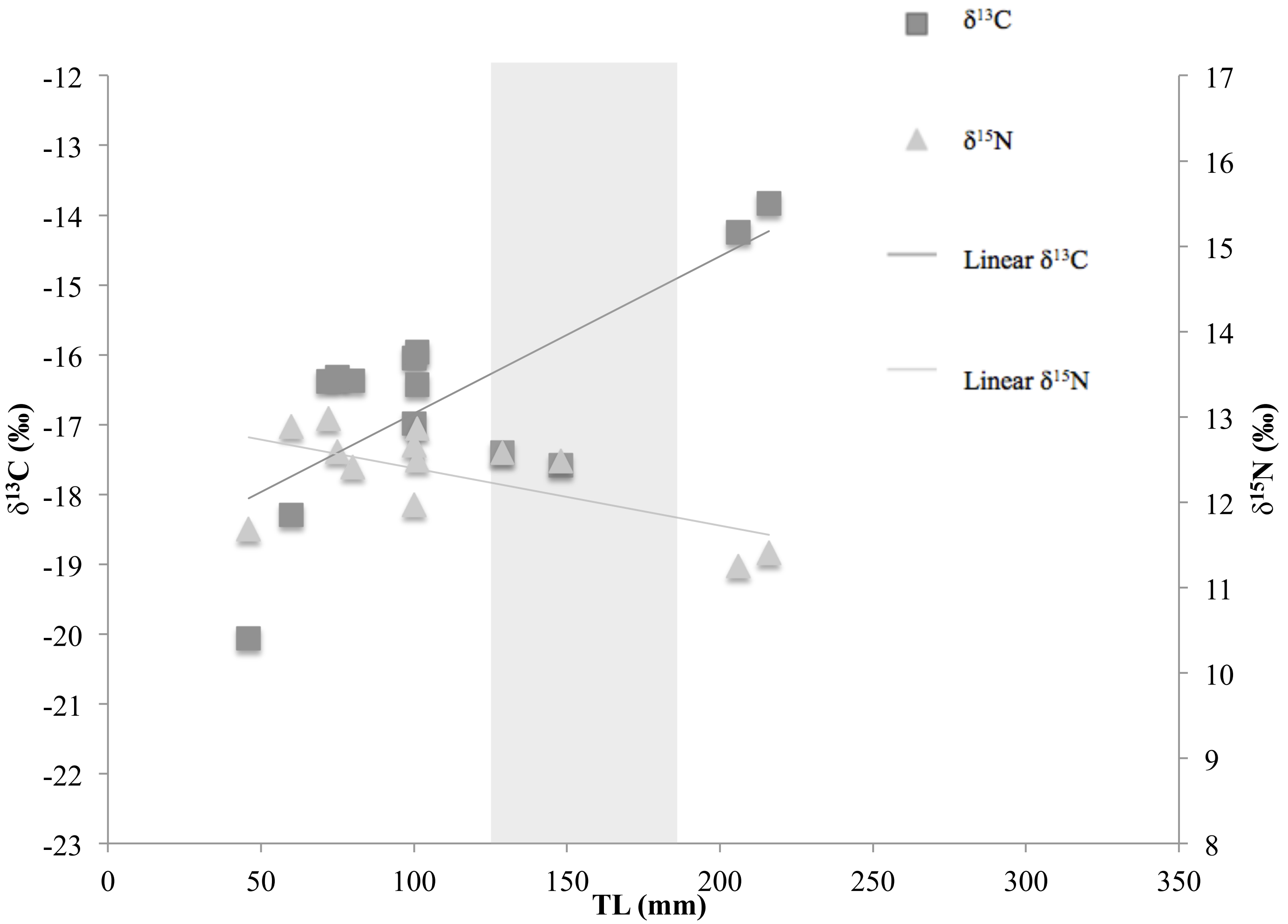

Figure 5b. Muscle δ^{13}C (‰) and δ^{15}N (‰) compared to TL for lane snapper. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

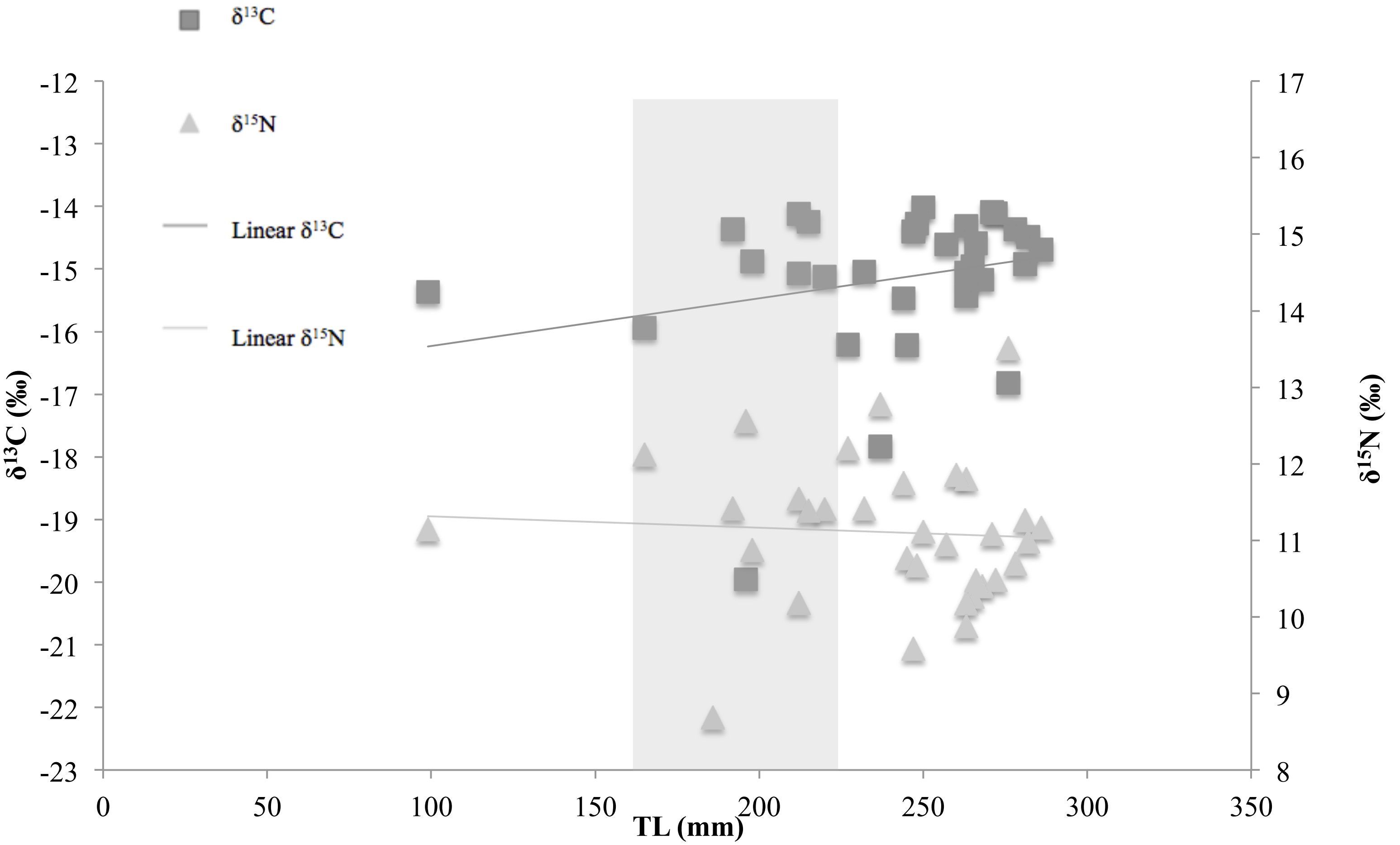

Figure 5c. Muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) compared to TL for bluestriped grunt. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

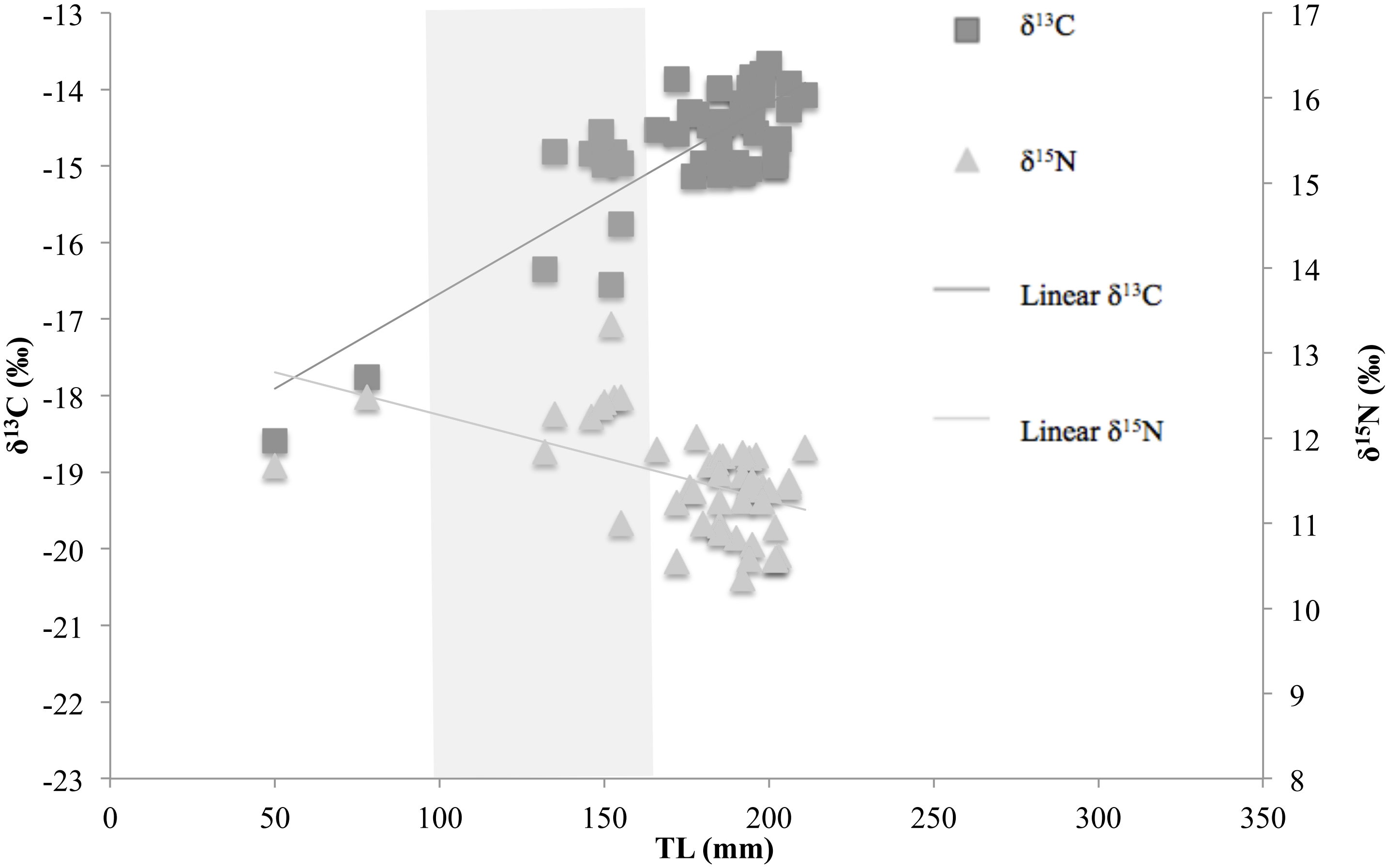

Figure 5d. Muscle δ^{13}C (‰) and δ^{15}N (‰) compared to TL for French grunt. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

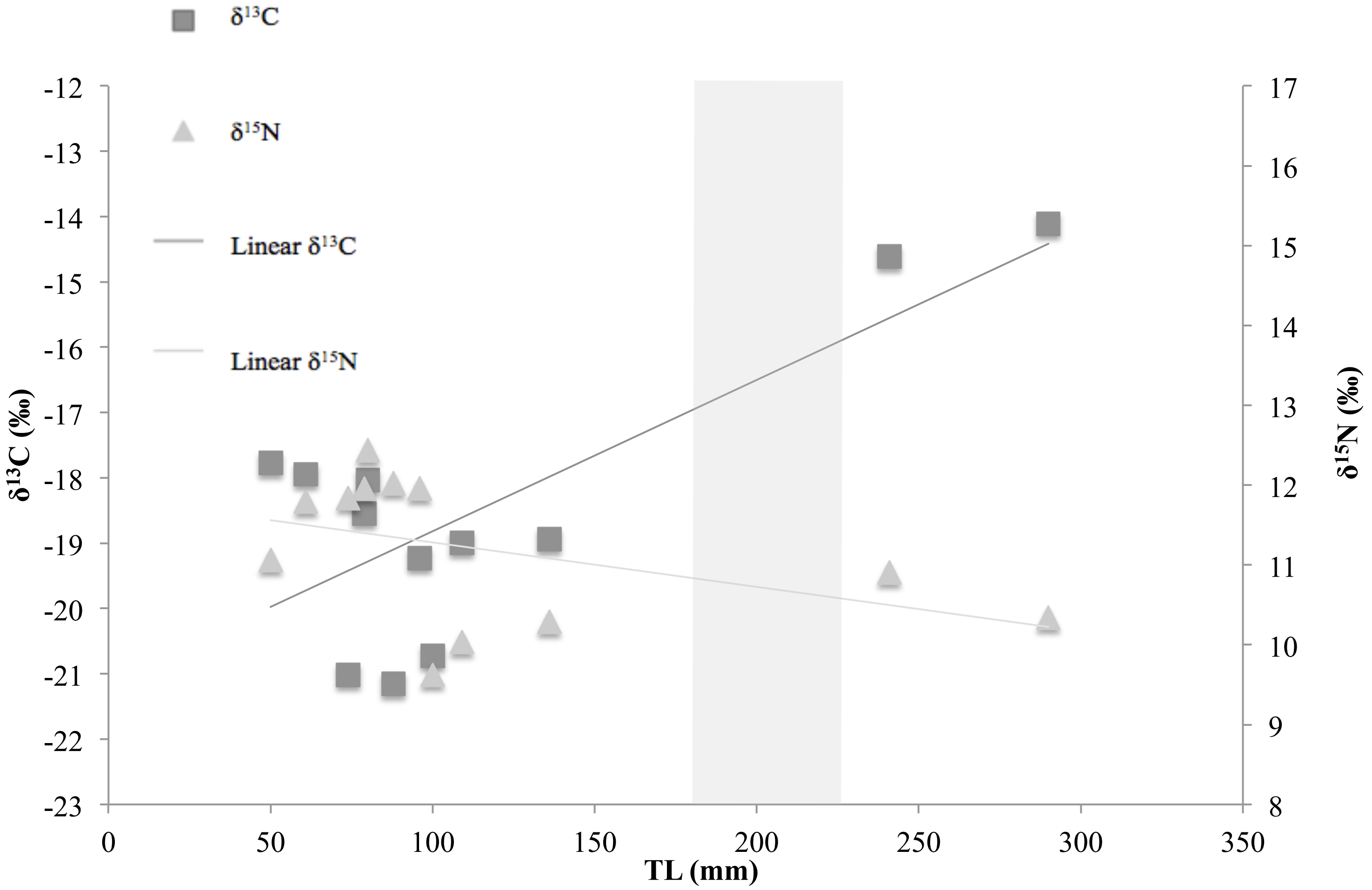

Figure 5e. Muscle δ^{13}C (‰) and δ^{15}N (‰) compared to TL for sailor's choice. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

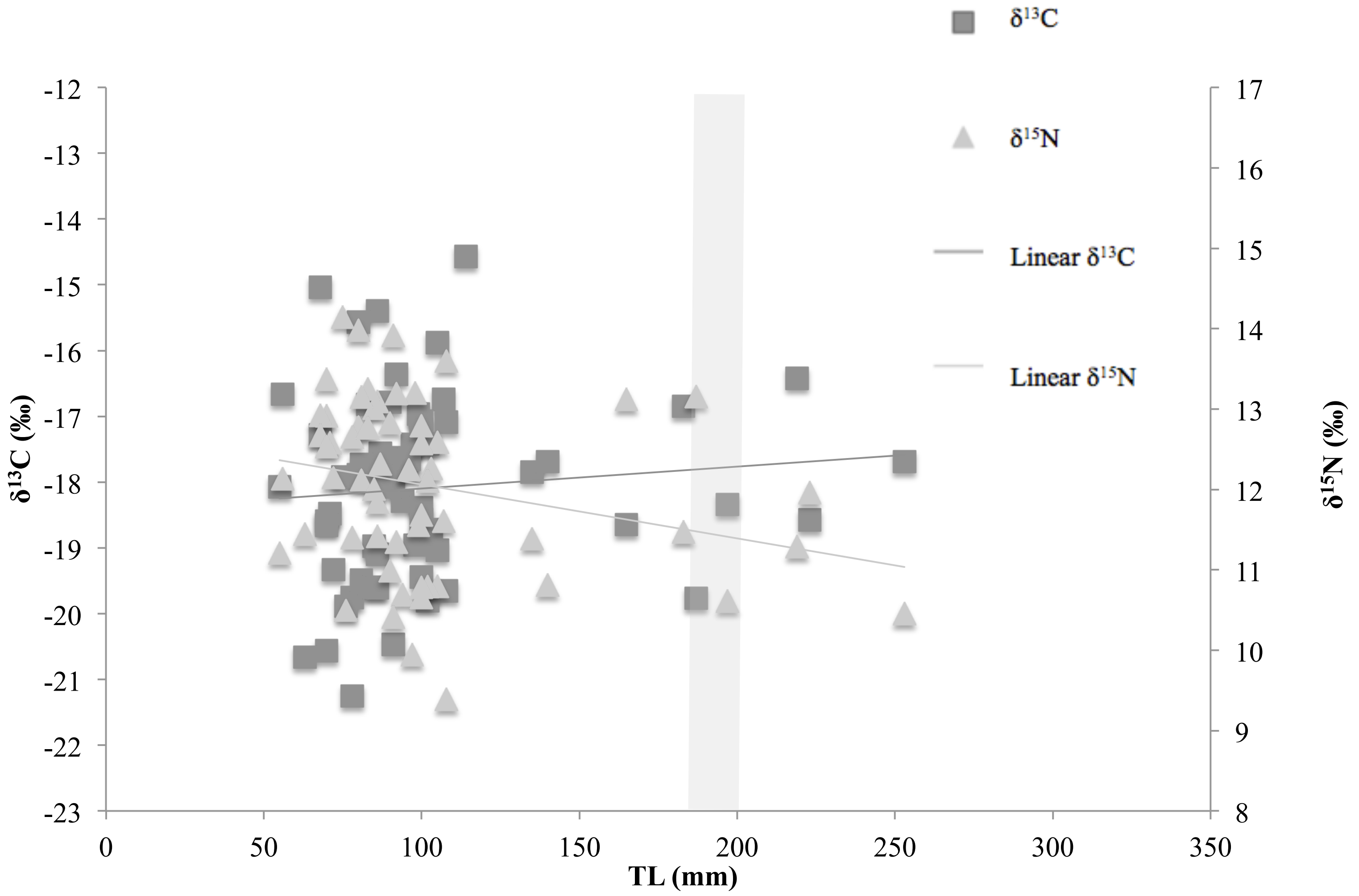

Figure 5f. Muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) compared to TL for yellowfin mojarra. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

