Vertical Movements of Dolphinfish (*Coryphaena hippurus*) in the Western North Atlantic as Determined by Use of Pop-Up Satellite Archival Transmitters

Los Movimientos Verticales de Dorado (*Coryphaena hippurus*) en el Atlántico Norte Occidental, Determinado por el Uso de Pop-Up Archivos Transmisores Satelitales

Des Mouvements Verticaux de la Coryphène (*Coryphaena hippurus*) dans l'Atlantique Nord-Ouest Tel Que Déterminé par l'Utilisation de Pop-Up Satellite Emetteurs d'Archives

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ABSTRACT

Dolphinfish (*Coryphaena hippurus*) are circumtropical migratory species of significant importance to recreational, sport, and commercial fisheries. In the western North Atlantic, dolphinfish occur from the George's Bank, off New England, south to Trinidad and Tobago. Throughout this distribution there have been no studies on the vertical movements of dolphinfish. Understanding these is essential in defining dolphinfish preferred habitat, daily diving patterns, feeding strategies, and predator-prey relationships. We deployed pop-up satellite archival transmitters (PSATs) on 11 adult dolphinfish (95 – 120 cm estimated fork length (FL)) from 2005 – 2011 in the western North Atlantic to investigate vertical movements and habitat use. For the first time data was recorded indicating the species' use of the vertical water column to depths of at least 255 m. Diving behavior was classified into four time periods, dawn, day, dusk, and night. Dolphinfish spent 66% of their time in the surface layer (0 – 9.9 m). The most extensive vertical movements (> 30 m) occurred during night rather than during the day. Results suggest a diel activity pattern. These data can be used to further define factors limiting dolphinfish vertical movements, improve stock assessments, resource allocation, and stock-based resource management.

KEY WORDS: *Coryphaena hippurus*, vertical movements, habitat use

INTRODUCTION

Dolphinfish, *Corypahena hippurus* L, is an epipelagic circumtropical predator, of significant economic importance to commercial and sport fishing industries, and artisanal fisheries worldwide (Oxenford and Hunte 1986, Rodriguez-Ferrer et al. 2004, Mahon 1999). Despite this economic importance, relatively little is known about the vertical movements and habitat use of the common dolphinfish throughout its distribution. Understanding dolphinfish movements and habitat use is important for both fishing and managerial interests in order to predict vertical movements within the water column relative to crepuscular, day, and night time periods, identify temperature limits, examine feeding strategies, and understand if their vertical distribution varies between regions, throughout the year, relative to changes in the thermocline, or by gender. Therefore, compiling this information is essential to allow for better resource allocation for fishermen through enhanced fishery management.

Reasonably little is known about the vertical movements and habitat use of dolphinfish in the western north Atlantic and Caribbean Sea. Dagorn et al. (2007) tagged 26 dolphinfish with coded transmitters and monitored their site fidelity, habitat use, and movements relative to drifting fish aggregating devices (DFADs) in the Indian Ocean and found that dolphinfish remained with objects on the open ocean for as much as 14.91 days, and spent the majority of their time within the first 35 m of the surface. Girard et al. (2007) observed the ability of dolphinfish caught near stationary FADs (SFAD) to return back to the SFAD when displaced up to 1600 m away and showed variable vertical distributions with some dolphinfish closer to the surface more often than others after being actively tracked for up to 29 minutes after being released. While these data begin to describe the residency, site-fidelity, and homing abilities of dolphinfish relative to a drifting or stationary object, they do not depict the temporal periodicity and overall vertical movement strategy of dolphinfish.

In this study we investigated the vertical movements and habitat use of dolphinfish in the western north Atlantic and Caribbean Sea as inferred from the use of pop-up satellite archival transmitters (PSATs). The main objective of this study was to determine if dolphinfish vertical movements varied by time of day i.e. crepuscular, day and night time periods. A secondary objective was to assess how vertical movements changed if there were discernible differences between time periods. To achieve this, data from 11 PSATs deployed on dolphinfish in different regions of the western north Atlantic and Caribbean Sea were analyzed.

