Using Pop-off Satellite Archival Tags To Monitor and Track Dolphinfish and Cobia

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SEDAR58-RD30

6 March 2019

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Conducted for the Hilton Head Reef Foundation, Hilton Head, South Carolina
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South Carolina Sea Grant Consortium
Project Completion Report for Grant R60A

Project Title: Use of Pop-off Satellite Archival Tags to Monitor Cobia Utilizing Port Royal Sound, South Carolina and Dolphinfish Present off the East Coast of the U. S.

Abstract: Cobia, *Rachycentron canadum*, and dolphinfish, *Corypheana hippurus*, are important species in the marine recreational fisheries of South Carolina as well as the South Atlantic Bight and Gulf of Mexico. Little information is available on the movements, associated water temperatures encountered and water depths occupied by these two species. The Microwave Telemetry's model PTT-100 pop-off satellite archival tag (PSAT) was used to monitor temperature, pressure and, on certain instruments, geo-position information. These were attached to 5 dolphinfish off the U.S. East Coast and western Caribbean Sea and 4 cobia in or adjacent to Port Royal Sound, SC. Data were received from 4 instruments placed on dolphinfish and 3 attached to cobia. Dolphinfish were monitored for periods up to 23 days while cobia were monitored for as long as 92 days. Data received from the instruments showed that cobia used waters as deep as 70m and rose to the surface more frequently during May/June than July/August. Cobia were observed to utilize water temperatures from 20.7 to 29.33°C but spent the majority of their time in waters from 22.0 to 26.99°C. Dolphinfish were shown to utilize ocean waters with temperatures ranging from 16.0 to 30.5°C. The highest temperatures were recorded by fish off south Florida while those off South Carolina entered the coldest waters. Dolphinfish off south Florida spent most their time in surface waters of 27.2 to 28.9°C while fish off South Carolina spent most of their time in surface waters of 26.3 to 27.2°C. Data showed that dolphinfish spend the majority of their time in the top 10 m of the water column but regularly made dives below 30 m going as deep as 124 m. Deep diving behavior was shown to be most prevalent at night.

Introduction:

Dolphinfish sustain an important recreational fishery as well as a limited commercial fishery -- not just off South Carolina but in U.S. coastal and oceanic waters of the Gulf of Mexico, South Atlantic Bight and Mid-Atlantic Bight. Cobia support major recreational fisheries along the much of eastern seaboard including the Gulf of Mexico coast and from Key West, Florida to Virginia on the Atlantic coast. In South Carolina, the cobia fishery is centered in the inshore and nearshore waters of Beaufort County. Both fish are highly esteemed for their food quality. Dolphinfish is the most frequently harvested fish by recreational anglers trolling in Federal waters off South Carolina as well as in the Gulf of Mexico and South Atlantic Bight. Harvest data from the National Marine Fisheries Service's Marine Recreational Fishing Survey (MRFSS) and the South Carolina Commercial Landings show dolphinfish to be an important recreational as well as commercial species in South Carolina. However, MRFSS provides very little useful information on cobia because it is such a short-term and localized fishery. Dolphinfish are heavily targeted by charter boats throughout the state, but cobia are primarily targeted by for-hire boats operating in Beaufort County.

Little data are available on the movements and migrations of these economically important species – especially for their South Carolina occurrence. While dolphinfish are considered little more than nomads passing by the state, many fishermen have a different view of cobia, questioning if there is a unique group of fish that use Port Royal Sound (PRS) and spawn in nearshore waters. The Marine Gamefish Tagging Program operated by the South Carolina Department of Natural Resources has shown that cobia tagged in PRS show a strong site fidelity returning to the sound after multiple years of liberty with very few fish being recovered off the coasts of other states. Where cobia migrate once they leave the Beaufort County inshore and coastal waters remains a mystery. The summer and winter grounds for cobia that use PRS during spring has received much speculation but little hard information actually exists. This information could be very useful in determining the vulnerability and impacts of harvest upon the species during the remainder of the year.

The South Atlantic Fisheries Management Council is responsible for the management of dolphin and cobia in the South and Mid Atlantic Bights and has recognized defining the essential habitat for the stocks under their management as a high priority. The fluid environment in which they live is an important part of the habitat. Most temperature information previously available for both species consisted of surface water readings, providing no information on subsurface water temperatures used by the animal. Information on the depth of water used by each species has primarily come from anecdotal recreational fishing reports or commercial fishing logs. This study offers the potential to follow free-swimming specimens of these species in their time-specific temperature selection and depth utilization.

Materials and Methods:
The Microwave Telemetry, Inc. model PTT-100 pop-off satellite archival tag (PSAT) was selected for this study (Figure 1). This instrument is preprogrammed to remain with the study subject a specified time period, 30 and 90 days for this study, recording time specific water temperature, pressure and light intensity at regular intervals. These instruments recorded water temperature in 0.17^{o}C increments for both 30 and 90-day units. The 30-day unit recorded water depth in 1.3-m increments while the 90-day units recorded in 5.4-m increments. A single depth increment started at its assigned value and extended to the next value. Subsequently, the 0-m depth for the 30-day/high resolution tag actually extended down to 1.299m while the standard rate tags would include depth increments up to 5.399m in the 0-m category. High resolution tags provide data sets that include both temperature and pressure for each specific sample-time transmitted. However, the 90-day, standard rate tags, often transmitted either temperature or pressure but not both for a specific sample-time. At the end of the monitoring period the device releases itself from the tether connecting it to the fish using electrolysis to dissolve the wire securing it to the tether. Once released from the fish, the device floats to the surface, contacts one of the Argos system satellites and begins transmitting data to Argos headquarters which forwards the information to the individual researcher and to the tag manufacturer. Due to the limitations of the battery, a subset of the instrument's archived data that is evenly distributed over the entire observation period, is actually transmitted. The resulting time interval between transmitted data points for high resolution tags is 3 to 4 minutes and 15 minutes for tags programmed for 90 days. When the tag has finished transmitting, Microwave Telemetry, Inc. converts the binary coded temperature data into degrees Centigrade, depth into meters and light into intensity units. The manufacturer also calculates daily geo-position for standard rate units (those programmed to record longer than 30 days), using proprietary software that uses time of sunrise to calculate longitude and water temperature to estimate latitude. This positioning system is reported by MTI to have accuracy $\pm$2 degrees of latitude and $\pm$1 degree of longitude.

The PTT-100 PSAT (Figure 1) measures 338 mm in length and has a maximum diameter of 41 mm. A 216-mm long antenna is included in its length. It weighs between 65 and 68g. A 254-mm long section of 1.6-mm diameter monofilament was used as the tether to connect the instrument to the fish. The monofilament was secured to the tag using a brass crimp to secure a loop through the wire attachment point of the device. The monofilament was then secured in the dorsal musculature of the fish using a stainless steel internal anchor dart (16mm X 50mm) or by inserting the monofilament laterally through the dorsal muscles from one side out through the other with a 8mm X 25-mm stainless steel plate slid on to the exiting line and secured using a brass crimp to form a stopper-loop. The size of the device did not change based on length of time of the monitoring period.

The PSATs used for dolphinfish along with two attached to cobia were programmed to record data for 30 days in a high-resolution format. Because of the short monitoring period, these units were programmed to record data every one to six minutes during the programmed period. This allowed the fish to be followed on its vertical movements through the water column. Three additional PSAT instruments attached to cobia were programmed to record for 90 days which recorded data every 15 minutes.

Figure 1. Microwave Telemetry, Inc PTT-100 PSAT.

Drifting PSATs can be tracked during the time that data are being transmitted. Argos satellites acquire a GPS position on these instruments each time they make contact with the satellite. System satellites provide full coverage of the earth on a variable time schedule for their passes over a given location. Time intervals between satellite passes range from a few minutes to hours. This can provide a position for where the tag surfaced which leads to a subsequent determination of water current patterns during its data-transmission life.

This study enlisted the aid of participants in a recreational fishing competition, private anglers and charter boat captains to secure cobia for tagging (Table 1). A reward of $300 was paid to the angler or boat captain for each fish accepted for tagging. In May 2006, participants in the Hilton Head Food and Beverage Tournament held in Hilton Head, South Carolina, were offered a $300 reward for the donation of a healthy cobia for use as a satellite tag specimen. Anglers were instructed to use a specific VHF radio frequency to contact the tagging boat. This vessel carried the biologist who would decide whether a fish was qualified (health and size) for use as a satellite tag subject. The boat spent the entire tournament fishing period motoring through Port Royal Sound ready to go to any vessel that might call to donate a cobia. Dave Harter provided the vessel and served as captain at no charge to the study. Few large fish were caught in the tournament and only fish too small to carry a satellite tag were offered to the study. However, by riding with charter boat captains on a day when they did not have a group of fishermen paying to go fishing, the project was able to tag one cobia in 2006 and 3 cobia in 2007. In total, 6 days were spent in the field to collect the four cobia used in the study.

Table 1. Recreational vessels participating in cobia satellite tag deployment.

Vessel	Owner/Captain	Type	Port
Black and Blue	Dave Harter	Private	Hilton Head, SC
Stray Cat	Jimmy Clark	Charter	Hilton Head, SC
Pole Cat	Jon Deloach	Charter	Hilton Head, SC
Carolina Morning	Brandon Thiess	Charter	Hilton Head, SC
Marsh Tacky	Zack Lyman	Charter	Hilton Head, SC
Fishing Coach	Dan Utley	Charter	Bluffton, SC

Captain Zack Lyman of the charter boat *Marsh Tacky* prepares to hand over a rod with a cobia on it for use as a specimen in the satellite tag tracking study.

Standard recreational fishing techniques were employed to collect specimens for tagging. All but one day of the cobia collections were conducted in the Broad River just east of the South Carolina highway 170 bridge crossing the Broad River. The remaining day was carried out on the Betsy Ross artificial reef, 29 km southeast of the entrance to Port Royal Sound. Cobia were captured using live and cut menhaden fished on circle and J hooks. Baits were fished at the surface and on the bottom. For fish to qualify as a candidate to receive a satellite tag, they had to be hooked in the outer part of the mouth causing no life threatening injury and must measure a minimum of 100cm fork length (FL). When other boats captured a fish to be tagged, the rod connected to the fish was passed to the tagging boat allowing the fish to be brought to the boat and a large dipnet was used to lift the fish into the boat for tag attachment. The fish was placed on a wet towel on the boat's deck with a second wet towel placed over its head to calm it and a specially designed mouth piece attached to a hose carrying saltwater from the bay was placed in its mouth to provide oxygen to its gills. Under this treatment, the fish would remain relatively still while the satellite tag was attached. The tag was secured to the fish below the anterior lobe of the second dorsal fin – either by inserting an internal anchor dart in the dorsal musculature or by passing the monofilament through the dorsal musculature using a stainless steel cannula. This was secured by sliding a stainless steel plate onto the protruding mono and then placing a double barrel brass crimp on the end preventing the plate from sliding off. The fish was returned to the water using the deck towel to lift the fish and lower it over the side to the water. All fish were returned to the water within 2 or 3 minutes of coming into the boat.

Private recreational vessels as well as charter boats were utilized in attempts to capture dolphin specimens for satellite tag deployment (Table 2). A $200 reward was offered to the boat captain or owner for the donation of a healthy dolphin of proper size for tagging. A total of eleven different offshore vessels were utilized in field trips attempting to collect dolphin large enough to carry the satellite tag. These vessels fished out of Beaufort Inlet, North Carolina, Charleston Harbor, South Carolina, Miami, Florida, Islamorada, Florida, and Isla Mujeres, Mexico. The captains and/or owners of four vessels were provided a satellite tag to keep aboard their vessel for a short period and instructed on how to handle the fish, activate the device and attach the instrument. A biologist carrying one or more satellite tags participated in each of 14 offshore trips to collect dolphinfish made by the other vessels.

Table 2. Recreational vessels participating in dolphin satellite tag deployment.

Vessel	Owner/Captain	Type	Port
Aggressor	Richard Coen	Charter	Mt. Pleasant, SC
Contagious	David Burnside	Private	Edisto Island, SC
Houdini	Jim Shannon	Private	Isle of Palms, SC
Jenny Lynn	Dick Rakovich	Private	Charleston, SC
Makara	Tom McMurray	Private	North Palm Beach, FL
My Time Out	Frank Gibson	Charter	Beaufort, SC
No Doubt	Jim Hardin	Private	Greenville, NC
Prowess	H. N. Ritter	Private	Charleston, SC
Rock Boat	Richard DeLizza	Private	Miami, FL
Special Lady	John Thomas	Charter	Mt. Pleasant, SC
Summer Girl	John Smith/Steve Leasure	Private	Charleston, SC

Normal recreational offshore trolling tackle and techniques were used to collect dolphinfish specimens. For fish to qualify for tagging, they were required to be a minimum of 110 cm FL and to be hooked in a fashion so as not to cause serious injury. The fish also was required to be actively swimming when brought to the boat as an indicator that it was not totally exhausted. Several methods of tag attachment were utilized. One method allowed the fish to remain in the water. One person held the leader to keep the fish close by the boat while a second person attached the tag using a stainless steel internal anchor dart. The tag was inserted into the dorsal musculature about one-third of the fish's length behind the head and half way between the spine and top of the dorsal muscle. The hook was either removed or the leader cut to release the fish.