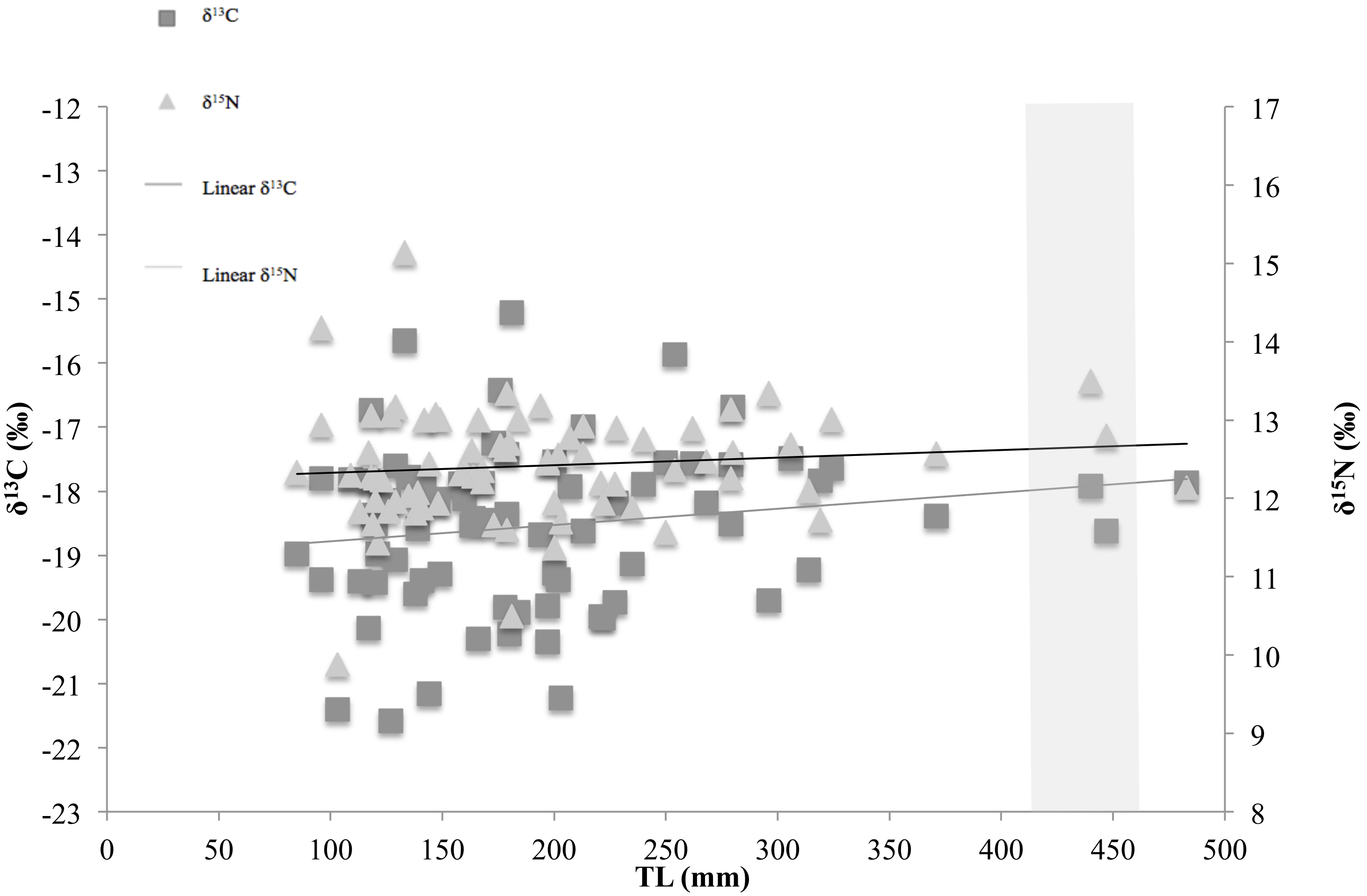

Figure 5g. Muscle $\delta^{13}C$ (‰) (dark gray square) and $\delta^{15}N$ (‰) (light gray triangle) compared to TL for great barracuda. Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

Table 5. Total number, mean (x̄), standard deviation (SD), and range of muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for juvenile and adult fishes for all species

	Age Class					
	$\delta^{13}C$ Muscle Data					
	Juvenile			**Adult**		
Species	**N**	**Range**	**x̄ ± SD**	**N**	**Range**	**x̄ ± SD**
Gray Snapper	8	-22.13 to -14.02	-18.69 ± 3.11	11	-18.09 to -12.44	-14.77 ± 1.86
Lane Snapper	11	-20.06 to -15.96	-17.08 ± 1.22	2	-14.24 to -13.84	-14.04 ± 0.29
Bluestriped Grunt	18	-19.95 to -12.40	-15.66 ± 1.91	14	-16.22 to -14.11	-14.79 ± 0.63
French Grunt	6	-18.59 to -14.81	-16.19 ± 1.66	43	-16.55 to -13.79	-14.55 ± 0.56
Sailor's Choice	10	-21.15 to -17.77	-19.24 ± 1.22	2	-14.61 to -14.11	-14.36 ± 0.36
Yellowfin Mojarra	57	-21.25 to -14.57	-18.07 ± 1.46	4	-18.57 to -17.69	-18.31 ± 0.44
Great Barracuda	75	-21.58 to -15.86	-15.86 ± 1.24	2	-17.86 to -15.65	-16.76 ± 1.56

	Age Class					
	$\delta^{15}N$ Muscle Data					
	Juvenile			**Adult**		
Species	**N**	**Range**	**x̄ ± SD**	**N**	**Range**	**x̄ ± SD**
Gray Snapper	8	9.40 to 13.41	11.75 ± 1.54	11	10.34 to 16.02	12.43 ± 1.86
Lane Snapper	11	11.97 to 12.98	12.51 ± 0.39	2	11.25 to 11.40	11.33 ± 0.11
Bluestriped Grunt	18	8.68 to 13.51	11.38 ± 1.17	14	9.58 to 11.75	10.88 ± 0.67
French Grunt	6	11.68 to 12.49	12.17 ± 0.34	43	10.36 to 12.48	11.4 ± 0.6
Sailor's Choice	10	9.62 to 12.43	11.30 ± 0.98	2	10.34 to 10.91	10.62 ± 0.40
Yellowfin Mojarra	57	9.39 to 14.14	12.03 ± 1.04	4	10.80 to 13.92	12.35 ± 1.47
Great Barracuda	75	9.88 to 14.17	12.39 ± 0.66	2	12.14 to 15.13	13.64 ± 2.12

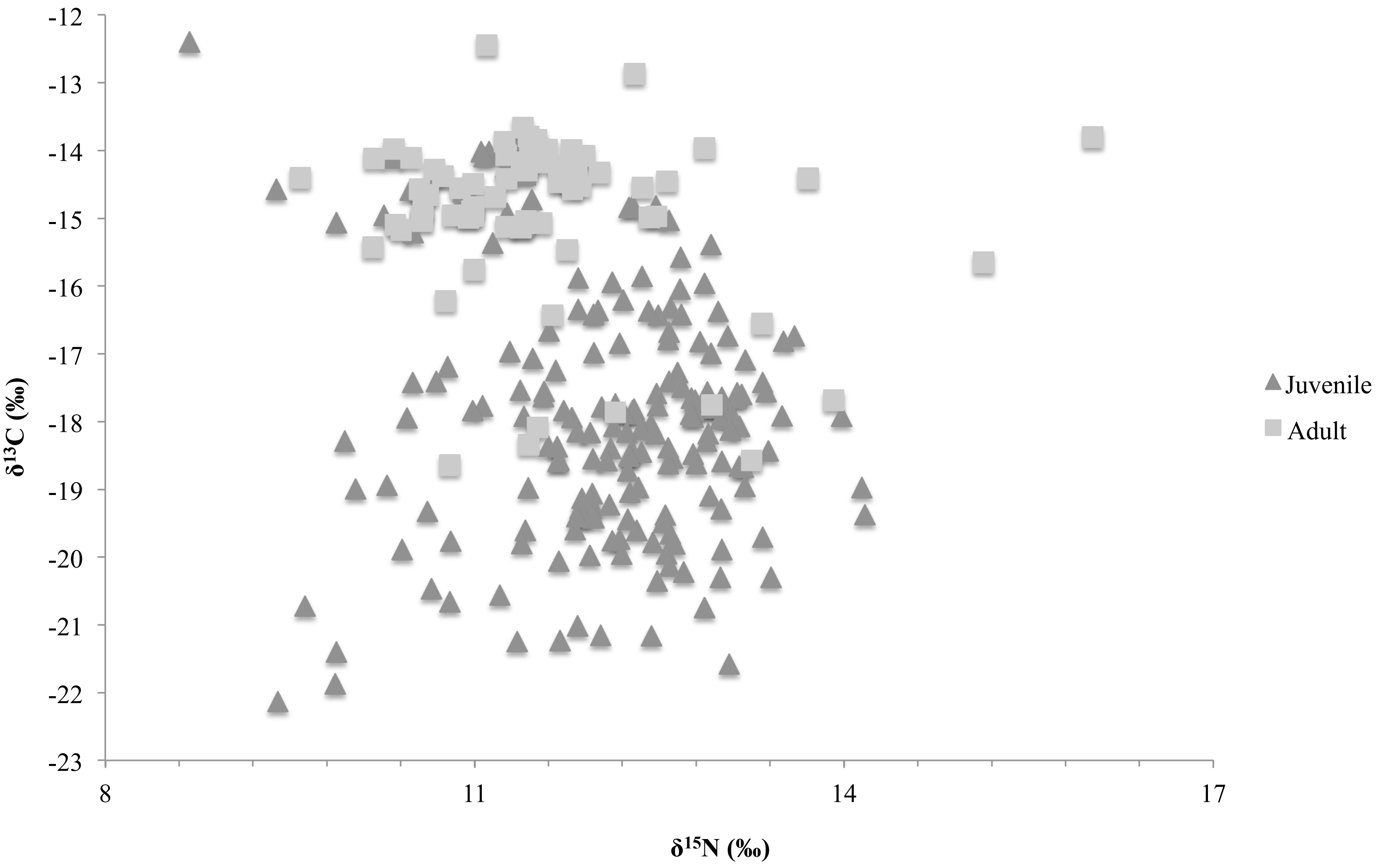

Figure 6. Comparisons of muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for juvenile (dark gray triangle) versus adult (light gray square) fishes caught in Broward County, Florida.

Muscle Season Data

A total of 92 fish were collected in the dry season and 170 samples were collected during the wet season. Also, no significant difference was found between reef tracts and season (DF = 1, p = 0.683). On average δ^{13}C was -16.56‰ ±2.05 and ranged from -22.13 to -12.40‰ for all samples collected during the dry season. The δ^{13}C ranged from -21.58 to -12.86‰, with a mean of -17.32‰ ± 2.21 during the wet season. Fish collected during the wet season were not significantly different in δ^{13}C than samples collected during the dry season (DF = 1, F = 2.459, p = 0.117). Yellowfin mojarra were the most depleted species in δ^{13}C, which was collected during the dry season, followed by great barracuda, lane snapper, sailor's choice, gray snapper, bluestriped grunt, and French grunt. Sailor's choice was the most depleted in δ^{13}C during the wet season, followed by great barracuda, yellowfin mojarra, gray snapper, lane snapper, bluestriped grunt, and French grunt (Table 7).

The δ^{15}N ranged from 8.68 to 16.02‰, with a mean of 11.96‰ ± 1.08 for all fish during the wet season. During the wet season δ^{15}N ranged from 9.38 to 14.17‰, with a mean of 11.89‰ ± 0.99. No significant difference was found in δ^{15}N between seasons (DF = 1, F = 1.926, p = 0.336). During the dry season, bluestriped grunt were the most depleted in δ^{15}N, followed by sailor's choice, French grunt, gray snapper, yellowfin mojarra, lane snapper, and great barracuda. During the wet season, sailor's choice was the most depleted in δ^{15}N, followed by bluestriped grunt, French grunts, yellowfin mojarra, lane snapper, great barracuda, and gray snapper (Table 7) (Figure 8).

Table 6. Total number, mean ($\bar{x}$), standard deviation (SD), and range of muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) in the mangroves and on the reef for all species

	Habitat					
	$\delta^{13}C$ Muscle Data					
	Mangroves			**Reef**		
Species	**N**	**Range (‰)**	**$\bar{x} \pm$ SD (‰)**	**N**	**Range (‰)**	**$\bar{x} \pm$ SD (‰)**
Gray Snapper	5	-22.13 to -17.9	-20.59 ± 1.69	14	-18.09 to -12.44	-14.93 ± 1.84
Lane Snapper	11	-20.06 to - 15.96	-17.08 ± 1.25	2	-14.24 to -13.84	-14.04 ± 0.29
Bluestriped Grunt	2	-18.43 to -16.82	-17.62 ± 1.14	30	-19.95 to -12.4	-15.16 ± 1.48
French Grunt	1	-18.59	-	48	-17.76 to -13.66	-14.67 ± 0.74
Sailor’s Choice	10	-21.15 to -17.77	-19.24 ± 1.28	2	-14.61 to -14.11	-14.36 ± 0.36
Yellowfin Mojarra	58	-20.66 to -14.57	-18.03 ± 1.38	3	-21.25 to -17.69	-19.17 ± 1.86
Great Barracuda	75	-24.58 to -15.21	-18.57 ± 1.23	2	-19.37 to -15.66	-17.51 ± 2.63

	Habitat					
	$\delta^{15}N$ Muscle Data					
	Mangroves			**Reef**		
Species	**N**	**Range (‰)**	**$\bar{x} \pm$ SD (‰)**	**N**	**Range (‰)**	**$\bar{x} \pm$ SD (‰)**
Gray Snapper	5	9.40 to 13.41	11.72 ± 1.92	14	10.4 to 16.02	12.29 ± 1.41
Lane Snapper	11	11.68 to 12.98	12.51 ± 0.39	2	11.25 to 11.40	11.33 ± 0.11
Bluestriped Grunt	2	13.39 to 13.51	13.45 ± 0.09	30	8.68 to 12.78	11.03 ± 0.86
French Grunt	1	11.68	-	48	10.36 to 12.49	11.49 ± 0.63
Sailor’s Choice	10	9.62 to 12.43	11.3 ± 0.98	2	10.34 to 10.91	10.62 ± 0.4
Yellowfin Mojarra	58	9.39 to 14.14	12.01 ± 1.05	3	11.34 to 13.92	12.84 ± 1.33
Great Barracuda	75	9.88 to 13.50	12.36 ± 0.63	2	14.17 to 15.13	14.65 ± 0.68

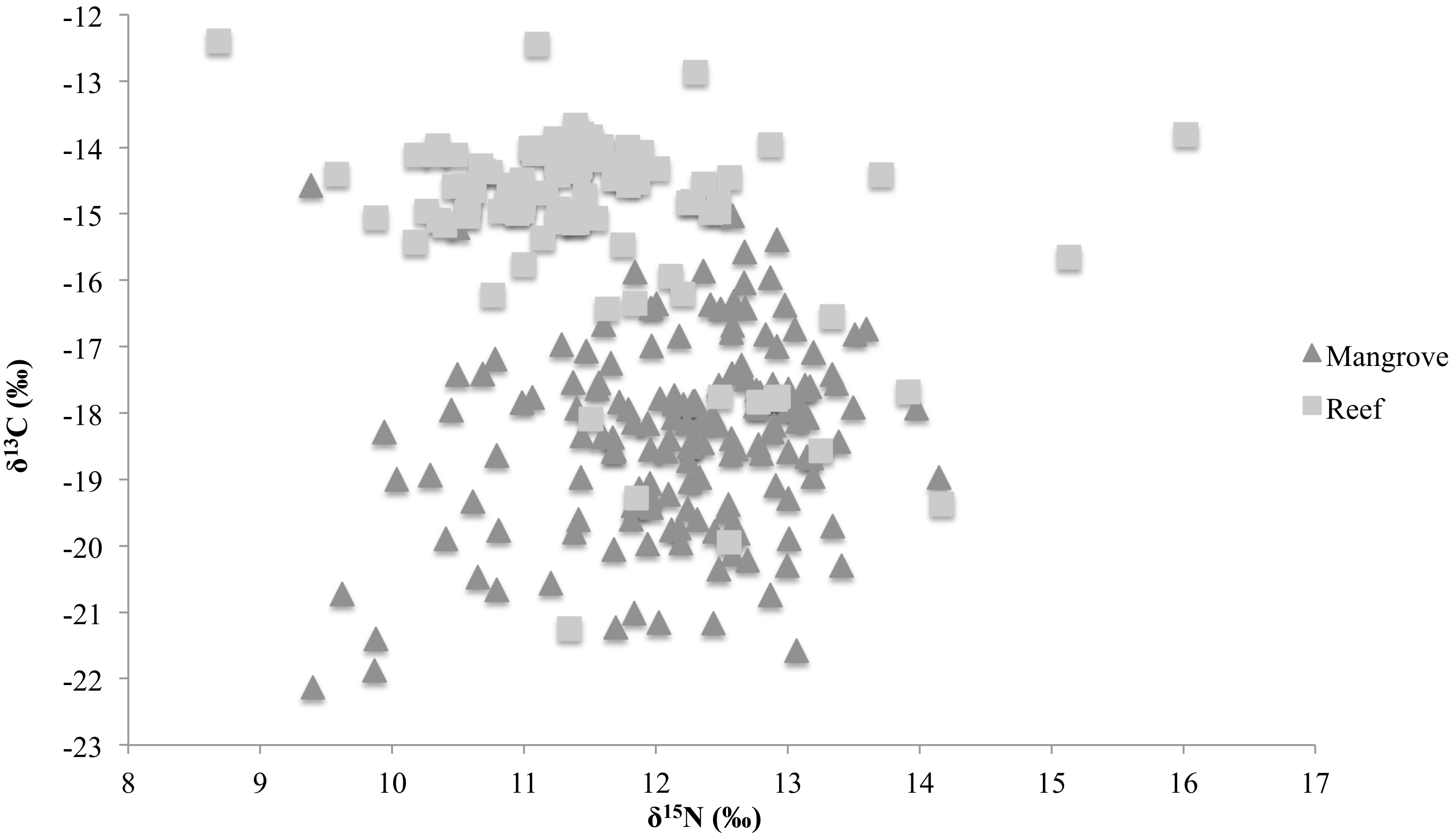

Figure 7. Comparisons of muscle δ^{13}C (‰) and δ^{15}N (‰) for fish specimens caught in the mangroves (dark gray triangle) versus reefs (light gray square) in Broward County, Florida.

Otolith Stable Isotope Results

Otolith samples consisted of a core and an edge sample. Core samples are laid down during the fish's developmental stages, whereas the edge samples are laid down in the most recent period of the fish's life from the environment in which the fish was caught. A total of 138 otolith samples were processed, 70 core samples and 68 edge samples, from 74 individuals. Sixty-three individual fishes had both core and edge samples processed, including nine gray snappers, nine lane snappers, ten bluestriped grunt, ten French grunt, nine sailor's choice, six yellowfin mojarra, and ten great barracuda. The difference in number of core and edge samples was due to the fact that some samples from juvenile fish were too small to obtain both a core and edge sample. In particular, the yellowfin mojarra and juvenile snapper have very thin otoliths; therefore, they were both more fragile and had less material. Also, some samples were lost in the mass spectrometry analysis. A Wilks' Lambda test found no significant difference between age class and season (DF = 3, F = 1.532, p = 0.220), age class and habitat (DF =3, F = 1.766, p = 0.467), and among age class, habitat, and season (DF = 5, F = 1.23, p = 0.794). However, a significant difference was found between habitat and season (DF = 3, F = 4.803, p =0.010).