METHODS

Satellite Telemetry

Eleven dolphinfish (10 male, 1 female) were tagged and released in four different areas in the western north Atlantic and Caribbean Sea: Three off South Carolina, 6 off Florida, one off Mexico, and one off Puerto Rico (Figure 1). All fish were tagged with pop-up archival satellite transmitters (PSAT PTT-100 standard, high-rate and high-rate x-tag models; Microwave Telemetry Inc., Columbia, MD, USA) during the spring months of 2005 – 2011. Each PSAT was attached to a stainless steel internal anchor dart (16 mm X 50 mm) using monofilament and a brass crimp to secure a loop through the wire attachment point on the top of the device. The tag was then secured in the dorsal musculature of the fish using the anchor dart and a 2 m tagging pole, or by inserting a 254 mm long section of 1.6 mm diameter monofilament laterally through the dorsal musculature from one side to the other. On the exiting line, a stainless steel plate (8 mm X 25 mm) was secured using a brass crimp to form a stopper-loop. The PSAT PTT-100 standard and high-rate transmitters measures 166 mm in length, has a maximum diameter of 41 mm, and a 171 mm long antenna. The device weighs between 65-68 grams. The PSAT high-rate x-tag measures 120 mm in length, with a maximum diameter of 32 mm, and antenna length of 185 mm; the x-tag weighs 40 grams. Dolphinfish were caught using traditional offshore pole and troll techniques using live bait and 7.0 circle hooks. Dolphinfish qualifying for tagging were required to be a minimum of 100 cm FL, be lip-hooked, and visually healthy. Two methods of tag attachment were utilized. One method allowed the fish to remain in the water while the other brought the fish onboard in a large net. In both instances, the tag was inserted into the dorsal musculature about one-third of the fish's length behind the head. While onboard, the fish was calmed by placing a wet towel over its eyes and inserting a hose carrying fresh ocean water into its mouth in an attempt to provide oxygen until it was returned to the water. Fish were returned to the water within two minutes.

In this study, PSATs were preprogrammed to remain with the fish for 30 and 180 days, recording time specific water temperature, pressure and light intensity at regular but different intervals based on tag type (Table 1). At the end of the monitoring period the device releases itself from the tether connecting it to the fish using electrolysis. Once released from the fish, the device floats to the surface and begins transmitting data to an Argos system satellite every 60 seconds on the SiV schedule *e.g.* tags transmit for blocks of several hours when the likelihood of a satellite pass is greatest, rather than transmitting continuously.

Private recreational vessels as well as charter boats were utilized in attempts to capture dolphinfish for satellite tag deployment. A total of twelve different offshore vessels were utilized in field trips attempting to collect dolphinfish large enough to carry the satellite tag. These vessels fished out of Beaufort Inlet, North Carolina, Charleston Harbor, South Carolina, Miami, Florida, Islamorada, Florida, Isla Mujeres, Mexico, and La Parguera, Puerto Rico.

Temporal and Spatial Data Analysis

In order to examine the periodicity of dolphinfish vertical movements, these data were binned into four time periods (6 hours each) positioned relative to the twilight *i.e.* dawn and dusk time periods. These categories were as follows: dawn (0300 – 0900), day (0900 – 1500), dusk (1500 – 2100), and night (2100 – 0300). These time periods were positioned according to sunrise and sunset times that occurred in locations along the U.S. east coast and Caribbean Sea during the spring and early summer months (April to July) that these transmitters were at liberty. This allowed for crepuscular movements to be revealed and analyzed in relation to depth.

Satellite archival data were examined related to depth fix and classified into six depth categories: Surface (0 m), surface layer (0 – 9.9 m), subsurface layer (10 – 29.9 m), mid-shallow depths (30 – 59.9 m), mid-deep depths (60 – 89.9 m), deep depths (> 90 m). These categories represent

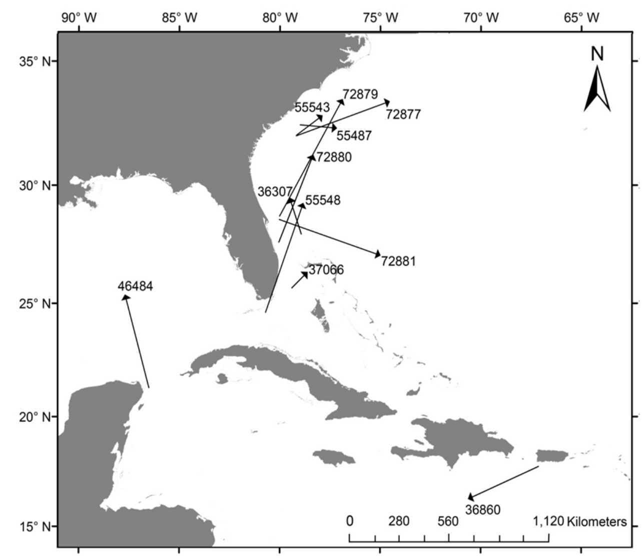

Figure 1. Horizontal dolphinfish displacments from pop-up archival satellite transmitter (PSAT) varied between locations around the western North Atlantic and Caribbean Sea.

