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Swordfish Vertical Distribution and Recreational Fishery in the Florida Straits

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SWORDFISH VERTICAL DISTRIBUTION AND RECREATIONAL FISHERY IN THE FLORIDA STRAITS

By

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This thesis is composed of two studies: (1) an assessment of the vertical habitat use of swordfish *Xiphias gladius* in the Florida Straits; and (2) a systematic description of the southeast Florida recreational swordfish fishery. First, the vertical distribution of swordfish (*Xiphias* gladius) was assessed in relation to diel cycles and lunar phase from data gathered utilizing popup satellite archival tags (PSATs). Seven tags were deployed in the Florida Straits during this study from recreational and commercial fishing vessels; two fish died shortly after deployment, and the remaining five were included in the analysis. Tags were deployed for periods ranging from 120 to 151 days and recorded data on temperature, depth, and light level every ten seconds. Transmitted data was summarized into one hour histograms. Swordfish vertical distribution in response to diel cycles was characterized by typically spending daytime hours below 500 m and nighttime hours in waters less than 75 m. Swordfish distribution differed significantly in response to lunar phase, with animals occupying successively deeper depths in response to increasing lunar illumination. This study is consistent with the widely accepted hypothesis that the swordfish vertical distribution is a function of ambient light levels. However, in contradiction to this hypothesis was the observation of a number of daytime

surfacing events recorded by the tags. This less pronounced but frequent behavior is hypothesized as a mechanism to warm the fish's body after extended daytime feeding dives to great depths. A recreational fishery targeting swordfish in southeast Florida has gained popularity in recent years. However, little data is currently available on the fishery and its participants. A survey was distributed to recreational swordfish anglers at local swordfish fishing club meetings and a swordfish fishing tournament to describe the fishery and its participants. Questions were organized into four sections: demographics, fishing habits, cost, and views on regulations. A total of 38 surveys were completed by anglers and included in the study. Recreational swordfish fishermen in southeast Florida were mainly Caucasian, with the largest group by percentage ranging from 41-50 years of age. Most fishers surveyed had over 20 years recreational fishing experience, with less than 10 years experience targeting swordfish. Anglers typically fished out of center console boats ranging from 21-35 feet, and usually made less than 50 trips per year. Costs associated with the fishery typically exceed those associated with general recreational saltwater fisheries by thousands of dollars (USFWS, 2006). Fishers were divided in their views on the current recreational swordfish regulations. Forty percent of anglers surveyed were unsatisfied, 37% were satisfied, and 23% remained neutral.

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CHAPTER 1: INTRODUCTION:

The Straits of Florida are an ideal location for a recreational fishery targeting swordfish. A narrow continental shelf with steep depth contours that occur relatively close to shore, as well as the close proximity of the Gulf Stream allows fishers easy access to swordfish feeding grounds, which are found close to the coast (Knauss, 1996; Prince et al., 2007). More importantly, the numerous canyons and seamounts present off the east coast of Florida cause upwelling, enhancing biological productivity and providing a fertile area for feeding, spawning and nursery activities (Taylor and Murphy, 1992; Fiechter and Mooers, 2003). Through catches by the recreational and commercial fisheries, swordfish are known to be present in the Florida Straits throughout the year, and the area is also believed to be an important spawning ground (Taylor and Murphy, 1992).

Recreational fisheries have targeted swordfish off the southeast coast of Florida since the late 1970's, with the world's first nighttime directed swordfish tournament-the Miami Swordfish Tournament-occurring in 1977 (Levesque and Kerstetter, 2007; NMFS, 2008). Recreational catches experienced a decline from 1977 to 1983, and no swordfish were caught during the last tournament held in 1983 (Levesque and Kerstetter, 2007). This trend was concurrent with a decrease in swordfish abundance and increase in commercial fishing effort (Levesque and Kerstetter, 2007).

In 1999, ICCAT implemented a ten-year rebuilding plan for Atlantic swordfish that included a reduction in the North Atlantic total allowable catch (TAC; NMFS, 2008). In addition, NMFS instituted a series of time-area closures for pelagic longline gear in federal waters of the Gulf of Mexico and southeastern United States, including the

Florida Straits (NMFS, 2008). Subsequently, recreational fishing for swordfish, including tournaments resumed in 2001, and the fishery expanded rapidly in subsequent years due to an increase in catch rates (Levesque and Kerstetter, 2007). Currently, southeast Florida is home to the largest group of recreational swordfish fishermen in the world and is also home to the Southeast Swordfish Club (Skip Smith, pers. comm.).

Although the traditional sport fishery has taken place at night, more recently a daytime fishery has developed that targets the fish when they are at great depths (Skip Smith, pers. comm.). Fishers raised questions about the effects of diel and lunar on the vertical distribution of the swordfish in the Florida straits. Electronic tagging techniques developed over the past decade using popup satellite archival tags (PSAT's) have been successfully utilized to examine the vertical distribution of many species of pelagic fishes (Block et al., 1998; Block et al., 2001; Musyl et al., 2003; Sedberry and Loefer, 2001; Dewar and Polovina, 2005; Goodyear et al., 2008). Such studies on swordfish have indicated a general, negative phototaxic response, which appeared also to be the case in the Straits of Florida.

Easy access to the swordfish fishing grounds, increased catch rates, the formation of recreational fishing clubs, and a large group of dedicated swordfish anglers presented an ideal opportunity to study recreational fisheries targeting swordfish and swordfish vertical distribution. This thesis is composed of two studies: (Chapter 2) an assessment of vertical habitat utilization of swordfish in the Florida Straits monitored with popup satellite archival technology; and (Chapter 3) a systematic socioeconomic survey of the southeast Florida swordfish fishery. Chapter 4 contextualizes the major results of both studies and provides recommendations for future research. Chapter 2 specifically focuses on testing hypotheses related to the vertical distribution of swordfish in relation to diel cycles and lunar phase, and Chapter 3 focuses on the description of the recreational fishery.

CHAPTER 2: PATTERNS OF VERTICAL MOVEMENT IN SWORDFISH (*Xiphias gladius*) IN THE WESTERN NORTH ATLANTIC

BACKGROUND:

The swordfish (*Xiphias gladius*, Linnaeus, 1758) is a large apex predator with a global distribution in the tropical and temperate oceanic waters of the Atlantic, Pacific, and Indian Oceans (Sedberry and Loefer, 2001). They are found across a wide range of temperatures, with daily temperature ranges between 10°C and 28°C and inhabiting depths from surface waters down to 1,500 m or greater (Sedberry and Loefer, 2001; Dewar and Polovina, 2005). Swordfish are defined as a highly migratory species (HMS) by the Magnuson-Stevens Act, and previous tagging studies have demonstrated that these fish are able to undertake large-scale migrations of over 3,000 km throughout ocean basins (Carey and Robison, 1981; Sedberry and Loefer, 2001; NMFS, 2006).

Swordfish are commercially exploited worldwide. The U.S. Atlantic commercial fishery was historically prosecuted with harpoons and small vessels in the waters from New England to New York, but larger vessels utilizing pelagic longline gear have constituted a vast majority of catches in recent decades (NMFS, 2008). In the Atlantic Ocean, swordfish are managed under the jurisdiction of the International Commission for the Conservation of Atlantic Tunas (ICCAT), headquartered in Madrid, Spain. In the United States, swordfish are managed by the National Marine Fisheries Service (NMFS) under the authority of Magnuson-Stevens Act and the Atlantic Tunas Convention Act (ATCA; NMFS, 2008).

Stock assessments in the late 1970's and 1980's showed swordfish stocks to be overexploited (ICCAT, 1995). In 1999, ICCAT implemented a ten-year rebuilding plan for Atlantic swordfish, which included a reduction in the North Atlantic total allowable catch (TAC, NMFS, 2008). As part of a swordfish rebuilding plan, NMFS also acted to protect juvenile swordfish populations by instituting a series of time-area closures for pelagic longline gear in federal waters of the Gulf of Mexico and southeastern United States (see map of closures in NMFS, 2008). Recent ICCAT assessments (2006) of North Atlantic swordfish have found the stock status to be near recovery, with a relative a biomass (B2006/BMSY) of 0.99 (0.87 – 1.27) (MSY, ICCAT, 2008). Improvements in biomass have been attributed to strong recruitment during the late 1990's coupled with reductions in catch (ICCAT, 2008).

Swordfish have been targeted by recreational anglers off the southeast Florida coast since the 1970's (Levesque and Kerstetter, 2007; NMFS, 2008). However, effort declined in the early 1980's in response to decreased catch rates (Levesque and Kerstetter, 2007). Recreational fisheries targeting swordfish have been expanding, and a recreational swordfish fishery off the southeast Florida coast has experienced a rebirth in recent years (Levesque and Kerstetter, 2007; NMFS, 2008). The domestic management of swordfish includes a recreational component; however, relatively little attention has been paid to this recent fishery (NMFS, 2007; Levesque and Kerstetter, 2007). Additionally, while popup satellite tagging studies on swordfish have been conducted in other oceanic areas, there has been little work done on the behaviors of swordfish in the Florida Straits.

The Straits of Florida are ideal for the development of a sport fishery for swordfish. The Straits are characterized by a narrow continental shelf, with steep depth contours that occur relatively close to shore (Prince et al., 2007). In addition, the Gulf Stream, with current velocities that often approach five knots and extend from the surface to the bottom, is found in close proximity to the southeast Florida coast (Knauss, 1996). Numerous canyons and seamounts found off the east coast of Florida cause upwelling, which enhances biological productivity and provides a fertile area for feeding, spawning and nursery activities (Fiechter and Mooers, 2003). Previous studies have suggested that the Florida Straits and nearby waters are an important spawning ground for Northwest Atlantic swordfish (Taylor and Murphy, 1992). The combination of these unique oceanographic features allows fishers easy access to swordfish feeding grounds, which lie a short distance from the coast. This environment differs from most other areas where swordfish are targeted along the U.S. east coast and Gulf of Mexico, which generally occur much further offshore due to a broader continental shelf (Knauss, 1996; Sedberry and Loefer, 2001; Fiechter and Mooers, 2003).

Previous studies utilizing electronic tagging techniques have provided evidence that swordfish in both the Atlantic and the Pacific Oceans make vertical migrations on a regular basis (Carey and Robison, 1981; Sedberry and Loefer, 2001; Dewar and Polovina, 2005). A study by Carey and Robison (1981) utilizing acoustic telemetry found swordfish followed a diel pattern of deep waters during hours of daylight and surface waters at night. However, acoustic telemetry requires tracking the fish on the open seas and can only be utilized to monitor fish behavior for relatively short periods of time (i.e., hours or days; Carey and Robison, 1981).

The advent of new electronic tagging technologies (i.e., popup satellite archival tags) has allowed a fishery-independent means for data retrieval that allows monitoring for weeks and months of behavior and habitat use of HMS over longer durations (Block et al., 1998; Prince and Goodyear, 2006). Popup satellite tagging technology has been used to successfully track the vertical movements of many HMS species, including swordfish (Sedberry and Loefer, 2001; Dewar and Polovina, 2005), Atlantic blue marlin (*Makaira nigricans*; Goodyear et al., 2008), bigeye tuna (*Thunnus obesus;* Musyl et al., 2003) and Atlantic bluefin tuna (*Thunnus thynnus*; Block et al., 2001). Knowledge of vertical distribution patterns in pelagic fish and subsequent habitat use is vital to the conduct of accurate stock assessments, and has significant implications in the management of Atlantic swordfish (Prince and Goodyear, 2006; Goodyear et al., 2008).

Previous popup satellite tagging studies conducted on swordfish have found differences in diel vertical distributions in the Atlantic and Pacific Oceans as well as the Mediterranean Sea (Sedberry and Loefer, 2001; Dewar et al., 2006; Canese et al., 2008). Additionally, previous studies of both longline CPUE and electronic tagging have also suggested a link between swordfish behavior and lunar phase (Carey and Robison, 1981; Santos and Garcia, 2005; Loefer et al., 2007).

Given the unique environment of the Florida Straits that permits easy access for recreational exploitation of the swordfish resource and the paucity of data on swordfish movements in this river-like environment, the objective of this study was to evaluate the vertical habitat use of swordfish in the Straits of Florida relative to diel cycles and lunar illumination. In this chapter, I will present the satellite tagging results on several swordfish that were tagged in the Florida Straits. Hypotheses tested were:

H_{O1}. There are no diel differences in the vertical distribution of swordfish

H_{A1}. There are diel differences in the vertical distribution of swordfish

H_{O2}. There are no differences in the vertical distribution of swordfish during different lunar illumination intervals.

$H_{A2.}$ There are differences in the vertical distribution of swordfish during different lunar illumination intervals.

MATERIALS AND METHODS:

Tagging Operations:

Swordfish were tagged from September to December 2007 about 10-25 miles offshore of the southeast Florida coast. A total of five tagging excursions took place out of the cities of Fort Lauderdale (n=1), Lighthouse Point (n=1), and Stuart, Florida (n=3). Tags were deployed during both nighttime hours (n=6) and daytime hours (n=1), aboard recreational fishing vessels (FV *Y Knot* and the FV *Skirt Chaser*) and a commercial buoy gear vessel (FV *Blue Baron*). The buoy gear fishery involves the use of free floating buoys attached to a leader with no more than two hooks (NMFS, 2006). Swordfish were captured using standard fishing techniques for the recreational nighttime and daytime swordfish fishery as well as techniques standard to the commercial swordfish buoy gear fishery (NMFS, 2006). Baits used for swordfish included squid (*Illex* sp.), "tinker" mackerel (*Scomber* sp.), and little tunny (*Euthynnus alletteratus*). Swordfish were caught at night on rod-and-reel and buoy gear near the surface and during the day by dropping baits to the bottom with an electric reel. The hooks used while recreational fishing for swordfish were size 11/0 J hooks, while hooks used during the buoy gear operations were size 14/0 and size 16/0 non-offset Lindgren-Pitman circle hooks (Lindgren-Pitman, Inc., Pompano Beach, FL). When possible, the use of circle hooks was preferred to reduce the chance of severe hook related trauma to the fish. The tag deployment locations were obtained from the vessel's onboard global positioning system (GPS).