$\delta^{18}O$

Shapiro-Wilk test showed no normality for δ^{18}O among species (DF = 137, p = 0.000). A Kruskal-Wallis test showed species were not significantly different among each other (DF = 6, F = 7.899, p = 0.246). The otolith δ^{18}O was not significantly different between reef tracts (DF = 1, F = 1.434, p = 0.512). Core and edge samples were not significantly different among species (Core: DF = 6, F = 4.309, p = 0.635) (Edge: DF = 6, F = 7.870, p = 0.248). Yellowfin mojarra were the most depleted in $\delta^{18}O$, followed by lane snapper, sailor's choice, gray snapper, French grunt, great barracuda, and bluestriped grunt. Lane snapper had the most depleted $\delta^{18}O$ core samples, followed by yellowfin mojarra, great barracuda, sailor's choice, gray snapper, French grunt, and bluestriped grunt. Yellowfin mojarra had the most depleted edge samples, followed by gray snapper, sailor's choice, French grunt, lane snapper, bluestriped grunt, and great barracuda. (Table 8) (Figures 10 and 11).

Table 7. Total number, mean (x̄), standard deviation (SD), and range of muscle $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for fish in the wet and dry seasons for all species

	Season					
	$\delta^{13}C$ Muscle Data					
	Dry			**Wet**		
Species	**N**	**Range (‰)**	**x̄ ± SD (‰)**	**N**	**Range (‰)**	**x̄ ± SD (‰)**
Gray Snapper	13	-22.13 to -12.44	-16.52 ± 3.32	6	-20.30 to -12.86	-16.19 ± 2.86
Lane Snapper	8	-20.08 to -15.98	-16.89 ± 1.39	5	-18.24 to -13.84	-16.15 ± 1.99
Bluestriped Grunt	15	-19.28 to -12.4	-15.5 ± 1.86	17	-19.95 to -14.01	-15.18 ± 1.39
French Grunt	19	-18.59 to -14.07	-15.04 ± 1.16	30	-16.55 to -13.66	-14.57 ± 0.7
Sailor’s Choice	5	-18.55 to -14.11	-16.65 ± 2.11	7	-21.15 to -17.77	-19.69 ± 1.28
Yellowfin Mojarra	19	-20.56 to -15.557	-17.83 ± 1.36	43	-21.25 to -14.57	-18.21 ± 1.44
Great Barracuda	13	-18.67 to -15.86	-17.69 ± 0.87	62	-21.58 to -17.0	-18.72 ± 1.27

	Season					
	$\delta^{15}N$ Muscle Data					
	Dry			**Wet**		
Species	**N**	**Range (‰)**	**x̄ ± SD (‰)**	**N**	**Range (‰)**	**x̄ ± SD (‰)**
Gray Snapper	13	9.40 to 16.02	12.02 ± 1.72	6	10.34 to 13.41	12.41 ± 1.08
Lane Snapper	8	11.68 to 12.98	12.52 ± 0.39	5	11.25 to 12.88	12.02 ± 0.71
Bluestriped Grunt	15	8.68 to 13.51	11.28 ± 1.32	17	9.58 to 12.78	11.11 ± 0.8
French Grunt	19	10.55 to 12.49	11.58 ± 0.77	30	10.36 to 12.01	11.44 ± 0.52
Sailor’s Choice	5	10.34 to 12.43	11.49 ± 0.85	7	9.62 to 12.02	10.97 ± 1.00
Yellowfin Mojarra	19	12.81 to 13.6	12.29 ± 0.82	42	9.39 to 14.14	11.94 ± 1.15

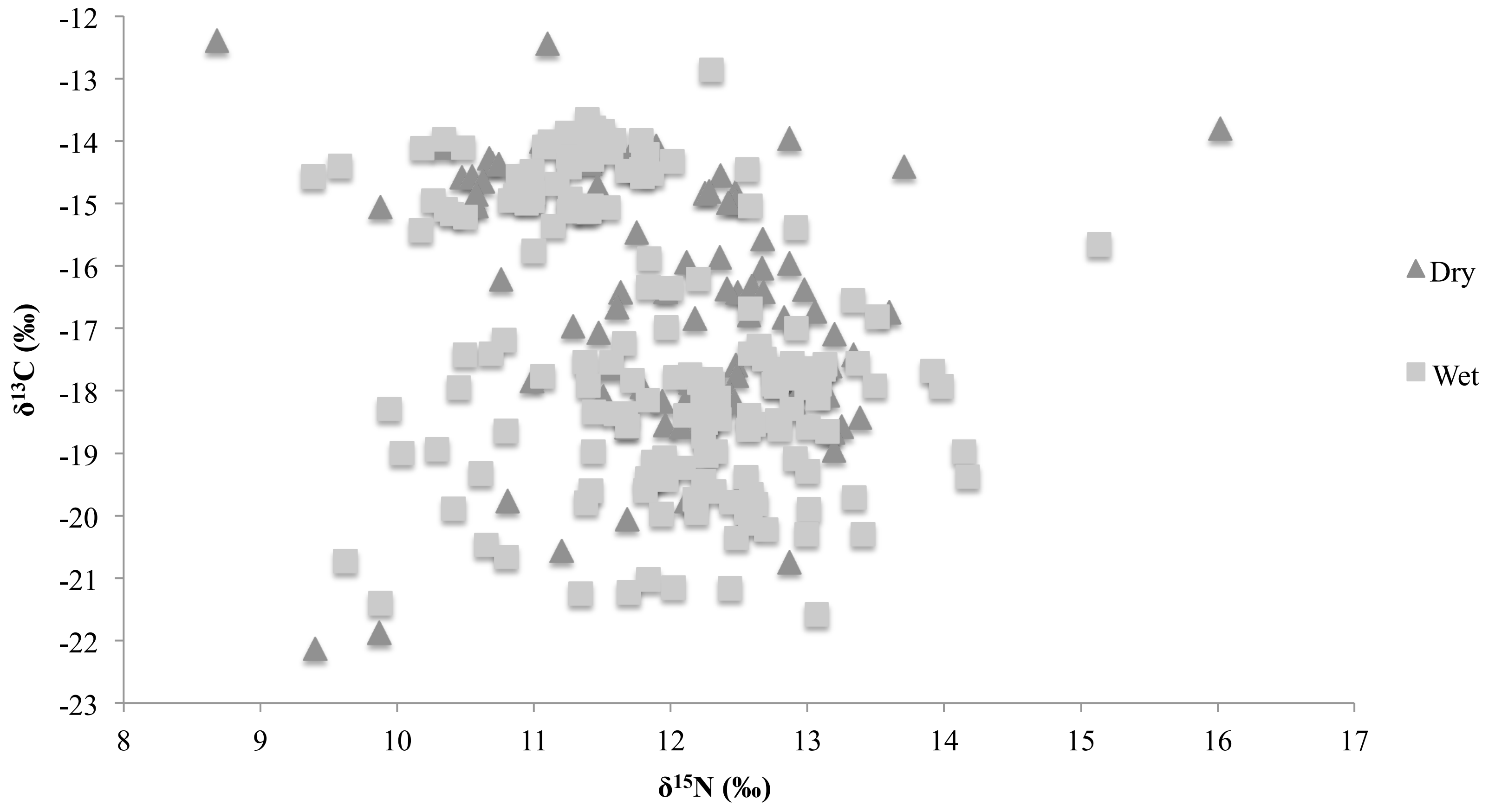

Figure 8. Comparisons of muscle δ^{13}C (‰) and δ^{15}N (‰) for fish specimens caught in the dry (December – April) (dark gray triangle) versus wet (May – November) (light gray square) seasons in Broward County, Florida.

There was no significant difference between core and edge samples; however, gray snapper core samples were more enriched compared to the paired edge samples (DF = 8, p = 0.787) (Figure 11a). Lane snapper had core samples, which were more depleted compared to edge samples (DF = 8, p = 0.208) (Figure 11b). Bluestriped grunt core samples were more depleted than the edge samples (DF = 9, p = 0.324) (Figure 11c). French grunt core samples were more depleted than the edge samples (DF = 9, p = 0.569) (Figure 11d). Sailor’s choice core samples were more enriched than edge samples (DF=8, p=0.441) (Figure 11e). Yellowfin mojarra core samples were more enriched than edge samples (DF=4, p=0.343) (Figure 11f). Barracuda core samples were more depleted compared to the edge samples (DF = 9, p = 0.203) (Figure 11g) (Table 8).

$\delta^{13}C$

Shapiro Wilk Test showed no normality among the otolith δ^{13}C (DF = 138, p = 0.038). Kruskal-Wallis test indicated significant difference among species’ δ^{13}C (DF = 6, F = 25.167, $p \leq 0.001$).. Core samples for all species were significantly different among each other (DF = 6, F = 2.576, p = 0.027), whereas edge samples were not (DF = 6, F = 2.727, p = 0.021). The δ^{13}C was not significantly different between reef tracts (DF =1, F = 1.01, p = 0.927). Out of all the samples, yellowfin mojarra were the most depleted in δ^{13}C, followed by gray snapper, sailor’s choice, great barracuda, lane snapper, bluestriped grunt, and French grunt. Yellowfin mojarra had the most depleted core samples followed by great barracuda, gray snapper, lane snapper, sailor’s choice, bluestriped grunt, and French grunt. Gray snappers had the most depleted edge samples followed by yellowfin mojarra, sailor's choice, great barracuda, lane snapper, bluestriped grunt, and French grunt. (Table 9) (Figure 18).

Gray snapper, lane snapper, French grunt, yellowfin mojarra, and great barracuda each had core samples that were more depleted than their respective edge samples (Figure 11a – 12b, 12d, 12f – 12g). Bluestriped grunt, and sailor's choice had core samples that were more enriched than their respective edge samples (Figures 12c and 12e) (Table 9).

Age Class

A total of 72 juvenile and 66 adult otolith samples were analyzed for δ^{18}O and δ^{13}C. The δ^{18}O ranged from –2.99 to 0.136‰ for the juvenile fish and averaged –0.95‰ ± 0.71, while the adults ranged from –4.06 to -1.02‰, with a mean of –0.96‰ ± 0.967. Juvenile fish otoliths ranged from -7.87 to 0.23‰ in δ^{13}C and averaged -5.03‰ ± 2.00. The δ^{13}C in adult otoliths ranged from -8.92 to -0.38‰ and averaged -3.65‰ ± 2.05. Fish δ^{18}O was not significantly different between age classes (DF =1, F = 6.373, p = 0.371); however, fish were significantly different in δ^{13}C (DF = 1, F = 36.337, p = ≤ 0.001). Age classes were not significantly different between reef tracts for both δ^{18}O and δ^{13}C (DF =1, F = 2.985, p = 0.057).

Juveniles

A total of 72 juvenile samples were processed, 37 core samples and 35 edge samples. There were 12 (7 core and 5 edge) gray snapper, 5 (2 core and 3 edge) lane snapper, 12 (6 core and 6 edge) bluestriped grunt, 6 (3 core and 3 edge) French grunt, 12 (6 core and 6 edge) sailor's choice, 7 (4 core and 3 edge) yellowfin mojarra, and 18 (9 core and 9 edge) great barracuda samples processed. Juveniles were not significantly different in δ^{18}O among species (DF = 6, F = 7.074, p = 0.314, but were for δ^{13}C (DF = 6, F = 2.167, p = 0.58).

δ^{18}O

Juvenile core samples ranged from -2.99 to 0.01‰ with a mean of -1.0‰ ± 0.761. Edge samples ranged from -2.31 to 0.14‰ with a mean of -0.87‰ ± 0.648. Lane snapper was the most depleted, followed by yellowfin mojarra, gray snapper, sailor's choice, French grunt, great barracuda, and bluestriped grunt. Lane snapper, bluestriped grunt, French grunt, and yellowfin mojarra had core samples that were more depleted than edge samples while gray snapper, sailor's choice and great barracuda had core samples that were more enriched than edge samples (Table 10).

δ^{13}C

The δ^{13}C samples for juveniles ranged from -7.87 to 0.23‰ with a mean of -5.03‰ ± 2.00. Core samples ranged from -7.85 to 0.23‰ with a mean of -5.16‰ ± 2.05, and edge samples ranged from -7.87‰ to -0.15‰, with a mean of -4.89‰ ± 1.97. Yellowfin mojarra had the most depleted δ^{13}C otolith samples followed by gray snappers, sailor's choice, lane snapper, bluestriped grunt, great barracuda, and French grunt. Gray snapper, lane snapper, French grunt, yellowfin mojarra, and great barracuda core samples were more depleted than edge samples while bluestriped grunt and sailor's choice core samples were more enriched than edge samples (Table 12).

Adults

A total of 66 adult samples were processed, 32 core and 34 edge samples. Of those 66 samples, there were eight (four core and four edge) mangrove snapper, 15 (eight core and seven edge) lane snapper, 12 (six core and six edge) bluestriped grunt, 17 (eight core and nine edge) French grunts, 5 (two core and three edge) sailor’s choice, seven (three core and four edge) yellowfin mojarra, and two (one core and one edge) great barracuda samples processed. A Kruskal-Wallis test found species’ $\delta^{13}C$ were significantly different among each other (DF = 6, F = 17.423, p = 0.008); however they were not significantly different in $\delta^{18}O$ (DF = 6, F = 5.827, p = 0.443).

$\delta^{18}O$

The $\delta^{18}O$ adult samples ranged from -4.06 to 1.02‰ with a mean of -0.96‰ ± 0.97. Core samples ranged from -3.74 to 0.10‰ with a mean of -1.06‰ ± 0.93, while edge samples ranged from -4.06 to 1.02‰ with a mean of -0.86‰ ± 1.00. On average, yellowfin mojarra were the most depleted, followed by great barracuda, lane snapper, sailor’s choice, gray snapper, French grunt, and bluestriped grunt. Gray snapper, lane snapper, sailor’s choice, and great barracuda core samples were more depleted than edge samples, while French grunt and yellowfin mojarra core samples were more enriched compared to edge samples. Bluestriped grunt core samples were relatively the same as their edge samples (Table 11).

Table 8. Total number, range, mean (x̄), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for seven teleost fish species

δ^{18}O Otolith Data									
	All Samples								
Species	**N**	**Nc**	**Ne**	**Range (‰)**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄ Core±SD**	**x̄ Edge±SD**
Gray Snapper	20	11	9	-2.8 to 0.31	-2.8 to 0.1	-2.31 to 0.31	-0.99 ± 0.86	-0.92 ± 0.97	-1.08 ± 0.74
Lane Snapper	20	10	10	-3.74 to 0.48	-3.74 to -0.31	-2.32 to 0.48	- 1.10 ± 0.97	-1.43 ± 1.05	-0.76 ± 0.79
Bluestriped Grunt	23	12	11	-1.96 to 0.72	-1.96 to -0.02	-1.79 to 0.72	-0.68 ± 0.75	-0.75 ± 0.64	-0.62 ± 0.82
French Grunt	23	11	12	-2.22 to -0.05	-2.22 to -0.19	-1.83 to -0.05	-0.83 ± 0.54	-0.89 ± 0.64	-0.79 ± 0.44
Sailor’s Choice	18	9	9	-2.87 to 1.02	-2.87 to -0.35	-2.35 to 1.02	-0.90 ± 0.90	-1.13 ± 0.77	-0.97 ± 1.04
Yellowfin Mojarra	14	7	7	-4.06 to -0.15	-1.95 to -0.15	-4.06 to -0.52	-1.4 ± 0.996	-1.17 ± 0.64	-1.65 ± 1.27
Great Barracuda	20	10	10	-2.99 to -0.14	-2.31 to 0.01	-1.45 to 0.14	-0.83 ± 0.84	-1.14 ± 0.98	-0.51 ± 0.56

Table 9. Total number, range, mean (x̄), and standard deviation (SD) for otolith δ^{13}C (‰) for all samples (core and edge), core samples, and edge samples for seven teleost fish species

δ^{13}C Otolith Data									
	All Samples								
Species	**N**	**Nc**	**Ne**	**Range (‰)**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄ Core±SD**	**x̄ Edge±SD**
Gray Snapper	20	11	9	-8.92 to -0.97	-7.18 to -0.97	-8.92 to -2.45	-5.11 ± 2.33	-4.64 ± 2.34	-5.69 ± 2.44
Lane Snapper	20	10	10	-7.85 to -1.68	7.85 to -1.68	-6.74 to -1.95	-4.26 ±1 .89	-4.64 ± 2.12	-3.87 ± 1.64
Bluestriped Grunt	23	12	11	-7.62 to -0.41	-7.62 to -1.07	-6.69 to -0.41	-3.49 ± 2.04	-3.59 ± 2.07	-3.39 ± 2.10
French Grunt	23	11	12	-8.51to -0.38	-5.32 to -1.51	-8.51 to -0.38	-3.18 ± 1.66	-3.15 ± 1.17	-3.20 ± 2.07
Sailor’s Choice	18	9	9	-7.69 to -1.28	-7.41 to -1.28	-7.69 to -1.59	-4.87 ± 2.01	-4.55 ±2.19	-5.16 ± 2.11
Yellowfin Mojarra	14	7	7	-8.32 to -3.59	-8.32 to -5.33	-7.50 to -3.59	-6.11 ± 1.20	-6.51 ± 1.14	-5.71 ± 1.22
Great Barracuda	20	10	10	-7.11 to 0.23	-6.83 to 0.23	-6.61 to -0.15	4.43 ± 2.27	-4.83 ± 2.46	-4.04 ± 2.11

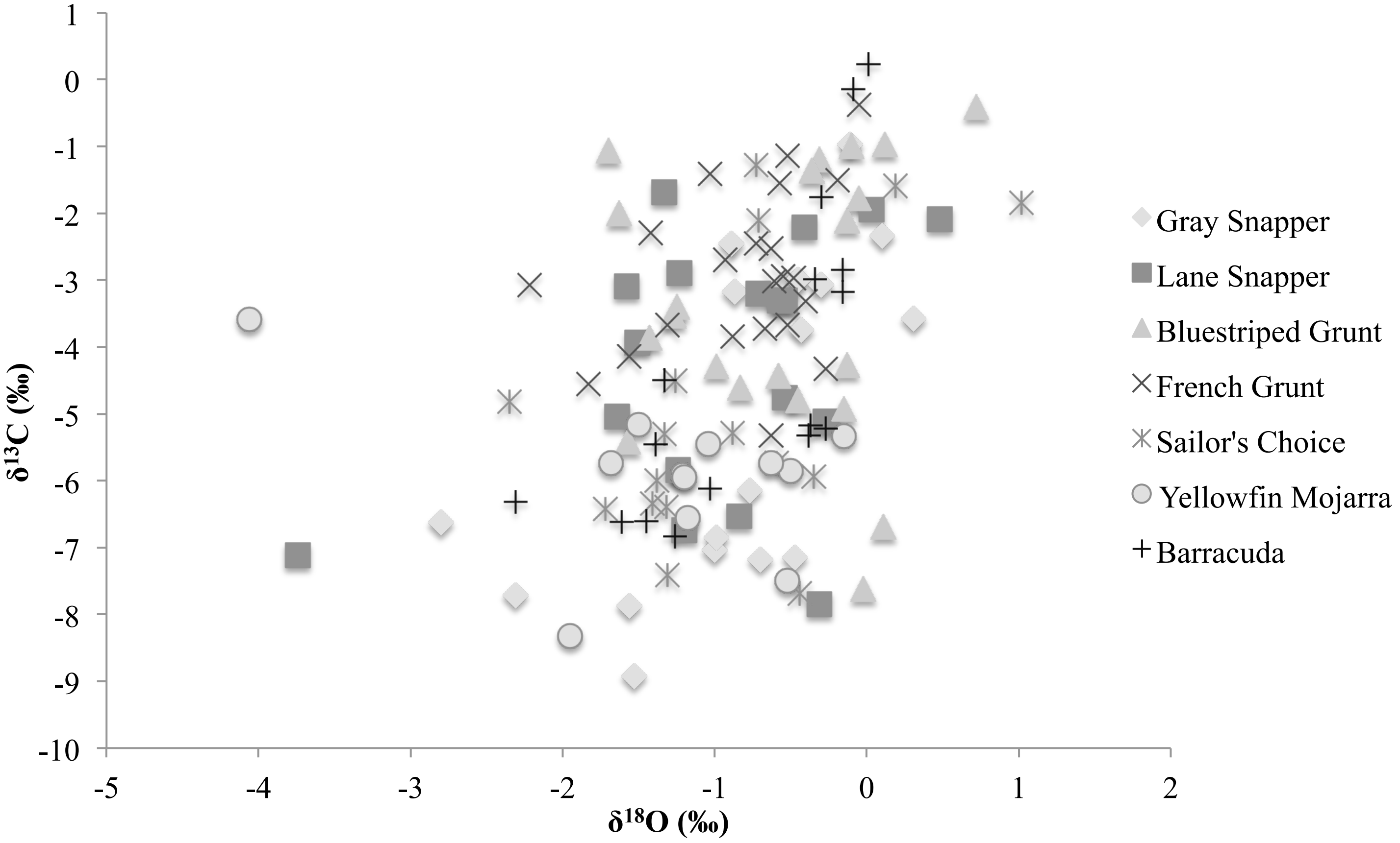

Figure 9. Otolith δ^{18}O (‰) and δ^{13}C (‰) for seven teleost fish species caught in Broward County, Florida. All sizes were included.

