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SHORT COMMUNICATION

HABITAT USE AND VERTICAL DISTRIBUTION OF THE GREAT BARRACUDA *SPHYRAENA BARRACUDA* (EDWARDS 1771) IN THE WESTERN NORTH ATLANTIC USING ELECTRONIC ARCHIVAL TAGS

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INTRODUCTION

The Great Barracuda, *Sphyraena barracuda* (Edwards 1771), is a large predatory teleost that inhabits tropical and subtropical environments worldwide, with the exception of the eastern Pacific Ocean (de Sylva 1963). 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 size of *ca.* 300 mm total length (TL), they will leave these protected areas and associate more with offshore reefs and structure (de Sylva 1963, Blaber 1982). As adults, they inhabit the same trophic level as other large reef-associated predators (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 (Granek et al. 2008), and Great Barracuda are also prized as a sportfish by some anglers because of the species' fighting ability and acrobatics (Sosin 2000). Even when they are not intentionally targeted, the historical catch data for Great Barracuda show that they are frequently caught incidentally (NOAA Fisheries 2015). However, Great Barracuda are not regulated at the federal level, and at the state level in Florida, they fall in the "unregulated" fishes category, thereby allowing fishermen to keep "two fish or 100 pounds of fish, whichever is greater" (FWC 2015a). Anecdotal observations of long-term declines in Great Barracuda abundance and catch rates, combined with public pressure from stakeholders, have caused the Florida state Fish and Wildlife Conservation Commission (FWC) to impose additional regulations of a recreational and commercial daily bag limit of two fish per person and a daily vessel limit of six fish per vessel as of 1 November 2015 (FWC 2015b).

Previous studies have documented that Great Barracuda are capable of travelling up to 12 km per day (O'Toole et al. 2011) and across the Gulf of Mexico (*ca.* 1000 km) over a period of about nine months (Villareal et al. 2007). O'Toole et al. (2010) also documented a depth of 32.22 meters using

limited ultrasonic telemetry in the Bahamas. In April and August 2014, two Great Barracuda were tagged off Miami, Florida with pop-up satellite archival tags (PSATs) to further describe the habitat use and depth preferences of this species.

MATERIALS AND METHODS

Specimens were caught by traditional hook-and-line recreational angling methods in the waters off Dade County, Florida. During the tagging event, gear type, handling time, hook location, and GPS coordinates of release location were recorded, in addition to fork length (FL, cm). Great Barracuda were also measured on a modified ACCESS scale to determine the overall condition of the specimen. The ACCESS scale is an overall health assessment of the fish with a qualitative grade from 0–10 using physical characteristics such as overall activity and general state of the musculature (see Kerstetter et al. 2003); potential fish required a minimum of 7 on this scale in order to be tagged. Fish were also not tagged if there were other large predators, such as sharks, visible in the vicinity of the tagging vessel.

During the tagging, the individual fish was brought on board the boat using a large landing net, then tagged and immediately returned to the water. A PSAT tag was inserted near the anterior dorsal fin to lock the dart head behind the pterygiophore bones. By anchoring through the dorsal musculature, the tag tether was well supported and the tag float provided sufficient lift to keep the tag body from rubbing against the body at slow speeds (Block et al. 1998). A conventional streamer tag was also inserted into the dorsal musculature on the opposite side of the fish from the PSAT.

Two Microwave Telemetry (Columbia, MD, USA) X-Tag HR model tags were used. 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 entire tag and attachment tether combination weighed *ca.* 53 g. About 15 cm of 120 pound-test monofilament was used to attach the tag to a nylon dart anchor with aluminum crimps, and each crimped con-

nection 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) to allow the tag to rotate freely and not incur rotational torque stress around the attachment site (Bain 2004, Kerstetter et al. 2011).