Normal trolling techniques were used to collect dolphinfish for the study including fishing around large rafts of Sargassum that they are known to favor.

This system of attachment was also used with the fish being brought aboard the boat using a large dipnet and implanting the tag while the fish was restrained in the net. A hose carrying fresh ocean water was held in its mouth in an attempt to provide oxygen until it was returned to the water. A third method was employed on a larger boat that possessed a door in its transom designed for bringing large fish into the boat. In this instance, the fish was pulled through the door onto a wet towel using the leader. Three men placed a wet towel over the fish's head and restrained the fish. A special mouth piece attached to a hose carrying sea water was placed in its mouth to provide oxygen to the gills until it was returned to the water. The tag was attached using a stainless steel cannula to insert the monofilament tether laterally through the dorsal musculature at a point about one-third of the fish's length behind the head. The tether was secured by sliding a stainless steel plate onto the protruding mono and then a brass crimp was used to form a stopper-loop on the end preventing the plate from slipping off. In instances where the fish was removed from the water, it was returned to the water within two minutes.

Comparative data from climatology stations recording water temperatures for Port Royal Sound and adjacent nearshore ocean waters were very limited. The United States Geologic Survey maintains the only known continuous monitoring station for Port Royal Sound and its tributaries. It is located on the Beaufort River at Paris Island (Hydrologic Unit 03050208) which is a tributary on the north side of Port Royal Sound. This station is located roughly 13.2 km by water from the mouth of the sound. The water temperature sensor is mounted on a floating platform at this station and is positioned 1.5m below the surface. Ocean water datum was available only from a Carolinas Coastal Ocean Observing and Predicting System (CARCOOPS) weather buoy (FRP2) positioned 22.2 km E of the mouth of Port Royal sound. This station monitors both surface (0.9 m below surface) and near bottom (11.8 m below surface) water temperatures.

Tidal data for Port Royal Sound were acquired from the National Oceanic and Atmospheric Administration's Tides & Currents Web site. The NOAA tide predictions for the station at the north entrance to Skull Creek were used for comparison because of its proximity to the mid-point of the Port Royal Sound/Broad River estuarine system used by cobia.

Results:
Cobia:

Captain Jon DeLoach of the charter boat *Pole Cat* out of Hilton Head, South Carolina holds the satellite tag that has been attached to a cobia as it is prepared to be released.

Four satellite tags were successfully deployed on cobia captured in Port Royal sound or adjacent waters during this study (Table 3). Cobia selected for monitoring ranged in length from 102cm to 132cm FL and were estimated to range in weight from 15 to 30kg. The fish carrying tag 55504 was suspected to be a female because males seldom exceed 120cm FL. None of the fish were actually tested to determine sex. All fish to be tagged were hooked in the outer portion of the mouth with minimal tissue damage and required 12 to 35 minutes to bring to the boat for netting. One or more other cobia was observed swimming with each hooked fish. Following the tag attachment, each fish swam quickly away when returned to the water and did not require any special handling.

Table 3. Cobia specimens used in study.

ID No.	Data Recording Period	Fork Length	Est. Wt.	Fight Time
55504	30 days	132cm	30kg	35min
55550	90 days	122cm	23kg	12min
55551	90 days	112cm	17kg	20 min.
55552	90 days	102cm	15kg	15min

All cobia used in this study were captured by charter boats (Table 4). Each charter captain was paid $300 for providing a fish that was acceptable for tagging based on meeting size and health qualifications. The first tag was placed on a cobia captured at the Betsy Ross Artificial Reef in June 2006. The instrument, which was programmed for 90 days, never made contact with an Argos satellite. The three remaining monitoring devices were deployed May 12, 2007 on fish captured in Port Royal Sound. These cobia carried their instruments the full programmed period, one for 1 month and two for 3 months each.

Table 4. PSAT instrument deployment on cobia.

ID No.	Tagger	Boat	Location	Date	1st Satellite Contact	Distance From Release
55504	Hammond	Marsh Tacky	Port Royal Sound	5/12/2007	9-Jun-07	47.7kl
55550	Hammond	Pole Cat	Port Royal Sound	5/12/2007	12-Aug-07	129.3
55551	Hammond	Stray Cat	Betsy Ross Reef	6/7/2006	no contact	na
55552	Hammond	Carolina Morning	Port Royal Sound	5/12/2007	12-Aug-07	115.2

All tags were less than 161km from their release site when they made first contact with a satellite. The 30-day tag, 55504, was 0.8km north of the Betsy Ross artificial reef on June 9, 2007 when it first contacted a satellite. It had drifted at the surface for 0.54 day before its initial satellite contact. This placed it 47.7km southeast of the original release site. It floated southwest for six days transmitting data as it traveled the 96.9km. It was last heard from at a point 2.8km east of Ossabaw Island, Georgia. The two 90-day tags contacted Argos for the first time on August 12, 2007 following drift times of 0.29 days (tag number 55550) and 0.28 days (tag number 55552). Tag 55550 made first contact 17.9km south southeast of the Navy R8 tower off Savannah, Georgia which is 129.3km from the release site. PSAT 55552 made its initial contact from a location 35.6km north northeast of the Navy R8 tower which was 115.3km from the original release point. Both 90-day tags surfaced in waters approximately 45m deep adjacent to areas of known bottom fish habitat (Maps Unique, Savannah, GA map, 2000 edition).

Three out of the four instruments deployed transmitted data (Table 5). There is no way to determine why the PSAT deployed in 2006 never communicated with the satellite. The three remaining tags stayed with their fish until reaching their programmed completion date or the memory bank was full. Data were transmitted for just under 6 days by the 30-day tag. This resulted in only 24% of the potentially transmittable data being received. It is suspected that the tag may have washed ashore due to its proximity to a beach at its last known position thus terminating its data transmission early. These instruments will not transmit data in any position other than vertical. The other two tags recorded data for more than 92 days. Instrument 55550 downloaded data for 19.3 days sending back 76% of its transmittable data. Unit 55552 transmitted data for 13.5 days downloading 62% of its communicable data. The difference in the transmitting time was likely the result of the strength of the battery in each unit at the time of transmission.

Table 5. Performance of PSATs attached to cobia.

Tag Number	Programmed Monitor Period	Actual Monitor Period	Records Received	Contact Delay Time	Transmission Period	% of Memory Data transmitted
55504	30d	27.44d	2223	0.54d	5.98d	24%
55550	90d	92.31d	6,675	0.29d	19.31d	76%
55552	90d	92.53d	5,283	0.28d	13.53d	62%
55551	90d	n/a	n/a	n/a	n/a	n/a

Water Depths Utilized

More than 14,000 time-specific pressure observations were received from the three instruments during their collective 214 fish-days of monitoring. While the depth noted for the fish does not provide any indication of the actual water depth at that point in time, it can be used as a minimum depth indicator. These records show that during the three months monitored, the study-fish utilized waters from the surface down to depths of 70m. The average monthly water depths indicated that the fish gradually utilized deeper waters as time progressed (Table 6). While the shallow depths indicated for all fish in May does not rule out use of upper layers in areas of vast ocean depths, it most likely represents the use of shallow coastal and inshore waters such as found in Port Royal Sound. This bay and its main estuary, the Broad River, has a main channel with depths of 6.7m to 13.4m up to the SC highway 170 bridge with holes as deep as 18.3m.

Table 6. Comparison of average depth used monthly by three cobias Tagged in Port Royal Sound.

	Average Depth (m)		
Month	Tag 55504	Tag 55550	Tag 55552
May	10.3	10.87	9.62
June	18.24	21.34	13.51
July		35.93	28.83
August		38.14	40.49

Average daily depth tracks varied among the fish but all followed a general trend of increasing depth (Figures 2 through 5). Combining the depth readings each month for the three fish provides an overall trend for the water depth used. In May, the three fish occupied the shallowest waters of the study, averaging a depth of 10.5m. Tag 55504 terminated monitoring early in June and provided only 6 days of records, leaving the two 90-day tags to provide the remaining depth information. The average depth for June increased 66% to 17.4m. However, there was a sizable difference, 7.8m, in the average depth occupied with fish 55550 consistently using deeper water than 55552. In July the average depth occupied by the two fish increased almost 90% from the June depth, descending to 32.4m. Fish 55550 continued to occupy waters as much as 22m deeper than 55552 until July 25. From July 25 through July 28, 55552 move into waters with average depths of 58m to 61m daily and descended to a maximum depth of 70m. The greatest depth recorded for fish 55550 was 59m on July 28. Depth data were received only for the first 11 days of August but the records showed the fish continued to occupy increasingly deeper water with the overall average monthly depth descending to 39.3m.

Figure 2. Average daily depth used in May.

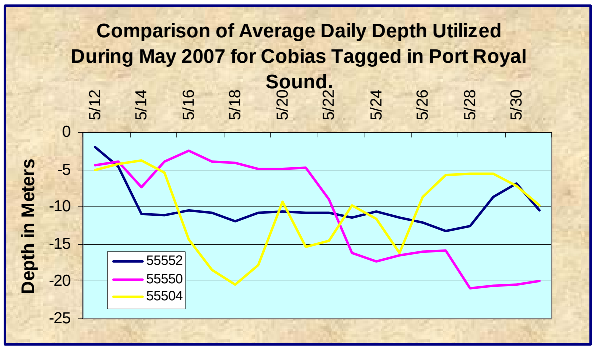


Figure 3. Average daily depth used in June.

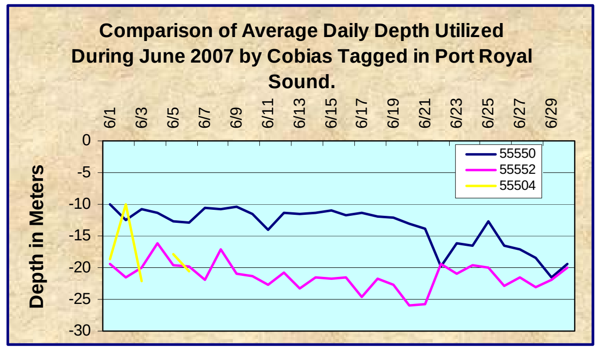


Figure 4. Average daily depth used in July.

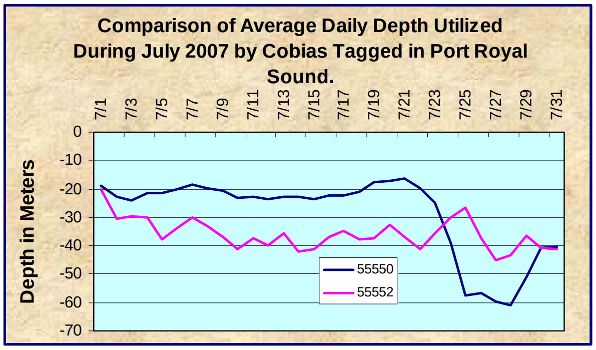
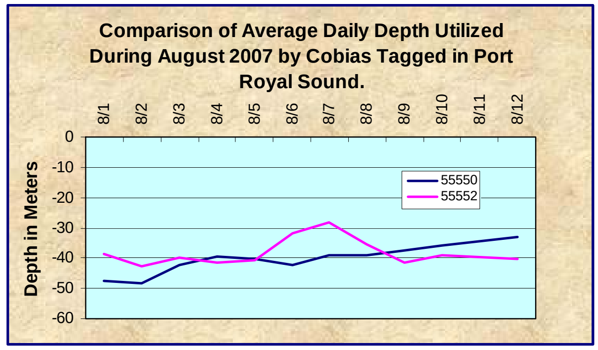


Figure 5. Average daily depth used in August.



Vertical Movement Behavior

Cobias are well known for their close association with the ocean floor and the bottoms of bays and sound. Fishermen also know that cobia will visit the surface waters especially in the spring of the year. Frequency of surface visits and amplitude of these vertical movements have never been examined. The minimum and maximum depths recorded each day by the PSAT can provide a good record of the amplitude of their vertical movements. Fish 55552 showed both the largest vertical movement, 53m and the longest period of least vertical movement, 11 days with 5.4m or less depth variation. The overall amplitude for daily movement for the three fish was similar in May and June at 12.1m and 11.4m respectively (Table 7). As the fish began to use deeper waters in July and August the amplitude of the overall daily vertical movements increased to 19.4m and 26.9m, respectively. Data showed that fish 55504 and 55550 exhibited similar daily vertical movements during May and June while fish 55552 made appreciably smaller daily vertical movements during May, June and July (Table 7). These depth records may not show the actual depth of the occupied water at any point, but the increasing depth does eliminate the possible occupation of shallower coastal and estuarine waters especially in July and August.