Tags:

The popup satellite archival tag technology used in this study was the MK10-PAT tag manufactured by Wildlife Computers (Redmond, WA USA). The tags are made up of a tube with a diameter of 21mm that houses the electrical components. At one end of the tube is a float measuring 40mm in diameter at its maximum width. Tags are 175mm long (excluding the antenna) with a weight of 75g in air.

PAT tags record pressure (depth), light level, and temperature data points at user-defined intervals and remain attached to a fish for a period of time determined by the researcher. Light level is measured as iridescence at a wavelength of 550nm, and the tags can measure light concentrations from 5×10^{-12} $W.cm^{-2}$ to 5×10^{-2} $W.cm^{-2}$ in logarithmic units (Wildlife Computers, Redmond, WA, USA). Depth is measured from 0 m to 1000 m with a resolution of 0.5 m. While the tags are verified to withstand pressures equivalent to depths of 2,000 m, the MK-10 PAT tags possess a pressure activated mechanical guillotine called an RD1800 that will sever the monofilament attaching the tag to the anchor in the event that the tag surpasses 1,800 m (RD1800; Wildlife Computers, Redmond, WA). This prevents the tag from being crushed and the subsequent loss of data. Temperature is recorded from -40 degrees Celsius to +60 degrees Celsius with a resolution of 0.05 degrees Celsius.

The MK-10 PAT tag is the first PAT tag model to incorporate the "Cricket," a type of ARGOS transmitter. This feature allows the tag to effectively transmit data even while dry. The power output is 0.5W, and the transmitter is able to receive messages of the highest quality and quantity through its high-efficiency and frequency-stability.

Tags were rigged using a piece of 400lb test monofilament fluorocarbon leader as a tether attached to double barb nylon tag anchors and to a wire pin in the anterior end of the tag (Prince and Goodyear, 2006; Eric D. Prince, pers comm.). Monitoring durations were programmed for 120 to 151 days to gather data on swordfish behavior over consecutive diel cycles and several lunar cycles. To prevent the loss of data, tags were also programmed to detach from the animal if it remained at the same depth (plus or minus 1.5 m) for a period of 24 hours. This was assumed to be a mortality event. Tags were programmed to record temperature, depth, and light data at 10 second intervals, with transmitted depth and temperature data summarized into 1 hour histograms. Temperature data was organized into fourteen bins starting with 6^{o}C, and continuing with intervals of 2^{o}C up to 30^{o}C, with a final bin of >30^{o}C. Depth data was similarly organized into fourteen bins, beginning with 25 m and continuing with a resolution of 25 m to 100 m; then with a resolution of 100 m until reaching 1000 m, with a final bin of >1000 m.

Tagging Procedures:

All tagging activites were conducted on swordfish while in the water. Fish that were initially determined to be of sufficient size (>100 cm) for tagging were secured with a "snooter", which is similar to a wire snare. The "snooter" is comprised of a polyvinyl chloride (PVC) pipe with a rope running through the center (Prince et al., 2002). The rope then connects to a multi-strand stainless-steel cable to form a loop at the terminal end. The snare end of the snooter was then placed over the upper bill of the swordfish and tightened to secure the animal alongside the boat while keeping its head under water for precise and accurate tag placement as well as for the safety of the fish, crew, and vessel (Prince et al., 2002).

Once the swordfish was secured alongside the vessel, it was visually assessed to determine if it was healthy enough to be tagged. Factors crucial to the decision to tag a fish were the location of the hook and the length of the fight time. Previous tagging studies have shown that the location of the hook and the length of fight time are critical to the survival of released fish (Horodysky and Graves, 2004; Prince et al., 2007). Swordfish caught during this study were assessed according to color and overall condition. Fish that appeared bright in color and were active were considered good candidates to tag. To aid in proper tag placement, a small hook tool described by Prince et al. (2006) was used to manipulate the fish at boat side during tagging procedures. Swordfish were tagged in the musculature below the first dorsal fin, with the tag anchor being inserted between the pterygiophores (spine roots) along the back of the fish to maximize tag retention (Sedberry and Loefer, 2001; Musyl et al., 2003; Prince and Goodyear, 2006). Each fish was also tagged with a conventional streamer tag in the dorsal musculature posterior the PAT tag using standard tagging procedures (Prince et al., 2002).

Lower jaw fork length (LJFL) measurements were then obtained using a measuring tape (to the nearest cm), and the fish’s weight was estimated by the crew.

Low gunnels on the sport fishing vessels allowed for the use of a 1.75m tag stick for the deployment of PAT tags. After the fish was tagged and measurement data was obtained, the hook was removed and the swordfish was then carefully resuscitated and released using the procedures described by Prince et al. (2002).

Data Analysis:

The resulting PAT data set was processed using software **(**WC-AMP 1.02.0007 and WC-GPE 1.02.0005**)** provided by Wildlife Computers. Diel cycles were defined as the daily cycles including daylight hours, crepuscular hours, and nighttime hours. The fraction of the moon illumination was used as a proxy for the level of moonlight. Data on the fraction of the moon illumination level, moonrise/moonset, and sunrise/sunset were obtained from the U. S. Naval observatory website (http://aa.usno.navy.mil). Sunrise/sunset and moonrise/moonset times were calculated in UTC at the coordinates W79 degrees 43 minutes by N26 degrees 54 minutes, which corresponds to an area in the Florida Straits close to where the swordfish were tagged and was a known location of the fish. These coordinates were used because tags only record light level data during infrequent daytime surfacing events. Therefore, the only location data available for each fish is the location where it is tagged, and where the tag "pops up" at the end of the predetermined deployment period.

To analyze the differences in distribution in reference to diel cycles, data was used from the time at depth data set, which measured the percentage of the hourly summary period the swordfish spent in each of the 14 pre-defined depth bins. Hour periods were separated into daytime, crepuscular, and nighttime hours. Crepuscular hours were defined as the hour summary period containing sunrise or sunset. Data from each tag was filtered to include days with six or more hour-long summary periods. Once the days with six or more hour bins were isolated, the data was then sorted by hour. The percent of time the swordfish spent in each of the fourteen depth bins was averaged for each hour summary period, and this data was organized and plotted in a matrix with hours as the independent variable (x) and depth in meters as the dependent variable (y). The percent of time spent in each of the 14 depth bins was multiplied by 60 to transform percentage data into minutes, and the corresponding values were rounded to the nearest whole minute. Cells were shaded for time periods until 30 minutes or more of the hour was reached. Shading was used to distinguish hours at the surface and hours distributed at depth. Tags that showed similar distributions were pooled and the resulting data sets were plotted.

In addition, a power spectral density analysis was performed on the data set to test for significant differences in diel distributions and to determine the dominant period in the time series of average depth utilizing techniques outlined by Press et al. (1986). The average depth was calculated for each hour summary period from the PDT measurements. Since there are records missing throughout the data, Press and Teukolsky's (1986) algorithm for unevenly spaced data was used. The resulting data was subsequently plotted with frequency (in units of cycles per day) as the independent variable and power density as the dependent variable.

The PDT data set was utilized to test for differences in vertical distribution in relation to periods of lunar illumination. Using sunrise and sunset times as well as moonrise and moonset times, the data was filtered to only include hour summaries which

Tag	Date Tagged	Length (LJFL) in cm	Deployment Duration (in days)	Days at Large (DAL)	Tagging Location	Popup Location	Net Displacement (km)
2007_01	**10/22/2007**	**132**	**120**	**57**	**27^{o}09'19.73" 79^{o}44'24"**	**26^{o}55'48" 76^{o}59'24"**	**274**
2007_02	**10/22/2007**	**150**	**120**	**116**	**27^{o}15'12.6" 79^{o}45'36"**	**12^{o}37'48" 70^{o}38'24"**	**1,976**
2007_03	**10/21/2007**	**173**	**130**	**132**	**26^{o}54'39.06" 79^{o}43'48"**	**26^{o}51'00" 76^{o}36'36"**	**350**
2007_04	**10/4/2007**	**109**	**120**	**103**	**27^{o}02'35.5" 79^{o}44'24"**	**21^{o}4'48" 70^{o}35'24"**	**1,165**
2007_05	**11/16/2007**	**249**	**120**	**2 (died)**	**27^{o}00'00" 79^{o}42'36"**	**30^{o}09'00" 79^{o}48'00"**	**344**
2007_06	**9/1/2007**	**140**	**140**	**died**	**n/a**	**n/a**	**n/a**
2007_07	**12/1/2007**	**183**	**151**	**133**	**25^{o}54'21.5" 79^{o}48'00"**	**19^{o}49'12" 81^{o}34'48"**	**1,226**

Table 2.1: Summary data gathered on the seven swordfish tagged in the Florida Straits during this study. LJFL indicates the lower jaw to fork length measurements of the swordfish.

occurred during nighttime hours when the moon was present. Hour summaries that included moonrise and moonset were excluded, and only data in which lunar illumination was present for the entire hourly period were included. However, due to uncertainties in the horizontal movements of the swordfish, percent cloud cover could not be factored in to the lunar analysis.

Data were then filtered to include nights with at least two hour summaries and at least six PDT data points. The fraction of the moon illuminated was determined for each night. Plots were created for each tag with depth as the dependent variable and the fraction of the moon illuminated as the independent variable. These plots were compared across tags, and tags with similar data were pooled to create a more robust data set.

The fraction of the moon illuminated was divided into a fine scale with intervals of 2 percent of the monthly illumination to increase the resolution of the data set. The illumination scale ranged from 0 to 100 percent illumination. The amount of PDT data points was calculated for each lunar illumination interval, and intervals with less than 30 PDT data points were subsequently excluded from the analysis. PDT data points were sorted and arranged from the shallowest depth to the deepest depth for each lunar illumination interval. The deepest depth of the shallowest 50% of depth files per interval was then selected. This process was repeated for all lunar illumination intervals. The selected depth points were then plotted against lunar illumination. A linear regression was performed on the resulting data set and an r^2 value as well as the statistical significance was then determined.

Data on surfacing behavior were determined from both the time at depth data and the PDT depth data. Surfacing events were defined in the time at depth data set as daytime hours in which the fish entered the 0-25 m depth bin, and as a minimum depth recording of 0 m during daytime hours in the PDT data set. When the same hourly summary for the same date was present in both the time at depth data and the PDT data, it was considered to be one surfacing event.

RESULTS:

A total of seven swordfish ranging in size from about 109 cm to 249 cm lower jaw fork length (LJFL) were tagged with pop-up satellite archival tags between September 1, 2007 and December 1, 2007 off the southeast coast of Florida (Table 2.1). Out of the seven swordfish tagged, two fish died within 52 hours of release. Data from these tags were omitted from analysis due to the fact that data obtained from the short deployment periods were not sufficient to address the hypothesis of this study. Of the five remaining tags, four tags released early (57 days out of a 120 day deployment (57/120 days), 116/120 days, 133/151 days, 103/120 days) and one tag released two days after the scheduled pop up date (132/130 days). A total of 474 monitoring days of data were transmitted from all the tags out of 541 days the five fish spent at large (87%).

Horizontal Movement

Horizontal displacements varied, with movements of three fish exceeding 1,000 km. Two of the swordfish fish moved east of the tagging location to the area off Green Turtle Cay in the Bahamas, traveling a straight line distance of 274 km and 350 km, respectively. One fish travelled southeast to the area around the Turks and Caicos

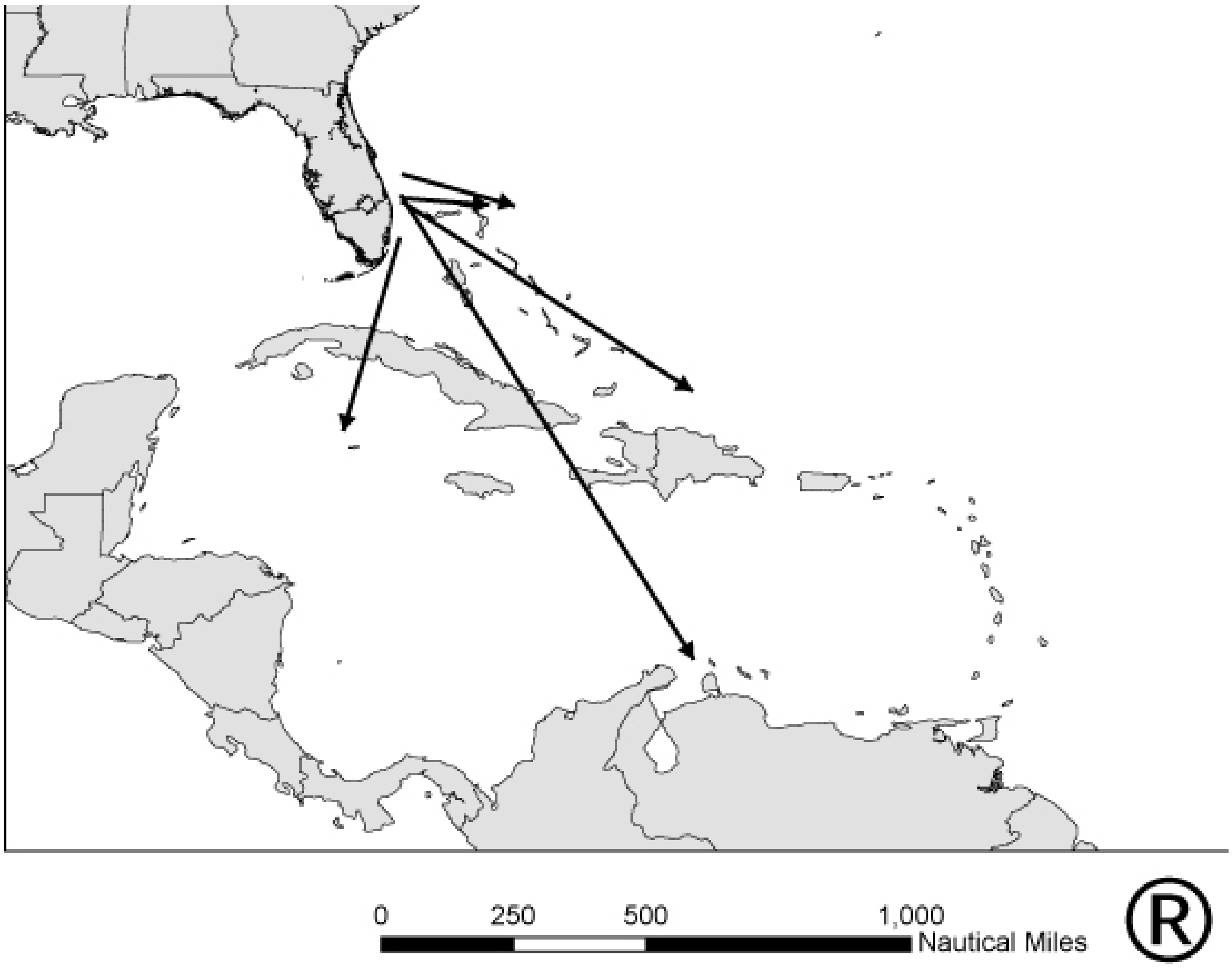

Fig. 2.1 Net displacement of swordfish tagged with pop-up satellite archival (PAT) tags. Arrows range from tagging location to the pop-up location of the tags at the end of the deployment period.