The PSATs were programmed to record a data point every 141 seconds. Water temperature ($^{\circ}\text{C}$ in 0.18° resolution), pressure (converted to depth in 1.3 m resolution), and light level (unit—less scale from 0–255) were recorded for 15 days. However, the X—tag HR model does not provide enough light level data for light—based geolocation estimates. All horizontal displacements were considered conservative based on the minimum straight—line distance (MSLD) between the location of tagging and the location of the first Argos transmission with < 1.5 km error (location class 1,

2, or 3). Survival was assessed through analysis of changes in the light, temperature, and depth data (see Kerstetter et al. 2011).

Data analysis

In order to evaluate diel changes in behavior, local sunrise and sunset time data were obtained from United States Naval Observatory (USNO; <http://www.usno.navy.mil>). Crepuscular periods were defined as 15 minutes before and after sunrise/sunset and were subsequently excluded from the diel analyses. USNO data were also used to assess day and night length to standardize habitat use. Variances were tested using an F—test, and found to be unequal. A two—sample t—test assuming unequal variances was used to evaluate diel differences over the 15—day deployment in the temperature and depth data, with significance assessed at $\alpha < 0.05$. Positions of the Florida Current and the Gulf Stream, as well as local sea surface temperatures (SSTs) during the deployment periods were assessed through satellite—derived imagery obtained from the Rutgers University Center for Ocean Observing Leadership (RUCOOL; <http://rucool.marine.rutgers.edu>).

RESULTS

Two Great Barracuda were caught using standard trolling techniques by a charter vessel operating out of Miami Beach, FL. The fish with PSAT 88094 measured 104 cm FL and was captured on 23 April 2014, while the fish with PSAT 88095 measured 101 cm FL and was captured on 17 August 2014. The hook was removed from the first individual, although it was determined that removal of the hook from the lower jaw in the other would have taken too long and harmed the fish further. Both scored a 9 on the ACCESS scale.

During the deployment periods, both fish travelled north. Tag 88094 was deployed at 25.702°N , 80.083°W , and travelled to 29.895°N , 80.548°W , *ca.* 100 km off the coast of northeast Florida (Figure 1). After detaching, tag 88094 transmitted 91% of its data. The MSLD for this fish was 471 km during the 15—day period, or a mean of 31.4 km per day. Recorded temperatures ranged from 18.6 – 28.4°C (Figure 2A). The maximum depth encountered by this tag was 145.2 m, with 90% of the deployment time being spent in water between 0 and 26.9 m (Figure 2B). Tag 88095 was deployed at 25.700°N , 80.083°W , and travelled to 35.297°N , 73.608°W , *ca.* 175 km off the coast of North Carolina (Figure 1). After detaching, tag 88095 transmitted 87% of its data. This individual travelled 1231 km MSLD during the 15—day deployment period, for a mean of 82 km per day. The temperature ranged from 17.8 – 31.7°C (Figure 2C). This Great Barracuda dove to a maximum depth of 186.9 m, but spent 90% of the time in water between 0 and 9.4 m deep (Figure 2D).

