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Nova Southeastern University, nhansen2@mail.usf.edu

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Feeding ecology and habitat utilization of the great barracuda *Sphyraena barracuda* (Edwards 1771) in southeast Florida

By

Noah R. Hansen

Submitted to the faculty of
Nova Southeastern University Oceanographic Center
in partial fulfillment for the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

February 2015

Thesis of

Noah R. Hansen

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science:

Marine Biology

Nova Southeastern University

Oceanographic Center

February 2015

Approved:

Thesis Committee

Major Professor: _____

David W. Kerstetter, Ph.D.

Committee Member: _____

Richard E. Spieler, Ph.D.

Committee Member: _____

Tracey T. Sutton, Ph.D.

Abstract

Great barracuda *Sphyraena barracuda* is a large predatory teleost found circumglobally, other than the Eastern Pacific Ocean. The species is commonly caught by both recreational and commercial fishermen as bycatch while targeting other, more economically or recreationally valuable fishes. This species also exhibits an ontogenetic shift in habitat, with juveniles inhabiting mangrove and seagrass habitats, while adults live near offshore reefs and associated structure.

This thesis consists of two separate studies of *S. barracuda*: 1) feeding ecology along an ontogenetic gradient and 2) habitat utilization of as derived through electronic tagging. The first chapter of this thesis describes the feeding ecology of great barracuda in South Florida, with an emphasis on the determination of when the ontogenetic shift in diet occurs between habitats and individual fish sizes. Specimens were collected primarily by seine net and hook-and-line fishing. The specimens were then dissected with the stomach contents examined. This study found that the ontogenetic diet shift in great barracuda begins around the second year, and that juveniles and adults are opportunistic predators with a wide diversity of teleost and crustacean prey items within the selected habitat. The second chapter of this thesis describes the habitat utilization and vertical movements of two great barracuda off of South Florida interpreted from data acquired from pop-up satellite archival tags (PSATs). This study found that large (>100 cm) great barracuda are capable of travelling hundreds of kilometers over a period of days to weeks. The results show that large great barracuda can tolerate temperatures ranging from 17.8° C to 31.3° C, and are capable of diving to depths greater than 175 m. It was also found that there was a significant difference in time spent at depth, with greater depths being inhabited more frequently at night.

Keywords: teleost, barracuda, feeding ecology, PSAT, habitat utilization

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Conclusion 55

Introduction

The great barracuda *Sphyraena barracuda* (Edwards, 1771) is a large predatory teleost found in South Florida waters. These fish are commonly caught by both recreational and commercial fishermen, but have little economic value due to the potential threat of ciguatera poisoning and are thus generally discarded as bycatch (Trent et al. 1997). As with many other bycatch species, little is known about the population dynamics of great barracuda, and the only partial stock assessment used catch data from the period 1979-1996 in the Florida Keys (Ault et al. 1998). This lack of information about the species could lead to great barracuda being overfished with the fisheries resource management agencies unaware of this status. This thesis will use stomach content analysis as well as electronic tagging to refine the known feeding ecology and habitat utilization parameters of great barracuda. The combination of these two methods will allow for a more comprehensive understanding of this high-level predator, which will facilitate more appropriate conservation and management measures.

Sphyraena barracuda biology

The great barracuda is a marine fish found in tropical and sub-tropical environments with the exception of the eastern Pacific and is thought to hold an important position as a top predator in nearshore environments (de Sylva 1963; Kadsion et al. 2010). Often there is confusion as to whether the great barracuda is a reef fish or a pelagic fish; however, despite their close association with coral reefs, the pattern of high environmental dispersal and connectivity in great barracuda more closely resembles oceanic predators than reef-associated teleosts (Daly-Engel et al. 2012).

Great barracuda show an ontogenetic shift in habitat. As juveniles, they inhabit inshore shallow mangrove and seagrass habitats that apparently provide greater shelter than the offshore shipwrecks and reefs, which are inhabited by the adults (de Sylva 1963). Adults are also known to associate with oil platforms in the Gulf of Mexico and off southern Florida (Seaman et al. 1989). Great barracuda growth is rapid after settlement, with an average size of 37.8 cm fork length (FL) at the end of the first year. They attain sexual maturity as early as 3-4 years and 58.0 cm FL in females and 1-2 years

and 46.0 cm FL in males. The oldest individual documented to date was 18 years old and female, with no males over age 11 having been recorded; suggesting females live longer (Kadison et al. 2010). Spawning is thought to occur offshore throughout spring and summer, with peak ingress of late stage larvae into nearshore waters from June to August (Kadison et al. 2010).

Typically, great barracuda will spend their first two years in the protected mangrove and seagrass habitats. By the winter of their second year and at a total length (TL) of around 30 cm, they leave these protected areas and move to the offshore wrecks and reefs they inhabit as adults (Blaber 1982). By the beginning of their third year, most fish have made their way to offshore structure and will stay there for the remainder of their lifespan. As adults, they are thought to inhabit the same trophic level as other large reef-associated predators (de Sylva 1963).

Juveniles inhabit mangroves and seagrass habitats for several different reasons. These areas are typically inhabited by other juvenile fishes, thereby providing ample prey. The structural complexity of these habitats also provides shelter against other predators (Nagelkerken et al. 2000). Juvenile great barracuda may also be the dominant fish predator in some of these mangrove and seagrass habitats, leading to less intraspecific competition and greater prey availability than at a less complex habitat.

Adult great barracuda are typically solitary in both reef and offshore habitats (de Sylva 1963). When group formation occurs, it is often influenced by social facilitation, prey availability, or areas with high current flow (Paterson 1998). Adults are also very territorial and are known to form social hierarchies. They have even been documented to attack one another in space-limited environments while in captivity (de Sylva 1963).

When feeding, great barracuda are generally visual daylight predators, though nocturnal feeding has been documented, particularly during periods of a full moon (Randall 1967). They are documented to be ram feeders, and move slowly toward the prey before a strike is initiated. They will orient toward the prey before striking, and visual stimulation often causes this orientation to occur quickly. This behavior is common among stalking predators, which often approach the prey head-on to reduce visible movement. When the strike is initiated, they capture prey head-first and rely on a large gape that overtakes the prey before the jaws close. Large great barracuda have been

observed to hold relatively large prey in their jaws, bite it in two, and then swallow the two separate pieces individually (Porter and Motta 2004).

Abundance of great barracuda was consistently higher in the Florida Keys during the wet seasons than during the dry seasons (Faunce and Serafy 2008). Juveniles are consistently found in greater abundances during the wet season and are randomly distributed among mangroves during the dry season. Great barracuda are habitat and foraging generalists, able to inhabit turbid estuaries as well as clear-water oceanic lagoons, while preying upon fishes in all types of conditions (Faunce and Serafy 2008).

Previous Studies

Feeding Ecology Studies

Stomach content analysis provides important insight into fish feeding patterns. Accurate information of fish diets can help to provide the basis for understanding trophic interactions in marine food webs (Zacharia and Abdurahiman 2004). The knowledge gained from conducting a diet study allows for a more comprehensive understanding of that particular species, and what resources they consume throughout their lifetime. Using stomach content analysis to provide primary quantitative baseline data of a particular species can also help fisheries biologists better estimate the amount of food consumed by that species and make predictions of the effects of the predator-prey relationship on the fishery (Trites 2003). This information can then contribute to the overall management of the species from an ecosystem perspective (Usmar 2012).

While analyzing stomach contents is essential in understanding the feeding ecology of a particular species, there are some drawbacks when using this method. These include: high digestion rates, identification of partially digested material, and delays between the capture of the specimen and the preservation of the stomach, thereby resulting in partial digestion of the contents prior to examination (Bowen 1996). In addition, stomach contents only provide data on the most recent prey items ingested before the predator was caught (Hyslop 1980).

Satellite Tracking Studies

Tagging and tracking of fishes has been utilized for over a hundred years (reviewed by Jensen 1962). Traditional tagging studies include the mark-recapture method to monitor movement and migration patterns, or to provide a system for the collection of population statistics. However, conventional tagging studies provide little information on the behavior of the fish from the time it is tagged to the time it is recaptured (CATAG 2003). Advances in satellite telemetry technology have enabled fisheries biologists to tag and track fishes in much more comprehensive methods (Guy et al. 1996). One of these advancements is the pop-up satellite archival tag (PSAT) technology, which allows researchers a more comprehensive way to study fish behavior by transmitting data to Argos satellites. Data received are much more comprehensive than traditional tagging methods; however, the major disadvantage is cost. The use of PSATs to track marine species has only been in practice for about 20 years. Typically, at this writing, PSATs cost between $3500-4500 new, and around $800-1200 to refurbish one that has been previously deployed and subsequently recovered. PSATs allow researchers a way to study general location by measuring the light levels at dawn and dusk, as well as temperature, depth and salinity. Once the data are archived and the tags releases from the fish, the data are transmitted to orbiting Argos satellites. Another major advantage of satellite tags is that it is not necessary to re-capture that fish to recover the archived data within the tag.

Understanding the diet of a top predator allows researchers to better comprehend what species are being consumed by that predator. Knowledge of the habitat utilization and vertical movements could also show how that species interacts with other species, habitats, or fishing gear. By combining habitat utilization and feeding ecology data, researchers will gain a more complete understanding of the ecology of great barracuda. This ecological information becomes crucial as fisheries managers are shifting away from species-specific management towards ecosystem based management, where multiple aspects of the ecosystem are important.

References

Ault JS, Bohnsack JA, Meester GA. 1998. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. Fishery Bulletin 96(3): 395-414.

Blaber SJM. 1982. The ecology of *Sphyraena barracuda* (Osteichthyes: Perciformes) in the Kosi system with notes on the Sphyraenidae of other Natal estuaries. South African Journal of Zoology. 17: 171-176.

Bowen SH. 1996. "Quantitative description of the diet." *Fisheries techniques, 2nd edition, American Fisheries Society, Maryland*. 513-532.

CATAG. 2003. Improvements in tagging methods for stock assessment and research in fisheries. Concerted Action for Tagging of Fishes Project, Marine Research Institute, Directorate of Fisheries, Reykjavik, Iceland. http:/www.hafro.is/catag/

Daly-Engel TS, Randall JE, Bowen BW. 2012. Is the great barracuda (*Sphyraena barracuda*) a reef fish or a pelagic fish? The phylogeographic perspective. Marine Biology. 159: 975-985.

De Sylva DP. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). Studies in Tropical Oceanography. 1: 1-179.

Faunce CH, Serafy JE. 2008. Selective use of mangrove shorelines by snappers, grunts, and great barracuda. Marine Ecology Progress Series. 356: 153-162.

Guy CS, Blankenship HL, and Nielsen LA. 1996. "Tagging and Marking". *Fisheries techniques, 2nd edition, American Fisheries Society, Maryland*. 353-383.

Hyslop EJ. 1980. Stomach content analysis: a review of the methods and their application. Journal of Fish Biology. 17: 411-429.

Jensen AC. 1962. Marking and Tagging Fishes. Fishery Leaflet 534. United States Department of the Interior, Fish and Wildlife Service.

Kadison E, D'Alessandro EK, Davis GO, Hood PB. 2010. Age, growth, and reproductive patterns of the great barracuda, *Sphyraena barracuda*, from the Florida Keys. Bulletin of Marine Science. 86(4): 773-784.

Nagelkerken I, van der Velde G, Gorissen MW, Meijer GJ, van't Hof T, den Hartog C.

2000. Importance of mangroves, seagrass beds and shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. Estuarine, Coastal and Shelf Science. 51: 31-44.

Paterson SE. 1998. Group occurrence of great barracuda (*Sphyraena barracuda*) in the Turks and Caicos Islands. Bulletin of Marine Science. 63(3): 633-638.

Porter HT, Motta PJ. 2004. A comparison of strike and prey capture kinematics of three species of piscivorous fishes: Florida gar (*Lepisosteus platyrhincus*), redfin needlefish (*Strongylura notata*), and great barracuda (*Sphyraena barracuda*). Marine Biology. 145: 989-1000.

Randall JE. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography. 5: 665-847.

Seaman J, Lindberg WJ, Gilbert CR, Frazer TK. 1989. Fish habitat provided by obsolete petroleum platforms off Southern Florida. Bulletin of Marine Science. 44(2): 1014-1022.

Trent L, Parshley DE, Carlson JK. 1997. Catch and bycatch in the shark drift gillnet fishery off Georgia and east Florida. Marine Fisheries Review. 59(1): 19-28.

Trites AW. 2003. Food webs in the ocean: who eats whom, and how much? In 'Responsible Fisheries in the Marine Ecosystem'. (Eds. M. Sinclair and R. Valdimarsson). FAO, Rome and CABI Publishing, Wallingford. 125-143.

Usmar NR. 2012. Ontogenetic diet shifts in snapper (*Pagrus auratus*: Sparidae) within a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research 46(1): 31-46.

Zacharia PU, Abdurahiman KP. 2004. Methods of stomach content analysis of fishes. Central Marine Fisheries Research Institute (CMFRI). 148-158.

Author's Note: This thesis is composed of two semi-independent chapters. With the approval of my master's program committee, the two chapters are not presented in the traditional combined format, but rather as two manuscripts to be submitted for peer-review journal publication.