Islands, a straight line distance of 1,165 km. Another fish travelled southwest to the waters off Aruba, a straight line distance of 1,976 km. The last fish moved southwest 1,226 km to the waters off the Cayman Islands (Fig. 2.1).

Vertical distributions

Swordfish tagged during this study demonstrated a distinct pattern of vertical distribution in relation to diel cycles. Plots of the power distribution for all tagged fish as a function of frequency (one sinusoidal cycle/day) show a distinct peak at a frequency of one, which indicates one day as the dominant behavioral cycle (Fig. 2.2). The mode of the daily cycle is one to two magnitudes greater in value than the other modes in the plotted values. Significance values obtained (for SWO_01, SWO_02, SWO_03, SWO_04, and SWO_07) were all significant at $P < 0.01$. These values indicate the probability of getting such a peak if the average depths were randomly distributed. Thus, the depth distribution of the swordfish differs between day and night and is dominated by the diel cycle.

Swordfish distributions were characterized by the animal remaining in surface waters less than 75 m during nighttime hours. Daytime hours were usually spent below 500 m. Movements between the surface and depth were typically undertaken during crepuscular periods. These patterns of diel vertical migration were similar across all five tags deployed during this study. Tags SWO_01- SWO_04 showed similar patterns of behavior in respect to diel cycles during all hourly summaries (Fig. 2.3a). The data from these tags was subsequently pooled to create a more robust data set. However, one tag (SWO_07) differed from the four other tags deployed during the study in regards to the

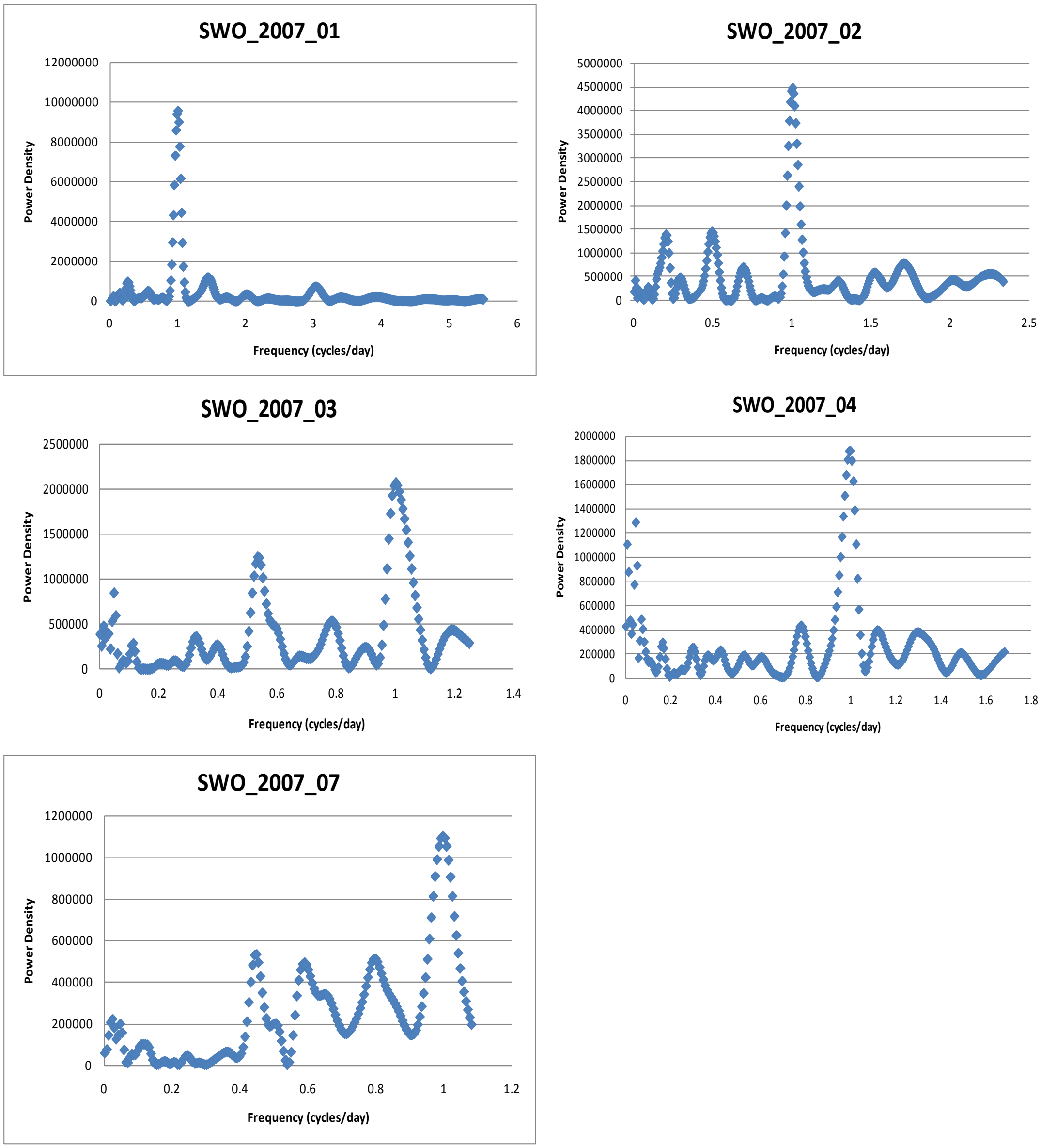

Fig. 2.2 *Xiphias gladius.* Plots generated from the spectral density analysis. The peak found at one indicates that the dominant period is one day.

depths visited during the 23:00 Universal Time (UTC) hour summary period (Fig. 2.3b). Thus, the data from Tag 7 was not pooled.

Pooled data from SWO_01-SWO_04 revealed that during the nighttime hours of 0:00-10:00 UTC, swordfish spent most of their time (66%) in the upper 75 m of the water column. Additionally, the vast majority of the time (96%) between the hours of 0:00-10:00 UTC was spent at 200 m or less. Swordfish began their descent to depth during 11:00 and 12:00 UTC, which corresponded to the crepuscular hour summary containing sunrise, depending on the month. During daytime hours (13:00-21:00 UTC), the fish spent most of their time (92%) from 500 to 800 m. Swordfish ascended to the surface during the hours of 22:00 and 23:00 UTC, which usually corresponded to the crepuscular hour containing sunset and the first hour of darkness.

Data from SWO_07 showed the same diel vertical migration patterns and similar distributions of the other 4 fish. This swordfish spent 69% of nighttime hours 0:00-10:00 UTC) in waters of 75 m or less, and nearly all of nighttime hours (98%) at 200 m or less. As the other tagged fish, it spent the majority (91%) of the daytime hours (13:00-21:00 UTC) in deeper water (between 500 and 800 m). SWO_07 also recorded the deepest dives of all five tags. On February 15, 2008 this swordfish spent 44% and 73% of hours 18:00 and 19:00 UTC respectively in waters > 1000 m, with a maximum recorded depth of 1,448 m

All five of the swordfish tagged during the study demonstrated similar patterns of increasing depth with increasing lunar illumination (Fig. 2.4). A linear regression was fitted to the deepest depth points of the shallowest 50% of the PDT depth files for each

DEPTH (m)	HOUR (UTC) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
25	20	21	20	16	15	17	15	14	15	16	9	0	0	0	0	0	0	0	1	0	0	1	0	16
50	16	17	13	12	11	11	13	12	15	13	12	0	0	0	0	0	0	0	0	0	0	0	0	9
75	9	9	10	12	12	10	11	11	8	11	12	2	0	0	0	0	0	0	0	0	0	0	1	13
100	7	4	7	9	8	7	7	7	7	7	6	1	0	0	0	0	0	0	0	0	0	0	1	8
200	7	8	8	9	11	11	13	15	13	12	14	6	0	0	0	0	0	0	0	0	0	0	5	10
300	1	2	2	2	3	3	1	1	2	1	5	10	1	1	0	0	0	1	1	1	1	1	8	3
400	0	0	0	0	0	0	0	0	0	0	2	15	9	5	4	2	3	4	5	4	1	4	13	1
500	0	0	0	0	0	0	0	0	0	0	0	14	15	17	9	10	9	7	8	6	7	10	14	0
600	0	0	0	0	0	0	0	0	0	0	0	8	14	9	13	7	9	8	8	11	10	14	15	0
700	0	0	0	0	0	0	0	0	0	0	0	5	20	23	19	20	16	14	15	21	29	26	4	0
800	0	0	0	0	0	0	0	0	0	0	0	0	2	7	15	19	21	25	21	16	12	3	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 2.3a Pooled data from Tags 2007_01, 2007_02, 2007_03 and 2007_04. Values indicate the number of minutes the swordfish spent in each depth bin. The number of minutes the swordfish spent in each depth bin was averaged for each individual fish, then the data was pooled and the hours were averaged across tags. Values were shaded until 30 minutes or more of each hour was reached. Shading began at the surface during nighttime hours and at depth when the fish was deep in the water column. Hours are in universal time (UTC).

DEPTH (m)	HOUR (UTC) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
25	32	37	30	28	20	33	34	20	24	19	13	2	0	0	0	0	0	2	1	0	0	2	0	3
50	1	4	9	9	11	5	9	12	9	8	14	1	0	0	0	0	0	0	0	0	0	0	0	1
75	10	4	9	3	5	2	4	6	10	10	11	3	0	0	0	0	0	0	0	0	0	1	0	1
100	3	7	6	6	4	4	4	8	5	3	7	1	0	0	0	0	0	0	0	0	1	1	0	6
200	10	6	6	14	19	15	9	13	12	20	13	20	0	0	0	0	0	0	0	0	0	1	2	5
300	4	0	0	0	0	1	0	1	0	0	2	17	3	0	0	0	0	1	0	0	0	4	9	11
400	1	0	0	0	0	0	0	0	0	0	0	7	28	7	1	0	0	1	0	0	2	7	17	8
500	0	1	0	0	0	0	0	0	0	0	0	6	17	20	32	26	12	10	11	12	23	21	33	16
600	0	0	0	0	0	0	0	0	0	0	0	2	12	22	15	17	27	32	26	22	23	15	0	3
700	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	12	17	13	13	10	11	9	0	2
800	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	3	4	0	2	12	0	0	0	4
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	3	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 2.3b Data from Tag 2007_07. This tag was not pooled due to differences in distribution regarding hour 23. The number of minutes the swordfish spent in each depth bin was averaged for each individual fish, then the data was pooled and the hours were averaged across tags. Values were shaded until 30 minutes or more of each hour was reached. Shading began at the surface during nighttime hours and at depth when the fish was deep in the water column. Hours are in universal time (UTC).

lunar illumination interval (Fig. 2.5). The regression between depth and the fraction of the moon illuminated was highly significant (r^2= 0.61; $P < 0.0001$).

Surfacing Behavior

All five tagged fish demonstrated daytime surfacing behavior during deployment periods, which took place over late fall, winter, and early spring. The five tagged fish provided a total of 42 daytime surfacing events gathered from both the time at depth data as well as the PDT data. The two largest fish in the study (173 and 183 cm) had the most recorded surfacing events (n=17), with the remaining fish (109 and 132 cm) recording three surfacing events and one fish (150 cm LJFL) recording two surfacing events. In addition, swordfish also frequently surfaced during nighttime hours.

<u>DISCUSSION:</u>

Horizontal Movement

These findings are consistent with the literature on horizontal movements by swordfish, which are known to undertake movements on the order of thousands of kilometers on an annual basis (NMFS, 2006). In a tagging study of both juvenile and adult swordfish off the Charleston Bump, Sedberry and Loefer (2001) reported the net displacement of tagged swordfish ranged from 11 km to 3,053.2 km over 30, 60, and 90 day deployments. The authors found no correlation with the size of swordfish and distance travelled (Sedberry and Loefer, 2001). Horizontal movements documented during this study were variable and ranged from 274 km to 1,976 km.