Table 1. Differences in pop-up archival satellite transmitter (PSAT) tag types.

Satellite Tag Type	Depth Resolution (m)	Temperature Resolution (°C)	Preset-Monitoring Period (days)
PTT-100 Standard Rate	5.4	0.23	180
PTT-100 High Rate	1.34	0.23	30
X TAG High Rate	0.34	0.014	30

observed depth values; theoretical values are the observed values plus the sensor resolution of 1.3 m for PTT-100 high-rate archival and high-rate x-tag, and 5.4 m for the standard-rate archival transmitter.

A dive was defined as any departure from the surface (0 m) and consecutive depth fixes > 0 for any amount of time. Therefore, theoretically, dives began when depth fixes were 1.3 m or greater for PTT-100 high-rate and high -rate x-tags, and 5.4 m or greater for PTT-100 standard-rate archival transmitters. Time spent diving in the surface layer was defined as any time recorded between 1.3 – 9.9 m; time spent diving below the surface layer equaled any observed value equal to or greater than 10 m. A surface interval was defined as any time spent and consecutive depth fixes at 0 m for all tag types. Dives were examined by depth, duration, and complexity using relative depth *e.g.* actual depth divided by maximum depth obtained during the monitoring period for each dolphinfish. After data transformation, non-parametric Kruskal-Wallis and pairwise Mann-Whitney tests were used to examine diving behavior relationships. Lastly, row by column chi-square tests were used to examine dive complexity by time of day. The least complex dive type was categorized as a "line" dive within the surface layer, followed by a "V" dive representative of an abrupt descent to depth then abrupt ascent back to the surface. The higher complexity dives were categorized as "U" and "W" dives with the former representing a continuous dive at or near a certain depth level until ascending to the surface, and the latter being a seesaw shaped dive with more than one abrupt change in location in the water column relative to depth with the dive terminating at the beginning of the next surface interval.

Data Filtering

Only adult male dolphinfish with high-rate satellite archival records > 3 days (n = 6) were included in analyses of vertical diving behavior; dolphinfish records not included in these analyses were standard rate transmitters, records < 3 days, and the only female. These archival records were excluded because PTT-100 standard rate transmitters vary markedly in resolution and preset monitoring period from PTT-100 high rate and high rate x-tags, any record less than three days in duration was not long enough to allow for a discernible diving pattern to emerge, and female and male dolphinfish appear to exhibit differences in diving behavior.

Table 2. Major conclusions from analysis of satellite monitored dolphinfish from the western north Atlantic and Caribbean Sea.

Diving Behavior Attribute	Major Conclusions
Maximum relative depth per dive	Highest percentage of deep dives conducted at night
Dive duration	The longest duration dives are conducted at night
Dive complexity	Dive complexity normally distributed during night
Diel patterns	Changes in light drives changes in dive complexity throughout the day

RESULTS

Of all 11 dolphinfish, the tracking duration (the time the PSAT remained attached to the dolphinfish) averaged 9.18 ± 9.43 d with a maximum tracking period of 30.24 days. We obtained 11 satellite tag release and endpoint locations from Argos for a total location dataset of 22 positions (Figure 1). Visually estimated and measured fork lengths (FL) for the dolphinfish in the study averaged 109.5 ± 2.50 cm. The archival records (102.76 days) were acquired over a six year period from 2005 until 2011 and represent 2,466.22 hours of dolphinfish movements in the water column. Average depth use from all depth fixes (n = 27,053) and all dolphinfish was 11.1 ± 22.77 m. Average depth occupancy between individual dolphinfish monitoring periods varied from 2.7 – 52.6 m. The mode for depth use below 10 m for all dolphinfish ranged from 10.8 – 44.4 m. Maximum diving depths ranged from 61.9 to 255.5 m.