Chapter 1: Feeding Ecology of the great barracuda *Sphyraena barracuda* (Edwards 1771) in southeast Florida

Abstract

The great barracuda *Sphyraena barracuda* is a large predatory fish found in tropical and sub-tropical waters around the globe. They are commonly caught as bycatch in both recreational and commercial fisheries. However, great barracuda have little economic value as a food fish and are generally discarded due to the threat of ciguatera poisoning. This study examined the feeding ecology of the great barracuda in South Florida. A total of 315 great barracuda were caught from both inshore and offshore habitats and their stomach contents examined. Sixty-eight great barracuda were caught in offshore environments and 247 were captured in inshore habitats. The sizes ranged from 6.4 cm to 133 cm total length. Of the 247 great barracuda caught in inshore habitats, teleosts made up the majority of prey items found (91%) in the stomachs. However, some crustaceans were present as well. Cyprinidontid killifishes (49.5%) were the most abundant prey types found in the stomach of inshore barracuda, followed by gerreid mojarras (29.3%) and penaeid shrimps (9.1%). In contrast to previous diet studies on juvenile great barracuda, this study found that great barracuda were not entirely piscivorous, as penaeid shrimps contributed to their diet. Of the 68 great barracuda caught in offshore habitats, only teleost fishes were present in the diet. Clupeidae (9.6%) was the most abundant prey taxon in offshore stomachs, followed by Carangidae (2.4%) and Exocoetidae (2.3%).

Keywords: barracuda, feeding ecology, diet, ontogenetic shift

1.0 Introduction

Barracudas form a group of 27 species, all belonging to the single genus *Sphyraena* within the family Sphyraenidae. Among this family, the great barracuda, *Sphyraena barracuda*, is the largest and most widespread species (D'Alessandro et al. 2011). Great barracuda are found in tropical and subtropical environments in all oceans, with the exception of the eastern Pacific Ocean. They reach 2.1 m in total length (TL) and 45 kg in weight (de Sylva 1963). The most comprehensive study on great barracuda ecology to date is de Sylva (1963), which most notably addressed the systematics and reproduction of Sphyraenidae.

Great barracuda exhibit an ontogenetic shift in habitat as they mature. Juveniles typically spend the first two years in sheltered mangrove or seagrass habitats. By the winter of the second year, and approaching a total length of *ca.* 300 mm TL, they will leave these protected areas and associate more with offshore reefs and structure (Blaber 1982). As adults, they inhabit the same trophic level as other large reef-associated predators (de Sylva 1963).

There is no dimorphism or length-weight difference between the sexes of great barracuda; de Sylva (1963) reported that males obtain maturity by the time they reach 2 years and *ca.* 500 mm TL, while most females mature at 3 years and *ca.* 660 mm TL. There appears to be no peak time of spawning in males, as milt was reportedly expressed from testes of mature males throughout the spawning season. Females ripen at a later date than males, and cease to be ripe earlier in the year. In May, 21.5 % of females were in spawning condition and 91.7 % had completed their spawning by October. Peak spawning for females is in July, with secondary peaks in May and September (de Sylva 1963).

Although great barracuda are not often targeted by commercial fisheries as a food fish due to the threat of ciguatera poisoning, they do provide economic value for surrounding communities. Recreational fishermen and charter boats contribute to local economies through revenue generated by tourism (O'Toole et al. 2010). Recreational divers are often attracted to areas where large fishes such as great barracuda are present, and these divers are willing to spend money to do so (Williams and Polunim 2000; Rudd and Tupper 2002). Great barracuda are prized as a sportfish by some anglers because of

the fishes fighting ability and acrobatics (Sosin 2000), and the species is even intentionally targeted occasionally by charter vessel fisheries when the usual target species are unavailable (pers. obs.). Even when they are not intentionally targeted, the historical catch data for great barracuda show that they are frequently caught incidentally. There has also been some stakeholder concern recently over declining great barracuda numbers in the Florida Keys, and there are reports of declining numbers elsewhere in southeast Florida (MyFWC 2014). However, great barracuda are not regulated at the federal level, and at the state level, they falls in the "unregulated" fishes category, thereby allowing fishermen to keep "two fish or 100 pounds of fish, whichever is greater" (MyFWC 2013).

1.1. Analysis of the diet

Quantitative assessment of a fish's diet is an important aspect of management (e.g., Zacharia and Abdurahiman 2004). The information gained from conducting a diet study allows for a more comprehensive understanding of that particular species, and what resources they consume throughout their lifetime. This knowledge allows for a better understanding of the ecosystem as a whole, which could lead to better management of all the species within that ecosystem (Usmar 2012).

There are currently several different techniques used to study the predator-prey relationships in an ecosystem. Traditional gut content analyses are the most common (Hyslop 1980) and are conducted by removing the stomach and intestines examining the contents found within. However, this method does have disadvantages, in addition to being lethal for the fish. For example, the fish species may have a high digestion rate, or there could be delays between the capture of the specimen and the preservation of the stomach.

Historically, the results of diet studies have been reported in three ways: percentage by number, percentage by weight, or percentage by frequency of occurrence. These three categories can then be combined to calculate the index of relative importance (IRI). IRI is calculated by adding the % by volume (%V) and the % by number (%N) and multiplying that total by the % by frequency of occurrence (%O) (Pinkas et al. 1971):

$$IRI = (\% N + \% V) \times (\% O).$$

IRI is used because it eliminates the bias that occurs when only analyzing one of the three previous methods, and it allows for comparison with other studies (Bowen 1996, Cortes 1997). IRI is also often expressed as the standard metric "%IRI," which makes it comparable among different studies and different food types. IRI is converted to %IRI by:

$$\%\mathrm{IRI}i = 100\,\mathrm{IRI}i \,/ \sum_{i=1}^{n} \mathrm{IRI}i$$

where *n* is the total number of food categories considered at a given taxonomic level.

Over the two-year study period, stomach contents were examined to provide insight into the feeding ecology of great barracuda. In order to examine the ontogenetic shift in great barracuda habitat, diet was classified by habitat, age class and size, and then compared within the groups.

2.0 Materials and Methods

In order to assess spatial variability in the diet of great barracuda, collection locations were classified into two categories. Specimens caught in mangrove and seagrass habitats were considered to be caught inshore, while specimens caught near coral reefs, artificial wrecks, or any other associated structure were considered caught offshore.

2.1 Field Collection

Adult and juvenile great barracuda were collected opportunistically via hook-and-line fishing, seine netting, spearfishing, and through donations by local anglers. Some specimens were also collected from the Gulf of Mexico using commercial greenstick fishing gear targeting surface tunas. De Sylva (1963) noted no evidence of regurgitation during hook-and-line fishing, thus all methods of capture in this study were considered satisfactory. However, it should be noted that there is inherent bias when using hook-and-line fishing to collect specimens for stomach content analysis. This method typically results in catching "hungry fish", which leads to a higher percentage of empty stomachs

(Opitz 1996). With respect to this potential bias, hook-and-line fishing was one of the main methods to obtain adult specimens in this study.

Juvenile great barracuda were predominately collected in Whiskey Creek, a tidal creek in Broward County, Florida, that empties into the Intracoastal Waterway. Juvenile. Adult specimens were also collected from other locations in Broward, Dade, and Monroe, FL counties (Figure 1). Juveniles were primarily collected by seine net due to difficulty collecting the smaller size classes with other (hook-and-line) methods. The seine nets used were 30-, 40-, or 50-foot bag seines with ¼ inch mesh. Adult fish offshore were primarily targeted by hook-and-line tackle (n= 66) and spearfishing (n= 2). When specimens were captured, they were placed in an ice bath as soon as possible to minimize further digestion of items in the stomach. If possible, the gut cavity (but not the stomach) was opened and filled with an ice-saltwater slurry to further retard digestion.

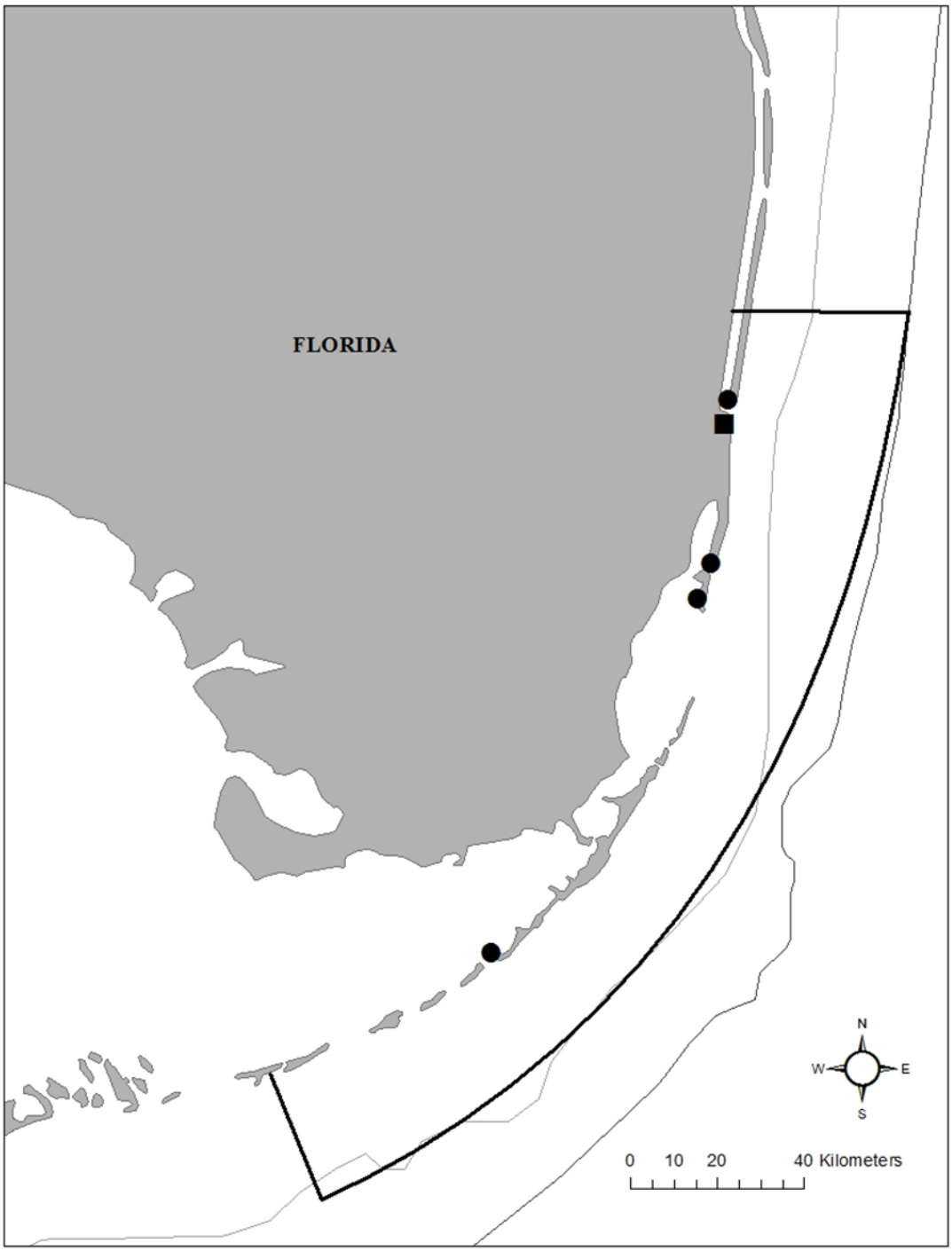
2.2 Laboratory Processing

Once in the laboratory, length and weight measurements were taken. Total, standard, and fork lengths of each great barracuda were recorded in millimeters, and weight recorded in grams. After the weight and length measurements were taken, the stomach was removed and its contents analyzed. When removing the stomach, the pyloric caecum was pushed aside, and the stomach was severed as close to the esophagus as possible. In some cases, when dissecting smaller fish, tweezers were used to pinch off the stomach and to help make the cut. This helped ensure that all the prey items remained in the stomach and were not pushed back through the esophagus and missed.

A wet weight of the full stomach was taken. After the stomach was removed from the body, a qualitative measurement of stomach fullness was recorded, per the methods of Young et al. (1997), with a range from 0 to 4. A value of 0 indicated the stomach was empty, with 4 being extremely full. The stomach was then cut lengthwise with scissors or a scalpel and the prey items removed. After all items were removed, a wet weight of the empty stomach was also taken.

When analyzing the contents of the stomach, prey items were identified to the most readily identifiable taxon. A weight and (if possible) a length of each prey item was also taken (Bowen 1996). Again, a qualitative measurement from 1 to 4 of the digestion

Figure 1. Study sampling area which included the U.S. waters off of Broward, Dade, and Monroe counties as indicated by the solid black line. The black square indicates Whiskey Creek, where the majority of juvenile *Sphyraena barracuda* were captured, while the black circles indicate general capture or collection locations.



state of each prey item was recorded, with 1 being fresh and 4 being completely digested or only hard parts remaining (Young et al. 1997). Any item presumed to be bait was excluded from the analysis; items were determined to be bait if hooks were present in the stomach with the associated prey or if the prey item shows definitive marks of where hooks were placed.

A stomach fullness index was used to estimate the degree of repletion (Shimose et al. 2013) and calculated as:

$$Isf = 100 \times M_{sc}M_b^{-1}$$

where M_{sc} is the mass of the stomach contents (g), and M_b is the mass of the fish (g). A one-way ANOVA was used to compare stomach fullness among great barracuda from different habitats per Shimose et al. (2010).

To estimate the diet overlap between predators of different age and size classes, the %IRI was used. For this comparison, the prey items were grouped together by family taxon. The diet overlap was computed via the Schoener's Index equation:

$$\alpha = 1.0 - 0.5 \times \sum | p_{xi} - p_{yi} |$$

where p_{xi} is the proportion of food category i in the diet of species x, and p_{yi} is the proportion of food category i in the diet of species y. Schoener's Index gives values from 0 (no overlap) to 1 (complete overlap), with a significant overlap value of $\alpha \geq 0.60$ (Wallace 1981). When resource-availability data are absent for the potential prey items, as they were in this study, Schoener's Index is the most suitable to compare diets among groups (Wallace 1981).