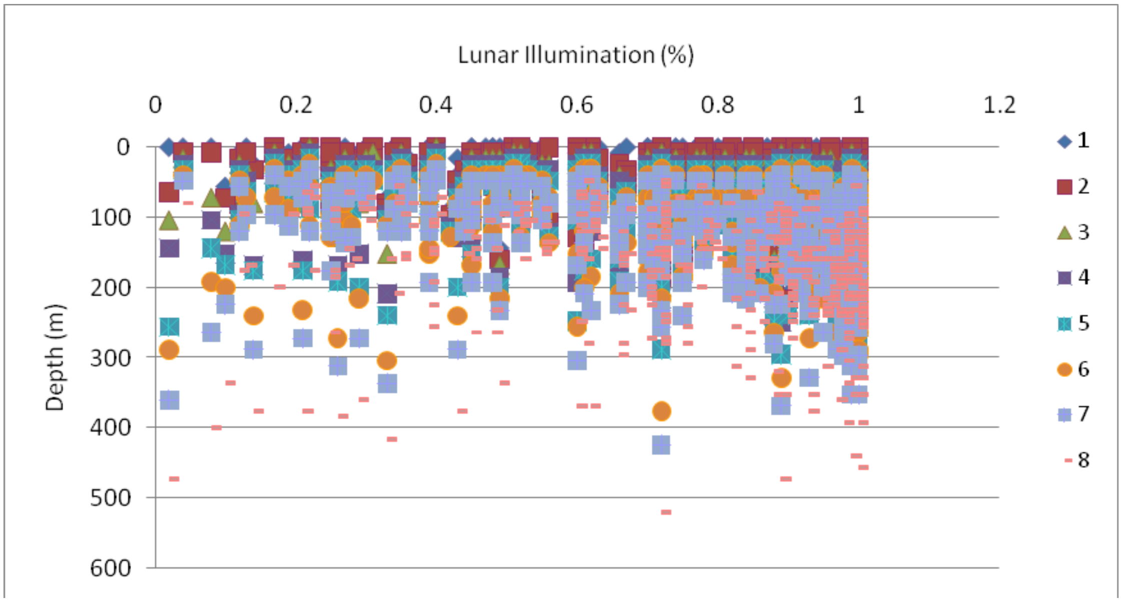

Fig. 2.4 Pooled data plotting depth (m) against the percentage of the moon illuminated from tags SWO_01, SWO_02, SWO_03, SWO_04, and SWO_07. Points indicate the order of the PDT depth readings, with 1 being the minimum depth and 8 indicating the maximum depth recorded over the particular hourly summary period.

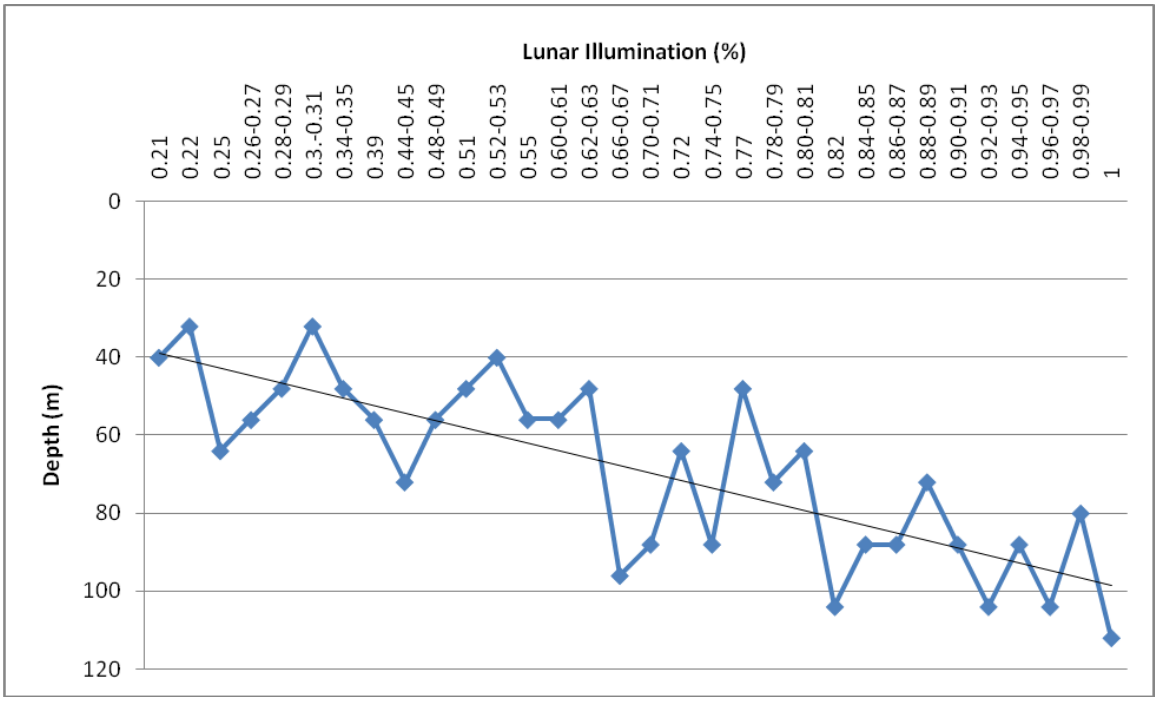

Fig. 2.5 Deepest depth points of the shallowest 50% of depth files were plotted for each lunar illumination interval. A linear regression was performed on the plotted data points with a significant r^2 value of 0.61 ($P < 0.0001$).

None of the swordfish with PSATs deployed in the Florida Straits remained residents to the area of release for the respective deployment periods of the tags. Additionally, all swordfish during this study travelled outside the Exclusive Economic Zone (EEZ) of the United States in a southerly direction.

Vertical distribution

This study's findings are consistent with the literature on vertical movements by swordfish. Specifically, vertical movements consisted of a relative change in depth between day and night, the relative change in depth at night with increasing moonlight, and the relative change in depth in the daylight. Although there was some variability, the trends in diel vertical movement patterns for all fish monitored in this study were consistent. In other words, swordfish monitored in the Florida Straits are low light preference species, as has been reported by others and confirmed in this study.

Diel Cycles

Observations of swordfish monitored during this study revealed regular vertical movements in response to diel cycles. Diel vertical movement patterns were characterized by descents to between 500 m and 800 m during daylight hours and ascents to less than 200 m at night; frequently spending nighttime hours at depths less than 75 m. Swordfish also demonstrated a significant relationship between nightly depths and the fraction of moon illuminated, showing a pattern of increasing nightly depths in response to increasing lunar illumination, which is negative phototaxis. Vertical movements did not change with the horizontal movement of the tagged fish; however, no tags were deployed during summer months.

Diel vertical movement patterns observed during this study were consistent with the results of previous electronic tagging studies of swordfish (Carey and Robison, 1981; Sedberry and Loefer, 2001; Canese et al., 2007). Carey and Robison (1981) reported diel vertical migration patterns of swordfish monitored using acoustic telemetry, with fish rising to surface waters at night followed by a return to deeper waters during daytime hours. Swordfish in the Pacific typically occupied shallower depths than fish monitored during this study in the Florida Straits. This may be due to habitat compression caused by hypoxic water underlying the thermocline or colder water temperatures present at shallower depths in the eastern Pacific (Carey and Robison, 1981; Prince and Goodyear, 2006). Previous popup satellite archival tagging studies in the Atlantic and Mediterranean Sea have also reported diel vertical movement patterns characterized by a descent to deep waters during the day followed by an ascent to surface waters during nocturnal periods (Carey and Robison, 1981; Sedberry and Loefer, 2001; Takashi et al., 2003; Canese et al., 2007).

Lunar Cycles

The relationship between swordfish behavior and lunar cycle has been suggested in past studies (Carey and Robison, 1981; Moreno et al., 1990; Santos and Garcia, 2005; Loefer et al., 2007). Studies of the catch per unit effort (CPUE) of swordfish in longline fisheries have been used to assess differences in catch in response to lunar phase. However, the results of these studies have provided conflicting reports on the influence of the lunar cycle on CPUE of swordfish (Moreno et al., 1990; Santos and Garcia, 2005). Santos and Garcia (2005) studied variation of swordfish CPUE in the Portuguese longline fishery and concluded that moon phase had a significant effect on swordfish catch rates, with the greatest CPUE occurring during the brightest moon. However, Moreno et al. (1990) reported no correlation between moon phase and the catchability of swordfish with longline gear in Cuban waters. Discrepancies in CPUE analysis are expected because the CPUE index is a function of the fisher's behavior as well as the fish's. Both behaviors are highly dynamic covariates and as such are highly influenced by gear type and deployment (Thomas, 1991)

Past electronic tagging studies have also observed swordfish movements in relation to lunar illumination (Carey and Robson, 1981; Loefer et al., 2007). Carey and Robison (1981), who monitored tagged swordfish for short periods of time using acoustic telemetry, concluded that the swordfish in the study responded to moon light by increasing depth. However, the authors mention that other factors (i.e., wind) may have also influenced behavior. In addition, limitations of acoustic telemetry only allowed fish to be monitored for brief periods of less than one lunar cycle (Carey and Robison, 1981; Loefer et al., 2007). Thus, caution should be used in interpreting this relationship based on data from less than one lunar cycle. A recent popup satellite archival tagging study on swordfish in the northwest Atlantic undertaken by Loefer et al. (2007) found a pattern of increasing depth in relation to increasing lunar illumination, regardless of the horizontal displacement of tagged fish. Vertical movements in response to lunar illumination observed during this study were consistent with the results of Carey and Robson (1981) and Loefer et al. (2007).

Adaptations for Low-Light Preference

Numerous authors have hypothesized that the daily migrations of swordfish are linked to light levels and are suggestive of an animal following an isolume (Carey and Robson, 1981; ICCAT, 1998; Loefer et al., 2007). Swordfish utilize an extraocular muscle in conjunction with a countercurrent heat mechanism located beneath the brain act to heat the eyes and brain by up to 10-15^{o}C to aid hunting in the cold, dark conditions that they frequent (Block et al., 1993; Fritsches et al., 2005). Large eyes and the physiological mechanisms that heat the eyes and brain imply that they are predators that rely heavily on vision while hunting, and are well adapted to hunting in the low light conditions found in the deep ocean as well as in surface waters during nocturnal periods (Fritsches et al., 2005). Swordfish may adjust their depth preferences in response to diel cycles and lunar illumination intervals in order to remain at a constant light level to maximize vision and to optimize feeding success (Carey and Robson, 1981; Loefer et al., 2007). Carey and Robson (1981) reported that a swordfish monitored in the northwest Atlantic altered its daytime depth in response to movements between shelf water and clear-blue slope water. The authors concluded that this may be due to the swordfish attempting to remain at a constant isolume (Carey and Robson, 1981). Unfortunately, at the present time popup satellite archival tag models are unable to register light data at the depths that swordfish typically frequent during daytime hours, due to low light levels.

Diel vertical movements of swordfish may also be linked to the daily migrations made by their prey. Gut content analysis of swordfish in the northwest Atlantic Ocean have found squid (mainly belonging to Ommastrephidae and *Illex illecebrosus*) to be a primary food source, with teleost species of several genera also being important components of their diet (Stillwell and Kohler, 1985). Pelagic squids and mesopelagic fishes are also known to undertake vertical migrations in response to diel cycles (Roper and Young, 1975; Hays, 2003). Stillwell and Kohler (1985) noted that the depths utilized by swordfish are within the range of the diel vertical movements made by several families of mesopelagic fishes and pelagic squids.

These patterns are also similar to the daily movements made by the organisms forming the deep scattering layer (DSL; ICCAT, 1998; Hays, 2003). The DSL is made up of many species of crustaceans, euphausiids, cephalopods, and small mesopelagic fish (Hays, 2003; Kaltenberg, 2004). Daily movements of organisms in the DSL typically follow a consistent pattern, descending to deep waters during the day and returning to surface waters at night (Hays, 2003; Kaltenberg, 2004). Evidence also suggests that the organisms composing the DSL may also be influenced by lunar illumination, with vertically migrating organisms being found further from the surface during periods of high lunar illumination (Horning and Trillmich, 1999). Pelagic squid and species of mesopelagic fish follow the diel vertical movements of the DSL, and there is considerable overlap between the movements of these food sources and the daily movements made by swordfish (Stillwell and Kohler, 1985; Hays, 2003).

Estimates made in previous studies regarding the daily food consumption values of swordfish indicate these can range from 0.94 percent to 1.6 percent of their total body weight (Stillwell and Kohler, 1985). To meet metabolic and energetic needs, swordfish presumably need to feed frequently and by following the migrations of the DSL in response to diel cycles and lunar illumination, swordfish are able to maintain a constant, close proximity to food sources (Stillwell and Kohler, 1985).

Surfacing Behavior

While swordfish monitored during this study typically occupied deep waters (i.e. 500 m to 800 m) during daytime hours, all fish demonstrated surfacing behavior during the day. The number of surfacing events recorded by the tags varied, with the two largest fish (173 and 183cm) recording the most surfacing events (n=17). This behavior was recorded during the fall, winter, and early spring. However, it is important to note that deployment durations occurred between the months of October and April and the trends observed may not hold for the summer months.

Daytime surfacing and basking behavior in swordfish has been documented in many areas of the world's oceans, including the North Atlantic Ocean, the Pacific Ocean, and the Mediterranean Sea (Carey and Robson, 1981; Bedford and Hagerman, 1983; NMFS 2006; Canese et al., 2007). Past and present fisheries in many areas of the world have relied on using harpoons to harvest swordfish basking on the surface during the day, which usually consisted of adult fish over 200 pounds (Carey and Robson, 1981; NMFS, 2008; Canese et al., 2007; ICCAT, 2008). Prior electronic tagging studies in the Pacific Ocean and the Mediterranean Sea have also provided evidence of daytime surfacing behavior in swordfish (Carey and Robson, 1981; Canese et al., 2007). However, this behavior has been documented less frequently in the tropics than in temperate regions (Eric D. Prince, pers. comm.; Dewar et al. abstract in Catalina BF symposium.).