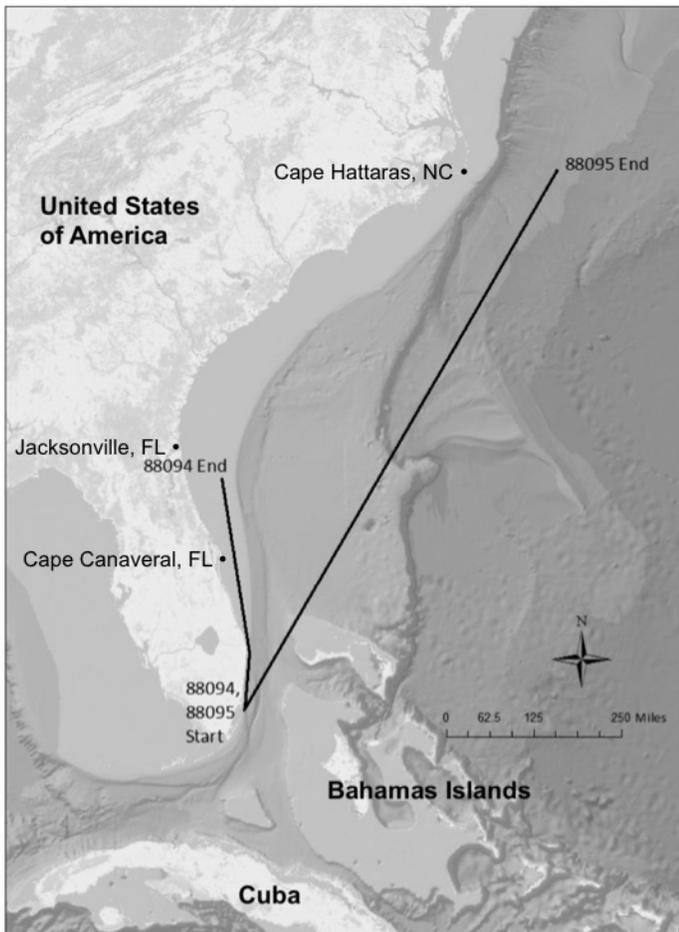


FIGURE 1. Tagging and first transmission locations for two pop-up satellite archival tags (PSATs) deployed on Great Barracuda *Sphyræna barracuda* in April 2014 (88094) and August 2014 (88095) in the western North Atlantic Ocean. Tag 88094 travelled 471 km to the north-northwest and tag 88095 travelled 1231 km to the north-northeast during the 15-day PSAT deployment periods (lines denote approximate minimum straight-line distances, not actual tracks). The dashed line represents the Florida Current, which broadens into the western and eastern walls of the Gulf Stream south of Cape Canaveral, Florida.

Both tagged Great Barracuda travelled north for the entire 15-day deployment duration, presumably following the mainstem of the Gulf Stream current. If either fish had died and the combined tag–carcass just drifted north in the current, the depth and temperature would be expected to stay somewhat unchanged. However, both individuals are thought to have stayed alive for the entire deployment duration because the depth and temperature values were constantly changing within diel patterning until the tags detached.

Both tag datasets were also examined for potential differences in behavior related to diel patterns. Great Barracuda 88094 showed a significant diel difference in overall time at depth ($t_{4901} = 25.35$, $p < 0.0001$). Daytime depth averaged 7.03 m and ranged from 0–86.1 m. Nighttime depth averaged 15.6 m and ranged from 0–145.2 m (Figure 2B). There was also a significant difference in time at temperature ($t_{7525} = 5.85$, $p < 0.0001$). Mean daytime temperature was 26.1°C and ranged from 20.4–28.4°C, while the mean nighttime temperature was 25.9°C and ranged from 18.6–27.7°C (Figure 2A). Great Barracuda 88095 also showed a significant diel difference in overall time at depth and temperature ($t_{5533} = 9.37$, $p < 0.0001$; $t_{6461} = 11.29$, $p < 0.0001$, respectively).

Mean daytime depth was 4.3 m and ranged from 0–72.6 m. Mean nighttime depth was 6.4, and ranged 0–186.9 m (Figure 2D). Mean daytime temperature was 30.1°C, and ranged from 24.9–31.7°C, while mean nighttime temperature was 29.8°C and ranged from 17.8–31.7°C (Figure 2C).

Detailed analyses of daily temperature use patterns for both tagged fish indicated a change in local water conditions; temperature–at–depth profiles indicated this transition on 3 May for 88094 and 27 August for 88095. Daily comparisons of ambient surface temperature data from the PSAT records and the satellite–derived SST data from RUCOOL strongly suggest movements by both tagged fish from the warmer waters of the Gulf Stream to somewhat cooler inshore waters at the end of both deployments.