The estimated von Bertalanffy growth equation for male great barracuda is $L_F = 1155.0(1 - \exp[-0.30(t + 0.64)])$ and $L_F = 1276.2(1 - \exp[-0.24(t + 0.69)])$ for females. However, no significant difference was found between male and female growth models (Kadison et al. 2010), so the combined model of $L_F = 1236.4(1 - \exp[-0.26(t + 0.71)])$ will be used for the purposes of this diet study, particularly for the assessment of the overlap in the diet of great barracuda by estimated age class calculated from length.

The feeding habits of inshore great barracuda were also analyzed by annual seasons. For this analysis, the year was divided into four seasons: spring (March, April, May); summer (June, July, August); fall (September, October, November) and winter (December, January, February). In addition to being analyzed by season, the feeding

habits were also compared with respect to the wet and dry seasons. In South Florida, the wet season is from May to October, while the dry season is from November to April.

3.0 Results

A total of 323 great barracuda were caught and measured for this study. Only 315 stomachs of the 323 fish were analyzed due to the 8 stomachs being torn upon removal or otherwise unsuitable or unavailable for analysis. Of the 315 stomachs analyzed, 247 were from inshore habitats and 68 were from offshore environments.

Of this group, 29% of these were mature, with sex identified by visual examination of gonads. A total of 61 specimens were identified as males and 31 as females. The sex of the remaining 227 great barracuda collected could not be determined due to the lack of gonad maturation.

Of the 315 stomachs, 192 (60.9%) held prey items; however, only 95 (30.2%) specimens contained prey items subsequently identifiable to the family taxonomic level. The results of the total diet study, including great barracuda caught in both inshore and offshore environments, are shown in Table 1.

The majority of inshore great barracuda were caught by using seine nets in Whiskey Creek, Florida. Whiskey Creek is a shallow mangrove creek in Broward County, Florida (Figure 1). From September 2012 thru August 2014, a total of 26 seining trips were conducted in Whiskey Creek and other inshore habitats, resulting in the collection of 235 great barracuda (*ca.* 9 per trip) (Figure 2).

Of the 247 inshore caught great barracuda, 159 (60%) had prey items present in the stomach, with 81 (30%) of the prey items being identified to the family level. Cyprinidontidae (16.9%) had the highest %IRI of prey items, followed by Gerreidae being present in 10.1% of stomachs analyzed. Penaeid shrimp (*Farfantapenaeus* spp.) were also present in 3.1 % of stomachs (Table 2 and Figure 3).

A total of 68 great barracuda were collected opportunistically from the waters off Fort Lauderdale, Miami, and the Upper Florida Keys. Of the 68 specimens caught offshore, 39 (57.3%) had prey items in the stomach, with 14 (20.6%) having identifiable prey items. For these offshore specimens, Clupeidae (9.6%) had the highest % IRI of prey, followed by Carangidae (2.4%) (Table 3 and Figure 4).

Figure 2. Numbers of *Sphyraena barracuda* caught by seine within inshore environments per month in South Florida.

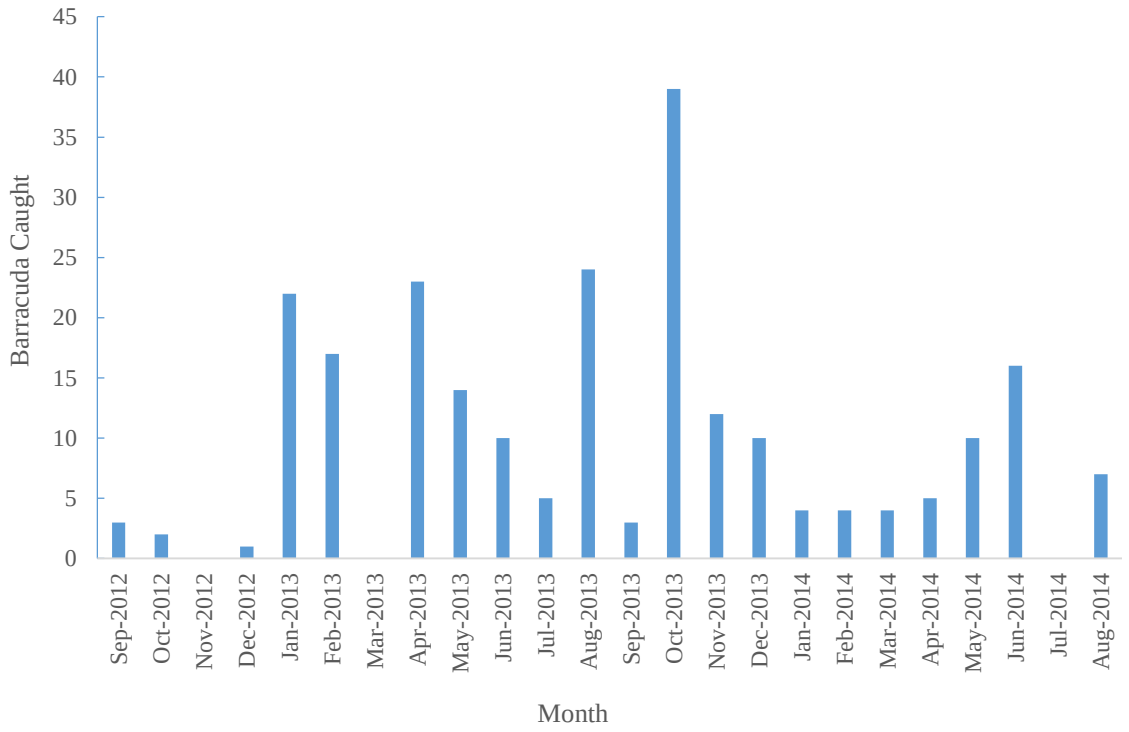


Table 1. Summary of the diet of *Sphyraena barracuda* caught off South Florida. Prey is listed by occurrence, % occurrence, number of individuals, % number, weight in grams, % weight, index of relative importance IRI, and percent index of relative importance %IRI. Unidentified teleosts, un-identified tissue and plant material are also included.

	Occurrence	% O	Number	% N	Weight (g)	% W	IRI	%IRI
Teleost								
Order Clupeiformes								
Family Clupeidae	5	2.2	7	2.8	243.4	17.0	42.9	1.3
Harengula jaguana	1	0.4	2	0.8	59.8	4.2	2.2	0.1
Family Engraulidae	4	1.7	9	3.5	11.2	0.8	7.5	0.2
Order Mugiliformes								
Family Mugilidae	5	2.2	5	2.0	123.4	8.6	23.0	0.7
Order Atheriniformes								
Family Atherinidae	12	5.2	15	5.9	13.4	0.9	35.7	1.1
Order Perciformes								
Family Gerreidae	19	8.3	19	7.5	68.3	4.8	101.2	3.0
Family Carangidae	2	0.9	3	1.2	14.1	1.0	1.9	0.1
Caranx crysos	1	0.4	2	0.8	13.3	0.9	0.7	0.0
Family Scaridae	1	0.4	1	0.4	6.9	0.5	0.4	0.0
Family Sparidae	1	0.4	1	0.4	30.6	2.1	1.1	0.0
Family Gobiidae	1	0.4	1	0.4	0.5	0.0	0.2	0.0
Order Beloniformes								
Family Exocoetidae	2	0.9	2	0.8	220.3	15.4	14.1	0.4
Family Belonidae	2	0.9	2	0.8	1.7	0.1	0.8	0.0
Order Cyprinodontiformes								
Family Cyprinodontidae	28	12.2	36	14.2	37.1	2.6	240.7	7.1
Floridichthys carpio	12	5.2	17	6.7	25.9	1.8	44.4	1.3
Family Fundulidae								
Fundulus grandis	2	0.9	2	0.8	14.7	1.0	1.6	0.0
Order Tetraodontiformes								
Family Balistidae	1	0.4	1	0.4	58.8	4.1	2.0	0.1
Order Beryciformes								
Family Holocentridae	1	0.4	1	0.4	112	7.8	3.6	0.1
Un-Identified Teleost	92	40.0	95	37.4	450.7	31.5	2754.8	81.2
Crustacean								
Order Decapoda								
Family Penaeidae								
Farfantepenaeus spp.	15	6.5	17	6.7	13.4	0.9	49.8	1.5
Plant								
Miscellaneous Vegetation	17	7.4	17	6.7	4.9	0.3	52.0	1.5
Un-Identified Tissue	20	8.7	20	7.9	6.8	0.5	72.6	2.1
Total	230	100	254	100	1432.2	100	3391.7	100

Table 2. Prey composition of 247 *Sphyraena barracuda* caught in inshore environments throughout South Florida. Prey is listed by occurrence, % occurrence, number of individuals, % number, weight in grams, % weight, index of relative importance (IRI), and percent index of relative importance (%IRI). Unidentified teleosts, unidentified tissue, and plant material are also included.

	Occurrence	% O	Number	% N	Weight (g)	% W	IRI	%IRI
Teleost	144	74.2	163	76.2	281	92.7	12537.5	
Order Clupeiformes								
Family Engraulidae	4	2.1	9	4.2	11.2	3.7	16.3	0.5
Order Mugiliformes								
Family Mugilidae	4	2.1	4	1.9	67.2	22.2	49.6	1.6
Order Atheriniformes								
Family Atherinidae	11	5.7	14	6.5	9.1	3.0	54.1	1.8
Order Perciformes								
Family Gerreidae	19	9.8	19	8.9	68.3	22.5	307.7	10.1
Family Sparidae	1	0.5	1	0.5	30.6	10.1	5.4	0.2
Family Gobiidae	1	0.5	1	0.5	0.5	0.2	0.3	0.0
Order Beloniformes								
Family Belonidae	2	1.0	2	0.9	1.7	0.6	1.5	0.1
Order Cyprinodontiformes								
Family Cyprinodontidae	27	13.9	36	16.8	37	12.2	514.5	16.9
Floridichthys carpio	12	6.2	17	7.9	25.9	8.5	102.0	3.3
Family Fundulidae								
Fundulus grandis	2	1.0	2	0.9	14.7	4.9	6.0	0.2
Unidentified Teleost	73	37.6	75	35.0	40.7	13.4	1824.2	59.8
Crustacean								
Order Decapoda								
Family Penaeidae	15	7.7	17	7.9	13.4	4.4	95.6	3.1
Farfantepenaeus spp.								
Plant								
Miscellaneous Vegetation	15	7.7	14	6.5	1.8	0.6	55.2	1.8
Unidentified Tissue	20	10.3	20	9.3	6.8	2.2	119.5	3.9
Total	194	100	214	100	303	100	3050.0	100

Figure 3. Percentages of identified prey items taken from 247 inshore-caught *Sphyraena barracuda* from September 2012 to August 2014, listed by percent index of relative importance.

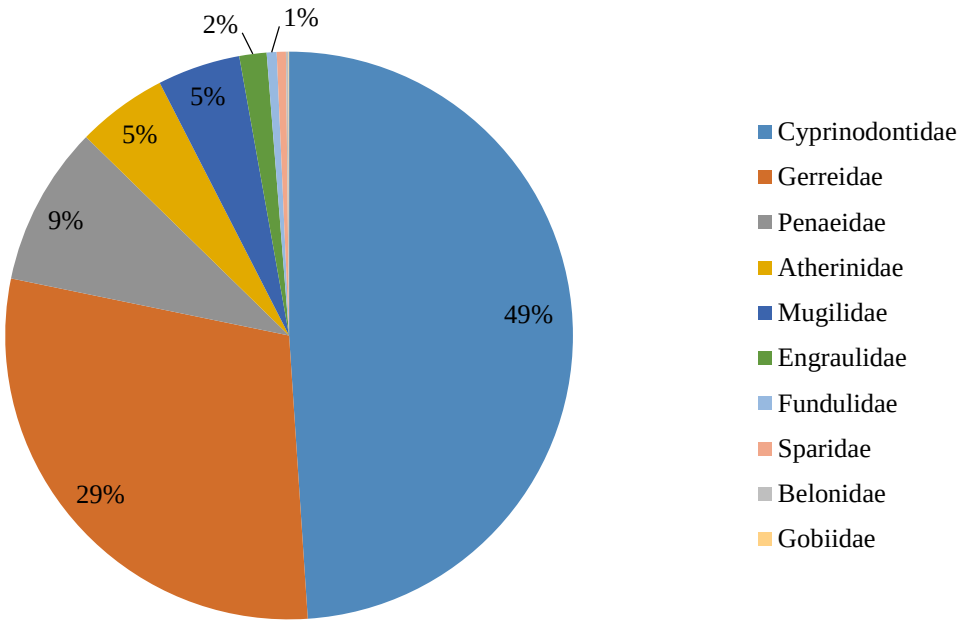
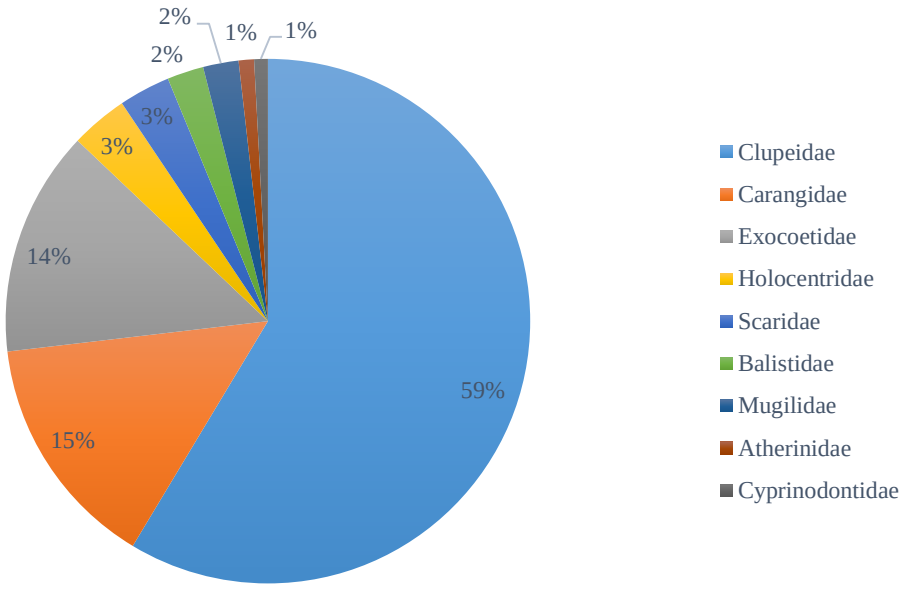


Table 3. Breakdown of the stomach contents of 68 *Sphyraena barracuda* caught in offshore environments in South Florida. Prey is listed by occurrence, % occurrence, number of individuals, % number, weight in grams, % weight, index of relative importance IRI, and percent index of relative importance %IRI. Unidentified teleosts and plant material are also included.