Table 7. Average daily amplitude of vertical movement.

Month	Average Daily Range of Depth Variation (m)			
	55504	55550	55552	Overall
May	14	13.1	9.1	12.1
June	17.5	14.2	7.4	11.4
July		26.2	12.7	19.4
August		27.5	26.4	26.9

The frequency that cobia visit the surface is important since many fishermen sight-fish for them. Such movements also help to define the importance of surface waters in the cobia's life. For the purpose of this study, a surface visit for a cobia was defined as any time that the fish came within 2m of the surface because inshore water visibility would allow the fish to see the surface at this depth in most instances. A surface visit ended as soon as the fish went below 2m. This could be as short as a one record to the next or could last more than an hour. All fish visited the surface more days during May, 63% of the days overall, than any other month (Table 8). The high rate of surface-visit days by 55504 in June is likely due to the sampling being limited to the first 9 days of June. Overall surface-visit days declined 75% in June to 15% of the days. The overall surface-visit frequency declined further in July to only 10% of the days. August exhibited a major rise in the overall surface-visit rate, 27% of the days, which may have been related to the sampling being limited to only the first 11 days of the month.

Table 8. Frequency of days when the surface was visited

Month	Percent of Days Surface Visited			
	55504	55550	55552	Overall
May	80	65	45	63
June	50	7	13	15
July		19	0	10
August		45	9	27

The number of visits that a cobia made to the surface on a given day (for days when the surface was visited) ranged from 1 to 27. Most surface-visits lasted just a few minutes (Table 9). Fish 55504 exhibited the single longest surface-visit on May 15 when it remained at the surface for seven consecutive readings spanning 62 minutes. While the number of daily surface-visits varied among the fish each month, all exhibited a steady decline in surface-visits from May through July. Overall daily surface-visits in May (9.7 visits per day) for the three fish were twice as high as June (4.8 visits per day). July's level (2.8 visits per day) was 42% lower than June's. These data suggests that as the fish utilize progressively deeper waters from one month to the next, they visit the surface less often as well.

Table 9. Average number of surface-visits on days when surface was visited.

Month	55504	55550	55552	Overall
May	10.8	11.6	5.0	9.7
June	6.0	5.0	3.5	4.8
July		2.8	0.0	2.8
August		1.8	1.0	1.7

Fishermen regularly sight-fish for cobia looking for them cruising just under the surface and lingering around buoys and other surface structure.

An attempt was made to examine tidal influence on visits/time at the surface. However, without knowledge of where the fish was located at any given time, there was no way to determine what tidal schedule to use in the comparison. During May 12 through 15 and May 27 through 30, 2006 data indicate that the fish were likely in PRS. The cobia's surface activity during this period was compared to the tidal schedule for those days using the tidal predictions for the mouth of Skull Creek which is the prediction point closest to the middle of the sound and Broad River. Three flow periods were created for this analysis: high tide with slow flow which comprised one hour either side of high tide; Low tide with slow flow one hour either side of low tide; and fast flow period which included all times between the slow flow periods. During the eight days examined, the fish was observed in >2m of water in 170 records. The high tide slow current period was involved in 16% of the observations while the low tide, slow current period accounted for 13% of the surface observations. It was the fast flow period that saw the majority of the surface activity, 71% of the surface records. With such a small data set and the surface occurrences so evenly scattered, the effect of tidal stage, if any, on the cobia's surface behavior could not be determined.

Water Temperatures Utilized

More than 14,500 time-specific water temperature observations were reported for the three fish during their tracking periods. Combined records indicated that the fish utilized waters ranging from 20.7^{o}C to 29.3^{o}C. Combined temperature records showed that more than 86% of the observed water temperature readings fell between 22^{o}C to 27^{o}C. Daily variations in water temperature rarely exceeded 2^{o}C. The largest daily temperature variation was 7.06^{o}C and was noted in July for a fish moving between 37.7m and the surface. A comparison of the average monthly temperatures for the monitored period showed the lowest average temperatures were utilized during May and the highest during June (Table 10). The reason highest average temperatures did not occur during July or August is probably because of the cobia's occupation of deeper ocean waters at that time. Supporting this hypothesis is the fact that the lowest water temperature recorded, 20.7^{o}C, was in August at a depth of 53.8m. Water temperatures of 28.0^{o}C and higher were recorded starting in late June with the highest temperature, 29.3°C recorded in August. The highest temperatures were associated with the surface waters.

Table 10. Average monthly water temperatures encountered by tagged fish.

Month	Average Water Temperature, °C		
	55504	55550	55552
May	22.8	23.1	22.7
June	24.0	25.1	25.4
July		24.3	25.0
August		24.9	24.2

Comparing the average daily temperature occupied by each cobia shows how minor the variations were among the fish each month (Figures 6 through 9). The graphs show that the temperatures used by the cobia steadily increasing into late June and early July where they peak around 26°C. Over the next week, the average daily water temperature declines roughly 2°C and then oscillated around 24°C for the remainder of the monitored period. This temperature decline is suspected to be the product of the movement of fish into deeper waters, presumably offshore. Comparing the tag-provided temperatures to the bottom water temperature recorded at the CARCOOPS FRP2 buoy shows the fish to closely match the weather station's observations or slightly exceed them during May and into June. By the first part of July the observed temperatures for the fish have dropped well below those recorded in the shallow nearshore waters off Port Royal Sound.

Figure 6. Average daily temperature used in May.

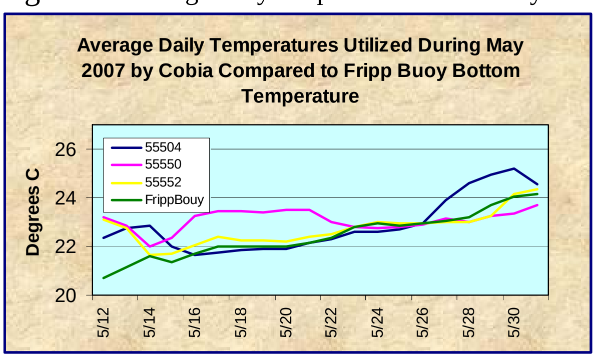


Figure 7. Average daily temperature used in June.

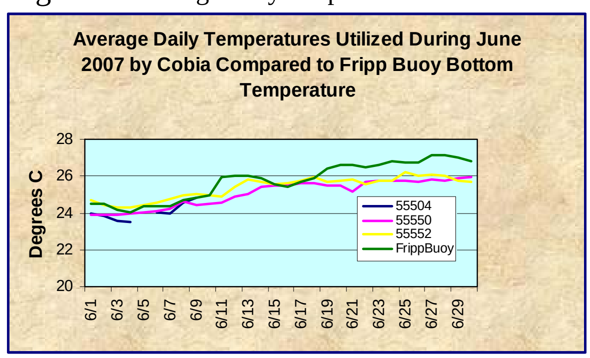


Figure 8. Average daily temperature used in July.

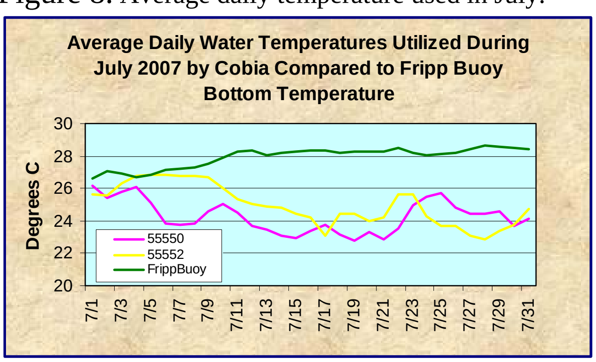
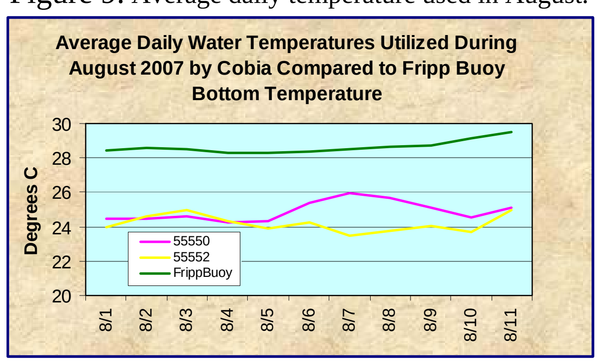
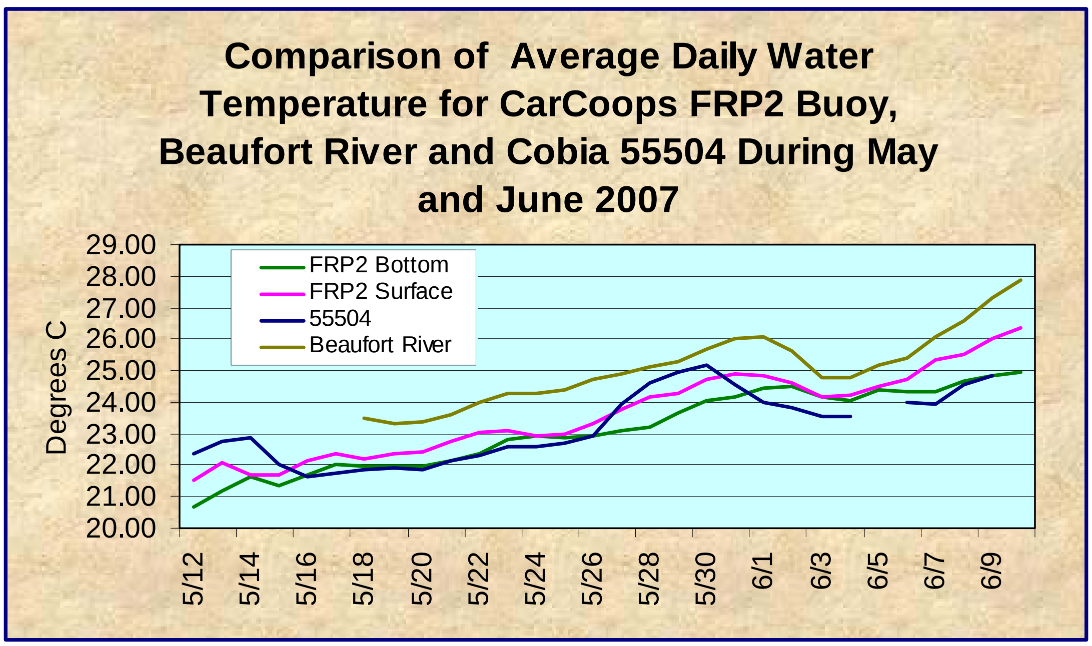


Figure 9. Average daily temperature used in August.



These temperature tracks also offer clues to the location of the fish. Using the bottom water temperature data collected by the CARCOOPS FRP2 weather buoy located in 12.5m of water 13.2km northeast of the mouth of Port Royal Sound provides a thermal reference point to the location of the fish. The daily average temperature track seen in figures 6 through 9, suggests that during May and June the fish were in the same general nearshore waters possibly entering the shallower estuaries when their temperatures exceeded those observed for the nearshore waters. When tag-recorded temperature readings fell below the FRP2 bottom water temperatures, it is likely that the fish had moved offshore where they occupied much deeper and cooler waters. When data from the high resolution tag, 55504, are plotted against the nearshore observations from the FRP2 buoy and water temperature data from an estuary feeding into the PRS, the resulting graph suggests possible inshore movements. During the periods of May 12 through 15 and May 27 through 30 the average daily water temperature recorded for the cobia exceeded both bottom and surface temperatures recorded at the FRP2 buoy showing the fish to be in a different water mass (Figure 10). Similarly fish 55550 reported water temperatures above the FRP2 buoy from May 15 through May 22, suggesting that it may have moved back into PRS. While the temperatures recorded for the fish during these periods did not quite rise to those recorded in the Beaufort River, it is possible that the deeper, larger PRS system maintained slightly lower temperatures (Figure 10). Knowing that the fish was released in the sound on May 12 when the higher temperatures began being recorded, adds support that these periods of higher temperatures indicated times when the fish was in the PRS system. This would suggest that cobia may make multiple incursions into PRS during May and June.

Figure 10. Water temperature comparison for ocean nearshore, inshore and cobia 55504.