For the 6 adult male dolphinfish, 1,096 (59.1%) dives were conducted within the surface layer (1.3 – 9.9 m), with 756 (40.8%) dives occurring deeper than 10 m. Dolphinfish spent the majority of their time in the surface layer (0-9.9 m; 1,339.9 hours; 66.8%) with the remaining time being spent below 10 m (663.1 hours; 33.2%). Of the 66.8% of time spent in the surface layer, 52.6% of that was spent at the top of the surface layer (0 m). More conclusions from these results can be seen in Table 2.

DISCUSSION

This study reports the vertical movements and habitat use of the dolphinfish as depicted through the use of pop-up satellite archival transmitter data (Table 2). Dolphinfish prefer shallow depths more than deeper depths but do make frequent vertical excursions to depths below 30 m and sometimes deeper than 200 m. Dolphinfish analyzed here spent the majority of their time at the surface presumably orienting themselves with surface objects, flotsum, or *Sargassum* (Hemphill 2005). When away from the top of the surface layer (0 m), dolphinfish were most often occupying depths within the surface layer and sub-surface to mid- shallow depths (10 – 59.9 m), and least often at mid-deep depths (60 – 89.9 m) or deep depths (> 90 m). These data are only representative of large male dolphinfish and are not representative of the vertical movements and habitat use of younger dolphinfish.

This study provides the first indication of different day and night time dolphinfish habitat use patterns. These patterns may be induced due to surface object fidelity during the day, feeding and/or foraging preferences, or due to variations in the position of the thermocline. Surface object fidelity has been observed for dolphinfish with maximum drifting fish aggregating device (DFAD) residency times of 14.9 days (Dajorn et al. 2007) and the ability to navigate back to a stationary fish aggregating device (SFAD) after being displaced away from the SFAD 1.6 km (Girard et al. 2006). These studies confirm daytime surface object fidelity and corroborate data analyzed in the present study that dolphinfish may be strongly tied to the surface due to the presence of surface objects. Analysis of gut contents in various studies have found that the majority of the daytime diet of dolphinfish consists of telelost fish presumably consumed near the surface under floating mats of sargassum or any other structure that promotes the aggregation of juvenile fish and invertebrates (Rothschild 1964, Massutí et al. 1998, Oxenford and Hunte 1999). Simultaneous presence of S*argassum* spp. and teleost prey items in the stomachs of sampled dolphinfish confirms the voracious feeding activity of dolphinfish and the importance of structure associated prey in their diet (Manooch et al. 1983)

Studies conducted in the Indian Ocean, central Pacific, Mediterranean Sea, and eastern Caribean all concluded that dolphinifish feed at night as well as during the day (Rothschild 1964, Massutí et al. 1998, Oxenford and Hunte 1999). Massutí et al. (1998) observed that dolphinfish stomachs sampled at sunrise contained mesopelagic prey items such as *Eledone moschata*, *Argyropelecus hemigymnus*, *Chauliodus sloani* and *Notolepis rissoi*. Samples of dolphinfish stomach contents taken in the Indian Ocean confirms a night time feeding pattern where partially digested flying fishes, myctophid fishes, and squids indicated that dolphinfish feed at all times of day (Shcherbachev 1973). However, across all studies, the greater proportion of epipelagic prey items indicates that dolphinfish forage mainly in surface and subsurface layers (0 – 30 m) but can make excursions to depths to feed opportunistically on mesopelagic fishes and invertebrates that take part in their diel vertical migration from depth during the day to the surface at night.

Further research on the movements and habitat use of dolphinfish is needed in order to empirically determine the periodicity of habitat use and diel movement patterns. To achieve this, more high-rate PSATs (< 30 day monitoring periods) should be deployed on dolphinfish in order to acquire more data to test statistically. In addition, in this study only PSAT records from large adult male dolphinfish were examined and are therefore un-representative of younger and smaller dolphinfish (< 8 – 10 months), and females. While there exist some data on movements of small dolphinfish relative to DFADs and SFADs (Dajorn *et al.* 2007, Girard et al. 2007), young of the year dolphinfish need to be tagged with high-rate PSATs if comparisons of habitat use between dolphinfish size classes are to be determined. In addition, large adult female dolphinfish need to be sampled in order to assess sex-specific differences in vertical movement strategies by time of day. Satellite tagging programs are expensive but necessary in order to define the movements, habitat use, and behavior of pelagic fish, including dolphinfish. Deploying both high-rate and standard-rate PSATs on male and female dolphinfish of small and large size classes will benefit both fishing and managerial interests.These data will enhance our understanding of dolphinfish habitat use in the open ocean and can lead to improved fishery resource allocation through better fishery management.

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