		Occurrence	% O	Number	% N	Weight (g)	% W	IRI	%IRI
Teleost		34	94.4	38	95	1400.1	99.8	18395.8	365.3
	Order Clupeiformes								
	Family Clupeidae	5	13.9	7	17.5	243.4	17.3	484.0	9.6
	Harengula jaguana	1	2.8	2	5	59.8	4.3	25.7	0.5
	Order Perciformes								
	Family Carangidae	2	5.6	3	7.5	197.9	14.1	120.0	2.4
	Caranx crysos	1	2.8	2	5	186.9	13.3	50.9	1.0
	Family Scaridae	1	2.8	1	2.5	97.1	6.9	26.2	0.5
	Order Beloniformes								
	Family Exocoetidae	2	5.6	2	5	220.3	15.7	115.0	2.3
	Order Tetraodontiformes								
	Family Balistidae	1	2.8	1	2.5	58.8	4.2	18.6	0.4
	Order Atheriniformes								
	Family Atherinidae	1	2.8	1	2.5	4.3	0.3	7.8	0.2
	Order Mugiliformes								
	Family Mugilidae	1	2.8	1	2.5	56.2	4.0	18.1	0.4
	Order Cyprinodontiformes								
	Family Cyprinodontidae	1	2.8	1	2.5	0.1	0.0	7.0	0.1
	Order Beryciformes								
	Family Holocentridae	1	2.8	1	2.5	112	8.0	29.1	0.6
	Unidentified teleost	19	52.8	20	50	410	29.2	4181.0	83.0
Plant									
	Miscellaneous vegetation	2	5.6	2	5	3.1	0.2	29.0	0.6
Total		36	100	40	100	1403.2	100	5035.7	100

Figure 4. Percentages of identified prey items by family from 68 *Sphyraena barracuda* caught in offshore environments in South Florida from September 2012 to June 2014 by percent index of relative importance.



A single factor ANOVA test indicated no significant difference in stomach fullness between the two habitats (Inshore vs Offshore, 2.65 vs 3.63, $p > 0.05$). There was also no significant difference in the digestion state of prey items between the two habitats (Inshore vs Offshore, 2.28 vs 2.46, $p > 0.05$).

3.1 Degree of Overlap

Schoener's Index of Overlap was used to determine if there was any overlap in the diet among size classes. Specimens were classified by categories (habitat, age class, and 10-cm size class). When comparing the overlap within the diet of the different classes, %IRI of each prey item was used. Assuming a significant overlap value of $\alpha \geq 0.60$ per Wallace (1981), there was no significant overlap in the diet of inshore great barracuda vs. offshore great barracuda ($\alpha = 0.0435$). Age-0 vs. Age-1 specimens showed a significant overlap in their diets ($\alpha = 0.68$), as did Age-3 vs. Age-4 specimens ($\alpha = 0.635$) (Table 4).

When comparing diet by 10-cm size class, size class 0-10 cm vs. 11-20 cm showed a significant overlap in the diet ($\alpha = 0.66$), as well as size class 11-20 cm vs. 20-30 cm ($\alpha = 0.84$). No other size classes showed a significant degree of overlap (Table 5).

3.2 Prey by Season

The prey of inshore caught great barracuda was analyzed by season by percent number. Family Cyprinidontidae made up a large percentage of the stomach contents throughout the year, and had the highest percentage in the diet in spring (44.4%) and summer (30.3%) months. Cyprinidontidae (33.3%) was also equal to the amount of Family Atherinidae (33.3%) noted in fall months. Penaeid shrimp (30.4%) made up the highest percentage of inshore great barracuda prey in winter months (Table 6).

Prey item composition of inshore caught great barracuda was compared with respect to wet and dry season. Cyprinidontidae made up a much larger percentage of great barracuda diets during the wet season (40.9%) than during the dry season (25.0%). There was also a higher percentage of penaeid shrimp consumed during the dry season (29.5%) than during the wet season (6.0%) (Table 7).

Table 4. Schoener's Index comparing the overlap in diet of the different age classes of 315 *Sphyraena barracuda* caught in the western Florida Straits from 2012-2104. Asterisk (*) indicates a significant overlap.

	Age 0	**Age 1**	**Age 2**	**Age 3**
Age 0				
Age 1	0.68*			
Age 2	0	0		
Age 3	0	0	0	
Age 4+	0	0.049	0	0.635*

Table 5. Schoener's Index comparing the overlap in the diet of the different size classes of *Sphyraena barracuda* caught in the western Florida Straits from 2012-2014. Asterisk (*) highlighting indicated a significant overlap.

	0-10 cm	**11-20 cm**	**20-30 cm**	**30-40 cm**
0-10 cm				
11-20 cm	0.66*			
20-30 cm	0.51	0.84*		
30-40 cm	0.17	0.40	0.52	
>40 cm	0.01	0.01	0.02	0.03

Table 6. Percent prey, by number of individuals per family by season of inshore-caught *Sphyraena barracuda* from summer 2012 to fall 2014. Other prey includes any prey items that were not found in abundance throughout any season (e.g., Mugilidae, Sparidae, Gobiidae, and Belonidae).

Season	Cyprinidontidae	Gerreidae	Penaeidae	Atherinidae	Engraulidae	Other Prey
Winter	26.1	21.7	30.4	4.3	4.3	13.0
Spring	44.4	13.9	19.4	16.7	0.0	5.6
Summer	30.3	21.2	3.0	12.1	24.2	9.1
Fall	33.3	11.1	11.1	33.3	0.0	11.1

Table 7. Percent prey, by number of individuals per family by season of inshore-caught *Sphyraena barracuda* for the wet and dry season from 2012-2014. Other prey includes any prey items that were not found in abundance throughout any season (e.g., Mugilidae, Sparidae, Gobiidae, Belonidae and Fundulidae).

	Cyprinodontidae	**Gerreidae**	**Penaeidae**	**Atherinidae**	**Engraulidae**	**Other Prey**
Wet	40.9	18.2	6.1	15.2	12.1	7.6
Dry	25.0	15.9	29.5	15.9	2.3	11.4

4.0 Discussion

Both inshore- and offshore-caught specimens consumed prey from nine families, showing that they are both primarily piscivirous feeders. Offshore individuals were entirely piscivirous, with families Clupeidae (9.6%), Carangidae (2.4%), and Exocoetidae (2.3%) being the dominant identifiable prey items. Other prey species found include fishes from families Scaridae (0.5%), Holocentridae (0.6%), Atherinidae (0.2%), Balistidae (0.4%), Mugilidae (0.4%), and Cyprinidontidae (0.1%). Family Cyprinidontidae is found near inshore mangrove habitats, thus it is unclear how an offshore great barracuda consumed it. This could indicate some movement of adult great barracuda between offshore structure and inshore mangrove habitat. Miscellaneous vegetation, including *Sargassum* sp. macroalgae, was found in 0.6% of stomachs. However, this vegetation was likely ingested incidentally while consuming other prey items given the low presence in the examined stomachs.

Teleosts dominated the inshore diet by occurrence (74.2%), number (76.2%), weight (92.7%) and %IRI (91.6%). The only other prey taxon found in the study was penaeid shrimp, which was present in 3.1% of stomachs. Families Cyprinidontidae (16.9%) and Gerreidae (10.1%) were the two most common identifiable prey from inshore specimens. Other prey taxa found include fishes from families Atherinidae (1.8%), Mugilidae (1.6%), Engraulidae (0.5%), Sparidae (0.18%), Belonidae (0.05%), and Gobiidae (0.01%). Miscellaneous vegetation was found in 1.8 % of the stomachs as well. Vegetation was also found in a higher percentage in inshore versus offshore stomachs, likely due to the fact that inshore great barracuda live in seagrass and mangrove habitats, where much more vegetation is present. The remaining percentage (3.9%) was made up of unidentified tissue, which was too digested to even determine whether it was teleost or crustacean.

4.1 Comparison to previous studies

Stomach content analysis data presented in this study are consistent with results of previous studies. Inshore specimens fed primarily on families Cyprinidontidae and Gerreidae, and these results agree with those of Schmidt (1989). Families Atherinidae, Gerreidae, and Gobiidae were also found in abundance in the study of Schmidt (1989).

However, the sample size by Schmidt (1989) was smaller than the sample size in the present study (106 vs 315, respectively). Randall (1967) reported small great barracuda fed on schooling clupeoid and atherinid fishes. Hammerschlag et al. (2010) reported that the family Atherinidae comprised a significant proportion of juvenile great barracuda diet in both the wet and dry seasons. This study found that offshore specimens primarily fed on clupeoid and carangid fishes, and although these prey items were not the most abundant in the de Sylva (1963) study, both prey families were found in the diet of individuals from that study. Randall (1967) also found that a large individual (*ca.* 1070 mm) consumed 18 false pilchards (*H. clupeola*) from the family Clupeidae.

4.2 Seasonality

Only great barracuda caught in inshore habitats were analyzed by season, as there were not enough offshore specimens captured throughout the year for this analysis. Prey was evaluated by number and the top five prey families are described here. In contrast to a previous study by Hammerschlag et al. (2010) that found that there were no significant seasonal differences in the diet of juvenile great barracuda, this study found that there were differences across seasons. However, Hammerschlag et al. (2010) only analyzed the stomach contents of late-stage juveniles that measured larger than reported Age 1 sizes, but smaller than reported size at maturity, while this study compared the stomach contents of all great barracuda caught in inshore environments.

During the winter months, Penaeidae (30.4%), Cyprinidontidae (26.1%), and Gerreidae (21.7%) all made up the majority of the diet in similar proportions. In spring months, Cyprinidontidae (44.4%) dominated the diet. In summer months Cyprinidontidae (30.3%) made up the highest percentage of the diet, followed by Engraulidae (24.2%) and Gerreidae (21.2%). Finally, Cyprinidontidae and Atherinidae both dominated the diet in equal percentages (33.3%) during the fall months. It is apparent that Cyprinidontidae contribute a major percentage of the diet throughout the year. However, as prey abundances in the collection locations were not conducted for this study, it is unknown whether this seasonality in the diet is based on prey selectivity or abundance.

4.3 Degree of Overlap

One of the main objectives of this study was to determine if there was an overlap in the diet of great barracuda living in inshore environments with those in offshore environments. In order to compare the diet between these two habitats, %IRI was calculated and Schoener's Index of Overlap was used. The degree of overlap when comparing prey items from these two habitats was 0.0435, indicating very little overlap. This indicates a complete shift in diet as the prey move offshore. The only prey items found in both inshore and offshore environments were killifish (Cyprinidontidae), and silversides (Atherinidae). However, both of these prey items were only found once in the stomach of offshore-caught specimens.

In order to further evaluate if there was any diet overlap within this species, great barracuda were divided into yearly age categories. Age-0 individuals showed a significant degree of overlap with Age-1 individuals ($\alpha = 0.68$). Again, this is not unexpected because both of these age classes reside in mangrove and seagrass habitats. Age-3 and Age-4+ individuals also showed a significant overlap in the diet ($\alpha = 0.64$), which is again expected because the both age classes areas of offshore structure. None of the other age classes showed any significant dietary overlap.

Great barracuda diet was also compared by 10-cm size classes. The 0- to 10-cm and 10- to 20-cm size classes showed a significant degree of overlap ($\alpha = 0.66$). Size 10- to 20-cm and 20- to 30-cm also showed a strong significance in diet overlap ($\alpha = 0.84$). No other size classes showed any significant overlap when assessed using %IRI.

4.4 Mean Stomach Repletion

The index of stomach fullness can be used to show mean stomach repletion and relative foraging success (Graham et al. 2007). *Isf* values were not significantly different between inshore and offshore habitats (2.65 vs 3.63, ANOVA $p > 0.05$). Although both categories of great barracuda had a high percentage of empty stomachs, it was noticed that prey items in general were abundant in inshore habitats. Because sampling with seine nets was most effective at low tide, the sampling times varied for each trip. Although all seining trips were collected during daylight hours, the non-standardized

sampling time could have led to the collection of samples during non-ideal great barracuda feeding times.