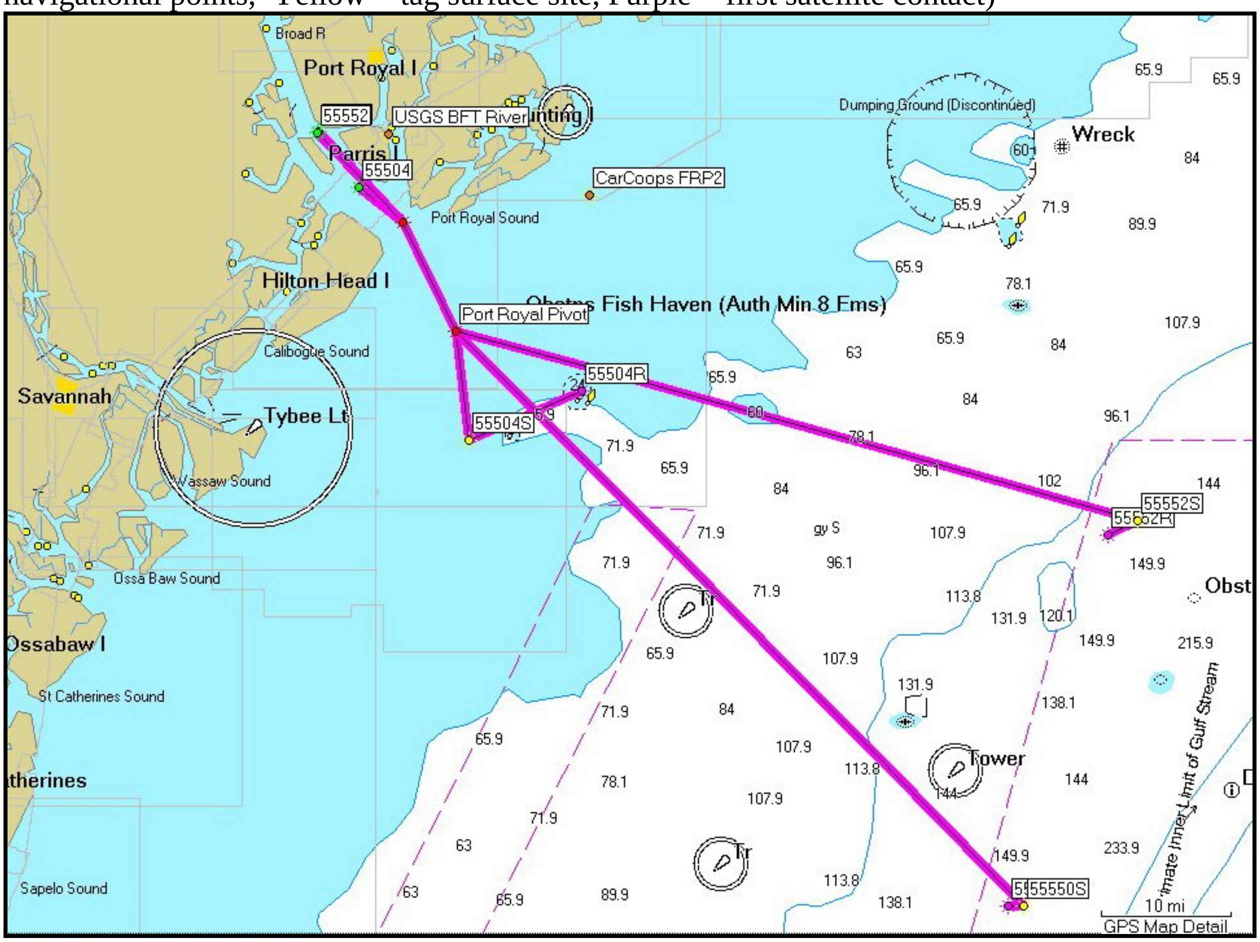


Fishermen have long held that lunar phases affect fish behavior, and biologists, as well, have documented many instances linking lunar phases with fish behavior. Both of the possible inshore incursions (May 12 – 15 and May 27 – 30) preceded the new and full moon phases which took place on May 16 and June 1, respectively. Also the five-day period preceding and including the day of the lunar event, new or full, saw more than twice as many visits to the surface by cobia than the five day period following these lunar events. The movement of 55550 did not follow the same pattern following its departure from PRS (May 13 through 15) temperatures indicated it may have return to the PRS system from May 16 through May 22.

Movements

All of the cobia satellite tags were located southeast of PRS when they first contacted an Argos satellite (Figure 11). After being at liberty for 29 days, tag 55504 was located 32.5kl offshore of the mouth of PRS at a position north of the Betsy Ross Artificial Reef. Using the speed and direction at which this tag drifted over the next 11 hours after first contacting the satellite, it appears that the tag may have surfaced 15.4km southwest of its first contact position. This would place it closer to shore northeast of the White Water Artificial Reef off Hilton Head Island. Back calculating the surfacing position for the two tags out for 92 days would suggest that 55552 surfaced at a point 4km east northeast of its first contact location and that tag 55550 surfaced just 0.7km southeast of its first contact point. These back-calculated positions for where the tags probably surfaced, still place the fish in areas offshore of Beaufort County commonly fished by local anglers.

Figure 11. Locations where PSATs were deployed first surfaced and made first contact with a satellite. (Map generated using Garmin Mapsource) (Green dots = release sites, Red = navigational points, Yellow = tag surface site, Purple = first satellite contact)



The most prominent feature of the PSAT is the ability to recreate a hypothetical daily track of the movements of the fish. Microwave Telemetry Inc. uses a copyrighted software program to calculate the geo-position of the tag each day for their standard rate PSAT. This movement track is generated when the tag manufacturer decompresses and summarizes the data received from the PSAT before delivering it to the researcher. This feature is not available on the 30-day, high resolution instruments. Figures 12 and 13 show the hypothetical tracks calculated by MTI for tags 55550 and 55552. These maps show both the calculated daily positions and the averaged position for the fish. The drift track of the unit during transmission recorded by Argos is also indicated. The magnitude of the possible error in any single position plot using this program becomes obvious as you note the plots at Cedar Key on Florida's west coast or the one near Orlando in Florida's central section. While the presented individual tracks may not be absolutely accurate, they do present useful information when viewed in general terms. One feature of these tracks to note is the heavily weighted trend toward offshore and southerly movements. When there are multiple tracks available that can be overlaid that show similar movement trends among many fish, then a meaningful pattern can emerge.

Figure 12. Calculated movement track for PSAT 55550, May 12 to August 12, 2007.

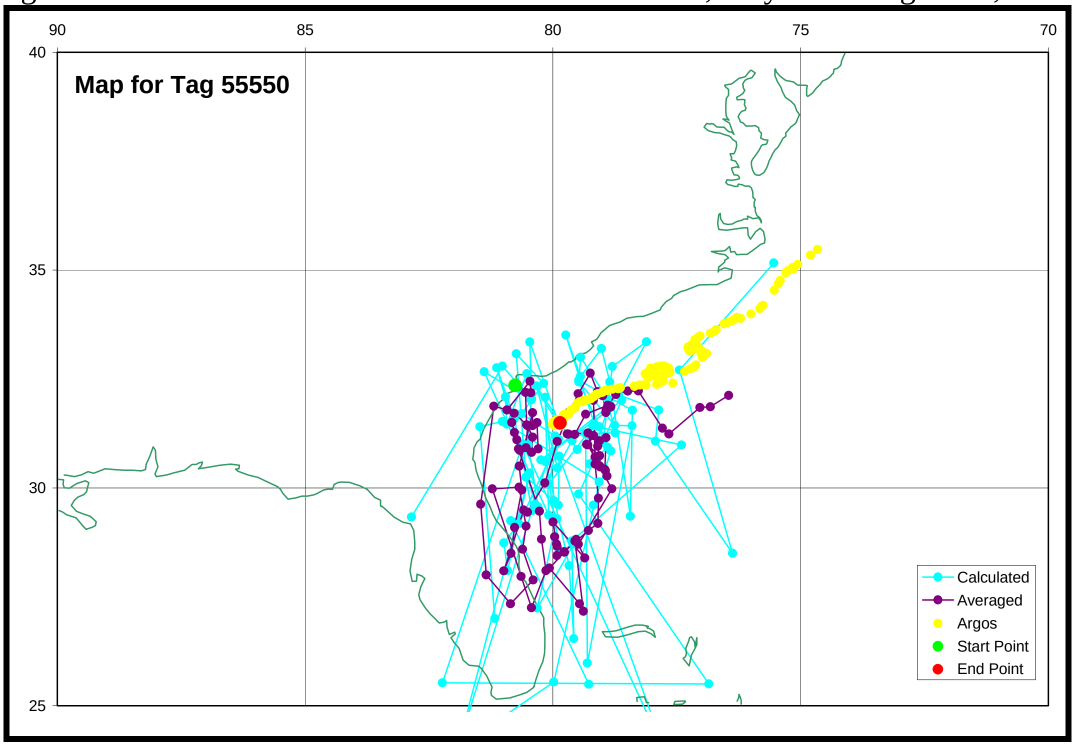
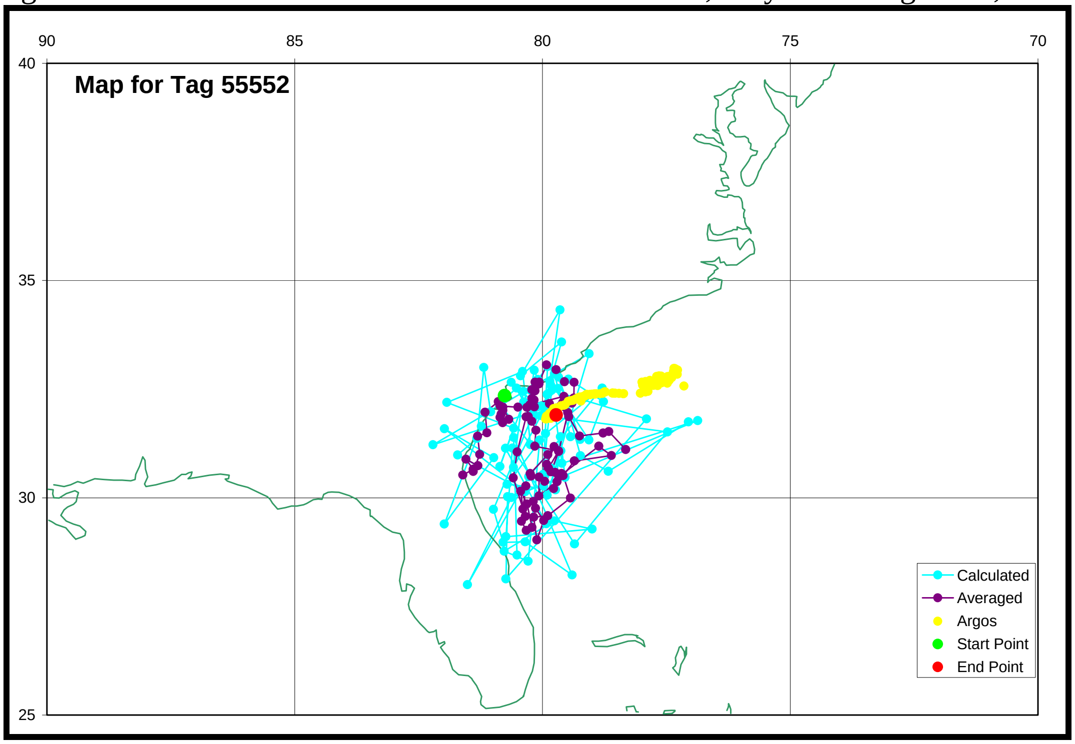


Figure 13. Calculated movement track for PSAT 55550, May 12 to August 12, 2007.



Dolphinfish:

Dolphinfish enjoy worldwide popularity as top rated game fish in tropical and subtropical waters.

Five PSAT instruments programmed to monitor for 30 days were placed on dolphinfish during the study (Table 11). Privately owned recreational fishing vessels captured the specimens used in this phase of the study. Only one $200 reward was paid because most boat owners declined the reward. The $200 reward for providing a qualifying dolphinfish for a satellite tag was found to be insufficient to convince charter boat clients to give up their trophy dolphin for a scientific study. Three satellite tags were deployed on dolphinfish in 2006 with two additional instruments placed on fish in 2007. One PSAT was deployed off Charleston, South Carolina and three were used on dolphinfish in the Florida Straits /south Florida. The PSAT deployed in July 2007 off the Florida Keys never contacted an Argos satellite and is assumed lost. The other four satellite tags monitored their host's movements and environment for periods ranging from 13 hours up to 559.9 hours with an average of 238.56 hours of monitoring per fish. The tags first established contact from 103km to 547km north to northeast of their deployment position.

Table 11. PSAT deployment on dolphinfish.