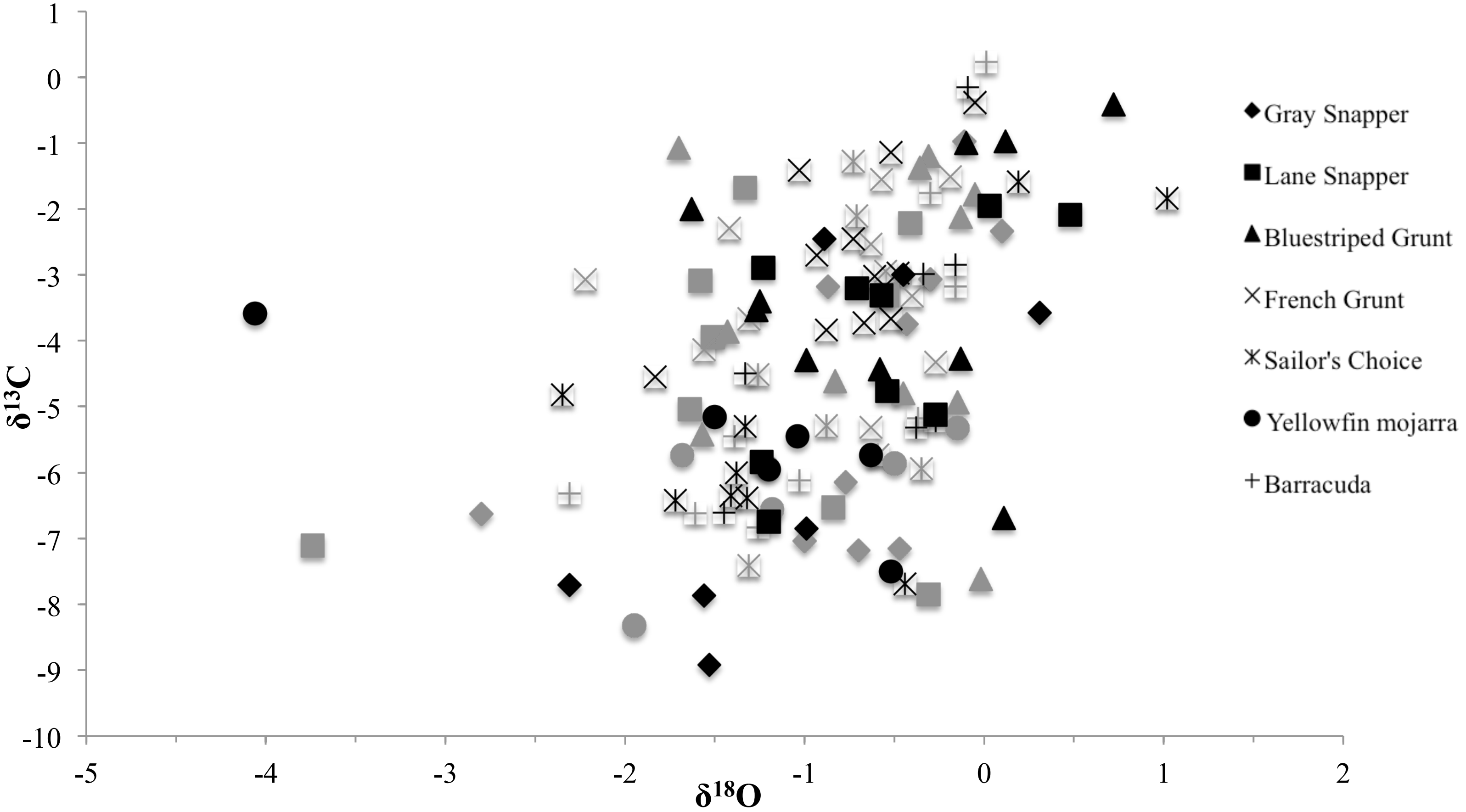

Figure 10. Otolith core and edge $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) values by species for specimens of seven teleost fish species caught in Broward County, Florida. All sizes were included. Gray symbols represent core samples. Black symbols represent edge samples.

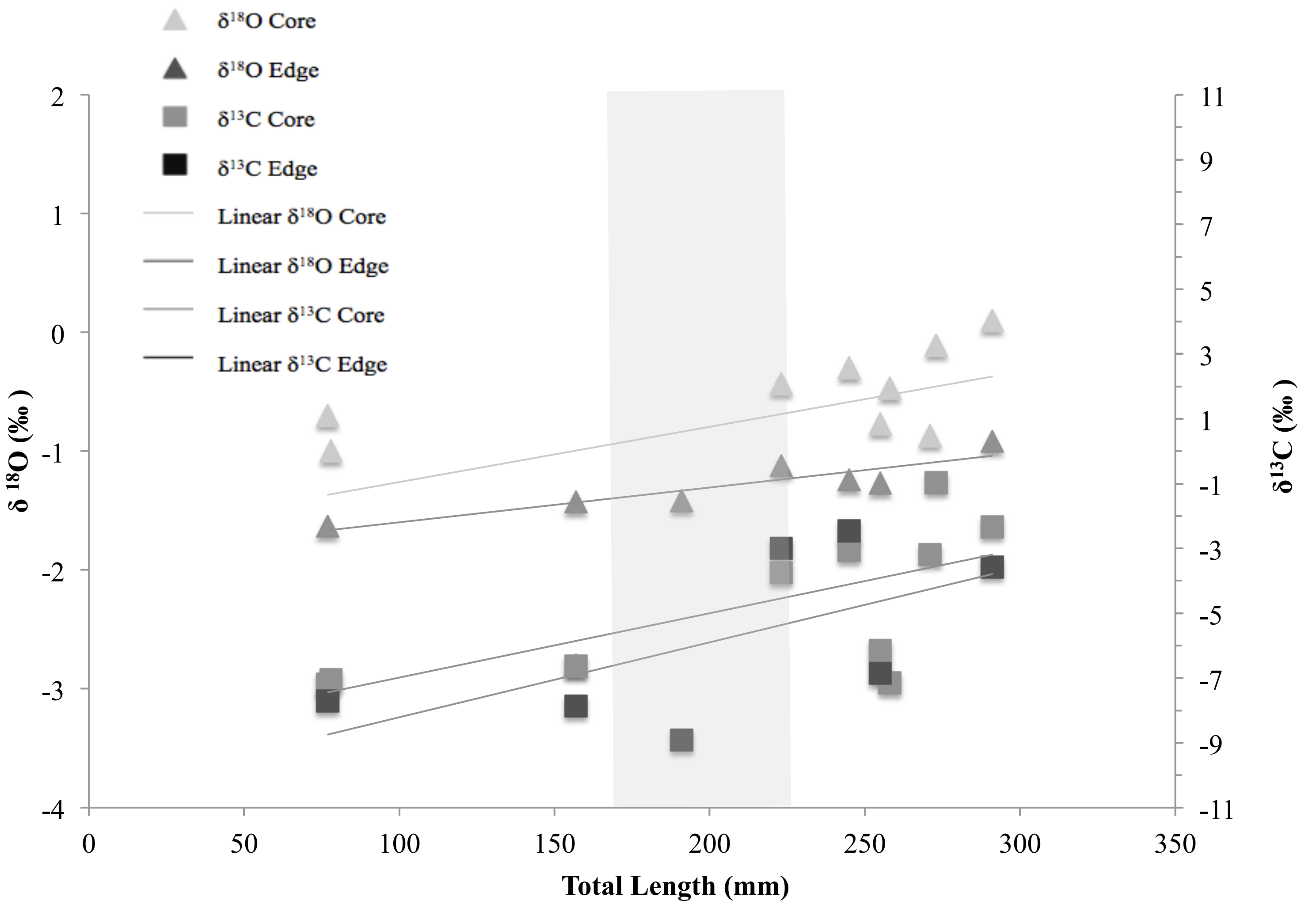

Figure 11a. Otolith core and edge δ^{18}O (‰) and δ^{13}C (‰) values for gray snapper by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

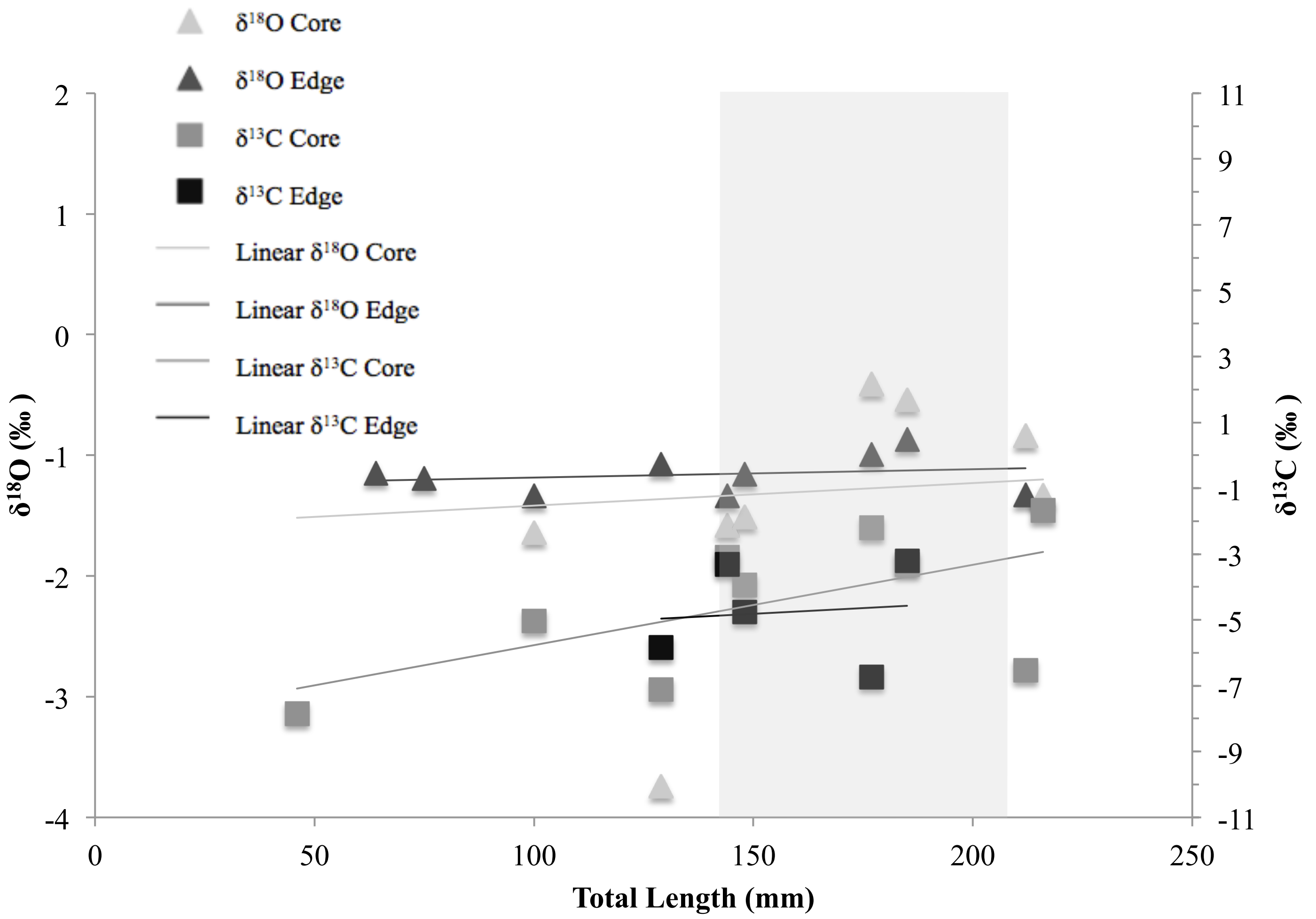

Figure 11b. Otolith core and edge $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) values for lane snapper by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

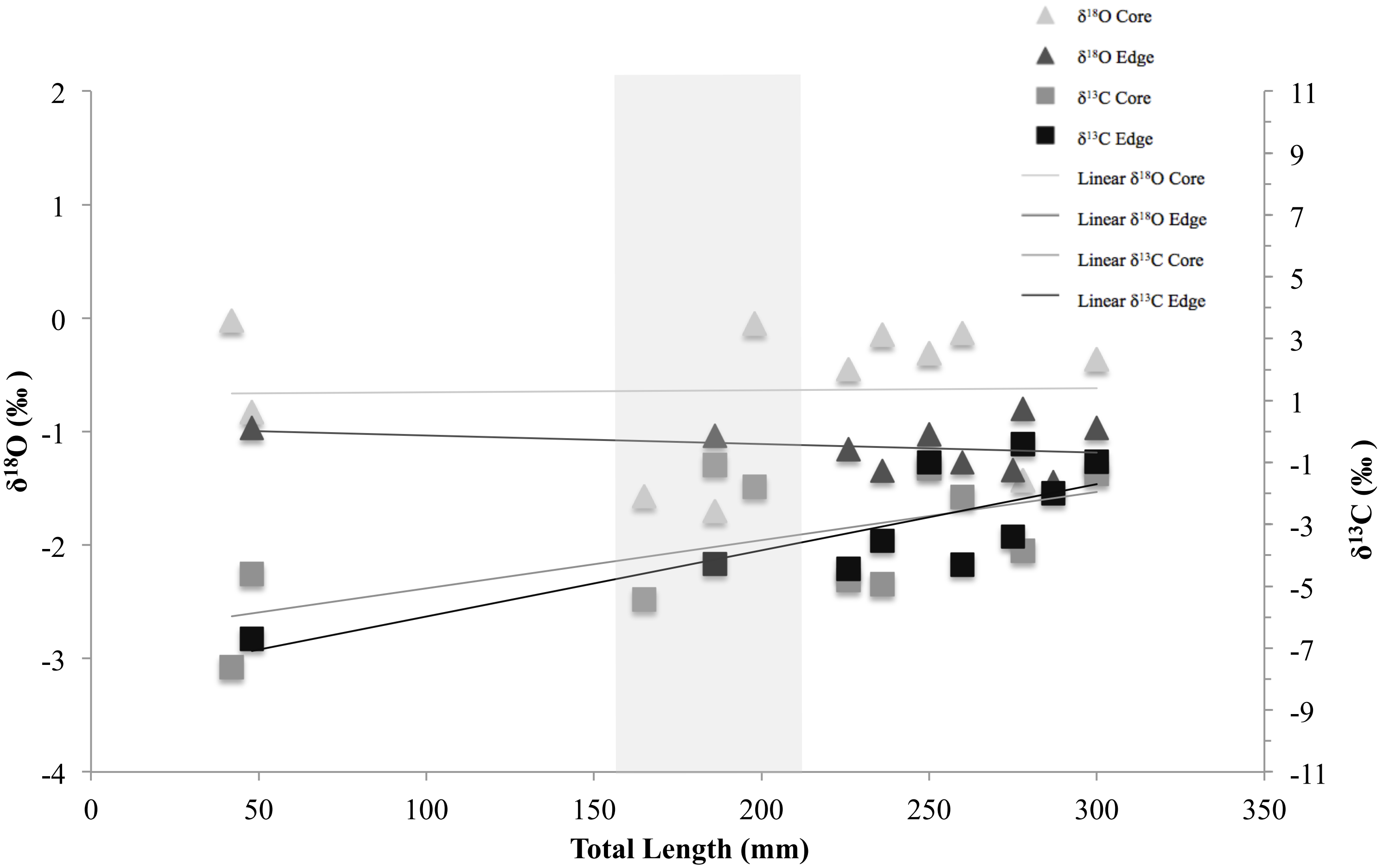

Figure 11c. Otolith core and edge $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) values for bluestriped grunt by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

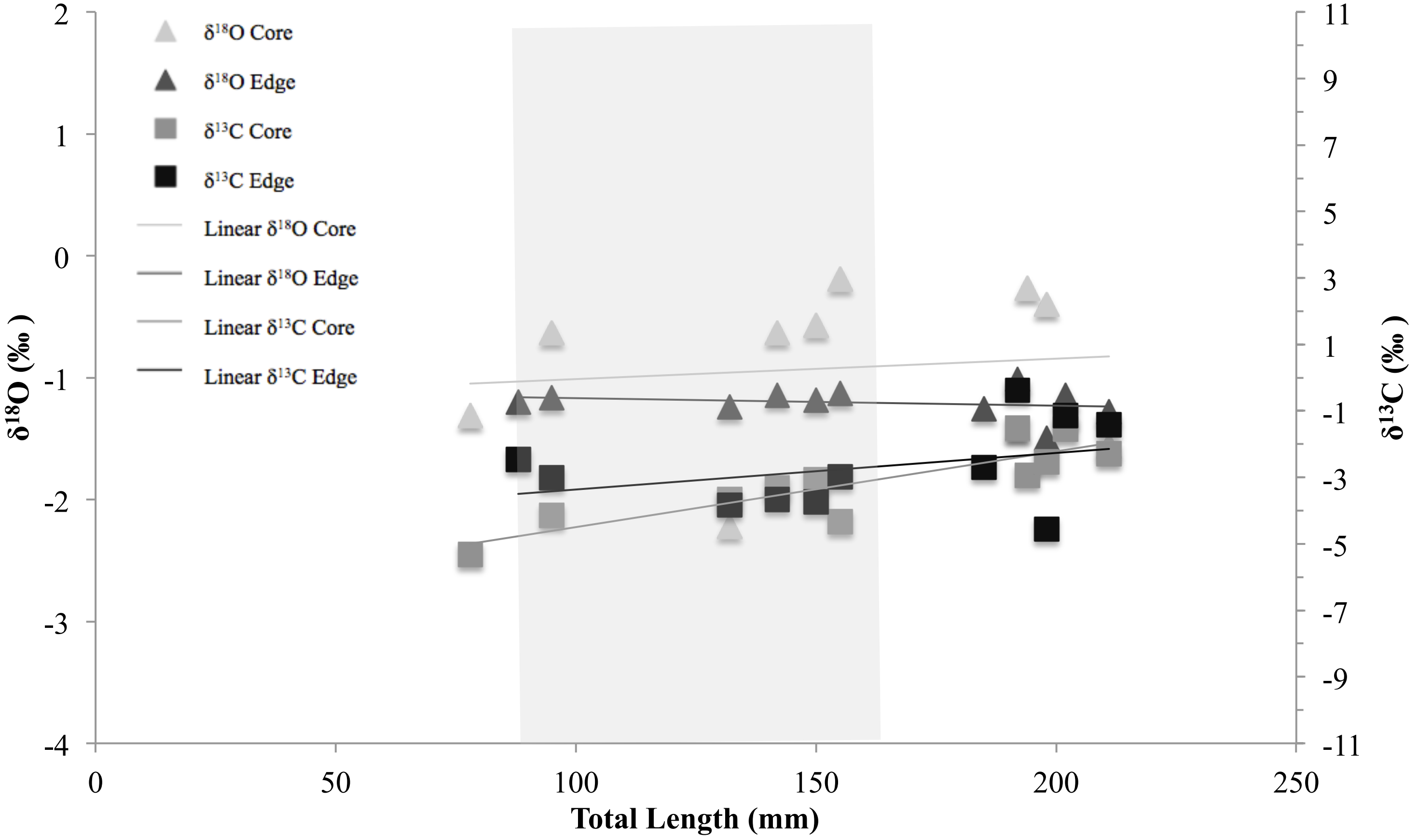

Figure 11d. Otolith core and edge δ^{18}O (‰) and δ^{13}C (‰) values for French grunt by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