Acknowledgements

I thank all the labmates who helped with the collection and dissection process, especially Jen Savaro and Joe Hornbeck. I also thank Captain Bouncer Smith, Monster Sportfishing, and all the other fishermen, anglers, and charter vessel captains that provided specimens throughout this project. Financial support for this research was provided in part by the Yamaha Contender Miami Billfish Tournament.

References

Blaber SJM. 1982. The ecology of *Sphyraena barracuda* (Osteichthyes: Perciformes) in the Kosi system with notes on the Sphyraenidae of other Natal estuaries. South African Journal of Zoology. 17: 171-176

Bowen SH. 1996. "Quantitative description of the diet." *Fisheries techniques, 2nd edition, American Fisheries Society, Maryland*. 513-532.

Cortes E. 1997. A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. Canadian Journal of Fisheries and Aquatic Sciences. 54: 726-738.

D'Alessandro EK, Sponaugle S, Llopiz JK, Cowen RK. 2011. Larval ecology of the great barracuda, *Sphyraena barracuda*, and other sphyraenids in the Straits of Florida. Marine Biology. 158(12): 2625-2638.

De Sylva DP. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). Studies in Tropical Oceanography. 1: 1-179.

Graham BS, Grubbs D, Holland K, Popp BN. 2007. A rapid ontogenetic shift in the diet of juvenile yellowfin tuna from Hawaii. Marine Biology. 150: 647-658.

Hammerschlag N, Ovando D, Serafy JE. 2010. Seasonal diet and feeding habits of juvenile fishes foraging along a tropical marine ecotone. Aquatic Biology. 9: 279-290.

Hyslop EJ. 1980. Stomach content analysis-a review of methods and their application. Journal of Fish Biology. 17: 411-429.

Kadison E, D'Alessandro EK, Davis GO, Hood PB. 2010. Age, growth, and reproductive patterns of the great barracuda, *Sphyraena barracuda*, from the Florida Keys. Bulletin of Marine Science. 86(4): 773-784.

MyFWC. Barracuda- Review and Discussion. Florida Fish and Wildlife Conservation Commission. November 2014 Commission Meeting. Authors: Recks, M., and Smith, M. November 20, 2014.

MyFWC. Unregulated Species- Florida Fish and Wildlife Conservation Commission. Taken October 21, 2013. http://myfwc.com/fishing/saltwater/recreational/unregulated-species/

Opitz S. 1996. Trophic Interaction in Caribbean Coral Reefs. ICLARM Technical Report. 43.

O'Toole AC, Danylchuk AJ, Suski CD, Cooke SJ. 2010. Consequences of catch-and-release angling on the physiological status, injury, and immediate mortality of great barracuda (*Sphyraena barracuda*) in The Bahamas. ICES Journal of Marine Science. 67: 1667-1675.

Pinkas L, Oliphant MS, Iverson ILK. 1971. Food habits of albacore, bluefin tuna, and bonito in California water. Fishery Bulletin 152. 1-105.

Randall JE. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography. 5: 665-847.

Rudd MA, Tupper MH. 2002. The impact of Nassau grouper size and abundance on scuba diver site selection and MPA economics. Coastal Management. 30: 133-151.

Schmidt TW. 1989. Food habits, Length-weight relationship and condition factor of young great barracuda, *Sphyraena barracuda* (Walbaum), from Florida Bay, Everglades National Park, Florida. Bulletin of Marine Science. 44(1): 163-170.

Shimose T, Yokawa K, Saito H. 2010. Habitat and food portioning of billfishes (Xiphioidei). Journal of Fish Biology. 76(10): 2418-2433.

Shimose T, Watanabe H, Tanabe T, Kubodera T. 2013. Ontogenetic diet shift of age-0 Pacific bluefin tuna *Thunnus orientalis*. Journal of Fish Biology. 82(1): 263-276.

Sosin M. 2000. The Complete Book of Light-tackle fishing. New York: The Lyons Press.

Usmar NR. 2012. Ontogenetic diet shifts in snapper (*Pagrus auratus*: Sparidae) within a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research 46(1): 31-46.

Wallace Jr RK. 1981. An assessment of diet-overlap indexes. Transactions of the American Fisheries Society. 110(1): 72-76.

Williams ID, Polunin NVC. 2000. Differences between protected and unprotected reefs of the western Caribbean in attributes preferred by dive tourists. Environmental Conservation. 27: 382-391.

Young JW, Lamb TB, Le D, Bradford RW, Whitelaw AW. 1997. Feeding ecology and

interannual variations in diet of southern bluefin tuna, *Thunnus maccoyii*, in relation to coastal and oceanic waters off eastern Tasmania, Australia. Environmental Biology of Fishes. 50: 275-291.

Zacharia PU, Abdurahiman KP. 2004. Methods of stomach content analysis of fishes. Central Marine Fisheries Research Institute (CMFRI). 148-158.

Chapter 2: Habitat utilization and vertical distribution of the great barracuda *Sphyraena barracuda* (Edwards 1771) in the western North Atlantic Ocean

Abstract

The great barracuda *Sphyraena barracuda* is a large predatory teleost commonly seen in the tropics of the Western North Atlantic. Using pop-up satellite archival tags (PSATs), six large great barracuda (85-118 cm) were tagged off the coast of South Florida and Bimini, Bahamas. Two of the six tags remained attached to the great barracuda for the duration of the deployment period. Great barracuda 88094 traveled 471 km MSLD over the 15-day tag duration, while great barracuda 88095 traveled 1231 km MSLD over its 15-day deployment period. Great barracuda 88094 dove to a maximum depth of 145.2 m, while 88095 dove to a maximum depth of 186.9 meters. The data obtained indicate significant differences in diel behavior, with both individuals utilizing deeper depths during nighttime periods. The results of this study show that great barracuda are capable of travelling great distances over short periods of time, and can inhabit depths greater than 175 meters. These data will allow fisheries managers to better understand great barracuda behavior and how they interact with more economically valuable species, with the ultimate goal of more effective species management.

Keywords: barracuda, PSAT, habitat utilization, vertical movements

1.0 Introduction

The coral reef ecosystem off South Florida provides habitat and refuge for commercially and economically important marine species. These include groupers (Serranidae), snappers (Lutjanidae), and jacks (Carangidae), as well as the Caribbean spiny lobster *Panulirus argus* and Florida stone crab *Menippe mercenaria*. The great barracuda *Sphyraena barracuda* is a high-level predator in this ecosystem. However, this species has little value to commercial fishermen due to the possibility of the flesh containing the toxin ciguatera (de Sylva 1994).

Despite being rarely targeted, great barracuda are frequently caught incidentally by both recreational and commercial fishermen (Figure 1 and 2). This fact causes concern among fisheries managers because there are currently no federal management regulations in place for great barracuda. At the state level, the species falls in the "unregulated" fishes category, thereby allowing fishermen to keep "two fish or 100 pounds of fish, whichever is greater" (MyFWC 2013). No comprehensive stock assessment has taken place to date, although a preliminary value was assigned in Ault et al. (1998) as one of the numerous non-assessed reef-associated fishes. Because they are not consumed, great barracuda are most frequently caught as bycatch and either discarded or used as bait, especially when targeting sharks (O'Toole et al. 2010a).

The great barracuda is a large predatory teleost that inhabits tropical and subtropical environments throughout the globe, with the exception of the eastern Pacific Ocean, ranging from Massachusetts to southeastern Brazil in the western Atlantic Ocean (D'Alessandro 2011). It inhabits a range of ecosystems through ontogeny, preferring mangrove and seagrass habitats as juveniles, and coral reefs and other deeper habitats in offshore waters as adults (de Sylva 1963). Spawning occurs throughout the spring and summer in both males and females (Kadison et al. 2010). The great barracuda is a high-level predator in the ecosystem it inhabits, and thus it affects the population of other species within that same habitat. Large individuals are thought to inhabit the same trophic level as other reef associated teleosts, including groupers, snappers, and jacks (de Sylva 1963).

As adults, great barracuda associate with offshore structure, such as natural coral reefs or artificial wrecks. However, overall movement between these locations is

Figure 1. Recreational harvest data for great barracuda *Sphyraena barracuda*, greater amberjack *Seriola dumerili*, wahoo *Acanthocybium solandri*, cobia *Rachycentron canadum*, and blackfin tuna *Thunnus atlanticus* caught in Florida waters from 2000-2011 (NOAA Fisheries July 17, 2013).

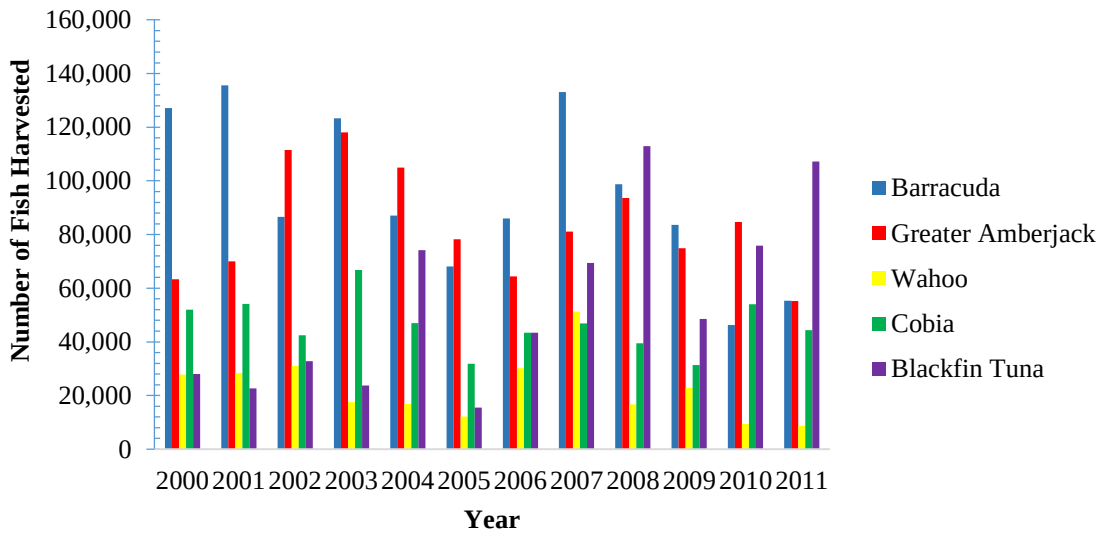
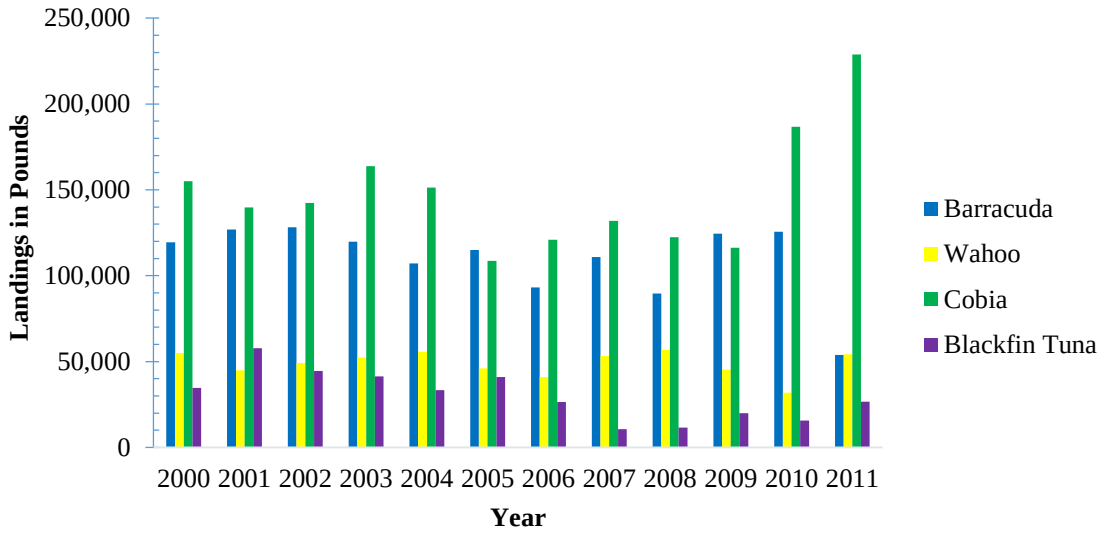


Figure 2. Commercial landings data in pounds for great barracuda *Sphyraena barracuda*, wahoo *Acanthocybium solandri*, cobia *Rachycentron canadum*, and blackfin tuna *Thunnus atlanticus* caught in Florida waters from 2000-2011 (NOAA Fisheries July 17, 2013).



relatively unknown, and the few studies that document this movement somewhat differ. De Sylva (1963) used commercial catch records to show that great barracuda migrate north in the spring and south in the fall. Springer and McErlean (1961) used traditional tags to show that small great barracuda move very little, but large individuals (>879 mm) are capable of moving over 50 miles in less than 20 days. Paterson (1998) showed that adult great barracuda congregate in large numbers around artificial reefs, wrecks and reef passes, many of which were subjected to strong current. Wilson et al. (2006) used natural body markings on great barracuda to confirm that they do show some degree of site fidelity, with 20% of individuals returning to the same area as previously photographed. Finally, O'Toole et al. (2010b) used acoustic transmitters to track great barracuda in the Bahamas. The results of this study showed great barracuda are capable of swimming faster than 3.47 m s^{-2}, and dove as deep as 32.22 m. Another study by O'Toole et al. (2011), again using acoustic transmitters, showed that great barracuda are capable of travelling greater than 12 km per day and over 100 km to other islands throughout the Bahamas.