The ultimate reason(s) for daytime surfacing events remain unknown; however, behavior observed during this study is consistent with the hypothesis that swordfish surface during the day to raise their body temperature to aid digestion (Carey and Robson, 1981; Canese et al., 2007). Swordfish monitored during this study spent daytime hours in temperatures as low as 4.4°C. Unlike tunas, which utilize physiological mechanisms to heat viscera and muscles, swordfish utilize cranial endothermy to only heat their eyes and brain (Block et al., 1993).

The results of this study show that daytime and nighttime surfacing behavior in swordfish in tropical regions of the oceans may be frequent enough to track horizontal migrations with smart position or temperature (SPOT) tag (manufactured by Wildlife Computers) technology. SPOT tags allow researchers to gather location data on pelagic species providing the tag is exposed to air (Holdsworth et al., 2009). Holdsworth et al., (2009) utilized SPOT tags to successfully track the horizontal movements of striped marlin in the Pacific Ocean in near real time. These tags coupled with surfacing behavior present new opportunities to gain greater insight into the horizontal movements of swordfish.

Knowledge of the horizontal movements of HMS is useful for establishing management units necessary to assess the status of stocks. In addition, these types of data can assist in determining trends in spawning and feeding site fidelity, and oceanic migrations, all of which are needed to manage these resources (Gary Thomas, pers. comm.; Ortiz et al., 2003). Current stock separation for Atlantic swordfish is supported by genetic analysis; however, precise boundaries between stocks remain uncertain (ICCAT, 2008). The mixing of stocks is also expected to occur in boundary areas such as the tropics (ICCAT, 2008). Thus, knowledge of the horizontal movements of swordfish is imperative to proper stock delineation and knowledge of the possible mixing of the north and south Atlantic stocks.

Further studies could serve to expand the geographical extent of tag deployments on swordfish in the tropics, with a focus on documenting surfacing events, particularly during the warmer summer months. In addition, the deployment of SPOT tags on swordfish could provide important data on the horizontal movements of swordfish previously not available utilizing satellite tags. The integration of high resolution horizontal and vertical movement data could provide insight vital to the understanding of swordfish biology.

CHAPTER 3: A SYSTEMATIC DESCRIPTION OF THE SOUTHEAST FLORIDA RECREATIONAL SWORDFISH FISHERY

BACKGROUND:

Fishing is an important recreational activity for many people in the United States, with a reported 44.4 million anglers participating in recreational fishing activities from 2002 to 2006. In 2006 alone, there were 7.7 million saltwater anglers out of a total of 30 million recreational fishers nationwide. In addition to being an important social activity, recreational anglers also provide an important input to the economy. In 2006, anglers in the United States spent a total of $42 billion in total for fishing related expenses. Saltwater anglers accounted for $8.9 billion of the total recreational fishing revenue (21%) in the U.S. (USFWS, 2006).

In Florida, a total of 2.8 million residents and non-residents fished in the state during 2006. Saltwater fishers accounted for 2 million of the total anglers for that year (71%). Revenues generated by Florida anglers in 2006 totaled $4.3 billion, which included fishing equipment, trip-related, and other expenditures (USFWS, 2006).

Swordfish are exploited in the Atlantic by both US recreational and commercial fisheries; however, landings are dominated by offshore pelagic longline fleets (ICCAT, 2008). Stock assessments in the late 1970's and 1980's showed swordfish stocks to be overexploited (ICCAT, 1995). In 1999, ICCAT implemented a ten-year rebuilding plan for Atlantic swordfish (NMFS, 2008). This plan included a reduction in the North Atlantic total allowable catch (TAC, NMFS, 2008). In addition, as part of a swordfish rebuilding plan, NMFS instituted a series of time-area closures for pelagic longline gear in federal waters of the Gulf of Mexico and southeastern United States to protect juvenile swordfish populations and reduce bycatch (see map of closures in NMFS, 2008). More recently, assessments of North Atlantic swordfish have found the stock to be near recovery status, with a relative a biomass (B2006/BMSY) of 0.99 (0.87 – 1.27) (MSY, ICCAT, 2008).

Beginning in 2003, US recreational anglers were required to report non-tournament landings of north Atlantic swordfish (NMFS, 2006). However, 2004 is the first full year of data on reported swordfish landings by recreational anglers. The reported landings of individual fish for the US recreational swordfish fishery from 2004-2008 were 290, 388, 549, 716, and 344 respectively (G. Fairclough, Pers. Comm.). Estimated commercial landings of swordfish by the US between the years of 1983 to 2006 ranged from a high of 6,411 tons in 1989 to a low of 1,865 tons in 2006 (ICCAT, 2008).

Swordfish are one of 30 species of fish that are designated as HMS by Annex I of the 1982 United Nations Convention on the Law of the Sea. Management of swordfish in the Atlantic Ocean is a multi-layered process. Swordfish in the Atlantic Ocean are managed internationally by the International Commission for the Conservation of Atlantic Tunas (ICCAT). ICCAT makes recommendations on aspects of fisheries such as size limits, total allowable catches (TAC), as well as member compliance to regulations. In addition to swordfish, ICCAT is also responsible for the international management of other Atlantic HMS fisheries. Domestically, swordfish are managed by the National Marine Fisheries Service (NMFS) HMS Management division, under the authority of the Magnuson-Stevens Fishery Conservation and Management Act

(Magnuson-Stevens Act) and the Atlantic Tunas Convention Act (ATCA). The Magnuson-Stevens Act requires NMFS to preserve optimal yield (OY) by ending overfishing and rebuilding stocks of managed fisheries that have already been overfished, as well as providing guidelines for the implementation of fishery management plans (FMP) for HMS in the Atlantic. NMFS, under ATCA, is also responsible for implementing the recommendations made by ICCAT through the dissemination of appropriate regulations (NMFS, 2006).

The current federal swordfish regulations for recreational anglers are as follows. The minimum size for swordfish is 47" lower jaw fork length. The bag limit is 1 fish per person or a maximum of 4 fish per boat. Recreational vessel owners who target and harvest Atlantic billfish, tunas (bluefin, bigeye, albacore, yellowfin, and skipjack), oceanic sharks, and swordfish are required to obtain a HMS Angling permit (NMFS, 2006). In addition, recreational charter boats and head boats are required to obtain a HMS charter/headboat (CHB) permit to target and harvest HMS, which also covers their passengers (NMFS, 2006). HMS species harvested aboard vessels with a HMS angling permit may not be sold (NMFS, 2006). Additionally, all non-tournament landed swordfish must be reported (either via telephone or online) to the NMFS within 24 hours of harvesting the fish (NMFS, 2008).

Recreational fisheries for highly migratory species (HMS) such as tunas, billfish, and swordfish have existed in the Atlantic since the early 1900's (Lent and Sutter, 2001). Recreational fisheries for swordfish utilizing rod-and-reel began in the 1920's from New York to Massachusetts. This fishery primarily relied on baiting swordfish during the daytime (NMFS, 2006). The recreational swordfish fishery of southeast Florida began in the 1970's offshore of Miami (Levesque and Kerstetter, 2007). Fishing techniques were adapted from commercial pelagic longline fisheries, and involved drifting baits at night (NMFS, 2006). Swordfish fishing quickly gained popularity with local fisherman, with swordfish being accessible to fisherman with a wide range of vessels. The first fishing tournament dedicated exclusively to the pursuit of swordfish was held in 1977. Recreational swordfish fishing tournaments continued for the next six years until 1983, when they were discontinued due to a loss of interest after a prolonged duration of low catch rates (Levesque and Kerstetter, 2007).

Tournaments resumed in 2001 off the coast of southeast Florida with the Swordlords tournament (Levesque and Kerstetter, 2007). A total of 18 vessels caught 15 swordfish, with three being retained (Levesque and Kerstetter, 2007). Three more swordfish fishing tournaments were held the next year. The number of vessels participating in 2002 tournaments totaled 156 vessels (Levesque and Kerstetter, 2007). Swordfish fishing continued to gain increasing popularity in the following seven years with an online forum dedicated to the pursuit of swordfish, swordfish fishing clubs (Southeast Swordfish Club and the Southern Anglers In Lauderdale Club, S.A.I.L.), as well as multiple yearly fishing tournaments. The Swordlords II tournament (held on the 24 August 2002) became the largest swordfish fishing tournament to date (Levesque and Kerstetter, 2007).

Interviews and surveys have been used successfully to learn more about the social and economic aspects of recreational fisheries, including offshore big-game fisheries (Ditton et al., 1995; Ditton et al., 1998; Jesien et al., 2006; NRC, 2006). These methods have been used to gather data such as demographic profiles of the participants, management preferences, fishing habits, and the potential economic value of recreational fisheries (Ditton et al., 1998; NRC, 2006). An understanding of the potential value of recreational fisheries can lead to better enforcement of current regulations, research, and management of the resource (Ditton et al., 1998). In addition, these data are also important in learning angler perspectives on different management policies and decisions, which are essential to the understanding of angler compliance to current regulations (NRC, 2006).

Despite increasing popularity and interest, there is little data currently available on the recreational swordfish fishery of southeast Florida and its participants (NMFS, 2006; Levesque and Kerstetter, 2007). Additionally, there has been no evaluation of the potential impact of the fishery to date (Levesque and Kerstetter, 2007). Thus, the objectives of the current study are to describe the demographics of the recreational swordfish anglers, their fishing gear, methods, perceptions of the current regulations, and expenditures. This data could serve to develop a more effective plan for managing, sustaining and possibly enhancing the current sport fishery for swordfish because it is a potentially valuable component of the local and state economies and may have greater potential in the future.

MATERIALS AND METHODS:

Study Area:

Unique oceanographic features present in the Florida Straits have permitted the growth of a recreational swordfish fishery. The Florida Straits are characterized by a by a narrow continental shelf, with steep depth contours that occur relatively close to shore

(Sedberry and Loefer, 2001; Prince et al., 2007). The Gulf Stream, with current velocities that often approach five knots and extend from the surface to the bottom, flows close to the southeast Florida coast (Knauss, 1996). These oceanographic features that attract prey species and swordfish occur in close proximity to the coast, which allows recreational fishers easy access to the swordfish stock. In contrast, most swordfish fisheries along the east coast of the United States occur further offshore due to a broader continental shelf, which functionally reduces the access and availability of swordfish to support a sportfishery (Knauss, 1996; Fiechter and Mooers, 2003; Sedberry and Loefer, 2001). Presently, southeast Florida is home to largest organized group of recreational swordfish anglers in the world as well as the Southeast Swordfish Club (Skip Smith, pers. comm.).

Interviews:

A written interview was distributed to swordfish anglers at public and private club meetings and fishing tournaments. A copy of the written interview may be found in Appendix 1. The interview template consisted of 22 questions arranged into four sections: demographics, fishing habits, fishing costs, and perceptions of current regulations. Questions included both multiple-choice and short answer formats. For the questions involving baits used, depths fished, and numbers of rods utilized respondents were permitted to choose more than one answer. This was due to the fact that anglers typically utilize several rods per trip to set baits at varying depths when targeting swordfish (Levesque and Kerstetter, 2007).

Costs associated with the recreational swordfish fishery of southeast Florida were divided into three categories: capital costs, finite costs, and variable costs. Capital costs involved the cost of items that were a onetime investment (or very infrequent purchases), such as rods, reels, miscellaneous gear, and fishing vessels. Operational costs included items that were purchased on a monthly basis (approximately), and included items such as terminal tackle (hooks, leader, ect.), line, and fishing lights. Variable costs included purchases that were incurred during every trip, such as fuel, bait, and other costs. In the analysis, capital costs are represented as one time purchases, while finite and variable costs were represented on an annual basis. The purpose of this section of the survey was to determine the financial investment necessary to pursue swordfish off the southeast Florida coast.

Data on management preferences was gathered to determine recreational swordfish angler's views of the current recreational swordfish regulations. Questions addressed angler's satisfaction level with the general recreational swordfish regulations, as well as opinions on size limit, bag limit, and mandatory reporting.

Data Analysis:

The data from the interview instrument was analyzed using Microsoft Office Excel 2007. Quality control was performed prior to encoding the data into Excel and only interview instruments that were at least 80% completed were included in this study. Each questionnaire was encoded into Microsoft Excel, and the frequencies of the responses to each question were summed for analysis. Data collected from the surveys was analyzed for statistical trends. Means were generated for expenditures from several aspects of the fishery. The results were illustrated in histograms. Given the unknown population size of swordfish anglers, the trends obtained for white swordfish anglers in the study are deemed preliminary which subsequent studies can build on.

Conduct of Interviews:

The interviews were conducted at meetings of the Southeast Swordfish Club (SESC) and the captain's meeting for the Hydro Glow Winter Swordfest (a local swordfish fishing tournament) on November 29, 2007. Tournaments have traditionally been used successfully as a venue for the distribution of surveys and interview instruments among anglers participating in pelagic fisheries (Ditton et al., 2000; Jesien et al., 2006). These venues were chosen for the distribution of the interview instruments because there would be a large number of dedicated swordfish fishermen in attendance. The fishermen who participate in these tournaments and club meetings mainly represent the serious swordfish fisherman in the area who target swordfish on a regular basis and have a serious interest in the fishery. These fishermen also participate in online forums, clubs, and tournaments that are held in and amongst the South Florida fishing community.

RESULTS:

Demographics:

There were 40 interviews conducted for this study, and 38 completed 80% of the questions. The pool of respondents was 94% Caucasian (Table 3.1). There were insufficient numbers of interviews from non-Caucasian anglers to evaluate for differences

Table 3.1 Demographic characteristics of southeast Florida swordfish anglers.