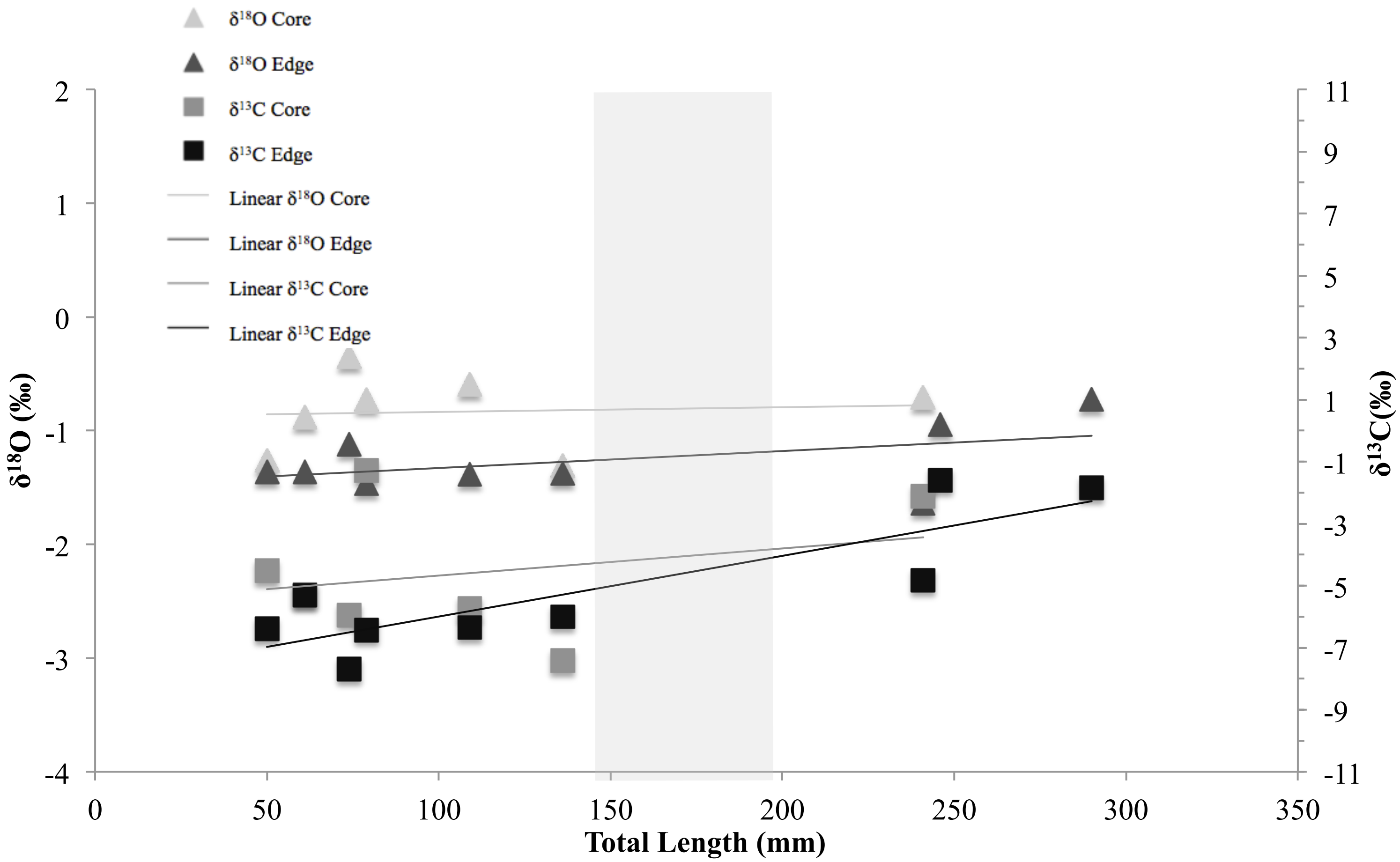

Figure 11e. Otolith core and edge $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) values for sailor's choice by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

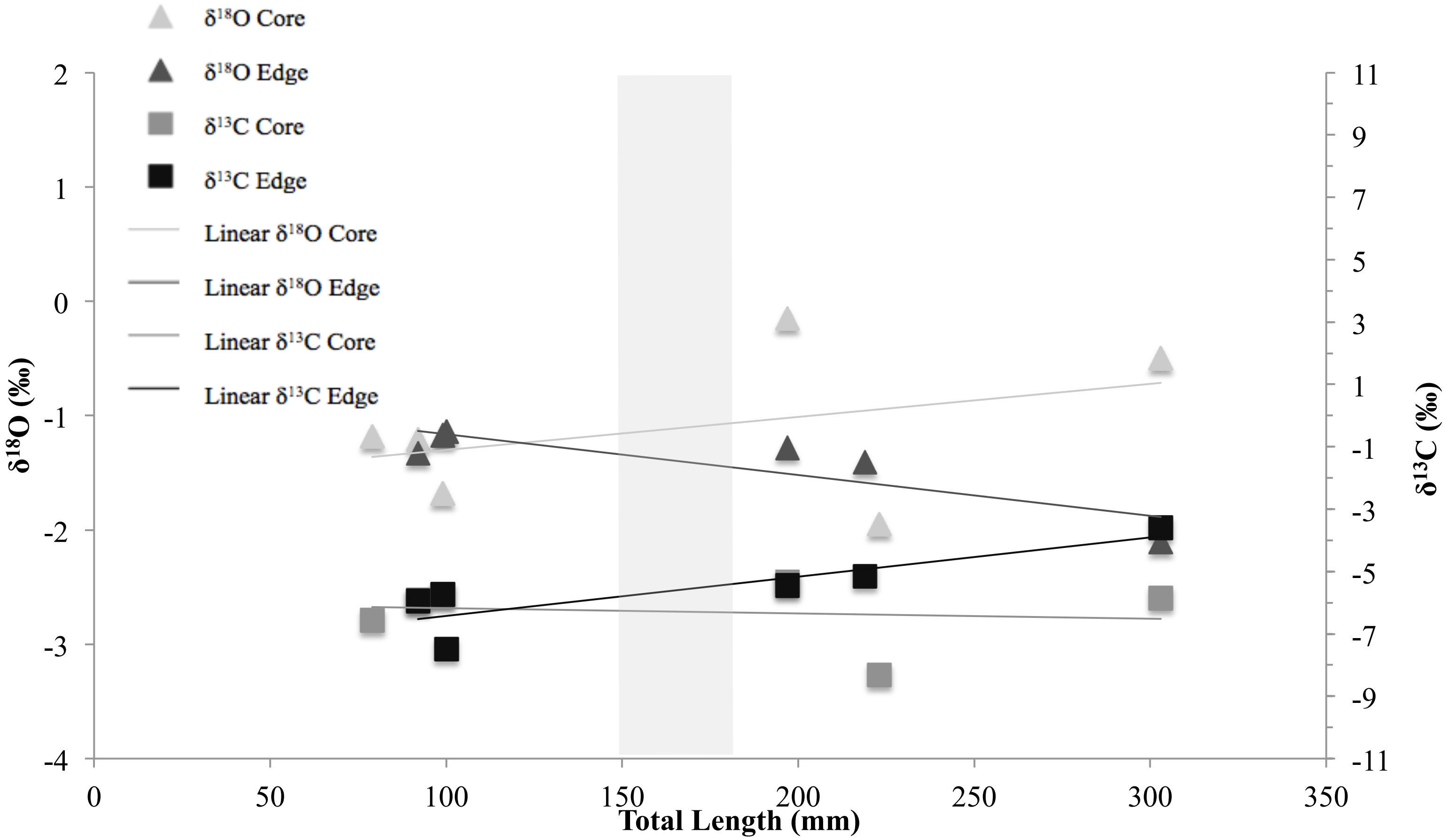

Figure 11f. Otolith core and edge δ^{18}O (‰) and δ^{13}C (‰) values for yellowfin mojarra by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

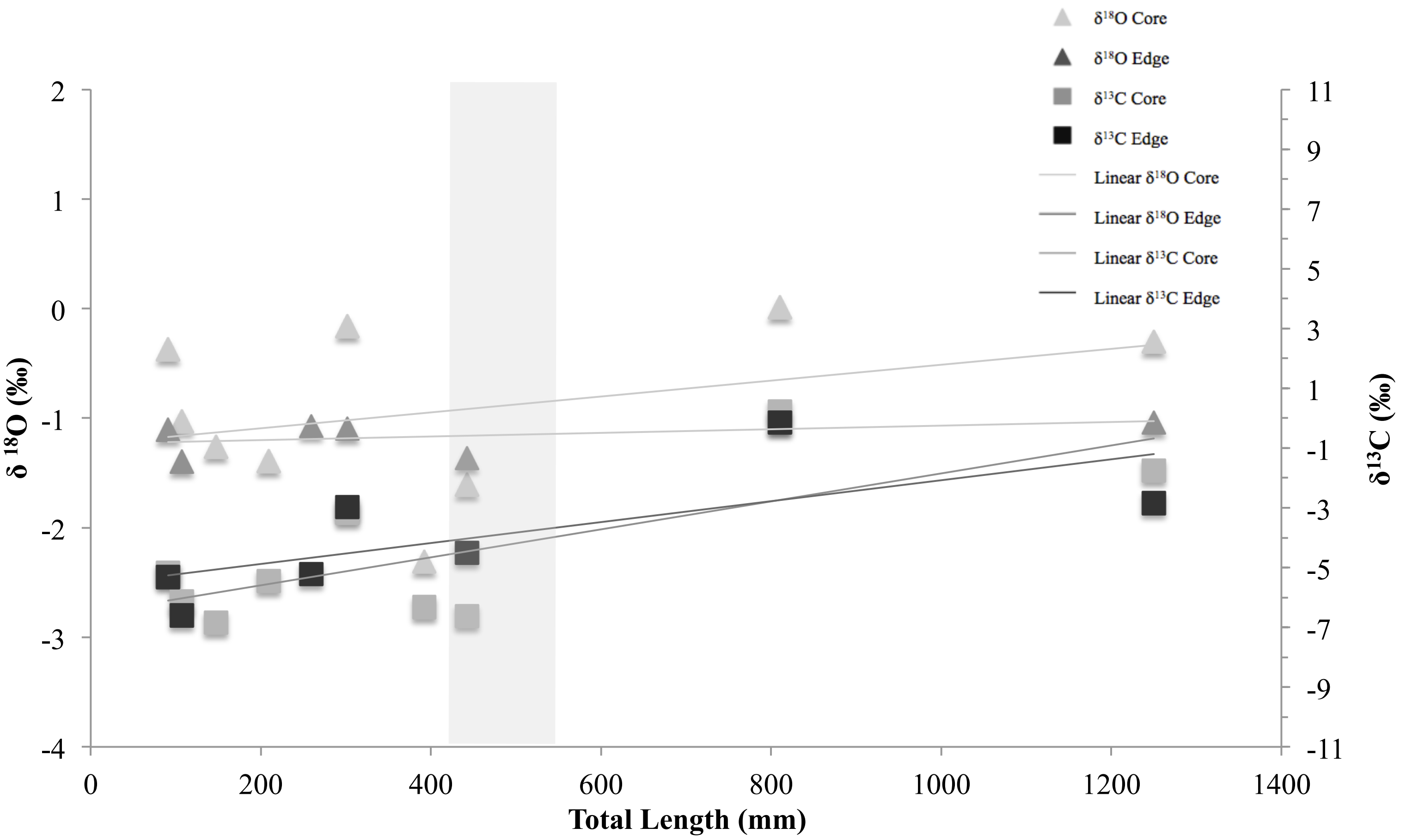

Figure 11g. Otolith core and edge δ^{18}O (‰) and δ^{13}C (‰) values for great barracuda by TL (mm). Gray bar represents length range at which > 0% are juveniles (low end) and < 100% are adults (high end) fishes.

δ^{13}C

Samples ranged from -8.92 to -0.38‰ with a mean of -3.65‰ ± 2.02. Core samples ranged from -8.32 to -0.97‰ with a mean of -3.58‰ ± 1.85, whereas edge samples ranged from -8.92 to -0.38‰ with a mean of -3.70‰ ± 2.20. On average, yellowfin mojarra were the most depleted in δ^{13}C followed by great barracuda, gray snapper, lane snapper, French grunt, sailor's choice, and bluestriped grunt. Bluestriped grunt, sailor's choice, yellowfin mojarra, and great barracuda core samples were more depleted than edge samples, while gray snapper and sailor's choice core samples were more enriched than edge (Table 13).

Juvenile vs. Adult

δ^{18}O

Gray snapper were the only species significantly different in δ^{18}O and δ^{13}C. Gray snapper (DF = 1, F = 3.857, p = 0.050), lane snapper (DF = 1, F = 3.467, p = 0.727), bluestriped grunt (DF = 1, F = 1.56, p = 0.697), and sailor's choice (DF = 1, F = 1.09, p = 0.926) juveniles were more depleted than the adults. French grunt (DF = 1, F = 1.670, p = 0.195), yellowfin mojarra (DF = 1, F = 1.075, p = 0.320), and great barracuda (DF = 1, F = 2.287, p = 0.130) juveniles were more enriched than adult samples (Tables 10 and 11).

δ^{13}C

Lane snapper (DF = 1, F = 1.674, p = 0.513), bluestriped grunt (DF = 1, F = 7.812, p = 0.011), French grunt (DF = 1, F = 1.927, p = 0.346), sailor's choice, and yellowfin mojarra (DF = 1, F = 1.213, p = 0.292) juveniles were more depleted than adults. Gray snapper (DF = 1, F = 5.350, p = 0.021), and great barracuda (DF = 1, F = 1, p = 0.529) juveniles were more enriched than the adults (Tables 12 and 13) (Figure 12).

Habitat Otolith Data

A total of 63 otolith samples were processed from mangrove caught fishes and 75 otolith samples from reef caught fishes were analyzed for δ^{18}O and δ^{13}C. The δ^{18}O ranged from –4.06 to 0.14‰ for fish caught in the mangroves and averaged –1.18‰ ± 0.88, while the fishes caught on the reef ranged from –2.87 to -1.02‰ with a mean of –0.77‰ ± 0.76. The δ^{13}C in the mangrove otoliths s ranged from -8.92 to -1.28‰ in δ^{13}C and averaged -5.66‰ ± 1.57. The δ^{13}C in reef otoliths ranged from -8.51 to 0.23‰ and averaged -3.29‰ ± 1.92. Kruskal-Wallis test detected a significant difference in habitats using δ^{18}O and δ^{13}C (DF = 1, F = 7.317, p = 0.007; DF = 1, F = 43.036, $p \leq 0.001$). Fish δ^{18}O and δ^{13}C were not significantly different between reef tracts and habitat (DF = 1, F = 1.121, p = 0.886).

Mangroves

A total of 63 otoliths were processed from fishes collected in the mangroves, with a total of 33 core samples and 30 edge samples. There were otoliths from 7 (4 core and 3 edge) gray snapper, 11 (5 core and 6 edge) lane snapper, 3(2 core and 1 edge) bluestriped grunt, 1(1 core) French grunt, 12 (6 core and 6 edge) sailor's choice, 13 (7 core and 6 edge) yellowfin mojarra, and 16 (8 core and 8 edge) great barracuda samples processed. Fishes caught in the mangroves were not significantly different in δ^{18}O but were for δ^{13}C among species (DF = 6, F = 9.255, p = 0.100; DF = 6, F = 54.187, $p \leq 0.000$, respectively).

Table 10. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for juvenile samples for all seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Age Class								
	Juveniles								
Species	**N**	**Nc**	**Ne**	**Range (‰)**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$ Core±SD**	**$\bar{x}$ Edge±SD**
Gray Snapper	12	7	5	-2.8 to -0.30	-2.8 to -0.30	-2.31 to -0.45	-1.075 ± 0.79	-0.92 ± 0.86	-1.29 ± 0.70
Lane Snapper	5	2	3	-2.48 to -1.27	-2.48 to -0.31	-2.32 to –0.54	-1.27 ± 1.04	-1.40 ±1.53	-1.19± 0.98
Bluestriped Grunt	12	6	6	-1.79 to 0.11	-1.70 to -0.02	-1.79 to 0.11	-0.75 ± 0.72	-0.77 ± 0.73	-0.73 ± 0.79
French Grunt	6	3	3	-1.56 to -0.61	-1.56 to -0.63	-0.88 to -0.61	-0.95 ± 0.39	-1.17 ± 0.48	-0.74 ± 0.14
Sailor's Choice	12	6	6	-1.72 to -0.35	-1.31 to -0.35	-1.72 to -0.44	-1.06 ± 0.44	-0.85 ± 0.38	-1.27 ± 0.43
Yellowfin Mojarra	7	4	3	-1.68 to -0.52	-1.68 to -1.18	-1.20 to -0.52	-1.13 ± 0.43	-1.39 ± 0.24	-0.78 ± 0.37
Great Barracuda	18	9	9	-2.99 to 0.10	-2.31 to 0.01	-1.45 to 0.14	-0.75 ± 0.85	-1.09 ± 1.03	-0.41 ± 0.52

Table 11. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for adult samples for all seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Age Class								
	Adults								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$ Core±SD**	**$\bar{x}$ Edge±SD**
Gray Snapper	8	4	4	-2.73 to 0.31	-2.73 to 0.10	-1.53 to 0.31	-0.86 ± 0.99	-0.90 ± 1.29	-0.825 ± 0.79
Lane Snapper	15	8	7	-3.74 to 0.48	-3.74 to -0.41	-6.74 to -1.95	-1.04 ± 0.97	-1.45 ± 1.04	-0.57 ± 0.69
Bluestriped Grunt	12	6	6	-1.96 to -0.72	-1.96 to -0.13	-1.79 to 0.11	-0.62 ± 0.81	-0.72 ± 0.78	-0.73 ± 0.79
French Grunt	17	8	9	-2.22 to -0.05	-2.22 to -0.19	-1.83 to -0.05	-0.79 ± 0.59	-0.78 ± 0.69	-0.80 ± 0.51
Sailor's Choice	5	2	3	-2.87 to 1.02	-2.87 to -1.06	-2.35 to 1.02	-1.01 ± 1.64	-1.97 ± 1.28	-0.38 ± 1.76
Yellowfin Mojarra	7	3	4	-4.06 to -0.15	-1.95 to -0.15	-4.06 to -1.04	-1.68 ± 1.33	-0.87 ± 0.954	-2.30 ± 1.34
Great Barracuda	2	1	1	-1.61 to -1.33	-1.61	-1.33	-1.47 ± 0.20	-1.61	-1.33