1.1 Tagging and Tracking

Advances in technology have enabled fisheries biologists to tag and track fishes (Guy et al. 1996). With the introduction of pop-up satellite archival tags (PSATs) into the fisheries sector approximately 20 years ago, large marine animals could now be tracked and the data reported in real-time. Early satellite tags were only applicable for large species that frequently broke the surface of the water, allowing the tag to transmit data to orbiting NOAA satellites (Block et al. 1998). However, PSAT technology is designed to track the movements of pelagic fishes where towed satellite tags are ineffective. The PSAT stays attached to the selected animal for a set amount of time, and then "pops-off" and floats to the surface, where it transmits to overhead Argos satellites. The tag can provide a fishery-independent measure of depth, temperature, and straight-line distance travelled from the point of tagging to the location of the first satellite transmission (Block et al. 1998).

Within the past few years, the knowledge of habitat utilization has been greatly enhanced for large pelagic species due to PSAT technology. The information gained

from PSAT deployments could also improve the understanding of interactions between top predators with overlapping habitats and similar foraging strategies (e.g., Theisen and Baldwin 2012). In addition, PSATs can be used to determine the post-release survival rates of large pelagic species. Kerstetter et al. (2003) used PSATs to analyze the survival of blue marlin *Makaira nigricans* released from pelagic longline gear in the western North Atlantic Ocean. While PSATs do provide a valuable insight into the habitat utilization of the targeted species, it should be noted that the tag is only attached to one individual, and every fish in the population may not behave in the same manner as the tagged fish.

The data recovered from this study will determine if PSATs can be successfully used to track barracuda movement. The data recovered from the tags will also help to improve the knowledge we have about great barracuda range, habitat utilization, and vertical movements. These data can then be used in the fisheries sector to provide better management of great barracuda.

2.0 Materials and Methods

Before tag deployments, all participants were trained in proper tagging methods. As recommended by CATAG (2003), a preserved great barracuda specimen was used to practice and determine the optimal location for tag placement. Specimens were caught by traditional hook-and-line recreational angling methods in South Florida and the Bahamas, particularly near Dade County, Florida, and off Bimini, Bahamas. During the tagging event, gear type, handling time, hook location, and GPS coordinates of release location were recorded. Fork length (FL) of each fish was measured.

In order to ensure that the individual fish was of sufficient size to carry the tag, all prospective great barracuda for tagging were a minimum of 85 cm FL and scored above a 7 on a modified ACESS scale. The ACESS scale is an overall health assessment of the fish with a qualitative grade from 0-10, and is determined by examining five characteristics and assigning each a score of 0-2 (poor to good). These characteristics include overall activity, color, condition of the eyes, bleeding of the mouth, and general state of the musculature (see Kerstetter et al. 2003). Fish were not tagged if there were other predators, such as sharks, visible in the vicinity of the tagging vessel.

During the tagging event, the great barracuda was brought on board the boat using a large landing net, then tagged and immediately returned to the water. Nash et al. (2002) showed that the use of a cradle or sling allows researchers a way to efficiently handle and measure the fish, while avoiding teeth. Tags were inserted near the anterior dorsal fin. When inserted in this region correctly, the barb will interlock behind (on the opposite side of the fish) the dorsal pterygiophore bones. By tagging the fish through the dorsal musculature, the tag tether should be well supported and the tag float should provide sufficient lift to keep the tag body from rubbing against the body at slow speeds (Block et al. 1998). When possible, a traditional streamer tag was also inserted into the dorsal musculature on the opposite side of the fish from the PSAT. Only after the fish was tagged and deemed healthy enough to be released was the hook removed. However, the hook was not removed in two of the tagged great barracuda, as it would have taken too long to remove and removal would have potentially harmed the fish further.

Five Microwave Telemetry (Columbia, MD, USA) "X-tags" and one Wildlife Computers (Redmond, CA, USA) Mk10-PAT tag were used in the study. The PSAT itself is contained in a composite, slightly positively buoyant, low drag housing towed by a short monofilament leader attached to a medical grade nylon dart. The buoyancy is molded to the rear of the tag, which will float vertically at the surface with the antenna breaking the water's surface (CATAG 2003). The PSAT was connected to the barb by a monofilament segment and a short wire segment that is easily corroded with a low power input at a scheduled time. The Microwave Telemetry X-Tag HR model weighed 40 grams, and the entire tag and attachment tether combination weighed approximately 53 grams. Approximately 15 cm of 120-pound test monofilament tethers were used to attach the tag to a nylon dart with aluminum crimps. Each crimped connection was covered with electrical shrink tubing to help prevent chafing and minimize reflection. The monofilament segment also included a 150-pound test ball bearing swivel (model BX4RZ, Sampo, Inc.; Barneveld, NY) so that the tag can rotate freely and not incur rotational torque stress around the attachment site (Bain 2005, Kerstetter et al. 2011).

The five Microwave Telemetry pop-up satellite archival X-tags (PSATs) were programmed to record a data point every 141 seconds. Water temperature (°C in 0.18 degree resolution), pressure (converted to depth in 1.3 meter resolution), and light level

(unit less scale 0-255) were recorded for 15 or 30 days. One Wildlife Computers PAT-Mk10 pop-up satellite archival tag was also deployed. The PAT-Mk10 tag records depth (0.5 m resolution), temperature (0.05° C resolution) and light level (5 x 10^{-12}W.cm^{-2} to 5 x 10^{-2}W.cm^{-2} resolution). The Microwave Telemetry tags did not provide enough light level data for light-based geolocation estimates. Because of this, all horizontal displacements were based on minimum straight-line distance (MSLD) between the location of tagging and the location of the first acceptable Argos transmission. The Wildlife Computers PAT-Mk10 PSAT bins temperature and depth data into specific ranges, and is thus slightly less accurate. However, the PAT-Mk10 PSAT does record enough light level for geolocation estimates. Time for both types of tag was reported in Greenwich Mean Time (GMT).

2.1 Data analysis

After the PSATs disengage from the fish, the tag floats to the surface and the data are transmitted to Argos satellites in hexadecimal code to minimize the number of necessary transmissions. In order to conserve battery life, the X-tag model PSAT only transmits data if there is a receiving satellite overhead (satellite overpass times are pre-programmed into the tag prior to deployment). After the data transmissions from the X-tag are complete, the manufacturer prepares a data report and sends it to the user (Microwave Telemetry 2014). In contrast, the PAT-Mk10 tag transmits the binned summaries of the archived data, including the proportion of time spent in each user-defined temperature and depth bin during each time interval, minimum and maximum depths and temperatures visited within each time interval, and profiles of light intensity used for geolocation estimates (Wildlife Computers 2014). In order to access the Wildlife Computers tag data, the company provides an analysis program (WC-DAP, v. 3.0.292.) which is used to decode and display the transmitted data. These data can then be subsequently exported into an Excel spreadsheet (Wildlife Computers 2014).

In order to determine if there were any diel changes in the great barracuda behavior, local sunrise and sunset times were obtained from United States Naval Observatory data (http://www.usno.navy.mil). Crepuscular periods were defined as 15 minutes before and after sunrise/sunset, and were thus excluded from the analysis. A

single-factor ANOVA test was used to determine if there were diel differences in the temperature and depth data, with an accepted significance α-level of $P < 0.05$.

3.0 Results

A total of six tags were deployed for this study (86997, 88094, 88095, 88096, 88271, and 89371). Of the six tags deployed, only two tags – 88094 and 88095 – remained attached to the fish for the duration of the deployment. Thus, only these two datasets were analyzed in this study. Table 1 shows the specifics of each great barracuda tagged, while Figure 3 shows each tag deployment location.

Tags 88094 and 88095

During the tagging period, both fish travelled north. The first reliable GPS transmission from tag 88094 showed it *ca.* 100 km off the coast of Northeast Florida (Figure 3). After detaching, tag 88094 transmitted 91% of its data to Argos satellites. The MSLD for this fish was 471 km over the 15-day period, or an average of 31.4 km per day. The maximum depth for this tag was 145.2 m, with 90% of the deployment time being spent in water less than 26.9 m. Temperature ranged from 18.6° C to 28.4° C, with 90% of time at temperature being less than 27.3° C.

Similarly, tag 88095 travelled north-east to *ca.* 175 km off the coast of Virginia (Figure 3). Tag 88095 detached after the 15-day deployment and transmitted 87% of its data to Argos satellites. This individual traveled 1231 km MSLD within the 15-day deployment period, for an average of 82 km per day. The temperature ranged from 17.8° C to 31.7° C, with 90% of time at deployment being less than 31.3° C. The great barracuda dove to a maximum depth of 186.9 m, but spent 90% of the time in water less than 9.4 m deep.

Both tag datasets were also examined for potential differences in behavior related to diel patterns. Tag 88094 showed a significant diel difference in overall diel time at depth ($F = 727.28$ and $p < 0.001$). Daytime depth averaged 7.03 m and ranged from 0 to 86.1 m. Nighttime depth averaged 15.6 m and ranged from 0 to 145.2 m (Figure 4a and 5a). There was also a significant difference in time at temperature ($F = 34.37$ and $p < 0.001$). Average daytime temperature was 26.1° C and ranged from 20.4-28.4° C.

Table 1. Specific information for each tag deployed on great barracuda in South Florida and Bimini, Bahamas waters from August 2013 to August 2014. The "MSLD" metric represents the "minimum straight-line distance" between initial release of the tagged fish and the location of the first Argos transmission.

PTT-ID	Tag Model	Date	Deployment time (days)	Hook Location	Hook Removed	Fork Length (cm)	ACESS Score	MSLD (km)
88095	X-Tag	8/17/2014	15	Jaw	N	109	9	1231
89371	X-Tag	6/20/2014	30	Corner jaw	N	118	9	n/a
88271	X-Tag	6/20/2014	30	Jaw	Y	102	10	n/a
88094	X-Tag	4/23/2014	15	Lower jaw	Y	104	9	471
88096	X-Tag	4/23/2014	15	Corner jaw	Y	107	10	n/a
86997	PAT-Mk10	8/16/2013	30	Upper jaw	Y	85	10	n/a

Figure 3. Tagging locations and movement of six *Sphyraena barracuda* tagged with PSATs from August 2013 to September 2014 in the western North Atlantic Ocean. Tag 88094 travelled 471 km (MSLD) while tag 88095 travelled 1231 km (MSLD) during the 15-day deployment period.

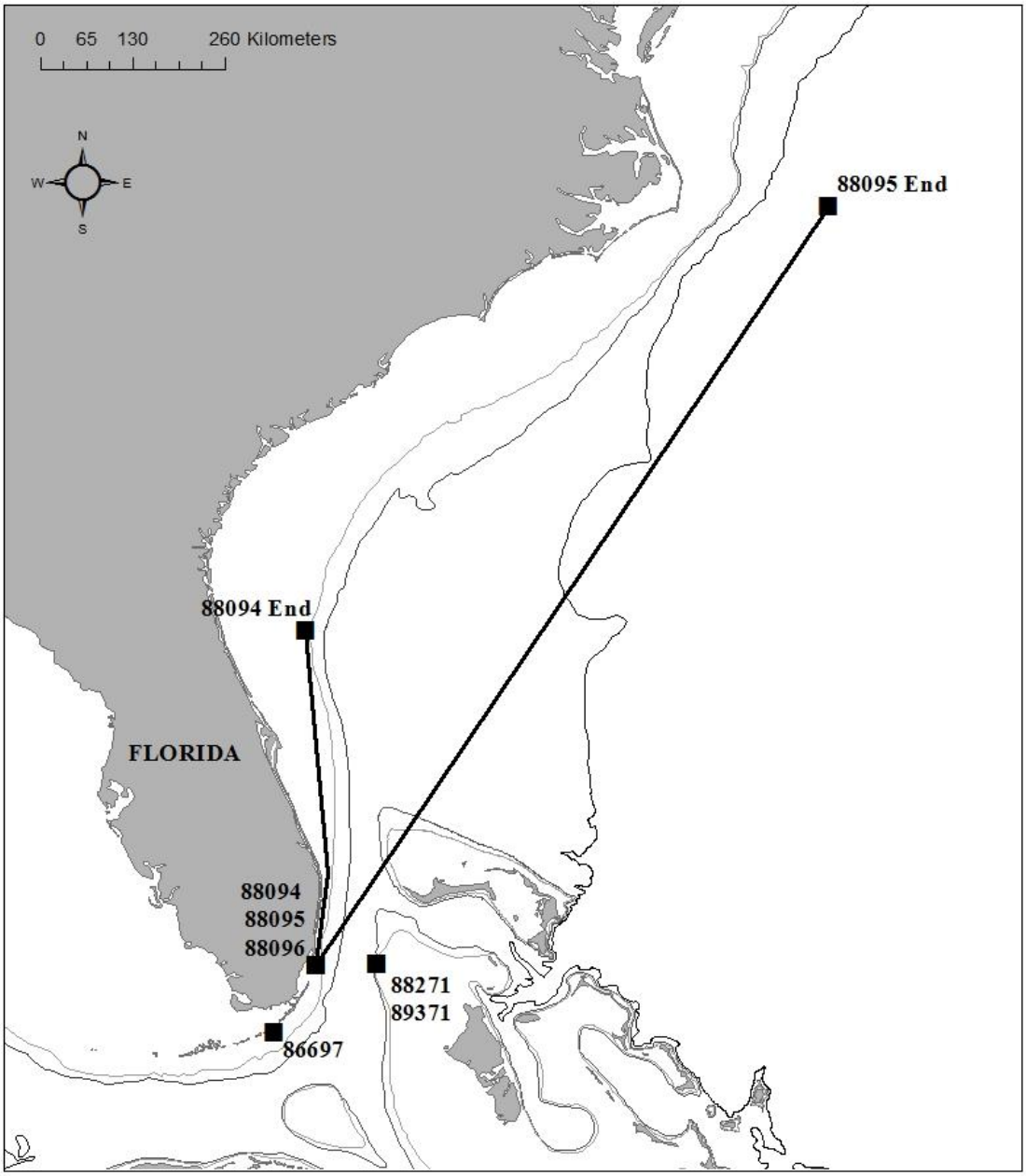


Figure 4. Average day and night depths of *Sphyraena barracuda* tagged with Microwave Telemetry X-Tags 88094 (A) and 88095 (B). Error bars are ± 1 standard error.