CATEGORY	ATTRIBUTES (%)								n
Ethnicity	**White**	**Hispanic**	**Other**						37
	94	3	3						
Age	**<10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**>70**	35
	0	8	17	20	29	23	3	0	
Education	**K-12**	**College**	**Graduate**						10
	20	50	30						
Occupation	**Self Employed**	**Healthcare**	**Communications**	**Transportation**	**Hospitality**	**Other**			30
	57	3	3	3	3	31			
Income	**0-30K**	**30-60K**	**60-100K**	**100-150K**	**150-200K**	**>200K**			33
	12	31	21	18	3	15			
Years Fishing	**1-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**31-35**	**>35**	35
	3	0	12	0	14	23	11	37	

in ethnicity. Thus, subsequent analysis were performed on the interviews completed by Caucasian anglers (n=35). Ages of the swordfish fishermen ranged from 11 to 70 years of age, and the largest percentage of respondents (29%) ranged from 41 to 50 years of age. The majority (89%) of people participating in the fishery ranged from 21 to 60 years of age.

Swordfish fishermen departed from several inlets located in Miami-Dade, Broward, Palm Beach, and other counties (Fig. 3.1). Most of the anglers surveyed departed from Broward county inlets (65%). The largest percentage of anglers left from Hillsborough Inlet, Broward County (34%).

Occupations of swordfish fishermen in South Florida ranged widely from healthcare, insurance, communications, transportation, hospitality, self-employment, education, retail, to other vocations. The largest percentage (57%) of the respondents listed themselves as being self-employed. 50% had received college degrees, and 30% had graduate degrees. However, the data gathered on education levels was based on a small sample size (n=10).

Annual earnings of southeast Florida swordfish fishermen ranged from $0-30,000 to $200,000 or more per year. The largest group of anglers by percentage (31%) earned from $30,000-60,000 per year. The majority of southeast Florida swordfish fishermen (82%) earned less than $150,000 per year.

Recreational fishing experience ranged from 1 to more than 35 years. Most swordfish anglers had greater than 26 years recreational fishing experience (71%), and the largest percentage of swordfish fishermen (37%) had greater than 35 years.

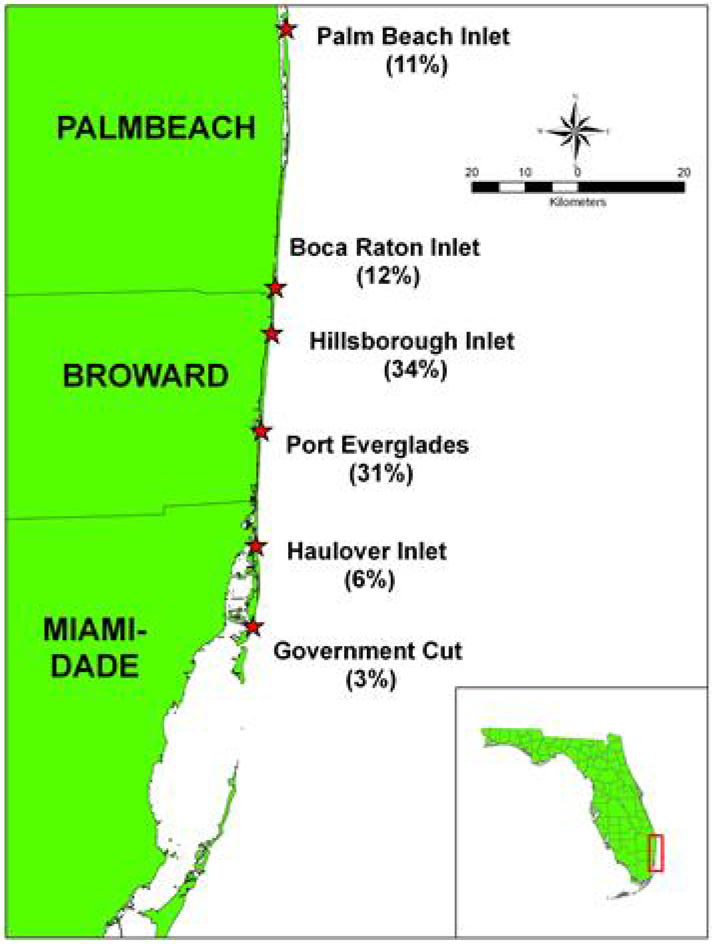

Fig. 3.1 Inlets of departure reported by southeast Florida swordfish anglers. n=35.

Experience in the south Florida swordfish fishery ranged from 1 to 35 years. However, most of the anglers (83%) were relatively new to swordfish fishing and had less than 10 years experience in the fishery.

The Fishery:

<u>Fishing Techniques:</u>

Vessels used by fishers in the southeast Florida swordfish fishery ranged in size from 15-20 feet up to 46-50 feet (Fig. 3.2). The largest percentage of vessels (40%) ranged in length from 31-35 feet. The majority of vessels (83%) ranged from 21-35 feet. Additionally, one angler (3%) surveyed did not own a vessel and fished from vessels owned by others. The make of the vessels utilized also varied; however, the largest percentage was made up of center consoles (44%).

Anglers participating in the Southeast Florida swordfish fishery used several different types of bait when targeting swordfish (Fig. 3.3). Respondents were presented with four commonly used types of bait and techniques for swordfish: squid baits (*Illex* spp.), live baits, dead baits, and trolling lures. The largest percentage of respondents fished squid baits (36%), followed by live baits (32%), dead baits (26%), and trolling lures (6%) respectively. The species of marine fish utilized as live baits by anglers fishing for swordfish in southeast Florida included blue runners (*Caranx crysos*), bigeye scad (*Selar crumenophthalmus*) termed locally as “goggle eye,” and tinker mackerel (*Scomber* sp.), which made up 40%, 23%, and 17% of live baits respectively. The other 20% of live baits included scad (*Decapterus* sp.) known locally as “speedos”, rainbow

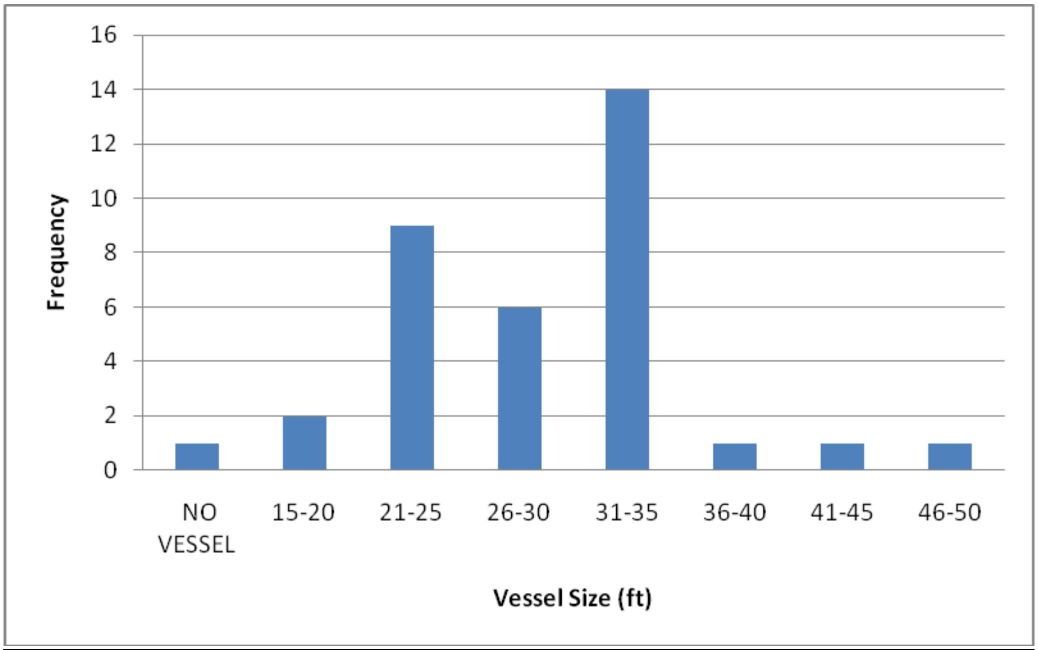

Fig 3.2 Sizes of vessels utilized by swordfish anglers fishing off the southeast coast of Florida. n=35

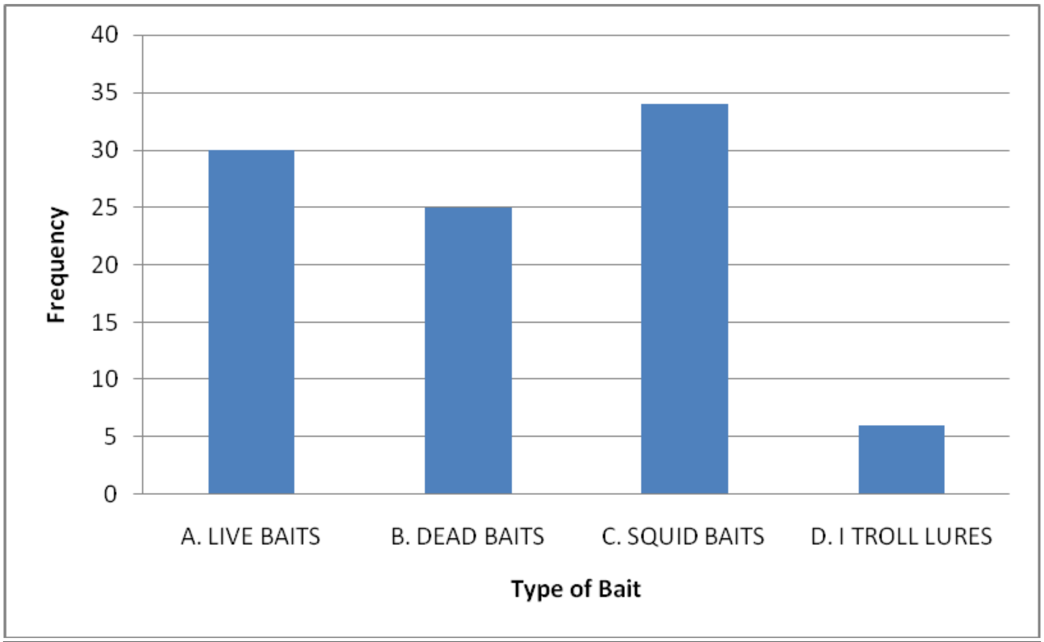

Fig 3.3 General categories of bait utilized by anglers targetting swordfish off the coast of southeast Florida. Due to the fact that fishermen usually utilize multiple rods when targetting swordfish, respondents were allowed to choose more than one type of bait that they use on a regular basis. n=95

runners (*Elagatis bipinnulata*), jacks (*Caranx* sp.), yellowtail snapper (*Ocyurus chrysurus*), pilchards (*Harengula jaguana*), and grunts (*Haemulon* sp.).

The most common dead baits used by anglers were “tinker” mackerel, bonito (*Euthynnus alleteratus*), and speedos, which made up 50%, 13%, and 13% respectively. The other 24% of dead baits included blue runners, goggle eye, jacks, and yellowtail snapper.

All anglers used from 2 rods to 9 rods while fishing for swordfish. The largest percentage of anglers surveyed (32%) used 5 fishing rods when targeting swordfish. The majority of respondents (92%) used from 4 to 7 fishing rods per trip.

Fishers targeted swordfish at a variety of depths but primarily fished baits at 300 feet (91.4m) or less (74%) (Fig. 3.4). Depths fished ranged from 50 feet (15.2m) to 1,200 feet (365.8m), and the most common depth where swordfish were targeted was 100 feet (30.5m) (14%). It is important to note that these are the depths that fishermen estimate they are fishing the baits. Conditions such as wind, current, and wave action can cause baits to be set at depths different from those perceived by the anglers.

A majority of the respondents (69%) changed their fishing tactics depending on whether they were fishing for swordfish during daytime hours or nighttime hours (Table 3). The majority of the fishermen altered their techniques by changing the depth at which they fished their baits (77%). Other changes fishermen made to their techniques included the type and color of bait, fishing locations, and differences in the amount of weight used on the fishing rig.

Most of the swordfish fishermen (60%) surveyed changed their fishing tactics depending on the current moon phase (Table 3.2). A majority of the fishermen who

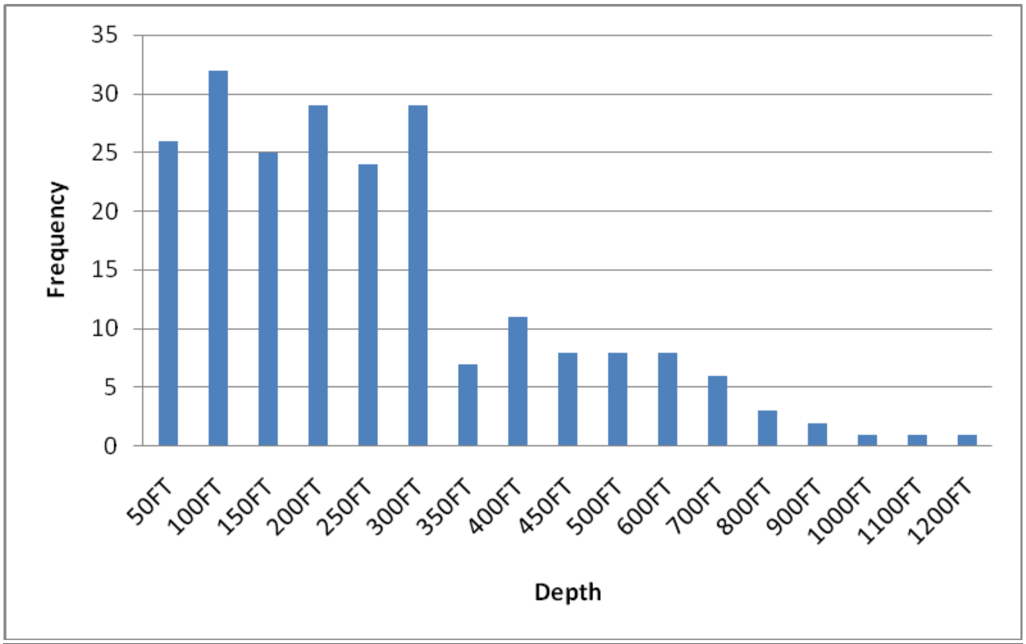

Fig. 3.4 Various depths at which swordfish anglers off southeast Florida suspend their baits. Anglers usually use several rods while swordfish fishing, thus fishermen were allowed to select multiple depths in which they suspended baits. n=221

Table 3.2 Change in fishing techniques in response to different environmental conditions.