ID No.	Tagger	Boat	Area	Date Deployed	First Contact	Distance from Release
37066	Richard DeLizza	Rock Boat	Miami, FL	9-Jun-06	03-Jul-06	103kl
46484	Don Hammond	Makara	Yucatan Strait, MX	6-Jun-07	12-Jun-07	454kl
55486	Richard DeLizza	Rock Boat	Islamorada, FL	21-Jul-07	no contact	Na
55487	Don Hammond	Jenny Lynn	Charleston, SC	21-Jun-06	01-Jul-06	163kl
55548	Richard DeLizza	Rock Boat	Islamorada, FL	10-May-06	24-May-06	547kl

All dolphin used in the study were males and ranged in size from 107cm to 123cm fork length (Table 12). They were estimated to weigh 11.4 to 15.9kg. Female dolphin seldom reach the size needed for these large instruments. All fish were captured using trolled natural baits on rod and reels and required from 15 to 23 minutes to bring to the boat for tagging.

Table 12. Dolphinfish used in PSAT monitoring. (est=estimated)

ID No.	Tag Program	Sex	FL	Est. Wt.	Fight Time
37066	30 days	Male	1.23m est	13.6kg+	20 min.
46484	30 days	Male	1.23m	15.9kg	23 min.
55486	30 days	Male	1.12m	13.6kg	20 min.
55487	30 days	Male	1.07m est	11.4kg	15 min.
55548	30 days	Male	1.14m est	13.6kg	15 min

Four of the five PSATs attached to dolphinfish successfully contacted Argos satellites and transmitted data (Table 13). Three instruments had short monitoring periods ranging from 13 hours to 10 days before the tag floated to the surface where they drifted from 3.6 to 4.5 days before contacting a satellite. One tag remained with a fish nearly to term, 23 days. The short monitoring periods appear to indicate the death of the fish but it is not known whether it was due to predation or some other cause. The fact that the tag drifted at the surface for roughly 4 days as prescribed for the constant pressure program to initiate early release and satellite contact indicates that its attachment to the fish was terminated. Whether the tethering anchor came loose or the monofilament tether was cut is not known. The resulting tag data transmissions spanned periods of 21.6 days to 22.7 days resulting in delivery of 63 to 84% of the transmittable archived data.

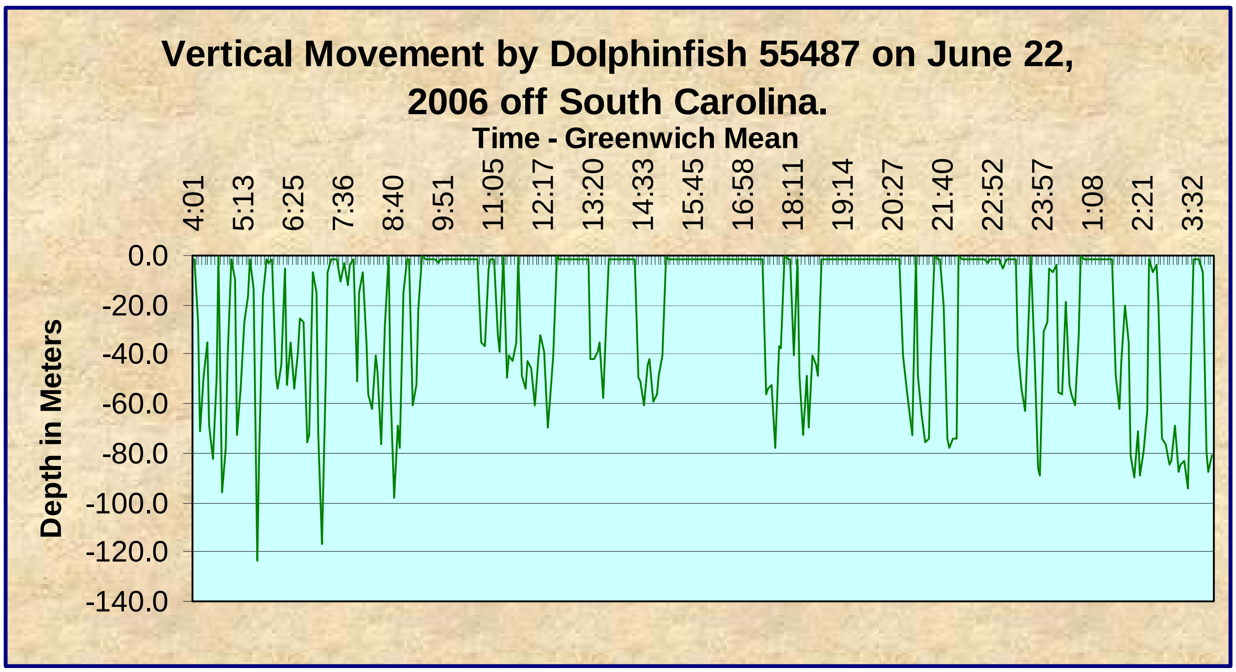
Table 13. Performance of PSATs attached to dolphin.

Tag #	Programmed Period	Period Monitored	Time – specific Data Sets Received	Contact Delay	Transmission Time	% of Data
37066	30d	23.33d	6335	0.28 d	21.6d	63%
46484	30d	0.57d	363	4.47d	21.6d	84%
55487	30d	6.9d	1907	4.06 d	21.7d	76%
55548	30d	10.0d	3092	3.64d	22.66d	73%
55486	30d	n/a	n/a	n/a	n/a	n/a

Depth Utilization

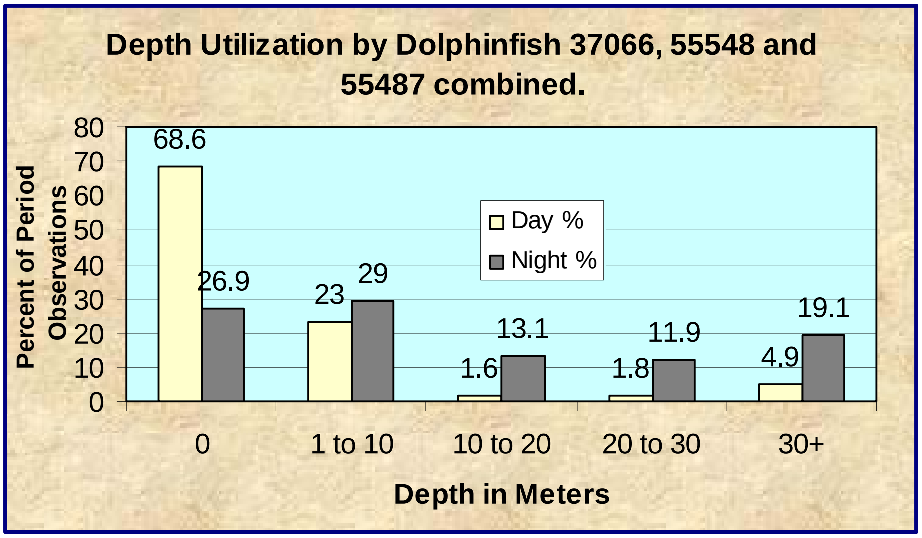
High resolution PSATs allow fish to be tracked as they move vertically through the water column throughout the day (Figure 14). These data provide insight into the diving behavior and water depths utilized by dolphinfish. Data received from these PSATs show that dolphin which are most commonly associated with the ocean's surface layer, actually utilize depths at least as deep as 120m and regularly move up and down in the water column.

Figure 14. Vertical movements by dolphinfish 55487 on June 22, 2006 off South Carolina.



Depth movements were found to be markedly different between diurnal and nocturnal periods for fish in the South Atlantic Bight (Figure 15). Differences in the use of the surface, 0m, was very pronounced with fish spending 69% of the diurnal period and only 27% of the nocturnal period at the ocean's surface. Little difference was shown between the two periods in the use of the upper layer just below the surface, 1 to 10m, diurnal 23% and nocturnal 29%. Monitored dolphins clearly utilized greater depths during the night than in the day. Fish 46484, tagged in the Yucatan Strait was monitored for too short a period to allow any comparison of depth selection and diving behavior and was not included in the analyses.

Figure 15. Comparison of diurnal and nocturnal depth utilization by dolphinfish in the South Atlantic Bight.



A difference in depth utilization was also indicated by the data between fish off southeast Florida and fish off South Carolina (Figures 16 and 17). The dolphinfish tracked off South Carolina was observed in waters below 10m eleven times more frequently during the diurnal period than the fish off south Florida. Differences in nocturnal depth utilization were not as dramatic with the South Carolina fish observed below 10m 58% more often than those off Florida. All fish showed a clear increase in use of waters below 10m during the night, but the fish off South Carolina used these waters far more frequently during all time periods. This behavior was also observed in a fish tagged off South Carolina with a PSAT in June 2005 in a pilot assessment study conducted by the South Carolina Department of Natural Resources. It showed similar utilization of waters below 10m with 39% of the diurnal observations at this depth and 56% of the nocturnal readings below 10m as well.

Figure 16. Comparison of light period depth utilization by fish 55487 off South Carolina.

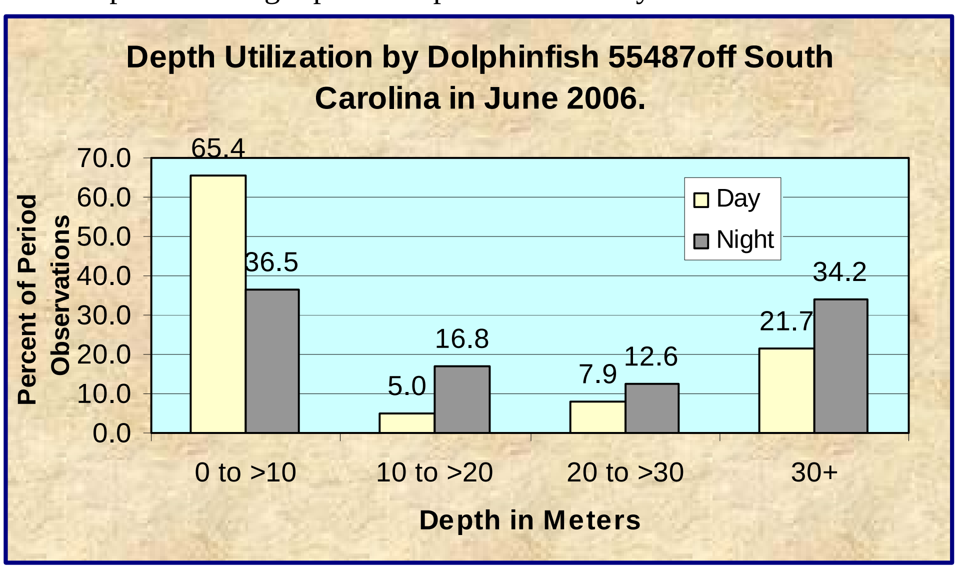
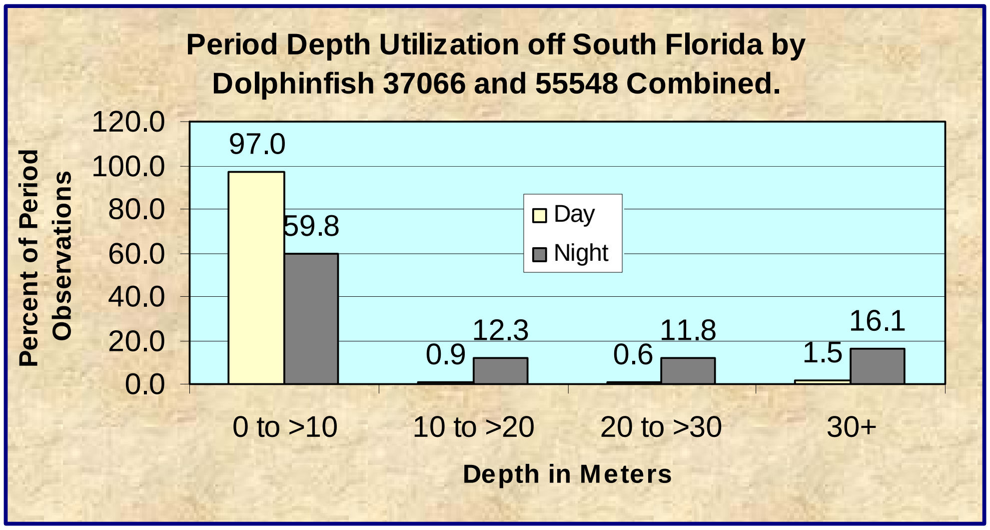
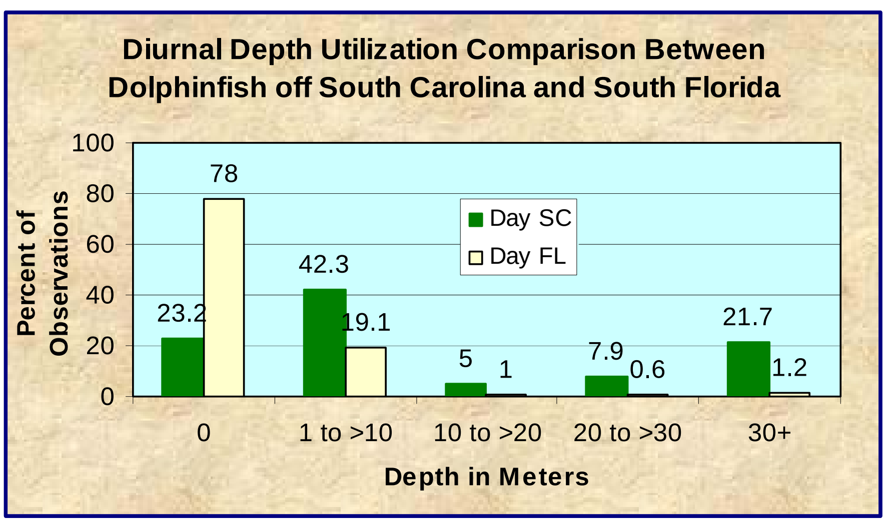


Figure 17. Comparison of light period depth utilization by fish off southeast Florida.