Table 12. Total number, range, means (x̄), and standard deviation (SD) for otolith $\delta^{13}C$ (‰) for all samples (core and edge), core samples, and edge samples for juvenile samples for all seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	$\delta^{13}C$ Otolith Data - Age Class								
	Juveniles								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄ Core±SD**	**x̄ Edge±SD**
Gray Snapper	12	7	5	-7.87 to -2.45	-7.18 to -3.07	-7.87 to -2.45	-5.75 ± 2.05	-5.85 ± 1.72	-5.60 ± 2.65
Lane Snapper	5	2	3	-7.85 to -2.81	-7.85 to -5.71	-4.76 to -2.81	-4.87 ± 2.04	-6.78 ±1.51	-3.59 ± 1.103
Bluestriped Grunt	12	6	6	-7.62 to -1.07	-7.62 to -1.07	-6.69 to -3.40	-4.58 ± 1.97	-4.22 ± 2.42	-5.01± 1.40
French Grunt	6	3	3	-5.32 to -2.45	-3.67 to -0.85	-3.84 to -2.45	-3.74 ± 0.99	-4.38 ± 0.85	-3.10 ± 0.70
Sailor's Choice	12	6	6	-7.69 to -1.28	-7.41 to -1.28	-7.69 to -5.3	-5.69 ± 1.64	-5.03 ± 2.07	-6.36 ± 0.78
Yellowfin Mojarra	7	4	3	-7.82 to -5.74	-7.82 to -5.74	-7.5 to -5.74	-6.46 ± 0.87	-6.51 ± 0.94	-6.40 ± 0.96
Great Barracuda	18	9	9	-7.11 to 0.23	-7.11 to 0.23	-6.61 to -0.15	-4.31 ± 2.34	-4.63 ± 2.52	-3.98 ± 2.33

Table 13. Total number, range, means (x̄), and standard deviation (SD) for otolith $\delta^{13}C$ (‰) for all samples (core and edge), core samples, and edge samples for adult samples for all seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	$\delta^{13}C$ Otolith Data - Age Class								
	Adults								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄ Core±SD**	**x̄ Edge±SD**
Gray Snapper	8	4	4	-8.92 to -0.97	-3.60 to -0.97	-8.92 to -3.58	-4.16 ± 2.54	-2.52 ± 1.56	-5.80 ± 2.55
Lane Snapper	15	8	7	-7.11 to -1.68	-7.11 to -1.68	-6.74 to -1.95	-4.06 ± 1.87	-4.11 ± 1.96	-3.99 ± 1.90
Bluestriped Grunt	12	6	6	-4.93 to -0.41	-4.93 to -1.20	-6.69 to -3.40	-2.50 ±1.56	-2.97 ± 1.60	-5.01 ± 1.40
French Grunt	17	8	9	-8.51 to -0.38	-4.33 to -1.51	-8.51 to -0.38	-2.98 ± 1.83	-2.69 ± 0.94	-3.22 ± 2.40
Sailor's Choice	5	2	3	-4.82 to -1.59	-3.66 to -2.56	-4.82 to -1.59	-2.89 ± 1.34	-3.11 ± 0.78	-2.75 ± 1.80
Yellowfin Mojarra	7	3	4	-8.32 to -3.59	-8.32 to -5.33	-6.59 to -3.59	-5.76 ± 1.45	-6.50 ± 1.60	-5.20 ± 1.24
Great Barracuda	2	1	1	-6.62 to -4.50	-6.62	-4.5	-5.56 ± 1.50	-6.62	-4.5

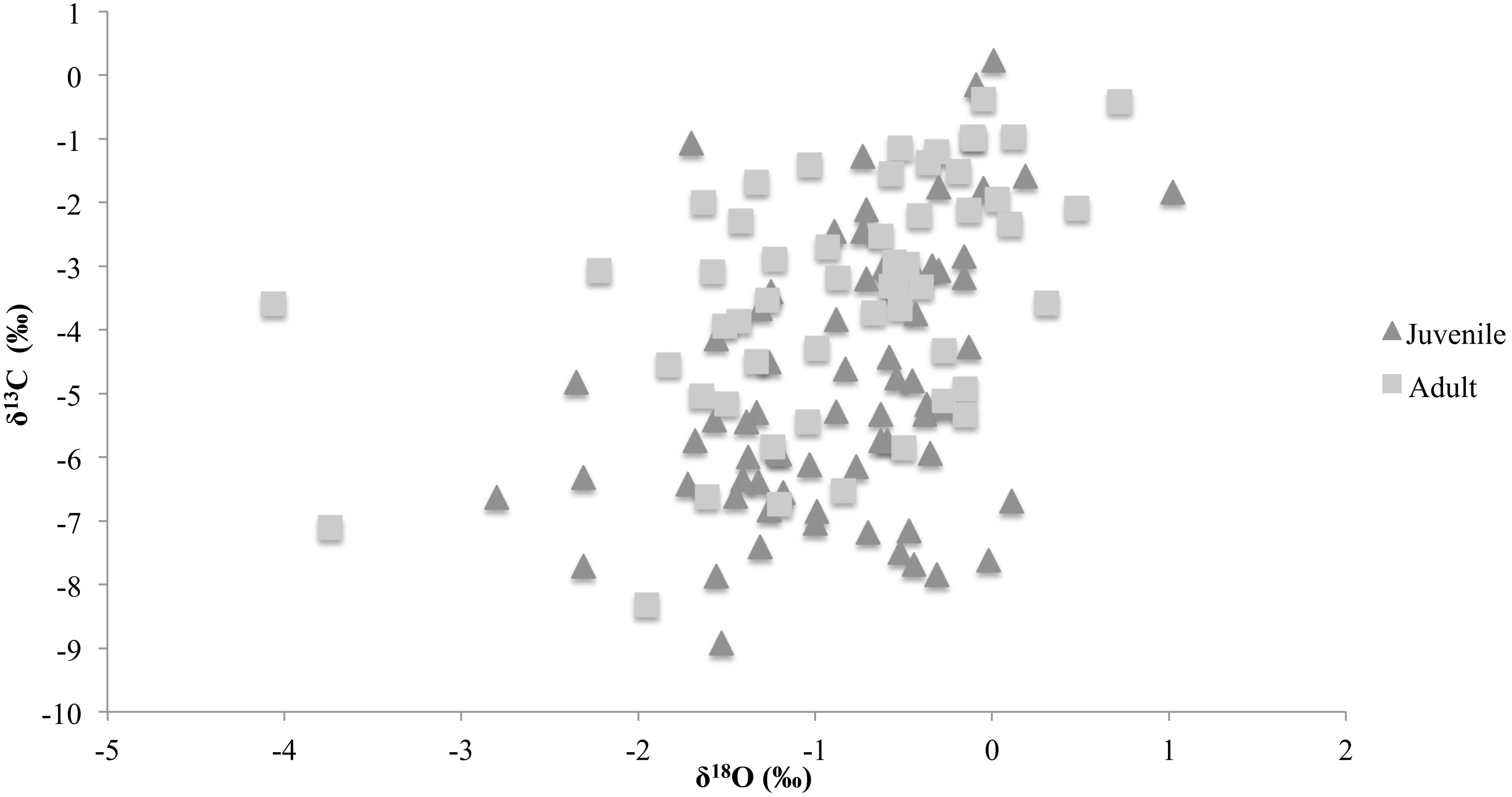

Figure 12. Comparisons of otolith δ^{18}O (‰) and δ^{13}C (‰) among juvenile (dark gray triangles) versus adult (light gray squares) fish specimens caught in Broward County, Florida.

$\delta^{18}O$

Otolith $\delta^{18}O$ from the mangroves ranged from -4.06 to 0.14‰ with a mean of -1.18‰ ± 0.88. Core samples ranged from -3.74 to -0.02‰ with a mean of -1.28‰ ± 0.91. Edge samples ranged from -4.06 to 0.14‰ with a mean of -1.08‰ ± 0.86. On average, the gray snapper was the most depleted followed by lane snapper, yellowfin mojarra, sailor's choice, great barracuda, and bluestriped grunt (Table 14).

Sailor's choice were the only species significantly different in core and edge samples. Gray snapper (DF = 2, p = 0.797), lane snapper (DF = 4, p = 0.355), bluestriped grunt, and great barrracuda (DF = 7, p = 0.114) core samples were more depleted than edge samples. Lane snapper core samples were more depleted than edge samples. There was only one sample processed for French grunt which had a value of -0.63‰. Sailor's choice (DF = 5, p = 0.028) and yellowfin mojarra (DF = 4, p = 0.893) core samples were more enriched than edge samples (Table 14).

$\delta^{13}C$

Samples from the mangroves ranged from -8.92 to -1.28‰ with a mean of -5.66‰ ± 1.57. Core samples ranged from -7.85 to -1.28‰ with a mean of -5.81‰ ± 1.45. Edge samples ranged from -8.92 to -1.38‰ with a mean of -5.50‰ ± 1.69. On average, the gray snapper was the most depleted followed by bluestriped grunt, yellowfin mojarra, sailor's choice, French grunt, great barracuda, and lane snapper.

There was no significant difference in core and edge samples for any of the species. Lane snapper (DF = 4, p = 0.186) and great barracuda (DF = 7, p = 0.600) had core samples more depleted than edge samples. There was only one sample processed for French grunt, which had a value of -5.32‰. Gray snapper (DF = 2, p = 0.797), bluestriped grunt, sailor's choice (DF = 5, p = 0.203), and yellowfin mojarra (DF = 4, p = 0.465) core samples were more enriched than the edge samples (Table 16).

Reefs

A total of 75 otoliths were processed from fishes collected on the reefs, 37 core samples and 37 edge samples. There were otoliths from 13 (7 core and 6 edge) gray snapper, 9 (5 core and 4 edge) lane snapper, 20 (10 core and 10 edge) bluestriped grunt, 22 (10 core and 12 edge) French grunt, 5 (2 core and 3 edge) sailor's choice, 2 (1 core and 1 edge) yellowfin mojarra, and 4 (2 core and 2 edge) great barracuda processed. Fishes caught on the reefs were not significantly different in δ^{18}O, but were in δ^{13}C among species (DF = 6, F = 10.338, p = 0.111; DF = 6, F = 2.583, p = 0.039, respectively).

δ^{18}O

Samples from the reefs ranged from -2.87 to 1.02‰ with a mean of -0.77‰ ± 0.76. Core samples ranged from -2.87 to 0.10‰ with a mean of -0.83‰ ± 0.72. Edge samples ranged from -2.59 to 1.02‰ with a mean of -3.35‰ ± 2.02. On average, the yellowfin mojarra was the most depleted followed by sailor's choice, French grunt, bluestriped grunt, lane snapper, gray snapper, and great barracuda (Table 15).

No significant difference was found for all species. Lane snapper (DF = 3, p = 0.290), bluestriped grunt (DF = 8, p = 0.515), French grunt (DF = 9, p = 0.599), sailor's choice (DF = 1, p = 0.302) and great barracuda (DF = 1, p = 0.655) core samples were more depleted than edge samples. Gray snapper core samples were more enriched than the edge samples (DF = 5, p = 0.126). The yellowfin mojarra core sample was -1.95‰ while the edge sample was -2.59‰ (Table 15).

$\delta^{13}C$

Fishes from the reefs ranged from -8.51 to 0.23‰ with a mean of -3.29‰ ± 1.92. Core samples ranged from -8.32 to 0.23‰ with a mean of -3.24‰ ± 1.84. Edge samples ranged from -8.51 to -0.15‰ with a mean of -3.35‰ ± 2.02. On average, yellowifn mojarra were the most depleted followed by gray snapper, lane snapper, French grunt, bluestriped grunt, sailor’s choice, and great barracuda (Table 17).

No significant difference was for between core and edge samples for all species. Bluestriped grunt (DF = 8, p = 0.515), sailor’s choice (DF = 1, p = 0.286), and yellowfin mojarra core samples were more depleted than edge samples. Gray snapper (DF = 5, p = 0.609), lane snapper (DF = 3, p = 0.312), French grunt (DF = 9, p = 0.573), and great barracuda (DF = 1, p = 0.180) core samples were more enriched than the edge samples (Table 17).

<u>Mangrove vs Reef</u>

$\delta^{18}O$

Based on otolith $\delta^{18}O$, gray snapper (DF = 1, F=18.977, $p \leq 0.001$), lane snapper (DF = 1, F = 2.46, p = 0.134), sailor’s choice (DF = 1, F = 1.01, p = 0.926), and great barracuda (DF = 1, F = 4.935, p = 0.026) caught in the mangroves were more depleted than fishes caught on the reef. However, only gray snapper and great barracuda were significant. Bluestriped grunt (DF = 1, F = 1.171, p = 0.292), French grunt (DF = 1, F = 1.145, p = 0.707) and yellowfin mojarra (DF = 1, F = 3.333, p = 0.068) caught in the mangroves were more enriched than the fishes caught on the reef (Tables 12 and 13) (13).

$\delta^{13}C$

All species were significantly different in otolith $\delta^{13}C$, except for lane snapper. Gray snapper (DF = 1, F = 10.482, p = 0.005), lane snapper (DF = 1, F = 4.033, p = 0.600), bluestriped grunt (DF = 1, F = 8.933, p = 0.007), French grunt (DF = 1, F = 1.793, p = 0.132), sailor's choice (DF = 1, F = 11.215, p = 0.004) and great barracuda (DF = 1, F = 22.620, p = 0.005) caught in the mangroves were more depleted compared to fishes caught on the reef. Yellowfin mojarra caught in the mangroves were more enriched than fishes caught on the reef (DF = 1, F = 3.456, p = 0.088) (Tables 16 and 17) (Figure 13).

Season

A total of 73 otolith samples were collected during the dry season and 65 from the wet season. The $\delta^{18}O$ ranged from –2.99 to 1.02‰ for fishes caught in the dry season and averaged –0.996‰ ± 0.86, while the fishes caught during the wet season ranged from –4.06 to -0.48‰ with a mean of –0.91‰ ± 0.83 Fishes caught during the dry season ranged from -8.92 to -0.41‰ in $\delta^{13}C$ and averaged -4.66‰ ± 2.09. The $\delta^{13}C$ in wet season otoliths ranged from -7.87 to 0.23‰ and averaged -4.03‰ ± 2.13. Both $\delta^{18}O$ and $\delta^{13}C$ in fishes otoliths were not significantly different between seasons (DF =1, F=14.180, p=0.412; DF = 1, F = 2.578, p = 0.108). Fishes were also not significantly different between reef tracts and season for both δ^{18}O and δ^{13}C (DF = 1, F = 2.462, p = 0.93).

Dry

A total of 73 otoliths were processed from fishes collected during the dry season, 37 core samples and 35 edge samples. There were otoliths from 18 (11 core and 7 edge) gray snapper, 7 (3 core and 4 edge) lane snapper, 14 (7 core and 7 edge) bluestriped grunt, 9 (5 core and 4 edge) French grunt, 10 (5 core and 5 edge) sailor's choice, 10 (5 core and 5 edge) yellowfin mojarra and 6 (3 core and 3 edge) great barracuda processed. Fishes caught during the dry season were not significantly different in δ^{18}O and δ^{13}C among species (DF = 6, F = 8.583, p = 0.600; DF = 6, F = 2.017, p = 0.076, respectively).

δ^{18}O

Fishes caught during the dry season ranged from -2.99 to 1.02‰ with a mean of -1.00‰ ± 0.86. Core samples ranged from -2.99 to 0.10‰ with a mean of -1.15‰ ± 0.86. Edge samples ranged from -2.59 to 1.02‰ with a mean of -0.834‰ ± 0.83. On average, the great barracuda was the most depleted followed by yellowfin mojarra, lane snapper, French grunt, sailor's choice, gray snapper, and bluestriped grunt (Table 18).

Gray snapper (DF = 4, p = 0.71), lane snapper (DF = 2, p = 0.830), bluestriped grunt (DF = 5, p = 0.280), sailor's choice (DF = 3, p = 0.410), yellowfin mojarra (DF = 3, p = 0.451), and great barracuda (DF = 2, p = 0.237) core samples were more depleted than the edge samples. French grunt core samples were more enriched than edge samples (DF = 3, p = 0.971) (Table 18). However, non of the species were significant.

$\delta^{13}C$

Fishes caught during the dry season ranged from -8.92 to -0.41‰ with a mean of -4.66‰ ± 2.09. Core samples ranged from -8.32 to -0.97‰ with a mean of -4.66‰ ± 2.08. No significant difference was found between core and edge samples for fishes caught in the dry season. Edge samples ranged from -8.92 to -0.41‰, with a mean of -4.65‰ ± 2.13. On average, yellowfin mojarra were the most depleted followed by great barracuda, gray snapper, lane snapper, bluestriped grunt, sailor's choice, and French grunt (Table 20).

Lane snapper (DF = 2, p = 0.261), yellowfin mojarra (DF = 3, p = 0.315), and great barracuda (DF = 2, p = 0.285) core samples were more depleted compared to edge samples. Gray snapper (DF = 4, p = 0.719), bluestriped grunt (DF = 5, p = 0.479), and sailor's choice (DF = 3, p = 0.564) core samples were more enriched than the edge samples. French grunt core samples core and edge samples were the same (DF = 3, p = 0.273) (Table 20).

Table 14. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for samples caught in the mangroves for all seven teleost fishes species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Habitat								
	Mangroves								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$ Core±SD**	**$\bar{x}$ Edge±SD**
Gray Snapper	7	4	3	-2.8 to -0.7	-2.8 to -0.70	-2.31 to -1.53	-1.80 ± 0.83	-1.81 ± 1.11	-1.80 ± 0.44
Lane Snapper	11	5	6	-3.74 to -0.27	-3.74 to -0.31	-2.32 to -0.27	-1.39 ± 1.09	-1.94 ± 1.27	-0.94 ± 0.75
Bluestriped Grunt	3	2	1	-0.83 to 0.11	-0.83 to -0.02	0.11	-0.25 ± 0.51	-0.43 ± 0.57	0.11 ± 0
French Grunt	1	1	0	-0.63	-0.63	-	-0.63	-0.63	-
Sailor's Choice	13	7	6	-1.72 to -0.35	-1.31 to -0.35	-1.72 to -0.44	-1.06 ± 0.44	-0.85 ± 0.38	-1.27 ± 0.43
Yellowfin Mojarra	12	6	6	-4.06 to -0.15	-1.68 to -0.15	-4.06 to -0.52	-1.27 ± 0.998	-1.04 ± 0.60	-1.49 ± 1.31
Great Barracuda	16	8	8	-2.99 to -0.14	-2.99 to -0.16	-1.45 to 0.14	-1.00 ± 0.86	-1.39 ± 0.94	-0.611 ± 0.60

Table 15. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for samples caught on the reefs for all seven teleost fishes species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Habitat								
	Reef								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$ Core±SD**	**$\bar{x}$ Edge±SD**
Gray Snapper	13	7	6	-1.22 to 0.31	-0.87 to 0.10	-1.22 to 0.31	-0.55 ± 0.47	-0.41 ± 0.34	-0.72 ± 0.57
Lane Snapper	9	5	4	-1.58 to 0.48	-1.58 to -0.41	-1.23 to 0.48	-0.74 ± 0.68	-0.94 ± 0.50	-0.48 ± 0.87
Bluestriped Grunt	20	10	10	-1.96 to 0.72	-1.96 to -0.05	-1.79 to 0.72	-0.75 ± 0.77	-0.81 ± 0.75	-0.69 ± 0.83
French Grunt	22	10	12	-2.22 to -0.05	-2.22 to -0.19	-1.83 to -0.05	-0.84 ± 0.55	-0.91 ± 0.67	-0.79 ± 0.44
Sailor's Choice	5	2	3	-2.87 to 1.02	-2.86 to -1.06	-2.35 to 1.02	-1.01 ± 1.64	-1.8 ± 1.28	-0.38 ± 1.76
Yellowfin Mojarra	2	1	1	-2.59 to -1.95	-1.95	-2.59	-2.27 ± 0.46	-1.95	-2.95
Great Barracuda	4	2	2	-0.30 to 0.01	-0.3 to 0.01	-0.16 to -0.09	-0.14 ± 0.13	-0.15 ± 0.22	-0.13 ± 0.05