CHANGE IN ENVIRONMENTAL CONDITIONS	YES (%)	n	MOST COMMON FISHING TECHNIQUE CHANGED (%)	n
Day to Night	69	32	Depth of Baits (77)	22
Change in Lunar Phase	60	35	Depth of Baits (71)	24

changed their techniques according to the current moon phase listed that they changed the depth in which they fished their baits (77%). Anglers adjusted their techniques by modifying the type and intensity of the light attached to the leader, as well as adjusting the distance between the light and the bait. Fishers also changed the locations in which they fished during different lunar phases and some anglers fished more frequently during the full moon period. Fishermen took an average of one swordfish fishing trip per week or three trips per month and 39 per year.

<u>Fishers Expenses:</u>

Capital costs included items that were purchased as a onetime cost. This included items such as vessels, rod and reels, and miscellaneous items. Anglers spent an average of $125,000 on fishing vessels purchased specifically for swordfish fishing. However, this is based on a limited number of respondents (n=8), as fishermen only listed the cost of their vessel if it was purchased specifically for swordfish fishing. Fishermen spent an average of $7,000 on rods and reels and an average of $1,710 on miscellaneous items.

Operational costs included items that were replaced on an approximate monthly cycle, such as terminal tackle, fishing line, and lights for swordfish fishing rigs. Anglers spent an average of $530 per year on fishing line. Swordfish fishermen spent an average of $960 per year on terminal tackle. Fishing lights attached to swordfish rigs cost swordfish fishermen an average of $280 per year.

Table 3.3 Costs associated with the southeast Florida recreational swordfish fishery. Average costs are calculated per angler. Capital costs represent items that are a onetime purchase. Finite costs represent items that are purchased on an infrequent basis, in this case on a monthly basis. Variable costs represent items that are purchased every trip. Finite costs and variable costs have been standardized to represent the cost per angler per annum.

COST TYPE	ITEM	COST ($)	N
Capital Cost (one time cost)	Vessel	125,000	8*
	Rods and Reels	7,000	30
	Miscellaneous Items	1,707	29
Finite Cost: replaced approximately on a monthly basis (annualized)	Line	533	23
	Lights	276	29
	Terminal Tackle	957	29
Variable (annualized)	Fuel	7,683	32
	Bait	1,716	35
	Other	3,042	24

*** Refers to vessels purchased specifically for swordfish fishing. Vessels purchased for multi-use fishing were not included.**

Running costs referred to items that were purchased on a per trip basis, such as fuel, bait, and other. Swordfish fishermen spent an average of $7,680 per year on fuel. Bait costs were an average of $1,720 per year, and other expenditures purchased during each swordfish fishing trip cost an average of $3,040 per year (Table 3.3).

<u>Fisher's opinions on regulations:</u>

Forty percent of anglers surveyed were unsatisfied with the regulations as a whole (unsatisfied (37%) and very unsatisfied (3%)), 39% were satisfied with the current regulations (satisfied (29%) and very satisfied (8%)), with 23% of the respondents remaining neutral (Fig. 3.5). Reasons given for dissatisfaction: "allowing the commercial buoy fishery to operate in the Florida Straits", "the prospect of longliners being allowed to fish in closed zones, the current size limit needs to be raised", "it is necessary to implement regulations to protect large female swordfish", and "the current bag limit needs to be reduced to two fish per vessel".

52% of southeast Florida swordfish fishermen surveyed favored an increase in the current size limit for swordfish. Anglers suggested the minimum size for swordfish be changed to 50 to 55 inches LJFL. The remainder of the anglers surveyed (48%) supported the current size limit. None of the respondents favored a decrease in the current swordfish size limit.

Most of the respondents (61%) favored no change in the current swordfish bag limit of one fish per person or up to four per vessel. Thirty percent of the anglers supported a reduction of the current bag limit. Anglers listed a reduction in the bag limit to one to three fish per vessel. The remainder of the fishermen surveyed (9%) supported

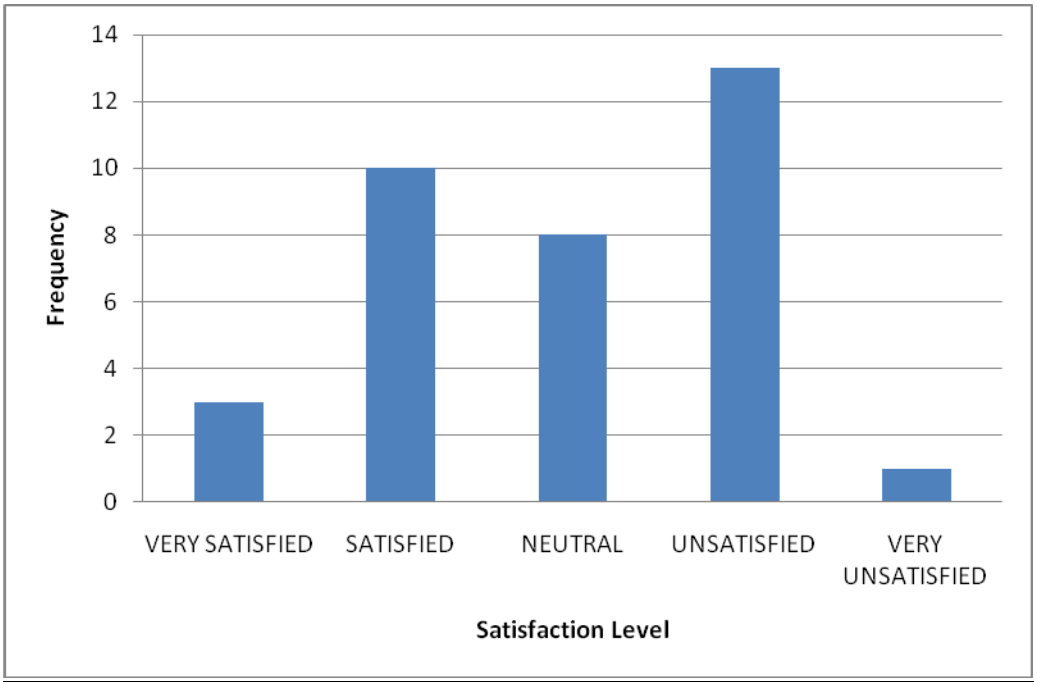

Fig. 3.5 Satisfaction levels of southeast Florida swordfish anglers in regards to the current regulations. n=35

an increase in the current bag limit. Ninety percent of the anglers surveyed supported the current regulation requiring swordfish fishermen to report non-tournament landed swordfish to the NMFS within 24 hours of the fishing expedition. Respondents said that mandatory reporting provides an accurate census of the number of fish caught by recreational fishermen, which is needed to help the US reach the current ICCAT swordfish quota. The use of fines was suggested for people who violate this regulation.

DISCUSSION:

A majority of the southeast Florida swordfish fishermen surveyed were Caucasian. This result is consistent with the ethnicity of participants in other recreational saltwater fisheries. A 2006 survey found that 90% of saltwater anglers in Florida were Caucasian (USFWS, 2006). Anderson and Ditton (2004), in a survey of saltwater anglers in Texas, found that 92% of respondents were Caucasian. The results of a Costa Rican billfish fishery also found that the majority of the billfish fishermen surveyed were Caucasian as well (Ditton and Grimes, 1995).

Most of the southeast Florida swordfish anglers surveyed in were between 41 and 50 years of age. These results were consistent with the U.S. Fish and Wildlife Service (USFWS) 2006 survey of saltwater anglers in Florida, with the largest group of anglers by percentage ranging from 45 to 54 years of age (USFWS, 2006). Also, a recreational study of Texas saltwater anglers listed the average age of fishers as 42 years (Anderson and Ditton, 2004). A study of the recreational bluefin tuna fishery off North Carolina, Ditton et al. (1998) found that most of the participants in the tuna fishery ranged from 30 to 50 years of age. Ditton and Grimes (1995) found that the average age of anglers surveyed in a Costa Rican billfish fishery was 49. The pursuit of tuna, billfish, and swordfish typically requires access to a vessel, as well as the knowledge and experience required to operate a fishing vessel offshore. Individuals within this age range may have steady income with the funds and time necessary to dedicate to pelagic fisheries. In addition, recreational swordfish fishing requires anglers to fish offshore, usually at night. Anglers of this age may also have more experience and expertise running vessels offshore.

Most of the swordfish anglers made $150,000 or less annually, with the largest group by percentage making $30,000-$60,000 annually. The average annual salary of surveyed southeast Florida swordfish fishermen was $75,606. According to a 2006 survey, the largest group by percentage of saltwater anglers in Florida made $50,000-$74,999 (USFWS, 2006). The average income of southeast Florida swordfish anglers was less than those reported by bluefin tuna anglers fishing off North Carolina, which were reported as $80,000-$99,999 annually (Ditton et al., 1998). The annual incomes of anglers participating in a Costa Rican billfish fishery were also greater than that of southeast Florida swordfish fishermen, with median incomes ranging $160,000 to $179,000 (Ditton and Grimes, 1995). Additionally, Ditton and Grimes 1995 found that 43% reported incomes of greater than $200,000 or more (compared to only 15% of swordfish anglers reporting incomes of $200,000 or greater). This discrepancy is likely due to the easy access of the swordfish fishery to anglers with a wide range of vessels. In addition, discrepancies may also be due to the additional expenditures required (airfare, charter boats) to travel abroad to target billfish. Anglers travelling abroad to target billfish typically need to charter local vessels, while many of the southeast Florida swordfish anglers fished from private vessels (Ditton and Grimes, 1995).

The majority of the fishermen surveyed had over 20 years of recreational fishing experience. This was consistent with findings on other offshore big game fisheries for large species such as billfish and tuna, in which most of the anglers typically had more than 20 years of recreational fishing experience (Ditton et al., 1998; Ditton and Grimes, 1995). This may be due to the large size of the targeted species as well as specialized techniques utilized in the pursuit of pelagic game fish. Logistic difficulties involved in the fishery (e.g. rigging and specialized tackle) likely require expertise. However, while most anglers had over 20 years of general recreational fishing experience, a majority of the southeast Florida swordfish fishermen had less than 10 years experience targeting swordfish. This is consistent with the fact that the southeast Florida swordfish fishery experienced a rebirth and a subsequent increase in popularity within the past 10 years after effort waned in the 1980's due to poor catch rates in response to commercial overfishing (Levesque and Kerstetter, 2007). Tournaments and media attention over the past decade have sparked an interest in recreational swordfish fishing in southeast Florida (Levesque and Kerstetter, 2007). While most of the anglers surveyed were relatively new to the fishery, some of the anglers surveyed had been swordfish fishing since the fishery began in the late 1970's.

Baits utilized in the southeast Florida swordfish fishery are representative of baits traditionally used in swordfish fisheries as well as species that are locally common and popular with offshore fishermen in Florida. In a study of southeast Florida swordfish fishing tournaments, Levesque and Kerstetter (2007) reported similar baits being utilized by southeast Florida swordfish anglers. Squid are the most commonly used bait (by percentage) by southeast Florida swordfish anglers. Squid are commonly used for bait in both commercial longline fisheries and in recreational fisheries targeting swordfish throughout the Atlantic Ocean (Garza-Gil et al. 2003; Watson et al. 2005; Levesque and Kerstetter 2007). In addition to squid, anglers commonly used live baits such as bigeye scad and blue runners. These species are indigenous to the waters off south Florida and are also commonly used in other local fisheries targeting pelagics such as sailfish (Prince et al., 2007). Mackerel and squid are commonly used by south Florida swordfish anglers, and are also frequently used in other swordfish fisheries such as the commercial longline fishery (Garza-Gil et al., 2003; Watson et al., 2005). However, anglers surveyed during this study also reported targeting swordfish by trolling lures at night.

The preliminary results of this study suggest that costs associated with the swordfish fishery are typically greater than the costs associated with other fisheries in Florida. A marine angler survey of fishers in eastern Florida conducted in 1999 and 2000 found that the mean expenditures on fishing rods and tackle were $115.28 (Gentner et al., 2001). Additionally, a 2006 survey found that the average Florida angler's expenditures on fishing equipment (rods, reels, line, ect.) was $262 annually (USFWS, 2006). Annual swordfish angler expenditures greatly exceeded the costs of these other fisheries, with expenditures on fishing equipment such as rods, reels, line, terminal tackle, and other totaling $10,473. Average annual per trip costs by Florida residents in other Florida recreational fisheries totaled $702 in 2006, which was also less than the average annual per trip costs associated with the swordfish fishery, which totaled $12,441 (USFWS, 2006). These differences are likely due to the nature of the fishery and the large size of the targeted species. Swordfish are large, pelagic fish that can attain weights of up to 530 kg (NMFS, 2006). Thus, swordfish need to be pursued with specialized gear that is capable of landing large, powerful fish. In addition, a vessel is necessary to access the fishery. The swordfish fishing grounds are found approximately 27.8 to 37 km offshore of the coast, which is typically further offshore than other fisheries in southeast Florida (Levesque and Kerstetter, 2007). Consequently, fuel costs may also exceed those for other fisheries.