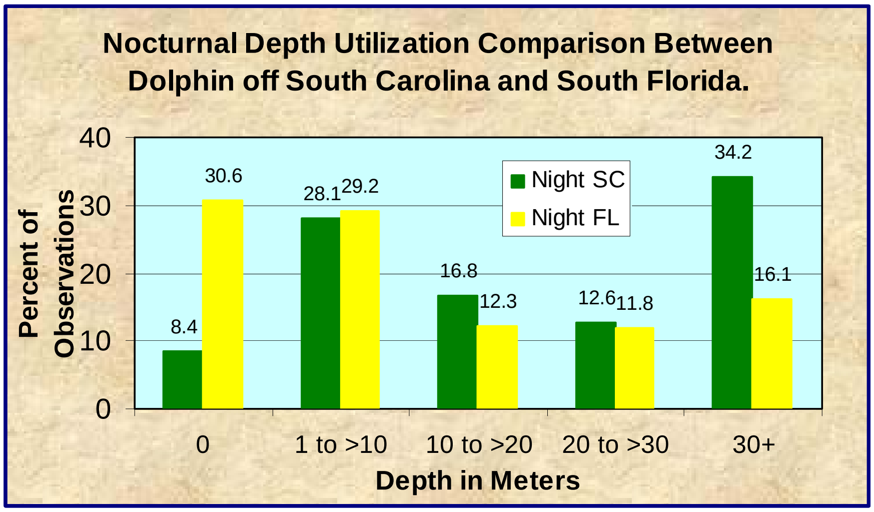
Diurnal depth behavior is of particular importance since this is the period when fishermen most frequently target the species. The time spent at the surface, 0m, or in the surface layer, <10m, would likely be the period when the fish would be most vulnerable to fishing pressure, especially from recreational fishermen. Dolphin off south Florida were found to have 97% of their daylight depth readings in this range with ¾ of these observations at 0m level (Figure 18). The dolphin off South Carolina behaved markedly different with 66% of its daylight observations in <10m of water and just 1/3 of those being at 0m. While the Florida fish used waters below 10m in less than 3% of the diurnal readings, the fish off South Carolina occupied these depths in more than 34% of the total observations. The fact that the dolphin off South Carolina occupied depths at or below 30m in 22% of the diurnal depth records indicates there may be a change in behavior as the fish moves from area to area throughout its migration.

Figure 18. Comparison of average diurnal depth utilization between monitored dolphin off South Carolina and south Florida.



Nocturnal depth selection also showed a marked difference between the two areas (Figure 19). South Florida fish occupied the surface, 0m, almost 4 times the amount of observations as did the fish off South Carolina. But it is very interesting that fish in both areas spent almost equal amounts of time in the surface layer, 1 to<10. The use of the intermediate depths, 10 to 20m and 20 to 30m, were also similar between the two areas. However, the fish off South Carolina utilized waters at or below 30m more than twice as frequently, 34% of the depth records, as did the fish off Florida, 16% of the depth records.

Figure 19. Comparison of nocturnal depth utilization for dolphinfish off South Carolina and south Florida.



Water Column Use:
Vertical water column movements by three dolphinfish were recorded for a total of 41 days. During the tracking period each fish rose to the surface every day at first light and usually spent the majority of the daylight period near the surface. However, they did use more of the water column than just the surface. The fish made dives daily below 40m with the exception of only five days out of the 41 monitored. (Figures 20, 21 and 22). The deepest dive was made by the fish off South Carolina which descended to 123.7m, and which also used the deepest average daily depth, 79.9m. The fish tracked in May off Florida showed an average daily maximum depth of 55.9m while the fish tracked in June/July averaged diving to a maximum depth of 45.3m daily. Average depth occupied daily varied the most with the fish off South Carolina ranging from 4.4 to 39.7m. The fish tracked in May off Florida had an average daily depth range of 1.0 to 15.6m while the one tracked in June/July showed the least variation in average daily depth range at 1.0 to 10.2m.

Figure 20. Daily water column use by dolphin 55487 off South Carolina.

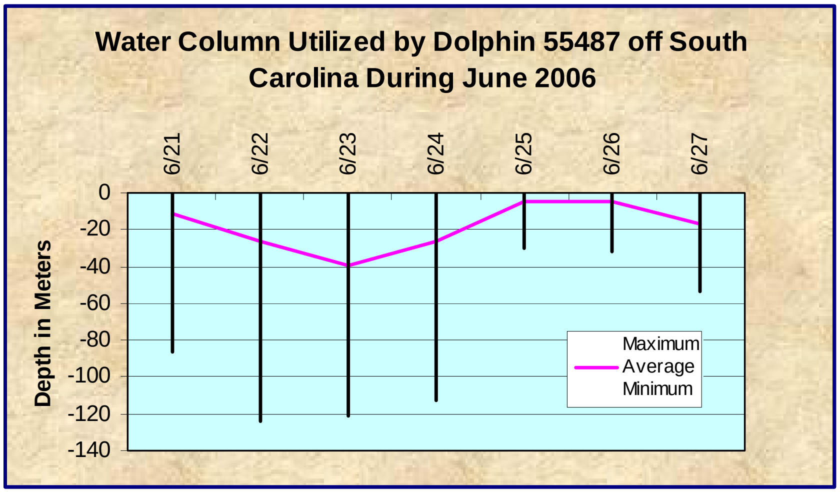


Figure 21. Daily water column use by dolphin 55548 off south Florida.

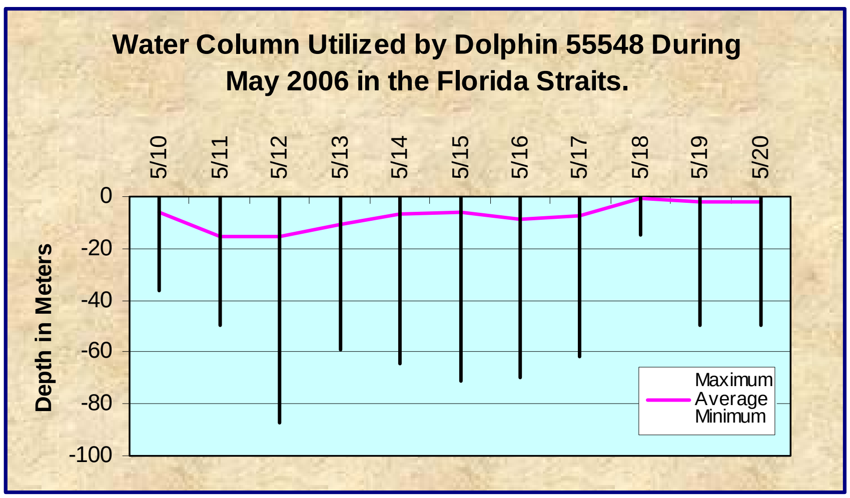
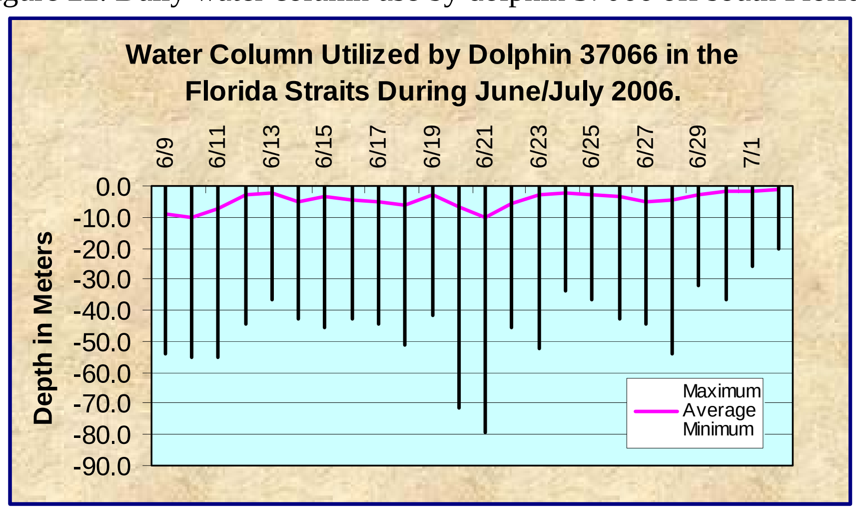


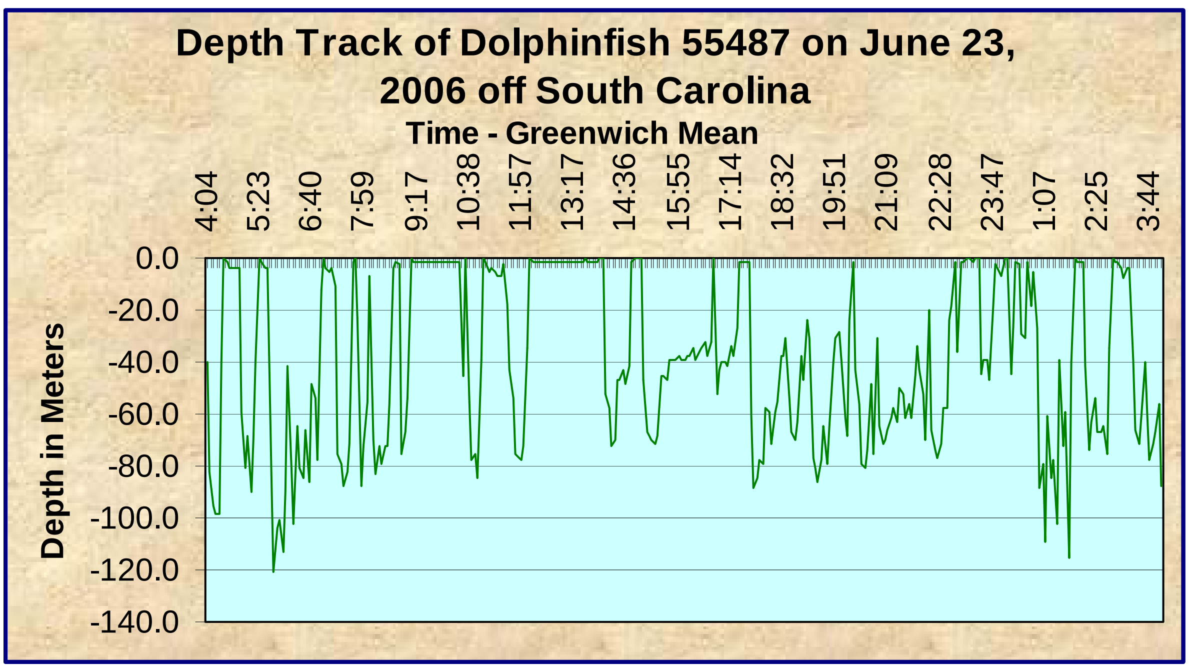
Figure 22. Daily water column use by dolphin 37066 off south Florida.



Diving Behavior:
Data indicated that the three fish commonly made dives to or below 30m (deep-dives) and such dives could exceed 100m. Deep-diving behavior was shown by fish off Florida and South Carolina. The majority of the descents below 30m were short in nature usually lasting from 1 to 15 minutes. However, some dives turned into excursions lasting as long as 5 hours. Data also showed that a fish would commonly make several sequential dives to roughly the same depth. The regularity of this diving behavior would indicate that it was not random but serves a specific purpose. Also of note was that regardless of the fish's depth at time of first light each day, it would rise to the surface.

Deep-diving was exhibited more often by the fish off South Carolina. The depth track for the South Carolina fish shown in Figure 23 represents the most extensive use of waters below 30m recorded. During June 23, 2006, data indicated that the dolphin occupied depths of 30m or greater in 62.9% of the observations for that 24 hour period. During the diurnal period of June 23rd, the fish made 11 dives during which it spent a total of 8.7 hours at or below 30m for an average dive period of 47 minutes below 30m. The longest stay at this level was 4.9 hours. The fish spent at least 55% of the diurnal period on June 23 at these deeper levels. During the nocturnal periods of June 23rd, 69.9% of the depth readings were at or below 30m. The fish made 10 dives during the night periods that totaled 5.1 hours resulting in an average stay of 30 minutes per dive below 30m. Intervals between deep-dives ranged from 3 minutes to as long as 113 minutes.