Table 16. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith δ^{13}C(‰) for all samples (core and edge), core samples, and edge samples for samples caught in the mangroves for all seven teleost fishes species (Nc=total core samples, Ne = total edge samples)

	δ^{13}C Otolith Data - Habitat								
	Mangroves								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$Core±SD**	**$\bar{x}$Edge±SD**
Gray Snapper	7	4	3	-8.92 to -3.60	-7.18 to -3.60	-8.92 to -7.71	-6.99 ± 1.67	-6.11 ± 1.69	-8.17 ± 0.66
Lane Snapper	11	5	6	-7.85 to -2.81	-7.85 to -3.94	-5.84 to -2.81	-4.97 ± 1.61	-5.93 ± 1.57	-4.17 ± 1.23
Bluestriped Grunt	3	2	1	-7.62 to -4.61	-7.62 to -4.61	-6.69	-6.31 ± 1.54	-6.12 ± 2.13	-6.69
French Grunt	1	1	0	-5.32	-5.32	-	-5.32	-5.32	-
Sailor's Choice	13	7	6	-7.69 to -1.28	-7.41 to -1.28	-7.69 to -5.3	-5.69 ± 1.64	-5.03 ± 2.07	-6.36 ± 0.78
Yellowfin Mojarra	12	6	6	-7.82 to -3.59	-7.82 to -5.33	-7.50 to -3.59	-5.88 ± 1.09	-6.20 ± 0.89	-5.57 ± 1.26
Great Barracuda	16	8	8	-7.11 to -1.38	-7.11 to -3.18	-6.61 to -1.38	-5.26 ± 1.58	-5.85 ± 1.26	-4.67 ± 1.71

Table 17. Total number, range, means (x̄), and standard deviation (SD) for otolith δ^{13}C (‰) for all samples (core and edge), core samples, and edge samples for samples caught on the reefs for seven teleost fishes species (Nc=total core samples, Ne = total edge samples)

	δ^{13}C Otolith Data - Habitat								
	Reef								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄Core±SD**	**x̄Edge±SD**
Gray Snapper	13	7	6	-7.15 to -0.97	-7.15 to -0.97	-6.85 to -2.45	-4.10 ± 2.01	-3.80 ± 2.15	-4.45 ± 1.97
Lane Snapper	9	5	4	-6.74 to -1.68	-6.53 to -1.68	-6.74 to -1.95	-3.39 ± 1.92	-3.36 ± 1.89	-3.42 ± 2.5
Bluestriped Grunt	20	10	10	-6.27 to -0.41	-5.42 to -1.07	-6.27 to -0.41	-3.07 ± 1.77	-3.09 ± 1.74	-3.06 ± 1.89
French Grunt	22	10	12	-8.51 to -0.38	-4.33 to -1.51	-8.51 to -0.38	-3.08 ± 1.63	-2.94 ± 0.98	-3.20 ± 2.07
Sailor’s Choice	5	2	3	-4.82 to -1.59	-3.66 to -2.56	-4.82 to -1.59	-2.90 ± 1.34	-3.11 ± 0.78	-2.75 ± 1.80
Yellowfin Mojarra	2	1	1	-8.32 to -6.59	-8.32	-6.59	-7.45 ± 1.23	-8.32	-6.59
Great Barracuda	4	2	2	-2.85 to 0.23	-1.76 to 0.23	-2.85 to -0.15	-1.13 ± 1.43	-0.77 ± 1.41	-1.5 ± 1.91

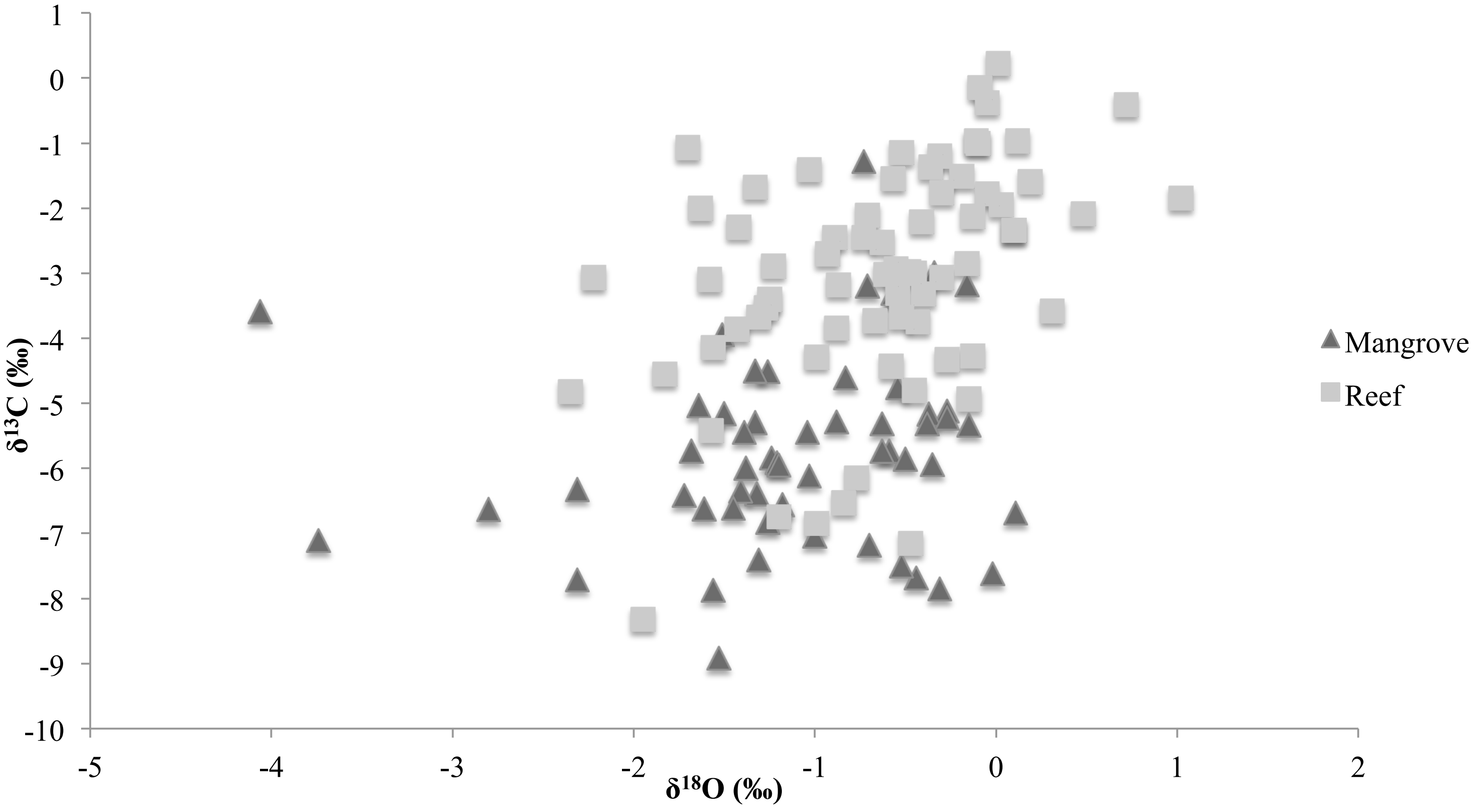

Figure 13. Comparisons of otolith $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) for fish specimens caught in mangroves (dark gray triangle) and on the reefs (light gray square) in Broward County, Florida.

Wet

A total of 65 otoliths were processed from fishes collected during the wet sea with a total of 32 core samples and 33 edge samples. There were otoliths from 3 (1 c and 2 edge) gray snapper 13 (7 core and 6 edge) lane snapper, 9 (5 core and 4 edge) bluestriped grunt, 14 (6 core and 8 edge) French grunt, 8 (4 core and 4 edge) sailor's choice, 4 (2 core and 2 edge) yellowfin mojarra, and 14 (7 core and 7 edge) great barracuda processed. Fishes caught during the wet season were not significantly diff in δ^{18}O among species (DF = 6, F = 8.112, p = 0.230), but were for δ^{13}C (DF = 6, F 6.630, $p \leq 0.001$).

δ^{18}O

Fishes caught during the wet season ranged from -4.06 to 0.48‰ with a mea 0.90‰ ± 0.83. Core samples ranged from -3.74 to 0.10‰ with a mean of -0.91‰ ± Edge samples ranged from -4.06 to 0.480‰ with a mean of -0.903‰ ± 0.86. On ave gray snapper were the most depleted followed by yellowfin mojarra, sailor's choice, snapper, great barracuda, French grunt, and bluestriped grunt (Table 19).

Bluestriped grunt (DF = 3, p = 0.715) and sailor's choice (DF = 3, p = 0.149) samples were more enriched than the edge samples. Lane snapper (DF = 5, p = 0.16 French grunt (DF = 5, p = 0.289), and great barracuda (DF = 6, p = 0.399) core sam were more depleted than edge samples (Table 19). No significant difference was fou

$\delta^{13}C$

Fishes caught during the wet season ranged from -7.87 to 0.230‰ with a mean of -4.04‰ ± 2.13. Core samples ranged from -7.41 to 0.23‰ with a mean of -4.16‰ ± 2.13. Edge samples ranged from -7.87 to -0.15‰ with a mean of -3.92‰ ± 2.16. On average, gray snapper were the most depleted followed by sailor's choice, yellowfin mojarra, great barracuda, lane snapper, French grunt, and bluestriped grunt (Table 21).

No significant difference was found. Bluestriped grunt (DF = 3, p = 0.115), French grunt (DF = 5, p = 0.107), yellowfin mojarra (DF = 1, p = 0.534), and great barracuda (DF = 6, p = 0.482) core samples were more depleted compared to edge samples. Gray snapper (DF = 5, p = 0.330) and sailor's choice (DF = 3, p = 0.717) core sample was more enriched than the edge samples (Table 21).

Dry vs. Wet

$\delta^{18}O$

French grunts were the only species with a significant difference between core and edge samples. Lane snappers (DF = 1, F = 1.129, p = 0.724), bluestriped grunt (DF = 1, F = 1.063, p = 0.804), French grunt (DF = 1, F = 5.148, p = 0.023) caught during the dry season were more depleted in $\delta^{18}O$ than the fishes caught during the wet season. Gray snapper (DF = 1, F = 1.397, p = 0.253), sailor's choice (DF = 1, F = 1.344, p = 0.566), yellowfin mojarra (DF = 1, F = 1.004, p = 0.950) and great barracuda (DF = 1, F = 1.108, p = 0.680) caught during the dry season were more enriched than the fishes caught during the wet season (Table 18 and 19) (Figure 14).

$\delta^{13}C$

All species, except lane snapper, French grunt, and great barracuda were significantly different. Lane snappers (DF = 1, F = 1.183, p = 0.674), bluestriped grunt (DF = 1, F = 5.706, p = 0.026), French grunt (DF = 1, F = 2.31, p = 0.143), and great barracuda (DF = 1, F = 1.416, p = 0.527) caught during the dry season were more depleted in $\delta^{13}C$ than the fishes caught during the wet season. Gray snapper (DF = 1, F = 4.757, p = 0.043), sailor's choice (DF = 1, F = 4.622, p = 0.048), and yellowfin mojarra (DF = 1, F = 5.849, p = 0.032) caught during the dry season was more enriched than the fishes caught during the wet season (Table 20 and 21).

Discussion

Ecological Data

Salinity and water temperature differed significantly between the wet and dry seasons in the mangroves; however, salinity did not differ significantly on the reef between seasons. Mean salinity was expected to be significantly lower in the mangroves during the wet season due to greater rainfall and runoff, 12.06 cm compared to 3.17 cm during the dry season (NOAA, 2015). The increased freshwater input into the mangroves diluted the coastal salinity by 1.1-14.1‰, whereas on the reef the salinity only decreased from 0.4-1.1‰. Significantly higher mean water temperatures during the wet season (mean temperatures of 28.42°C in the mangroves and 26.34°C on the reef) than in the dry

Table 18. Total number, range, means (x̄), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for samples caught in the dry season (December – April) for all seven teleost fishes species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Season								
	Dry								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̄±SD**	**x̄Core±SD**	**x̄Edge±SD**
Gray Snapper	18	11	7	-2.80 to 0.31	-2.80 to 0.10	-1.53 to 0.31	-0.89 ± 0.83	-0.92 ± 0.97	-0.84 ± 0.60
Lane Snapper	7	3	4	-2.48 to -0.31	-2.48 to -0.31	-1.04 to -0.54	-1.21 ± 0.90	-1.43 ± 1.09	-1.04 ± 0.86
Bluestriped Grunt	14	7	7	-1.78 to 0.72	-1.70 to -0.02	-1.79 to 0.72	-0.71 ± 0.77	-0.88 ± 0.70	-0.56 ± 0.86
French Grunt	9	5	3	-2.22 to -0.55	-2.22 to -0.55	-1.83 to -0.67	-1.13 ± 0.59	-1.09 ± 0.72	-1.18 ± 0.59
Sailor’s Choice	10	5	5	-2.87 to 1.02	-2.87 to -0.35	-2.35 to 1.02	-0.92 ± 1.23	-1.25 ± 1.11	-0.66 ± 1.38
Yellowfin Mojarra	10	5	5	-2.59 to -0.52	-1.95 to -1.18	-2.59 to -0.52	-1.39 ± 0.61	-1.51 ± 0.33	-1.29 ± 0.84
Great Barracuda	6	3	3	-2.99 to -0.37	-1.39 to -0.37	-0.38 to -0.15	-1.58 ± 1.32	-0.88 ± 0.72	-0.27 ± 0.12

Table 19. Total number, range, means (x̅), and standard deviation (SD) for otolith δ^{18}O (‰) for all samples (core and edge), core samples, and edge samples for samples caught in the wet season (May – November) for seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	δ^{18}O Otolith Data - Season								
	Wet								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̅±SD**	**x̅Core±SD**	**x̅Edge±SD**
Gray Snapper	3	1	2	-2.31 to -0.70	-0.70	-2.31 to -1.56	-1.52 ± 0.81	-0.70	-1.94 ± 0.53
Lane Snapper	13	7	6	-3.74 to 0.48	-3.74 to -0.41	-1.24 to 0.48	-1.04 ± 1.04	-1.44 ± 1.12	-0.57 ± 0.75
Bluestriped Grunt	9	5	4	-1.95 to 0.12	-1.96 to -0.05	-1.63 to 0.12	-0.63 ± 0.77	-0.57 ± 0.79	-0.72 ± 0.86
French Grunt	14	6	8	-1.56 to -0.05	-1.56 to -0.27	-0.93 to -0.05	-0.64 ± 0.41	-0.72 ± 0.58	-0.59 ± 0.28
Sailor’s Choice	8	4	4	-1.41 to -0.59	-1.31 to -0.59	-1.38 to -1.32	-1.19 ± 0.29	-1.01 ± 0.34	-1.36 ± 0.04
Yellowfin Mojarra	4	2	2	-4.06 to -0.15	-0.5 to -0.15	-4.06 to -1.04	-1.44 ± 1.79	-0.33 ± 0.25	-2.5 ± 2.14
Great Barracuda	14	7	7	-2.31 to 0.14	-2.31 to 0.01	-1.45 to 0.14	-0.79 ± 0.75	-0.95 ± 0.85	-0.62 ± 0.66

Table 20. Total number, range, means ($\bar{x}$), and standard deviation (SD) for otolith $\delta^{13}C$ (‰) for all samples (core and edge), core samples, and edge samples for samples caught in the dry season (December – April) for seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	$\delta^{13}C$ Otolith Data - Season								
	Dry								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**$\bar{x}$±SD**	**$\bar{x}$Core±SD**	**$\bar{x}$Edge±SD**
Gray Snapper	18	11	7	-8.92 to -0.97	-7.18 to -0.97	-8.92 to -2.45	-4.82 ± 2.27	-4.64 ± 2.24	-5.09 ± 2.47
Lane Snapper	7	3	4	-7.85 to -2.81	-7.85 to -3.94	-4.76 to -2.81	-4.51 ± 1.78	-5.83 ± 1.96	-3.52 ± 0.85
Bluestriped Grunt	14	7	7	-7.62 to -0.41	-7.62 to -1.07	-6.69 to -0.41	-4.23 ± 2.03	-4.21 ± 2.16	-4.25 ± 2.06
French Grunt	9	5	3	-8.51 to -1.41	-5.32 to - 2.29	-4.55 to -1.41	-3.82 ± 2.12	-3.23 ± 1.21	-3.23 ± 1.63
Sailor’s Choice	10	5	5	-7.69 to -1.28	-5.94 to -1.28	-7.69 to -1.59	-3.98 ± 2.34	-3.36 ± 1.98	-4.47 ± 2.72
Yellowfin Mojarra	10	5	5	-8.32 to -5.16	-8.32 to -5.74	-7.50 to -5.16	-6.53 ± 1.04	-6.87 ± 1.15	-6.19 ± 0.89
Great Barracuda	6	3	3	-7.11 to -5.17	-5.45 to -5.17	-5.32 to -1.39	-5.91 ± 1.04	-5.31 ± 0.20	-3.97± 2.24

Table 21. Total number, range, means (x̅), and standard deviation (SD) for otolith δ^{13}C (‰) for all samples (core and edge), core samples, and edge samples for samples caught in the wet season (May – November) for seven teleost fish species (Nc=total core samples, Ne = total edge samples)

	δ^{13}C Otolith Data - Season								
	Wet								
Species	**N**	**Nc**	**Ne**	**Range**	**Range Core**	**Range Edge**	**x̅±SD**	**x̅Core±SD**	**x̅Edge±SD**
Gray Snapper	3	1	2	-7.87 to -7.18	-7.18	-7.87 to -7.71	-7.59 ± 0.36	-7.18	-7.79 ± 0.11
Lane Snapper	13	7	6	-7.11 to -1.68	-7.11 to -1.68	-6.74 to -1.95	-4.12 ± 2.00	-4.14 ± 2.12	-4.11 ± 2.06
Bluestriped Grunt	9	5	4	-4.93 to -0.97	-4.93 to -1.2	-3.53 to -0.97	-2.34 ± 1.51	-2.72 ± 1.77	-1.88 ± 1.20
French Grunt	14	6	8	-4.33 to -0.38	-4.33 to -1.51	-3.84 to -0.38	-2.76 ± 1.21	-3.09 ± 1.26	-2.52 ± 1.20
Sailor’s Choice	8	4	4	-7.41 to -4.51	-7.41 to -4.51	-6.39 to -5.30	-5.87 ± 0.88	-5.74 ± 1.23	-6.01 ± 0.50
Yellowfin Mojarra	4	2	2	-5.86 to -3.59	-5.86 to -5.33	5.45 to -3.59	-5.06 ± 1.00	-5.60 ± 0.37	-4.52 ± 1.32
Great Barracuda	14	7	7	-6.83 to 0.23	-6.83 to 0.23	-6.61 to -0.15	-4.22 ± 2.45	-4.37 ± 2.81	-4.06 ± 2.24