Figure 5. Percent time-at-depth (A) and time-at-temperature (B) histograms from the Microwave Telemetry X-Tag deployed on *Sphyraena barracuda* 88094 in South Florida during April and May 2014.

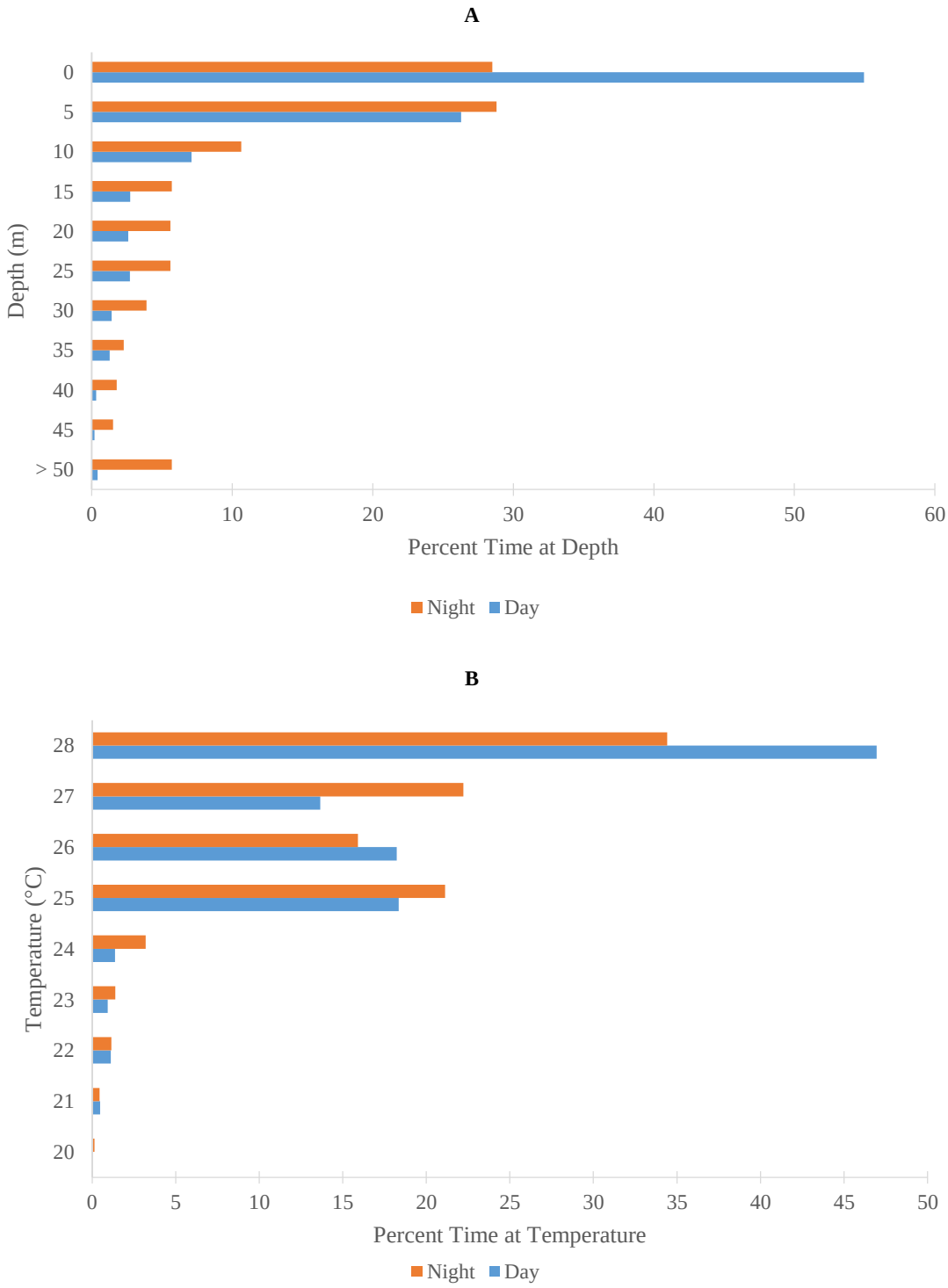
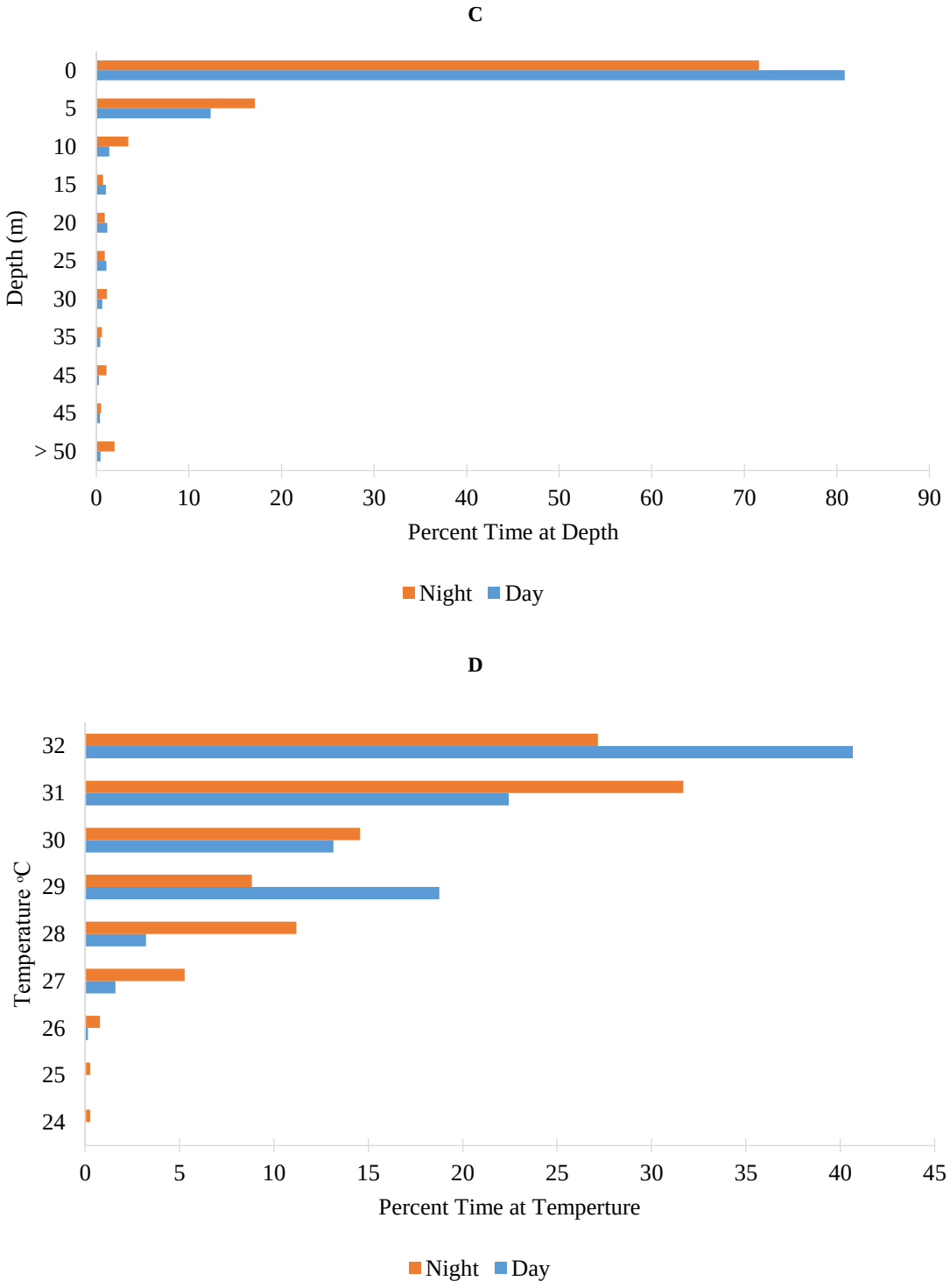


Figure 5 cont. Percent time-at-depth (C) and time-at-temperature (D) histograms from the Microwave Telemetry X-Tag deployed on *Sphyraena barracuda* 88095 in South Florida during August and September 2014.



Average nighttime temperature was 25.9° C and ranged from 18.6-27.7° C (Figure 5b). Tag 88095 also showed a significant diel difference in overall time at depth and temperature ($F = 95.41$ and $p < 0.001$; $F = 133.35$ and $p < 0.001$, respectively). Average daytime depth was 4.3 m and ranged from 0 to 72.6 m. Mean nighttime depth was 6.4, and ranged 0 to 186.9 m (Figure 4b and 5c). Average daytime temperature was 30.1° C, and ranged from 24.9 to 31.7° C, while mean nighttime temperature was 29.8° C and ranged from 17.8 to 31.7° C (Figure 5d).

Tags 88096

The data from tag 88096 were unusual, in that the fish experienced a probable predation event after three days of attachment. However, for the first three days of attachment, there was a significant difference between day and night depth and day and night temperature. Although the tag did not stay attached for the duration of the tagging period, the results from tag 88096 help to confirm the results from tags 88094 and 88095, specifically, that there is a significant differences between day and night utilizations of depth and temperature regimes.

Tag 88096's probable predation event after three days is assumed due to the tag's light levels not returning to 255 after sunrise, while the tag was still active in the water column.

Remaining tags

Tag 89371 never transmitted to Argos satellites after deployment. Tag 88271 detached from the fish after a few hours of deployment, and no valuable data were obtained. Tag 86997 did not transmit enough data to Argos satellites for any valuable information to be obtained.

4.0 Discussion

Several previous studies have examined the short-duration movements of great barracuda. For example, Springer and McErlean (1961) used conventional tags in the Florida Keys to demonstrate short-terms displacements of up to 193 km over a period of 90 days. Villareal (2007) also used traditional tags to show that great barracuda are

capable of travelling over 1000 km across the Gulf of Mexico over a period of years. Similarly, O'Toole et al. (2011) used an acoustic receiver array and tagged great barracuda in the Bahamas to show that they are capable of travelling 12 km per day and over 100 km to other islands in the Bahamas. In contrast, the archiving data and longer deployment durations of PSATs allow for a better description of great barracuda movement and depth preferences in a much finer detail.

However, the results from this study are comparable to some previous studies. Great barracuda 88094 travelled over 471 km MSLD, while individual 88095 traveled 1231 km MSLD in the 15-day deployment period. While it has been shown that great barracuda are capable of moving great distances (Springer and McErlean 1961; Villareal 2007; O'Toole et al. 2011), this much movement in such a short time span was unexpected. As noted by de Sylva (1963), great barracuda may migrate northward in the spring, and specimen 88094's movement may be correlated to this. However, such migration has not been documented by any other sources. This migratory pattern would also not explain the movements from tag 88095, as it travelled father north in the same 15-day time span, but was tagged in the late summer months. Specimen 88095 also contradicts de Sylva (1963) speculation that great barracuda migrate southward in the fall. While none of the previous studies showed individual great barracuda traveling as far as in the present study, Villareal (2007) did show that they were capable of migrating across the Gulf of Mexico within the span of a year. O'Toole (2011) also showed that great barracuda can travel up to 12 km per day and up to 100 km total. O'Toole et al. (2010b) is also the only paper to scientifically document the depth of great barracuda, but the deepest depth noted in their paper was 32.2 m. Also, contrary to the Wilson (2006) study, neither of the tagged individual great barracuda in the present study displayed any degree of residency during the tagging deployment.

Both tagged individuals spent the majority of the time in the upper portion of the water column during daylight hours. Previous studies have shown that great barracuda are visual feeders (Porter and Motta 2004, de Sylva 1963). Great barracuda may be opportunistically feeding near the surface of the water during daylight hours. The majority of prey items found in large great barracuda in the previous chapter (Clupeidae, Exocoetidae) also inhabit the upper region of the water column. However, the previous

chapter also showed that great barracuda prey on some reef associated bottom dwelling species (Holocentridae, Balistidae, Scaridae). The infrequent deep dives during both daytime and nighttime hours could be associated with feeding on these deeper dwelling prey items.

Both tagged great barracuda also displayed frequent short-duration movements of more than 30 m deeper than the mean depth over the entire deployment period. These short duration dives were more frequent for both individuals during night as well (88094: 23 during the day versus 81 at night). As shown by other studies (e.g., Kerstetter et al. 2011; Loefer et al. 2005), these short duration dives are presumably associated with feeding events. However, great barracuda are thought to be sight feeders, and would spend more time during daylight close to the surface.