Figure 23. Water column movement for dolphin 55487 on June 23, 2007 off South Carolina.



On average, dolphin off Florida made fewer and shallower dives than the South Carolina fish (Figure 24). Fish off the Sunshine state made only half as many diurnal deep-dives on average during the days that deep-dives were made (Table 14). Diurnal deep-dives took place on roughly one out of four days (25.7%) off Florida, but occurred on about 3 out of four days (71.4%) off

South Carolina. The length of the diurnal dives in Florida was also much shorter in duration averaging only 7.2 minutes compared to 18.9 minutes off South Carolina. Florida fish also utilized shallower waters, 30% shallower, than the fish off South Carolina.

Figure 24. Water column movement for dolphin55548 on May 14, 2006 off south Florida.

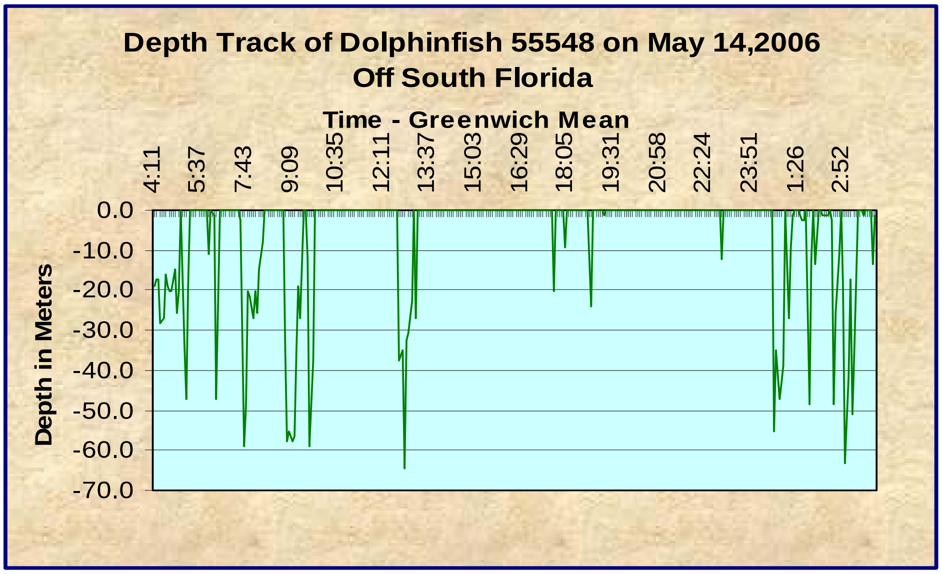


Table 14. Comparison of diurnal diving behavior to or below 30 meters for fish monitored off Florida and South Carolina.

State	Daytime				Percent of Days Dives Made
	Ave. Number	Max. Time	Ave. Time	Max Depth	
SC	10	39 min.	18.9 min.	65.6m	71.43%
FL	4.42	7.42 min.	7.19 min.	45.72m	25.70%

Nocturnal diving activity exceeded daylight diving in all fish but were similar between the two areas (Table 15). Fish in both areas averaged about the same number of dives per night, 11 deep-dives and made such dives on about the same number of nights, 8 out of 10 nights. The nocturnal diving behavior by the fish off Florida double the number of dives made in a period and increased the average maximum depth by 23% over their diurnal diving pattern. The fish off South Carolina exhibited a smaller increase in nocturnal deep-dives over their diurnal behavior with an 18% increase in the number of dives in a period and a 5% increase in the average maximum depth used. Interestingly, the average time spent below 30m per dive decreased at night by 28% for fish off Florida and by 46% for the fish off South Carolina.

Table 15. Comparison of nocturnal diving behavior to or below 30 meters for fish monitored off Florida and South Carolina.

State	Night				Percent of Nights ' Dives Made
	Ave. Number	Max Time	Ave. Time	Max Depth	
SC	11.78	16.37	8.73	68.12	83.33%
FL	10.74	16.31	5.2	56.28	82.40%

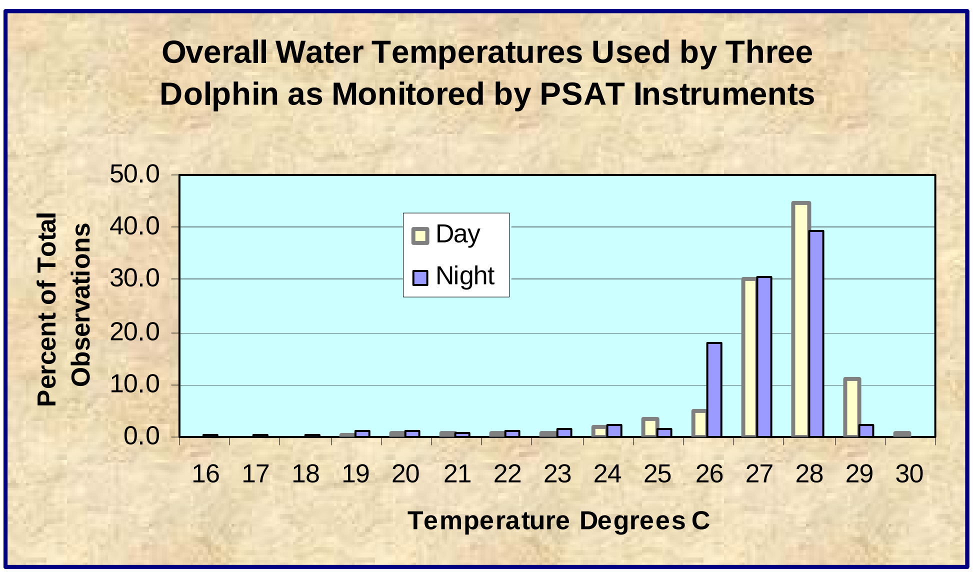
Temperature Utilization:
Temperature data were combined based on whole degree units so that 24°C actually included reported values from 24.000 to 24.999°C. Combined data showed that the dolphinfish utilized waters with temperatures ranging from 16.2 to 30.87°C (Table 16). Surface waters consistently exhibited the highest temperatures while the coolest waters with temperatures below 21°C were typically found below 40m only off South Carolina. Average daily water temperatures used by the fish off South Carolina ranged from 23.94 to 26.79°C while the Florida fish exhibited daily averages of 25.58 to 27.50°C and 27.70 to 29.00°C.

Table 16. Thermal ranges and average temperature observed for each dolphin tracked.

Fish	Area	Temperature		
		Maximum	Average	Minimum
55487	SC	28.57	25.49	16.20
37066	FL	30.87	28.44	24.08
55548	FL	29.14	26.86	22.20
46484	Yucatan Strait	29.14	28.58	26.73

Dolphin were shown to use waters that varied as much as 12°C range (16.2 to 28.2°C) in a single day off South Carolina or as little as 0.53°C off south Florida. Because of the difference in depth utilization observed between the diurnal and nocturnal periods, temperature selection was examined on a night and day basis. More than 11,000 temperature readings were collected from the three fish during the 965.5 hours the fish were monitored. During the daylight period the fish were found to occupy temperatures of 25 to 29°C in 95.9% of the observations (Figure 25). At night the fish used waters ranging from 24 to 29°C in 93.5% of the readings. Data from the three fish showed that they occupied waters of 26.0 to 28.99°C during 80% of the diurnal readings and 88% of the nocturnal observations.

Figure 25. Temperature selection by dolphin in the South Atlantic Bight.



Examination of the temperature records for the individual fish (Figures 26, 27, and 28) showed varying thermal profiles. Considering that the oceanic temperature is dynamic both in time and space, it is to be expected that dolphin would utilize slightly different temperatures at different times in an area or in different regions. Dolphinfish off South Carolina utilized cooler waters, up to 6^{o}C lower than fish off Florida. They also used a wider range of temperatures, averaging 7.73^{o}C variation per day, than the Florida fish which showed average variations of just over 3^{o}C. The fish off Florida did utilize warmer waters, as much as 2.3^{o}C above those used off South Carolina.

Figure 26. Daily temperatures occupied by dolphin 55487 off South Carolina.

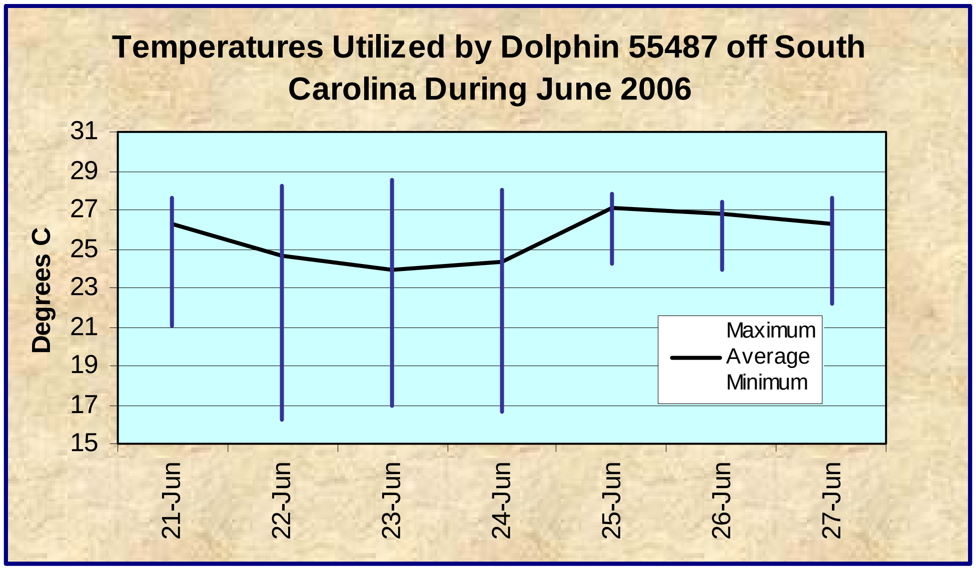


Figure 27. Daily temperatures occupied by dolphin 55548 off south Florida.

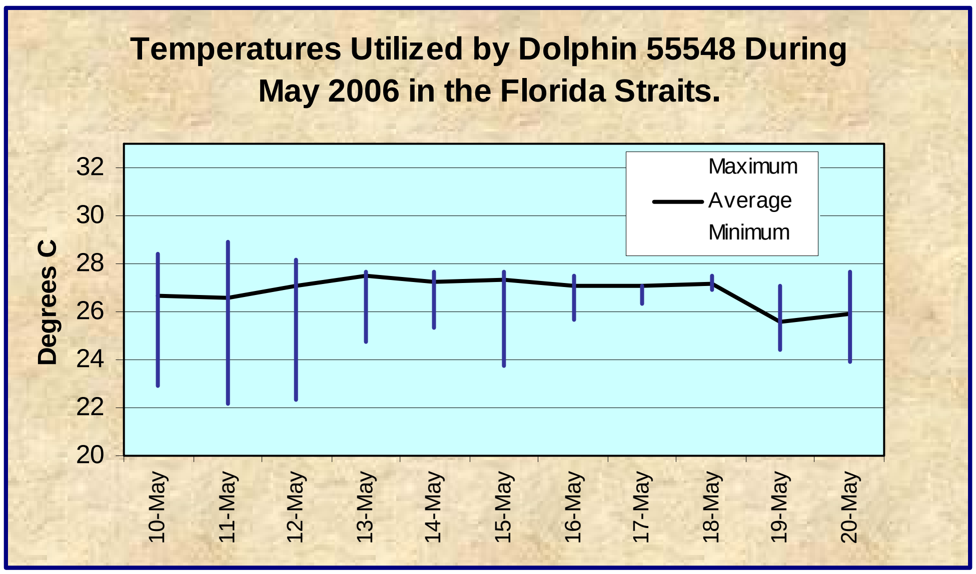
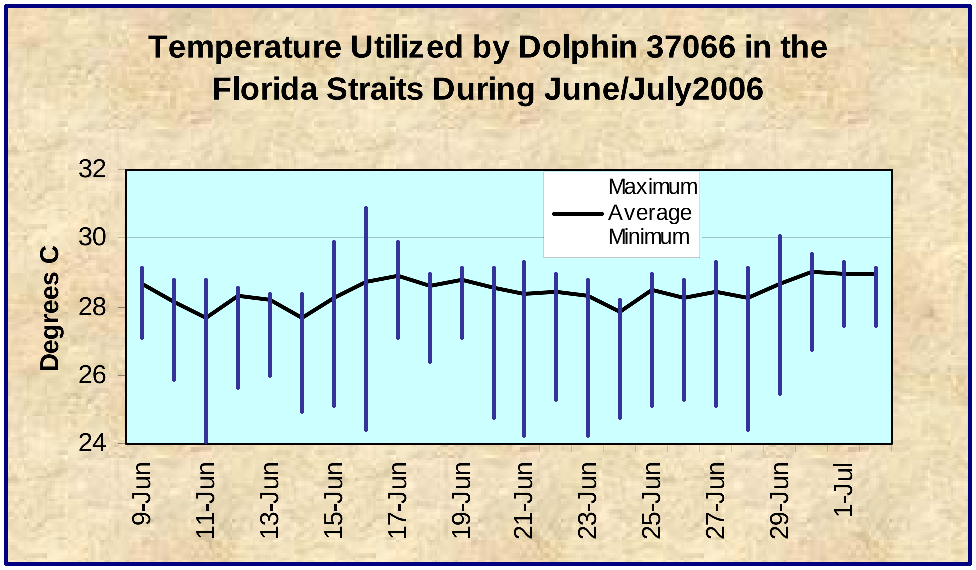


Figure 28. Daily temperatures occupied by dolphin 37066 off south Florida.