DISCUSSION

The two tagged individuals from this study are the only documented use of PSAT technology on the Great Barracuda, and thus represent the only long–duration behavior data available for this species. However, 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 demon-

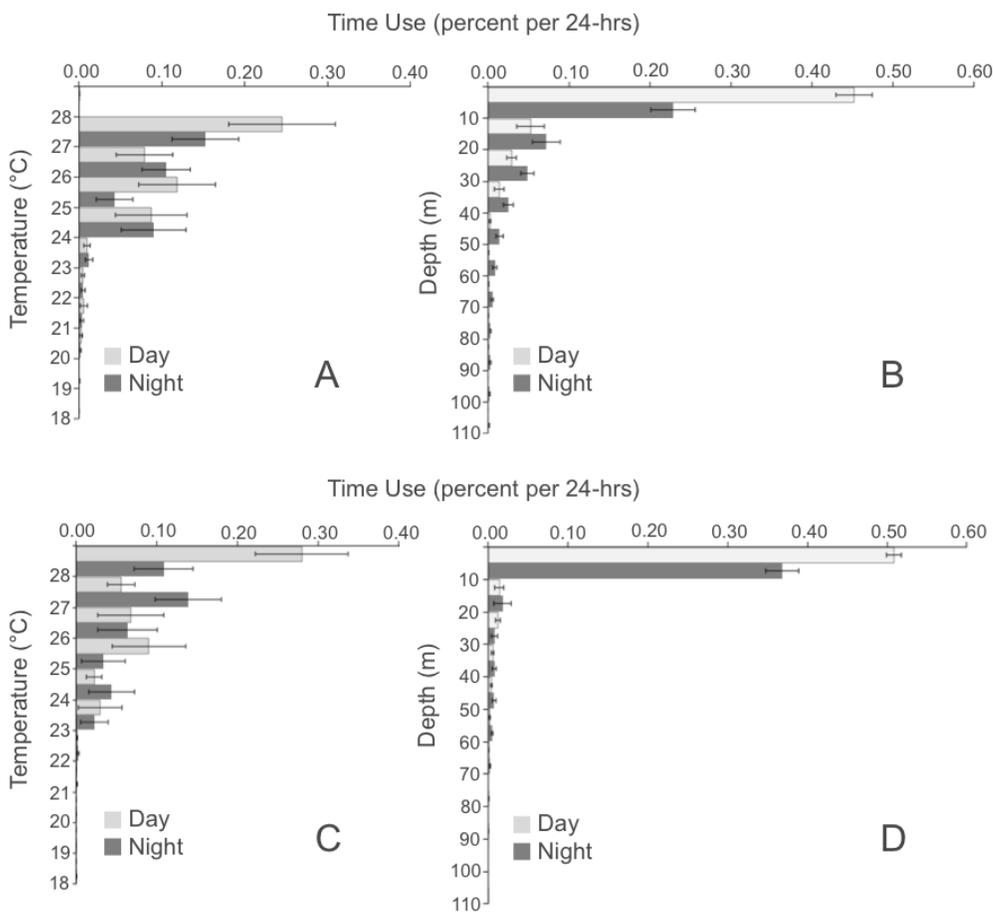


FIGURE 2. Time-at-temperature and time-at-depth histograms from two Microwave Telemetry HR model X-Tags deployed on Great Barracuda *Sphyraena barracuda* in South Florida during April and August 2014. A. Temperature, Fish 88094. B. Depth, Fish 88094. C. Temperature, Fish 88095. D. Depth, Fish 88095. Both day (light grey) and night (dark grey) results are presented as mean time use per 24-hour period over each 15-day deployment period, and error bars are ± 1 SE. Although both individual fish occasionally undertook short-duration movements to depths > 100 m, they constituted a small fraction of the total time utilization (0.6% for 88094 and 0.05% for 88095) and those depths are thus not shown.

strate short-term displacements of up to 193 km over a period of 90 days. Villareal et al. (2007) also used conventional 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. However, the archived data and longer deployment durations of PSATs allow for a better description of Great Barracuda movement and depth preferences in much finer detail.