As suggested by Hoolihan et al. (2011), there is the potential for bias in PSAT data due to irregular post-release behavior. The capture and tagging event is stressful for the tagged fish, and the immediate behavior may be altered due to this stress. Both great barracuda tagged in this study showed a significant amount of time spent ($p < 0.05$ in both tags) in deeper water during the first 24 hours of deployment. The mean depth for barracuda 88094 was 16.3 m for the first 24 hours of deployment, while the mean depth for the rest of the deployment period was 9.6 m. Likewise, the mean depth of barracuda 88095 during the first 24 hours was 13.7 m, while the mean depth for the rest of the deployment was 4.5 m. Possibly the tagged great barracuda sought shelter in deeper water or stayed deeper in the water column to avoid recapture, as both fish were caught near the surface. However, further PSAT tagging of great barracuda will be necessary to better understand the immediate and delayed post-release behaviors more completely.

4.2 Reason for tag failure

One objective of this study was to assess whether PSAT technology could be applied to the study of great barracuda. Only two tags stayed attached to the great barracuda for the entire tagging duration and reliably transmitted to Argos satellites, this suggests that PSAT technology may not be suited for the size ranges targeted in this study. However, very large individuals (>1.5 m) could still support the tag, and valuable data could be obtained for these large fish. For the medium to large great barracuda,

O'Toole et al. (2011) showed that acoustic transmitters are effective, and this may be the most appropriate way to track this species' habitat utilization.

O'Toole et al. (2010a) reported that great barracuda have a very low post-capture mortality rate. Thus, capture with traditional hook-and-line methods should not have caused the significant mortality of the tagged fish. All tagged specimens scored above a 7 on the ACESS scale, thus immediate post-release mortality is not likely a primary factor in the PSAT losses. Game-fish released in marine waters can also experience post-release predation, which could have caused the failure of the tag (Kerstetter et al. 2004). As shown by Graves et al. (2009), fish over 100 cm could potentially support a Microwave Telemetry X-tag, thus it unknown why there was such a high percentage of failure. For specimen 88096, a predation event may have occurred after three days of attachment, as light levels did not return to 255 after local sunrise. For the Mk10-PAT tag, insufficient data were transmitted to Argos satellites to determine the fate of the great barracuda or the tag itself. For specimen 88271, possibly the tag detached from the fish after only a few hours, then was caught in the Gulf Stream Current, and travelled up to Massachusetts. After the 30-day deployment the dart and swivel detached from the tag, and the tag broke the surface of the water and started transmitting to Argos satellites. Specimen 89371 never transmitted after deployment. Possibly a predation event occurred and the tag was never regurgitated, or the tag could be caught under some sort of underwater structure, and unable to float to the surface. It is equally possible that the tag malfunctioned, but all of these suggestions are purely speculative.

4.3 Fisheries Impact

Both successfully tagged individuals spent the majority of daytime hours in the upper portion of the water column. If this behavior holds true for all great barracuda, the fish could potentially interact with recreational fishing gear quite often. Many recreational anglers troll top-water lures in an attempt to catch other species, such as wahoo *Acanthocybium solandri*, kingfish *Scomberomorus cavalla,* and blackfin tuna *Thunnus atlanticus* (pers. obs.). Although this fishing technique is not likely to change within the local fleets, it could provide recreational anglers with more knowledge and potentially limit the interaction between the gear and the fish.

By understanding the depth and temperature preferences of a particular species, commercial fishermen could either target or avoid that particular range, depending on whether they wish to harvest that species. Great barracuda are known to interact with commercial fishing gear, particularly pelagic longline gear targeting swordfish *Xiphias gladius* and large tunas (NOAA Fisheries 2013). The data gained from this tagging study could be beneficial, as it could help reduce the number of great barracuda caught as bycatch. Commercial fishermen targeting other species could actively fish at deeper depths and alter deployment time to reduce the number of great barracuda caught.

5.0 Conclusion

With the introduction of the PSAT technology, the number of species that have been tagged is increasing. The results obtained from these studies allow researchers to better understand the habitat utilization of those particular species. The increase in knowledge of this behavior makes it possible to investigate behavioral patterns on an ecosystem scale (Block et al. 2011). This study has shown the great barracuda are capable of traveling great distances (>80 km per day) in a short time span. It also showed that they are capable of diving to depths greater than 150 m, and that they make frequent, short, deep dives; presumably during foraging events. The data obtained from this study will allow fisheries scientists to more effectively understand the habitat utilization of great barracuda. The data could also show how great barracuda interact with more economically valuable targeted species, which could be beneficial when implementing future management strategies.

Acknowledgements

I cannot express enough thanks to Captain Bouncer Smith and his mates. Without their assistance this project would not have been possible. I also thank Jesse Secord (Nova Southeastern University), who deployed two of the PSATs while fishing with Captain Bouncer. Financial support was provided, in part, by the Yamaha Contender Miami Billfish Tournament.

References

Ault JS, Bohnsack JA, Meester GA. 1998. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. Fishery Bulletin 96(3): 395-414.

Bain MB 2005. "Electronic Tags". *Stock Identification Methods, Applications in Fishery Science*. Elsevier Academic Press. 435-446.

Block BA, Dewar H., Farwell C., Prince E.D. 1998. A new satellite technology for tracking the movements of Atlantic Bluefin tuna. Proceedings of the National Academy of Sciences of the United States of America. Vol. 95 (16): 9384-9389.

Block BA, Jonsen ID, Jorgensen SJ, Winship AJ, Shaffer SA, Bograd SJ et al. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature. 475(7354): 86-90.

CATAG. 2003. Improvements in tagging methods for stock assessment and research in fisheries. Concerted Action for Tagging of Fishes Project, Marine Research Institute, Directorate of Fisheries, Reykjavik, Iceland. http:/www.hafro.is/catag/

D'Alessandro EK, Sponaugle S, Llopiz JK, Cowen RK. 2011. Larval ecology of the great barracuda, *Sphyraena barracuda*, and other sphyraenids in the Straits of Florida. Marine Biology. 158(12): 2625-2638.

De Sylva DP. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). Studies in Tropical Oceanography. 1: 1-179.

De Sylva DP. 1994. Distribution and ecology of ciguatera fish poisoning in Florida, with emphasis on the Florida Keys. Bulletin of Marine Science. 54(3): 944-954.

Guy C.S., Blankenship H.L., and Nielsen L.A. 1996. "Tagging and Marking". *Fisheries techniques, 2nd edition, American Fisheries Society, Maryland*. 353-383.

Graves JE, Horodysky AZ, Latour RJ. 2009. Use of pop-up satellite archival tag technology to study postrelease survival of and habitat use by estuarine and coastal fishes: An application to striped bass (*Morone saxatilis*). Fishery Bulletin. 107(3): 373-383.

Hoolihan JP, Luo J, Abascal FJ, Campana SE, De Metrio G, Dewar H, Domeier ML,

Howey LA, Lutcavage ME, Musyl MK, Neilson JD, Orbesen ES, Prince ED, Rooker JR. 2011. Evaluating post-release behaviour modification in large pelagic fish deployed with pop-up satellite archival tags. ICES Journal of Marine Science. 68(5): 880-889.

Kadison E, D'Alessandro EK, Davis GO, Hood PB. 2010. Age, growth, and reproductive patterns of the great barracuda, *Sphyraena barracuda*, from the Florida Keys. Bulletin of Marine Science. 86(4): 773-784.

Kerstetter DW, Luckhurst BE, Prince ED, Graves JE. 2003. Use of pop-up satellite archival tags to demonstrate survival of blue marlin (*Makaira nigricans*) released from pelagic longline gear. Fishery Bulletin-NOAA. 101(4): 989-948.

Kerstetter DW, Polovina JJ, Graves JE. 2004. Evidence of shark predation and scavenging on fishes equipped with pop-up satellite tags. Fishery Bulletin. 102: 750-756.

Kerstetter DW, Bayse SM, Fenton JL, Graves JE. 2011. Sailfish habitat utilization and vertical movements in the Southern Gulf of Mexico and Florida Straits. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science. 3(1): 353-365.

Loefer JK, Sedberry GR, McGovern JC. 2005. Vertical movements of a shortfin mako in the Western North Atlantic as determined by pop-up satellite tagging. Southeastern Naturalist. 4(2): 237-246.

Microwave Telemetry. 2014. Fish Tracking. Taken October 6, 2014. www.microwavetelemetry.com/fish

MyFWC. Unregulated Species- Florida Fish and Wildlife Conservation Commission. Taken October 21, 2013. http://myfwc.com/fishing/saltwater/recreational/unregulated-species/

Nash A, Whiting J, Luckhurst BE. 2002. A pneumatic cradle for handling and tagging of wahoo and other large pelagic fishes. American Fisheries Society Symposium. 30: 189-194.

NOAA Fisheries. NOAA Office of Science and Technology, National Marine Fisheries Service. Recreational and Commercial Fisheries Statistics. Taken July 17, 2013. http://www.st.nmfs.noaa.gov/st1/index.html

O'Toole AC, Danylchuk AJ, Suski CD, Cooke SJ. 2010a. Consequences of catch-and-release angling on the physiological status, injury, and immediate mortality of great barracuda (*Sphyraena barracuda*) in The Bahamas. ICES Journal of Marine Science. 67: 1667-1675.

O'Toole AC, Murchie KJ, Pullen C, Hanson KC, Suski CD, Danylchuk AJ, Cooke SJ. 2010b. Locomotory activity and depth distribution of adult great barracuda (*Sphyraena barracuda*) in Bahamian coastal habitats determined using acceleration and pressure biotelemetry transmitters. Marine and Freshwater Research, 61: 1446-1456.

O'Toole AC, Danylchuk AJ, Goldberg TL, Suski CD, Philipp DP, Brooks E, Cooke SJ. 2011. Spatial ecology and residency patterns of adult great barracuda (*Sphyraena barracuda)* in coastal waters of The Bahamas. Marine Biology. 158: 2227-2237.

Paterson SE. 1998. Group occurrence of great barracuda (*Sphyraena barracuda*) in the Turks and Caicos Islands. Bulletin of Marine Science. 63(3): 633-638.

Porter HT, Motta PJ. 2004. A comparison of strike and prey capture kinematics of three species of piscivorous fishes: Florida gar (*Lepisosteus platyrhincus*), redfin needlefish (*Strongylura notata*), and great barracuda (*Sphyraena barracuda*). Marine Biology. 145: 989-1000.

Springer VG, McErlean AJ. 1961. Tagging of great barracuda *Sphyraena barracuda* (Walbaum). Transactions of the American Fisheries Society. 90(4): 497-500.

Theisen TC, Baldwin JD. 2012. Movements and depth/temperature distribution of the ectothermic Scombrid, *Acanthocybium solandri* (wahoo), in the western North Atlantic. Marine Biology. 156: 2249-2258.

Villareal TA, Hanson S, Qualia S, Jester ELE, Granade HR, Dickey RW. 2007. Petroleum production platforms as sites for the expansion of ciguatera in the northwestern Gulf of Mexico. Harmful Algae. 6: 253-259.

Wildlife Computers. 2014. Wildlife Computers Product Overview. Taken October 6, 2014. www.wildlifecomputers.com

Wilson SK, Wilson DT, Lamont C, Evans M. 2006. Identifying individual great barracuda *Sphyraena barracuda* using natural body marks. Journal of Fish Biology. 69: 928-93

Conclusion

Little is known about the population of great barracuda, and the only partial stock assessment used catch data from the period 1979-1996 in the Florida Keys (Ault et al. 1998). This lack of knowledge combined with the little management in place for great barracuda makes them particularly susceptible to over-exploitation. Despite this, the species is still commonly caught by both recreational and commercial fishermen.

The feeding ecology data show that both inshore and offshore great barracuda are opportunistic feeders, feeding primarily on teleosts inshore habitats, and exclusively on teleosts on offshore habitats. Inshore great barracuda fed mostly on killifish (Cyprinidontidae) and mojarras (Gerreidae); while in offshore environments they preferred herring (Clupeidae), jacks (Carangidae), and flying fish (Exocoetidae). Utilizing the stomach content data, it was shown that great barracuda alter their diet around year two, presumably in correlation with the ontogenetic shift in habitat. These results coincide with most of the previous studies done on the diet of great barracuda.

Contrary to previous studies, the two great barracuda tagged during this study traveled an unexpected distance over a short period of time. While previous studies have shown that individuals are capable of moving hundreds of kilometers over a period of months to years, this study showed that they are capable of moving more than 82 km per day. Great barracuda also showed a significant diel difference in depth preference, spending night hours deeper in the water column. Frequent, deep dives were common during both light and dark periods, with them being more frequent during night hours. These deep dives are presumed to be in relation to feeding events. It was also shown that great barracuda can inhabit previously unknown depths, diving as deep as 186 m in one dive. Further tracking studies could ultimately improve the knowledge of great barracuda's movement patterns. Also, because of the potential bias of data following the immediate release of the tagged fish, a longer deployment period for the PSAT could be beneficial. Although the PSATs were successfully deployed for the full duration on only two of the six tagged individuals, other tracking methods (e.g., acoustic transmitters or traditional tags) may be appropriate for great barracuda in the smaller size classes.

Using stomach contents to study the feeding ecology of a species allows for researchers to assess the predator-prey relationships of a particular environment.

Tracking fish with PSATs allows for a better understanding of the migration patterns and habitat utilization of that individual species. By combining both of these approaches, it will allow fisheries managers to obtain a more comprehensive evaluation of the life history of the targeted species. As management shifts away from individual species management and towards ecosystem based fisheries management, it is vital to understand the life history of every species within the ecosystem. Although great barracuda are not economically important from commercial fisheries perspective, they do play a vital role in the ecosystem as a top predator, and therefore must be included in any ecosystem based approach to fisheries management, particularly in tropical, coral reef-dominated regions like South Florida.