Water temperatures of 21.0^{o}C or lower were only utilized by the fish monitored off South Carolina. This fish showed limited use of these lower temperatures – seldom remaining in these waters beyond 25 minutes before returning to warmer surface waters. The maximum continuous occupation of these cooler waters was 51 minutes, but most low temperature incursions lasted less than 4 minutes.

Dolphinfish spend the majority of their time at the surface and by knowing their preferred temperature range it will allow more accurate determination of their potential distribution.

Knowing the surface water temperatures utilized by dolphinfish is important to fishermen in their effort to locate concentrations of fish. Surface water temperatures are the basis for thermal imaging by satellite and the most common thermal monitoring done by fishing vessels. Data from all four fish indicated they used surface waters with temperatures ranging from 23.9 to 30.87°C (Table 17). However, they spent the majority of time in waters of 27.0 to 28.99°C. Fish off south Florida and the Yucatan Strait did utilize waters between 28.0 and 28.99°C than did the fish off South Carolina. The difference is probably due to thermal variations among areas.

Table 17. Surface temperatures occupied by monitored dolphinfish.

Fish	Area	Surface Temperature, oC		Dominant Surface Temperature, oC	
		Minimum	Maximum	Range	% Occupation
55487	SC	23.9	28.57	27.0 to 27.99	67.60%
37066	FL	26.55	30.87	28.0 to 28.99	75.90%
55548	FL	24.78	29.14	27.0 to 27.99	83.80%
46464	YS	28.39	29.14	28.0 to 28.99	98.80%

Discussion

Cobia

Working with the local charter boat captains fishing in Port Royal Sound and offering them a $300 incentive to donate the cobia they caught worked well. Physically working from a charter boat provided additional advantages since the captain had a close working relation with the other charter boat captains and was able to convince them to donate to science the fish they were catching. This direct one-on-one work with the charter captains helped impress upon them the importance of the study and made them feel a part of a high tech scientific study to assist the management of cobia.

The problem with pioneering research is that there little information available to guide the mechanics of the research showing what works and what does not work. The only other known use of PSAT tags on cobia was conducted by James Franks, University of Southern Mississippi, College of Marine Science, Ocean Springs, MS, (personal communication, 2007) in the Gulf of Mexico (five tags deployed 2002 through 2005) and by Donald Hammond, South Carolina Department of Natural Resources, Marine Resources Division, Charleston, SC, in 2005 in Port Royal Sound. These efforts met with limited success with both researchers not completely satisfied with the stainless steel internal anchor system used to secure the PSAT to the fish. The one instrument in this study secured using an internal anchor was never heard from but there is no way to determine if the attachment method played a role in the tag’s disappearance. Three units deployed on May 12, 2007 all completed their full monitoring period of 30 to 90 days. These units were attached using a body piercing method that minimized tissue trauma and should have less impact on the health of the fish. Also saltwater from the bay was continuously supplied to the gills for aeration via a hose during the attachment process. This system resulted in the successful monitoring of three specimens for the full programmed period and should be utilized in future PSAT studies involving cobia.

SCDNR scuba divers have often observed and videoed cobia cruising just off the bottom in vicinities of natural and manmade benthic reefs in coastal and offshore waters (Daryl Stubbs, SCDNR 2006, personal communication). Anglers have frequently reported catching cobia during the summer, fall and winter in offshore waters while fishing on the bottom for snapper and grouper. Considering the known bottom-cruising behavior of cobia, it is likely that the average daily depth observed for each fish was a close indicator of the actual depth of the water occupied especially from mid-June on when they made fewer surface visits. The steadily increasing average monthly water depth occupied would support the hypothesis that the cobia utilize PRS and nearshore waters during May and early June and then move offshore to the deeper natural reefs and live bottom areas adjacent to PRS where they join the offshore bottom fish ecosystem. Surface visits appear to be a behavior most commonly carried out in May when they are in shallow coastal and inshore waters. Data hints of a possible lunar correlation with the peak activity occurring in the days leading up to the new and full moon in May. Cobia reduce their rate of surface visits in June and only occasionally rise to the surface in July and August. Cobia spawned in laboratory tanks have been observed to rise to the surface for the actual act of spawning (Al Stokes, SCDNR, 2006, personal communication) which opens the possibility that at least some of the surface visit behavior could be related to spawning which is known to occur in the May/June time frame in the waters adjacent to the PRS area.

Cobia were observed to occupy a narrow thermal band spending the majority of their time in waters of 22 to 27^{o}C with less than a 2^{o}C variation daily. Temperatures occupied by the fish also support the inshore to offshore movement hypothesis. Only in May and early June did the water temperatures occupied by the fish exceed the observed nearshore bottom water temperature and approach the temperatures recorded at the Beaufort River inshore weather station. From early June on the water temperatures were either equal to or below those observed for the nearshore bottom water at the Fripp Inlet 2 weather buoy. The lower temperatures would be expected in the increasing depths occupied by the fish. This thermal profile would support the hypothesis that the fish moved offshore into deeper water as the summer advanced.

The fact that first satellite contact with each of the instruments placed the fish in offshore waters adjacent to Port Royal Sound is evidence that cobia either linger in or regularly return to these waters following their entry into the sound. First contact with the 30-day tag placed it in the vicinity of the Betsy Ross Artificial Reef while the two 90-day tags were first located further offshore northeast and southwest of the Navy R-8 tower off PRS giving additional support to the inshore-offshore movement hypothesis. It also provides documentation as to where the cobia go once they leave the sound. The movement of any tagged fish between its release and its recovery (the first satellite contact in this case) has been a perplexing question to biologists. Movement tracks calculated by staff at Microwave Telemetry, Inc. for the two cobia monitored for 90 days is suspect at best. The movements of cobia after they leave PRS will be determined by the trends shown when many individual tracks can be overlaid to generate common movement trends. Because the instruments did surface offshore of southern South Carolina, they did not offer any data to dispel the possibility of a unique subpopulation of Atlantic cobia that use PRS.

Dolphinfish

Dolphinfish proved to be a difficult species to work with in many respects. Because it is a species inhabiting open ocean waters, it requires use of the large, expensive boats equipped with full navigational, fish-finding and communication equipment. Fishing trips to areas where dolphin may be caught off South Carolina cost fishermen 5 to 10 times more than fishing trips targeting cobia. Because of the expense, these fishermen feel more compelled to bring large fish, especially ones that are considered good eating like dolphin, back to the dock. This results in the average offshore fishermen being reluctant to donate large, trophy size dolphin to be released.

Dolphinfish are also short-lived fish – seldom living beyond 2 years. Unfortunately, the large size of PSAT necessitates that a large 12 to 14-kg fish be used for study which is a fish in the latter part of its life and most likely a male. This means that only the oldest and largest specimens of the species are being monitored. Coupled with the age issue is the fact that dolphin are a primary blue-water forage species. Most of the larger marine predators (sharks, billfish, tuna, marine birds, marine mammals, and even other dolphinfish) regularly prey on dolphinfish. So an immediate problem for the project is relying on a fish whose movements are impaired because of a large device it is required to tow. Predators are known to target fish exhibiting abnormal swimming behavior since it can indicate an easily captured meal. Consequently, attaching a PSAT to a dolphinfish can make it a more attractive target for predation than it would be normally.

Results from this study suggest regional differences in how dolphinfish use water temperatures and portions of the water column. Data clearly supported dolphin as an epipelagic species spending the majority of its time in the ocean's surface layer, down to 10m, but readily using varying portions of the water column at least as deep as 123m. While the majority of the observed temperature readings fell in the narrow band of 26.0 to 29.0^{o}C (82.6% of total observations), dolphin were also shown to enter a wide range of water temperatures from 16.2 to 30.87^{o}C (a span of 14.7^{o}C).

This study begins the process of defining the third dimension in the dolphin's geographical habitat – depth. The very regular use of depths below 30m especially at night by dolphinfish in all areas suggests that the behavior fills a need in the fish's life. Data from the fish off South Carolina indicate a greater use of waters below 30m during both diurnal and nocturnal periods compared to fish monitored off south Florida. Fish off south Florida primarily used the deeper waters during only the nocturnal period. Additionally, fish off South Carolina used deeper waters, below 80m, more frequently than did the fish off Florida. The greater use of waters below 30m by fish off South Carolina would suggest that the fish may be less vulnerable to the standard recreational troll fishery than off south Florida.

Vertical movement patterns observed in the study also hint at a possible reason behind the deep diving behavior. Researchers have established that there is a geographical difference in the diet of dolphin and that it is most likely a function of prey abundance rather than selection by the fish. Animals that hide in the dark-depths of the ocean by day but rise to or near the surface at night, such as squid, have been shown to make up from 9 to 61% of the dolphins diet in the South Atlantic Bight. The increased diving behavior off South Carolina could reflect a shift in the dolphin's feeding behavior from surface prey species to those found at greater depths. The depth tracks frequently indicated that a fish would make several sequential dives to the same depth which could be interpreted as the fish finding food at that depth on the initial dive and returning for additional feedings. This hypothesis would suggest that dolphin continue actively feeding throughout the night but probably target different organisms than those preyed upon during the daylight. If true, this finding could alter our understanding of the dolphin's role in the food web and could possibly indicate a utilization of different trophic levels.

Performance of the PTT-100 PSAT

Microwave Telemetry Inc. promotes their PTT-100 high resolution, 30 day, tag as recording temperature, pressure and light levels every 1 to 4 minutes and every 15 minutes for tags programmed for 90 days. According to MTI the tags will transmit 100% of their transmittable data from a full memory in 22 days of active transmission at mid latitudes. The instruments are also reported to have an accuracy of + or – 0.1^{o}C and pressure sensitivity of 0.5m.

Instruments used in this study did indeed meet the performance specifications of the manufacturer. Four instruments transmitted data for 21.6 to 22.66 days and only transmitted a maximum of 84% of the available data and the 84% was a unit that had monitored the fish for only 13 hours. Two tags that monitored fish for 7 to 10 days only provided rough 75% of their available data. The two PSATs out for 90 days reported 62 and 76% of their available data. The 30 day high resolution tag 55504 that had indicated a full memory bank only managed to send in 24% of the data but it may have washed ashore preventing data transmission.

Also MTI is not readily forthcoming in explaining what its units of measure actually represent as reported by Argos. MTI manual for the PTT-100 provides no information or explanation regarding the accuracy of the temperature and pressure data collected or any explanation of the units in which the instrument reports them. The manual also does not explain that the instrument will use the first data readings to fill in the absent data from the preceding portion of the day for the day the unit was turned on. MTI also never mentions that the tag transmits data only if it is in a vertical position. If it washes ashore or is caught in Sargassum or other flotsam causing it to lay over on its side, it will not transmit. Failure of the tags to transmit data can be caused by damage from animal bites to the unit, by the tag host rubbing the unit against a hard surface or even by consumption by a large predator. Failure can also result from a defect in the instrument but there is no way to determine the cause of the failure.

The final assessment of the PTT-100 is whether the information generated is worth the cost. Regardless of the unit's short comings the instrument does provide data that previously was only available through the use of archival tags that had to be recovered to retrieve their data. External streamer tag studies of the two species indicate a 3% recovery rate for dolphinfish and a 15% recovery rate for cobia. Working with these recovery rates and the current cost of $1,500 for similar function archival tags, a study would have to deploy $10,500 in archival tags (7 tags) for each one retrieved from a cobia and $49,500 in tags (33 tags) for each one recovered from a dolphin.

One reason to continue working with this manufacturer's PSAT instruments is that the investigator in this study has becoming knowledgeable in operation of the unit, its strengths and weaknesses, and how to deal with the manufacturer. Another major reason to continue with MTI is that is has just introduced a new model PSAT that is roughly half the size of the old instrument which means that it will be of a size more appropriate for cobia and dolphinfish. No other PSAT manufacturer offers a unit the size of the new X model by MTI.

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