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 (de Sylva 1963; Porter and Motta 2004). Great Barracuda may be opportunistically feeding near the surface of the water during daylight hours, as the prey items found in mature individuals in the previous studies (e.g., Clupeidae, Exocoetidae) also inhabit the upper region of the water column (de Sylva 1963; Randall 1967). There may also be a thermal advantage to remaining in the warmer surface waters between foraging in colder depths, a behavior seen in other large pelagic fishes (e.g., White Marlin *Kajikia albida* in Horodysky et al. 2007). However, Great Barracuda have also been observed preying on some reef-associated bottom-dwelling species (e.g., Holocentridae, Balistidae, Scaridae; Hansen 2015). Although the times at temperature for both individuals tagged in this study were significantly higher during the day, it is hard to imagine that these differences are meaningful. More likely, these differences are an artifact of vertical movements rather than temperature preference. These infrequent vertical movements to depth during both daytime and nighttime hours could be associated with feeding on deeper-dwelling prey items, as have other fishes that are generally considered epipelagic predators (e.g., Sailfish *Istiophorus platypterus* in Kerstetter et al. 2011; Shortfin Mako *Isurus oxyrinchus* in Loefer et al. 2005). An increase in the number of PSAT tagged fish species is allowing a better understanding of habitat use and segregation, and the results from studies such as this one should be combined to investigate behavioral patterns on an ecosystem scale (Block et al. 2011).

The results from this study clearly complement prior works. 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 et al. 2007; O'Toole et al. 2011), this much movement in such a short time span was unexpected. Although de Sylva (1963) suggested that Great Barracuda may migrate northward in the spring, such migration has not been documented by any other sources.

Regardless, this migratory pattern would not explain the movements from tag 88095, as it travelled north during the late summer months when de Sylva (1963) speculated that Great Barracuda would be moving southward. While none of the previous studies showed individual Great Barracuda traveling as far as in the present study, Villareal et al. (2007) did show that they were capable of displacement across the Gulf of Mexico within the span of a year. O'Toole et al. (2010) is one of the only studies to scientifically document the depth of Great Barracuda, although the maximum observed depth in that acoustic telemetry study was only 32.2 m, as compared with the 145.2 and 186.9 m depths observed with PSATs. The Great Barracuda tagged in the O'Toole et al. (2011) study ranged in size from 62 to 120 cm TL, and would thus be considered mature specimens. It is likely that the movements to the shelf habitats as noted by O'Toole et al. (2011) represent a different forage base for Great Barracuda, with accordingly different behaviors.

A larger question regards the presumption of local residency by Great Barracuda. Contrary to the observations in Wilson et al. (2006), neither of the tagged individual Great Barracuda in the present study remained within the vicinity of the tagging location. Kerstetter and Graves (2006), among others, have long noted the occurrence of large Great Barracuda in the offshore pelagic longline fishery, which may suggest a complex behavior combining local residency and long-range movement. The association of this species with the upper water column should allow the derivation of geolocation estimates via light-based algorithms in other PSAT models, especially when these estimates are refined with ambient SST data (e.g., Lam et al. 2010). Additional electronic and conventional tagging efforts, including molecular genetic analyses that expand upon the work by Daly-Engel et al. (2012), are recommended to better elucidate the coastal and pelagic movement patterns within Great Barracuda populations. If the species consists of multiple stocks or regularly moves between neighboring state waters, then management of Great Barracuda should occur at the federal level instead of by the individual states.

CONCLUSION

This study has shown that Great Barracuda are capable of traveling great distances (> 80 km per day) in a short time span. It also expands the habitat utilization understanding of Great Barracuda by documenting movements to depths greater than 140 m, and that these movements are often short and relatively deep. Combining these data with results from other oceanic predators could also show how Great Barracuda interact with more economically valuable targeted species, which could be beneficial when implementing future management strategies.

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