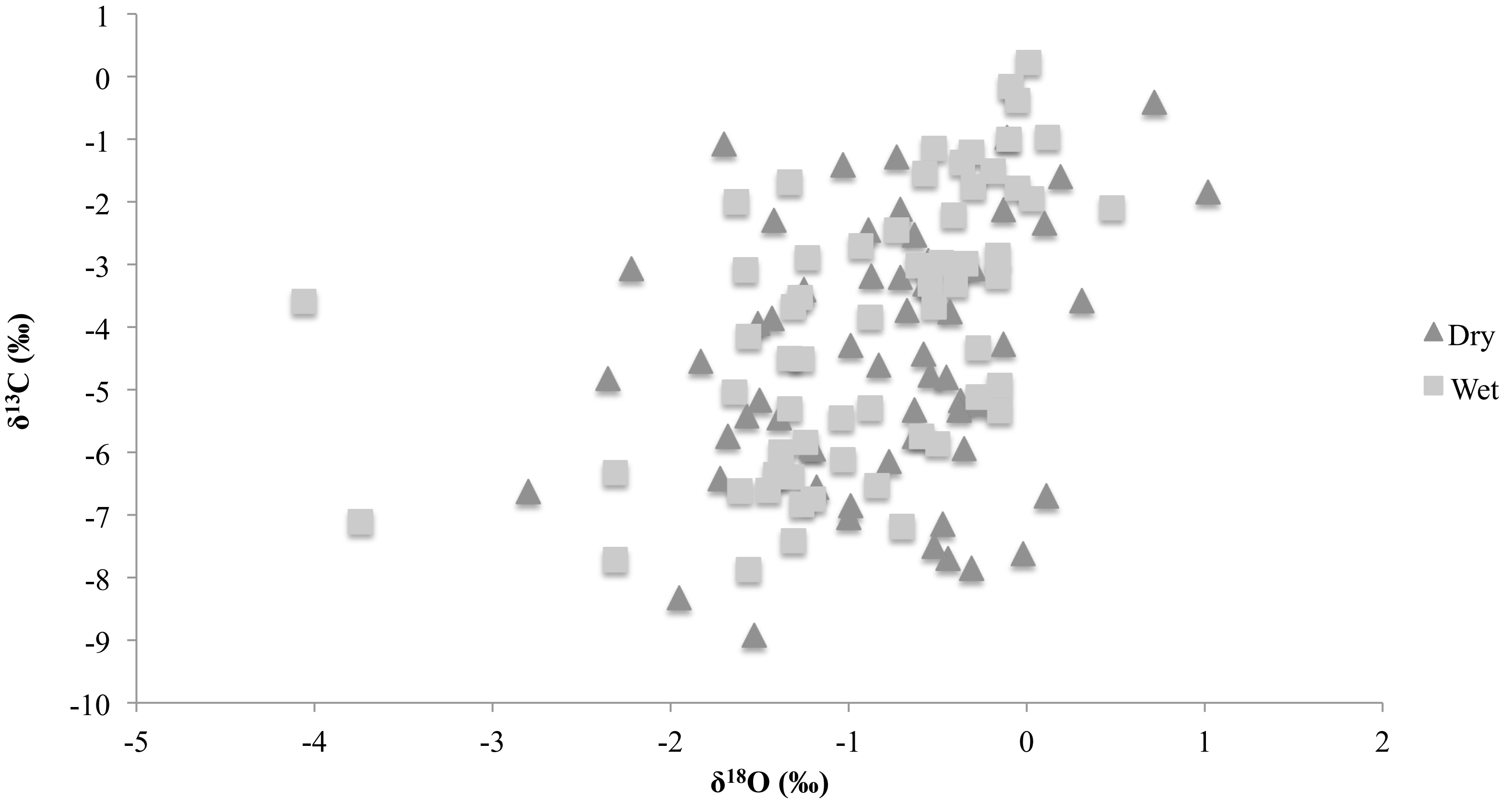

Figure 14. Comparisons of otolith $\delta^{18}O$ (‰) and $\delta^{13}C$ (‰) for fish specimens caught during the dry (December – April) (dark gray triangle) season versus the wet season (May – November) (light gray square) in Broward County, Florida.

season (means of 27.6°C and 23.26°C, respectively) were associated with the higher mean air temperature (28.9°C) compared to that during dry season (24.4°C).

Muscle Data

$\delta^{13}C$

Overall, the $\delta^{13}C$ signatures for each species differed significantly (Table 5). Typically, on average, animals are enriched in $\delta^{13}C$ by 1‰ relative to their diet (DeNiro and Epstein 1978). Great barracuda were the most depleted in $\delta^{13}C$, whereas the French grunt was the most enriched in $\delta^{13}C$. It was expected that great barracuda would be more enriched in $\delta^{13}C$ since barracuda are almost exclusively piscivores, feeding on small epibenthic fishes (Schmidt 1989). Whereas, the French grunt mainly feeds on small invertebrates such as forminferia, bivalves, crustaceans, and amphipods (Layman and Silliman 2002, Cochert de la Morinere 2003) (Table 1). However, the majority of barracuda were collected in the mangroves as compared to the reef. In contrast, the majority of French grunts were collected on the reef as compared to the mangroves.

Fishes collected in the mangroves were significantly more depleted in $\delta^{13}C$ compared to fishes collected on the reef $\delta^{13}C$ (Table 7). Mangrove detritus is more depleted than reef biota. The major energy flow into coastal ecosystems occurs via the incorporation of mangrove detritus into secondary producers, which in turn supports higher trophic levels (Odum and Heald 1975). Variations in photosynthetic pathways determine the $\delta^{13}C$ signatures for primary producers. Primary producers found in mangroves tend to be more depleted in $\delta^{13}C$. Mangroves, as well as terrestrial species, are C_3 plants (-24 to -34‰), which tend to be more depleted than C_4 (-6.0 to -13‰) and CAM plants (-10.0 to -22.0‰) (Bender 1971, Smith and Epstein 1971, Benedict 1978, DeNiro and Epstein 1978, O'Leary 1981). Fractionation in $\delta^{13}C$ is connected with photosynthesis within the plant and lowers the $^{12}C/^{13}C$ ratio ~20‰ for terrestrial plants and ~10‰ for marine primary producers relative to atmospheric CO_2 (Smith and Epstein 1971). Aquatic plants and algae utilize bicarbonate, which is enriched in $\delta^{13}C$ by *ca.* 7-8‰ compared to the atmospheric CO_2 used by terrestrial plants, which is usually *ca.* -8‰.

Lin et al. (1991) found that mangroves were depleted in $\delta^{13}C$ values because mangroves uptake ^{13}C-depleted dissolved inorganic carbon (DIC). In contrast, marine derived carbon is more enriched than DIC due to nutrient-recycling bacteria. Mangrove-derived carbon can be incorporated into other aquatic organisms causing $\delta^{13}C$ to become more depleted (Harrigan et al. 1989, Longeraga et al. 1997, Anderson and Fourqurean 2003). Cocheret de la Moriniere et al. (2003) found that mangrove leaf carbon was strongly depleted compared to biota from the seagrass, which was the most enriched in $\delta^{13}C$ and from the coral reefs, which had intermediate $\delta^{13}C$ values.

Based on this prior research, individual fish caught in the mangroves will likely have a more depleted $\delta^{13}C$ signature than the reef or seagrass habitats. Most studies that have investigated $\delta^{13}C$ signatures in estuarine fishes have found that estuarine fishes are more enriched in $\delta^{13}C$. However, most of these studies have study sites that are dominated by seagrass beds. While all of the mangrove sites for this study had little to no seagrass present, there were seagrass patches present in adjacent areas along the

Intracoastal Waterway that could be utilized by reef fishes. However, it is more likely that the fishes in this study fed and resided within the protection of the mangroves resulting in their depleted $\delta^{13}C$.

Juvenile fishes were significantly more depleted in $\delta^{13}C$ compared to adults (Table 6). Cocheret de la Moriniere et al. (2003) also found that the stable isotope ratios in juveniles had stable carbon signatures much lower than larger individuals of the same species, possibly reflecting the larval planktivorous phase in epipelagic waters before settment into the inshore nursery habitats (Herzka et al. 2001). Adults were more enriched in $\delta^{13}C$ because the majority of adults were caught on the reef which was more enriched in $\delta^{13}C$ compared to the mangrove habitat.

All species exhibited a positive linear relationship between $\delta^{13}C$ and total length. This suggests that there is an ontogenetic diet shift for each species as they grow. Suggesting that juvenile fishes in these habitats are supported by a phytoplankton-zooplankton-zooplanktivore-piscivore carbon flow, especially mysids.

For this study, fishes were separated into two age classes, juvenile and adult. However, many of the samples collected fell into an intermediate age class. Von Bertalanffy relationships were used for each species to separate juveniles and adults (Table 2). However, some of the juveniles in this study could be sub-adults feeding outside the mangroves and vice versa.

Unlike temperate climate location with four seasons, this study had two tropical seasons, wet and dry. Stable carbon isotopes essentially remained constant during the dry season (-16.41 ± 2.07‰) compared to the wet season (-16.83‰ ± 2.47‰) (Table 8). Large seasonal and spatial variations have been observed in zooplankton $\delta^{13}C$ and $\delta^{15}N$, both in offshore and coastal environments (e.g., Fry and Wainright 1991, Maley et al. 1993, Wainright and Fry, 1994, Zohary et al. 1994, Bouillon et al. 2000). Several laboratory and field studies have reported that increased salinity decreases stomatal conductance and, therefore, leads to a more enriched $\delta^{13}C$ (e.g., Medina and Francisco 1997, Lin and Sternberg 1992, Kao et al. 2001, Bouillon et al. 2008). In C_3 plants, like the mangroves of this study, the major components of the overall fractionation are the different diffusion rates of CO_2 through the stomata and fractionation by ribulose biphosphate carboxylase/oxygenase (RuBisCO), which is the initial enzyme of photosynthesis in C_3 plants (Bouillon et al. 2008). Therefore, it was expected that there would be enrichment in $\delta^{13}C$ during the dry season when there is less rainfall, and especially for the mangroves in this study, where there was a greater difference in the average salinity between the dry (31.0 ‰) and wet (28.7 ‰) seasons insinuating minor seasonal fluctuations in $\delta^{13}C$.

$\delta^{15}N$

Overall, great barracuda were the most enriched in $\delta^{15}N$ (12.42‰ ± 0.73‰), while the bluestriped grunt were the most depleted in $\delta^{15}N$ (11.17 ± 1.01‰) (Table 6). The isotopic composition of the nitrogen in an animal reflects the isotopic nitrogen composition of its diet (DeNiro and Epstein 1981). Barracuda were most enriched in $\delta^{15}N$ likely because of a diet based largely on epibenthic fish (Schmidt, 1989) (Table1); i.e., the barracuda are feeding on organisms at a higher trophic level than the other six study species.

Adults for all species were, on average, slightly enriched in $\delta^{15}N$ (12.14‰ ± 1.06‰) compared to juveniles (11.89‰ ± 0.47‰) (Table 6). The $\delta^{15}N$ generally increases with increasing trophic levels (Cocheret de la Moriniere et al. 2003). The expected enrichment was 3-4‰ $\delta^{15}N$ relative to their diets (DeNiro and Epstein 1981, Fry 1983, Minagawa and Wada 1984).

Many studies have found positive relationships between individual fish size and prey size (Edgar and Shaw 1995, Hyddes et al. 1997), which generally correspond to an increase in gape width for most fishes. Others have also reported an ontogenetic relationship between $\delta^{15}N$ and $\delta^{13}C$ and individual predator size (Sholto-Douglass et al. 1991, France et al. 1998, Jennings et al. 2002). These positive relationships between stable isotopes and body size are a result in changing allocation of the isotope or changes in tissue turnover rates during ontogeny. Therefore, the accumulation of $\delta^{15}N$ is a result of dietary changes (Fry and Arnold 1982, Hereka et al. 2001).

Otoliths

$\delta^{18}O$

Oxygen isotopes in otoliths are deposited in, or very near to, equilibrium with ambient water, and are inversely related to temperature and directly related to salinity. Evaporation and freshwater input can, thus, alter $\delta^{18}O$ values (Leganton et al. 2003). Lower $\delta^{18}O$ values indicate higher temperatures and lower salinity (Campana 1999, Radtke et al. 1999, Sluis 2010). Therefore, $\delta^{18}O$ values as migration markers will depend on the extent of differences in temperature and salinity within the proposed range of the species investigated (Huxham et al. 2007).

Values for $\delta^{18}O$ in this study ranged from -4.06 to 0.72‰. Kalish (1991) described a negative regression ($\delta^{18}O = 6.60-0.36\ T°C$) between otolith $\delta^{18}O$ and water temperature, where T°C is the temperature in degrees Celsius. Actual $\delta^{18}O$ values were compared to predicted $\delta^{18}O$ using a t-test. The actual mean $\delta^{18}O$ was found to be -0.892‰ ± 1.11, while the predicted $\delta^{18}O$ mean was found to be -2.82‰ ± 1.12 ($p \leq 0.001$). An alternate equation from Grossman (1982) has a higher intercept and would add 1.6°C to these temperatures, giving a range of 19.6 to 31.2°C. The predicted $\delta^{18}O$ for this equation was found to be -3.37‰ ± 1.11. Mangroves on average for this study were 3.2°C warmer than the reef. It is possible the depth in which the fish inhabited at different life stages could account for the variability. For example, adult mangrove snapper were more commonly caught at deeper reef sties, whereas French and bluestriped grunt were more common at shallow reef sites. A fish living in deeper water will have higher $\delta^{18}O$ values compared to fishes living in shallower water (Ishimura et al. 2012).

The otolith $\delta^{18}O$ was not significantly different (DF = 6, F = 1.394, p = 0.22) among species, which suggested the same elemental uptake in otoliths. Yellowfin mojarra were the most depleted (mean: -1.4 ± 1.00) in $\delta^{18}O$ while bluestriped grunt were the most enriched species (mean: -0.68 ± 0.75).

Four out of the seven species – lane snapper, bluestriped grunt, French grunt, and yellowfin mojarra – had $\delta^{18}O$ core samples that were more depleted than edge samples. Gray snappers, lane snapper, bluestriped grunt, and sailor's choices were more depleted in $\delta^{18}O$ as juveniles. Gray snapper, lane snapper, sailor's choice, and great barracuda caught from the mangroves were also more depleted. This suggests that these species resided in the mangroves as juveniles, which generally have higher water temperatures and lower salinities. They were more likely to be found in the mangroves as juveniles and then moved offshore to the reefs as they grew in size. Yellowfin mojarra and great barracuda were more enriched as juveniles; however, there were low numbers of adults collected for these species. It is possible that small juveniles had a $\delta^{18}O$ signature representative of the open ocean before they established themselves in the mangroves. Huxham et al. (2007) found that $\delta^{18}O$ values were slightly higher in the larval section of the otolith than the outer section, suggesting that the fishes are exposed to slightly lower water temperatures as larvae and move to waters with higher mean temperature as they mature.

Previous studies have found a high degree of temporal variation in otolith chemical signatures at a single site (e.g., Gillanders, 2002, Gillanders and Kingsford 2003, Swearer et al. 2003). Accordingly, it was expected that $\delta^{18}O$ during the wet season would be more depleted, with higher temperatures and lower salinities due to the higher summer temperatures and more rainfall, thereby reducing the salinity. However, sample values in this study were not significant between dry and wet seasons. Four out of the seven species – gray snapper, sailor's choice, yellowfin mojarra, and great barracuda – did show on average 1.4‰ depletion in $\delta^{18}O$ during the wet season. Per Lara et al. (2007), several years of additional sampling at the same sites are suggested to confirm this temporal variation in chemical signatures.

$\delta^{13}C$

Yellowfin mojarra had the most depleted $\delta^{13}C$ values (mean: -6.11 ± 1.20), while French grunt had the most enriched values (mean: -3.18 ± 1.66). These results were expected since the majority of yellowfin mojarra specimens were caught in the mangroves and feeding mostly on detritus feeds, such as polychaetes. While the majority of French grunt specimens were caught on the reef and feeding on more enriched fishes and crustaceans.

All species had a general trend of increasing $\delta^{13}C$ values with increasing size. Five out of seven species had juveniles that on average were more depleted in $\delta^{13}C$.Since sources of carbon are more depleted in the mangroves than on the reef, this suggests the juveniles utilized inshore mangrove habitats before moving offshore. This result was also expected. Organic material from mangroves is much more depleted in $\delta^{13}C$ than most marine carbon. No seasonal difference in $\delta^{13}C$ was found between fishes collected during the dry season and the wet season; however, $\delta^{13}C$ has poor resolution as a spatio-temporal marker (DeNiro and Epstein 1978; Huxham et al. 2007, Sluis 2011).

Spatial segregation of life history stages in the reef fish species was observed based on the $\delta^{13}C$ and $\delta^{15}N$ in muscle tissue and $\delta^{18}O$ and $\delta^{13}C$ in fish otoliths. Juvenile fishes generally occupy mangrove habitats and the adult forms inhabit the nearby reef, thereby suggesting that the mangrove and the reef ecosystems are connected through ontogentic migrations from their juvenile to adult habitats. Jones et al (2010) found that most species of reef fishes display a pattern of different habitat utilization with early life stages dominated in the mangroves and increasing importance of succeeding age classes on the reef. However, Serafy (2003) found a lack of ontogenetic patterns in reef fishes in Biscayne National Park. These may possibly be due to some snapper and grunt species (i.e gray snapper and bluestriped grunt). They do not undergo ontogenetic migration as much as they expand into nearby foraging habitats. Further studies are needed to better understand the ontogenetic migrations for these seven reef fish species.

Future studies should include detailed otolith aging which would ensure specific age classes or interannual variability were examined. For example, juvenile gray snapper are believed to reside within estuaries for up to 1.5 years, depending on geographic location, resulting in potential age/year overlaps versus the simple total length measurements used in this study (Lara et al. 2007). Adults classified during this study belonged to different age classes, such as sub-adults. Therefore, it would be important to age the otolith to determine the exact amount time spent within the mangroves. Otolith aging s was outside the scope of work for this study.

A possible source of error in the otolith analysis could have been in the varying amount of inorganic material collected from each otolith. At least 50 µg of tissue was needed for each analysis, core and edge; however, 50 µg from a smaller otolith might represent a longer period of the fish's life compared to a bigger otolith. The slight difference in otolith size could result in minor differences relative to a fish's age. Other techniques, such as laser ablation, could provide more precise sampling, thereby ensuring that the target material selected for analysis corresponds to a specific time in the fish's life. These techniques were unavailable for use in this study.

Summary and Conclusions

Many tropical marine reef fishes utilize mangrove ecosystem habitats for foraging, protection, and as a nursery habitat before moving to nearshore reef habitats. The goal of this study was to use seven representative teleost fishes from both habitats in South Florida waters to develop a better understanding of energy flow between them through analyses of stable isotope ratios.

We found that $\delta^{13}C$ signatures in muscle tissues differed significantly among species, age class, and habitat. Fishes collected in the mangroves had a more depleted $\delta^{13}C$ signature, likely since mangroves are C_3 plants and tend to be more depleted in carbon than those that use the C_4 or CAM photosynthesis pathways. Juvenile fishes were more depleted in $\delta^{13}C$ while adults were more enriched in $\delta^{13}C$. As total length of the fish increased, so did the $\delta^{13}C$. This suggests that these juveniles generally foraged in the mangroves while the adults tended to forage on the reef. Barracuda was the species most enriched in $\delta^{15}N$, along with adults of all species and those fishes collected on the reef. As the fish grows, there is a shift in diet, suggesting that the area in which the fish forages increases. For example, the diet of juvenile barracuda most likely reflects both the prey availability. As the barracuda grows, the selection of prey organisms grows to those of progressively larger size and more mobile fish due to the increase in mouth size (Kadison et al. 2010).

There were significant differences among species, age class, and habitat in $\delta^{18}O$; however, there was no difference between seasons and within paired otolith samples.

Four out the seven species were found to have more depleted $\delta^{18}O$ as juveniles, suggesting that they utilized the mangroves as juveniles before moving offshore. Fishes collected from the mangroves had more depleted $\delta^{13}C$ otolith values, while fishes collected on the reef were more enriched. Significant difference existed in $\delta^{13}C$ otolith values among species, age class, and habitat. There was also a general trend of increasing $\delta^{13}C$ otolith values with increasing size, also suggesting that the juvenile fishes tend to move offshore from the mangroves.

Overall, the findings of this study further confirm that several commercially and recreationally important reef fishes utilize mangrove ecosystems during their juvenile life stages. With mangroves becoming increasingly threatened by commercial development, additional efforts should be made to protect these essential fish habitats.

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