Swordfish anglers surveyed were divided on their views of the current Federal swordfish regulations. In regards to the overall regulations, 40% of the anglers surveyed were dissatisfied, 37% of the anglers were satisfied, and the remaining anglers (23%) remained neutral in regards to the current general regulations for swordfish. These results differed from the results of other saltwater recreational fishing surveys, in which the majority of anglers supported current regulations. Anderson and Ditton (2004) reported the majority (55%) of anglers who fished for spotted seatrout supported the current regulations. Additionally these findings differed from results of surveys conducted on other big game fisheries on the U.S. east coast, in which a majority of respondents were in favor of current management plans. Ditton et al. (1998) reported in a study of the recreational bluefin tuna fishery off North Carolina that 67% of anglers supported the current bluefin tuna regulations. According to open ended responses provided by some of the respondents of this survey (17%), swordfish angler's dissatisfaction with the regulations was due to two different issues: commercial fishing and the need for increased regulations in regards to certain aspects of the recreational fishery. At the present time, a commercial buoy gear fishery targeting swordfish operates on the swordfish grounds off the southeast coast of Florida (NMFS, 2006). Reasons listed for dissatisfaction in regard to commercial fisheries were the fact that commercial buoy gear was permitted to operate in the Florida Straits and concern about the prospect of longliners being allowed to once again operate in the Florida Straits. The area is one of several time/area closures for longlining in the North Atlantic (NMFS, 2006). Anglers providing responses also listed a need for increased size limits, decreased bag limits, and implementing regulations to protect large female fish from harvest in the recreational fishery as reasons for dissatisfaction.

In regards the current size limit of swordfish, most of the respondents were in favor of an increase in the current federal size limit for swordfish (47 inches LJFL). The remaining respondents were satisfied with the current size limit and none of the anglers surveyed supported a decrease in the size limit for swordfish. In addition to size limits, anglers responding to the open ended questions also supported the inclusion of a slot limit for swordfish. Swordfish over approximately 230 cm LJFL are female, and evidence suggests that the waters of the Florida Straits may be an important spawning ground for North Atlantic swordfish (Taylor and Murphy, 1992). Thus, regulations protecting large, sexually mature female swordfish off the southeast coast of Florida may be beneficial.

Most of the anglers surveyed (61%) were in favor of the current bag limit that for swordfish. These results are consistent with surveys completed on other recreational big game fisheries involving species that are highly valued as table fare. In a survey of bluefin tuna anglers fishing off the coast of North Carolina, Ditton et al. (1998) found that a majority of the fishers supported the current bag limit of one fish per vessel. However, the results of this study differed from the results of a study on recreational anglers pursuing other billfish such as marlin and sailfish, in which most anglers favored the option of catch and release only (Ditton and Grimes, 1995). However, this is most likely due to the fact that billfish (marlin and sailfish) are highly valued for their sporting qualities and thus are pursued as a game fish and usually released, while swordfish are typically targeted for both food and sport (Sedberry and Loefer 2001; Jesien et al., 2006; Prince et al., 2007). In addition to the bag limit, a majority of the swordfish anglers (90%) were in favor of continuing the mandatory reporting aspect of the regulations, which requires anglers to report any non-tournament landed fish to NMFS within 24 hours of the fishing trip. The reporting of landed swordfish is essential to create estimates of the recreational swordfish harvest.

The NMFS has traditionally used the Marine Recreational Fisheries Statistics Survey (MRFSS) to gather data on recreational fisheries. More specifically, the Large Pelagic Survey (LPS) was implemented to gather data on recreational fisheries targeting pelagic species such as swordfish (NMFS, 2006). The LPS uses telephone surveys and intercept surveys of HMS permit holders to estimate vessel effort by gathering data on species targeted, fishing locations and techniques, and conditions. LPS could benefit by gathering additional data on management preferences of anglers. This data is important in formulating regulations and understanding angler compliance (NRC, 2006).

However, the LPS is currently only utilized in the states of Maine through Virginia. Expanding the LPS to include Florida would allow the NMFS to gather valuable data on the state's various pelagic fisheries including the swordfish fishery, as well as important data on angler tactics and behavior. Currently, HMS anglers are required to report landings of Atlantic swordfish to the NMFS within 24 hours of the trip

(NMFS, 2006). This does not involve reporting swordfish that are released. Additional yearly data on releases could be utilized to better estimate the amount of swordfish captured by anglers off the Florida coast.

Southeast Florida has the potential to become a world-class destination for anglers targeting swordfish. World-class destinations for targeting big game sport fish provide valuable inputs to local, state, and regional economies (Ditton and Grimes, 1995; Ditton et al., 1998; Ehrhardt and Fitchett, 2006). Billfish remain among the most highly prized big game fish, with recreational fisheries for billfish in areas such as Guatemala and Cabo San Lucas, Mexico providing millions of dollars to the regional economies (Ortiz et al., 2003; Ehrhardt and Fitchett, 2006; Ditton et al., 1996). Currently, there are relatively few destinations in the world in which anglers can reliably target swordfish (Levesque and Kerstetter, 2007). Unique oceanographic features present in the Florida Straits place the swordfish grounds in close proximity to the coast, allowing anglers with a wide range of vessels easy access to the fishery (Levesque and Kerstetter, 2007; Prince et al., 2007). The popularity of the fishery has been increasing in recent years, and there are fishing clubs, online forums, and tournaments dedicated exclusively to the pursuit of swordfish. New techniques are being refined to successfully pursue swordfish during both day and night (Skip Smith, pers. comm.).

While this study focused on the costs involved with participating in the recreational swordfish fishery, it did not address the impact of the fishery on the local and regional economy. According to a study funded by the American Sportfishing Association (ASA) in 2007, Florida is the number one state in the country in terms of angler expenditures (Southwick Associates, 2007). Costs involved in the recreational swordfish fishery typically exceeded those of other recreational fisheries in Florida (USFWS, 2006). Additionally, local charter boats and head boats make trips specifically targeting swordfish. Further research is necessary to determine the economic impact the fishery provides to the local and regional economies as well as charter and party boat operations.

Given the unknown number of recreational swordfish anglers in southeast Florida, the trends obtained in this study should be deemed preliminary. Future studies could serve to build upon these results and further expand knowledge of the fishery. This study focused solely on recreational fishermen that regularly pursued swordfish. Anglers that did not participate in swordfish club meetings or tournaments were not surveyed. Additional research is necessary to expand the knowledge of participants in the fishery and determine the proportion of recreational anglers in southeast Florida that participate in the recreational swordfish fishery. Subsequent studies could also focus on anglers travelling to Florida from other areas to fish for swordfish. Future research could also serve to expand the geographic context of the survey to other regions in Florida as well as other areas where recreational swordfish fishing is prevalent on the U.S. east coast.

CHAPTER 4: SUMMARY:

The vertical distribution of swordfish was assessed in relation to diel cycles and lunar phase utilizing popup satellite archival tag (PSAT) technology. A total of seven swordfish were tagged in the Florida Straits from September to December, 2007. Tagging operations were conducted from both recreational and commercial fishing vessels. Two fish died shortly after release and thus were not included in the study. The remaining five swordfish transmitted a total of 474 days of data out of 541 days at large (87%). Horizontal movements were variable, and ranged from 274 km to 1,976 km.

Swordfish tagged during this study demonstrated differences in vertical distribution in response to diel cycles. Daytime hours (13:00-21:00 UTC) were typically spent at depths greater than 500 m (92%). Nighttime hours (0:00-10:00 UTC) were usually spent in near surface waters above 75 m, with the majority of nighttime hours spent in waters less than 200 m (96%). Movements between depth and relative surface waters were typically undertaken during crepuscular hours. Swordfish also showed differences in vertical distributions in relation to lunar illumination cycles. A linear regression demonstrated a highly significant relationship between depth and the fraction of the moon illuminated. Swordfish occupied successively deeper depths in response to increasing lunar illumination.

Vertical distribution patterns in response to diel cycles and lunar phase observed during this study may be due to several different mechanisms. Large eyes and specialized physiological adaptations that heat the eyes and brain imply swordfish sight feeders (Block et al., 1993; Fritsches et al., 2005). Swordfish may adjust their depth preferences to remain at a constant level of ambient light to maximize vision and to optimize feeding success (Carey and Robson, 1981; Loefer et al., 2007). Additionally, the vertical distributions observed may be a response to similar vertical movements undertaken by the DSL, squid, and other important prey items.

This study also provided quantitative evidence of daytime surfacing events in tropical regions. All five swordfish tagged during this study recorded daytime surfacing events. While the causes of this behavior are unknown, data gathered during this study supports the hypothesis that swordfish periodically come to the surface during daytime hours to raise their body temperatures and aid digestion.

Daytime and nighttime surfacing behavior documented by this study may present an opportunity to study the horizontal movements of swordfish utilizing SPOT tagging technology. Data on the horizontal movements of swordfish has traditionally been difficult to gather via satellite tagging methods due to sparse light level data. However, SPOT tags record GPS coordinates upon exposure to air, and surfacing events during both day and night could provide data necessary to better resolve horizontal movements of swordfish. This new technology has been used successfully to track the horizontal movements of striped marlin (Holdsworth et al., 2009). In addition, future research could expand the geographical extent of tag deployments on swordfish in the tropics, with a focus on documenting surfacing events. The integration of data on both horizontal and vertical movements of swordfish could be used to better define the spatial and temporal distribution of swordfish and provide important implications to management.

A recreational swordfish fishery off the southeast Florida coast has experienced an increase in popularity in recent years, including the resumption of swordfish directed tournaments (NMFS, 2006; Levesque and Kerstetter, 2007). However, despite the recent increase in popularity, there is little data available on the fishery and its participants (NMFS, 2006; Levesque and Kerstetter, 2007). The objectives of this study were to describe the demographics of recreational swordfish anglers in southeast Florida, their fishing gear, methods, perceptions of the current regulations, and expenditures. A survey was distributed to recreational swordfish fishers at a local fishing tournament and meetings of the Southeast Swordfish Club (SESC). A total of 40 surveys were conducted, and 35 were included in the study.

Anglers participating in the recreational swordfish fishery of southeast Florida are typically white and self employed, with most of the fishers earning $150,000 dollars or less per year. Ages of participants in the fishery ranged from 11-20 years to 61-70 years of age, with the largest group by percentage ranging from 41 to 50 years of age. Swordfish fishermen typically had many years of recreational fishing experience, with less than 10 years experience targeting swordfish. Anglers typically fish out of center console style boats ranging from 21-35 feet in length, and depart from inlets located in Broward County, with the remainder fishing out of Miami-Dade, Palm Beach, and Martin counties. Fishers typically take less than 50 trips for swordfish per year. Swordfish fishermen surveyed spent an average of $8,707 (excluding vessels) on capital costs, $1,766 on finite costs, and $12,441 on variable (per trip) costs on an annual basis. Anglers were divided in their views of the current swordfish fishing regulations, with 40% reported being unsatisfied, 37% satisfied, and 23% remaining neutral.

The results of this study provide an initial description of the participants, fishing methods, and expenditures of the growing recreational swordfish fishery in southeast

Florida. Future research could focus on addressing the potential impact of the fishery on both the local and state economies. Additional studies could also serve to build upon the results of this survey in southeast Florida and expand the geographical context of the study to other areas of the country where swordfish are actively targeted by recreational fishermen.

Appendix I

I. Fishing habits

1. What is your home port (or launch area)?
    a. Lower Florida Keys (Key West to South of the 7 mile Bridge)
    b. Middle Florida Keys (Marathon to Islamorada)
    c. Upper Florida Keys (Tavernier to Key Largo)
    d. Miami-Government Cut
    e. Miami-Haulover
    f. Ft. Lauderdale-Port Everglades
    g. Hillsborough
    h. Boca Raton
    i. Palm Beach
    j. Other (please specify)

2. What is the size, make and manufacturer of your vessel (if you do not own a boat, respond with "none")?
    Size:
    Make:
    Manufacturer:

3. What kind of baits do you fish (you can select more than one)?
    a. Live baits (specify)
    b. Dead baits (specify)
    c. Squid (live or dead, circle one)
    d. I troll lures

4. How many rods do you typically fish?
    a. 2
    b. 3
    c. 4
    d. 5
    e. 6
    f. 7
    g. More than 7 (please specify)

5. What depths do you fish your baits (circle more than one if applicable)?
    a. 50ft
    b. 100ft
    c. 150ft
    d. 200ft
    e. 250ft

f. 300ft
g. other (please specify)

6. Do your fishing tactics change according to the time of the year?
   a. yes
   b. no

If yes, how?

7. Do your fishing tactics change according to time of day/night?
   a. yes
   b. no

If yes, how?

8. Do your fishing tactics change according to the phase of the moon?
   a. yes
   b. no

If yes, how?

9. How many swordfish fishing trips do you take on an average week?
   a. 1
   b. 2
   c. 3
   d. 4
   e. more than 4

10. How many swordfish fishing trips do you take on the average month?
    a. less than 4
    b. 4
    c. 8
    d. more than 8

11. How many swordfish fishing trips do you take each year?
    a. less than 25
    b. 25-50
    c. 50-75
    d. 75-100
    e. more than 100

II. Fishing Costs:

12. What are your fixed costs (rods, reels, boat, gear, tackle)?

ITEM	**COST**
Rods	
Reels	
Line (including backing)	
Terminal tackle/Rigging (hooks, weights, leader, swivels, rigging needles)	
Lights/lightsticks (for use on rigs)	
Boat (if the vessel was purchased specifically for swordfishing (if not, leave blank)	
Misc. Gear (hydroglow/swordlight, sea anchor, rod holders)	

13. What are your average costs per trip?

ITEM	**COST**
Fuel	
Bait	
Other	

III. Regulations

14. What is your view of the current swordfish regulations?
    a. very satisfied
    b. satisfied
    c. neutral
    d. unsatisfied
    e. very unsatisfied (If e, please explain)

15. In your opinion, what changes (if any) should be made to the following current swordfish regulations (if you think an increase/decrease needs to be made, check the corresponding box and write how you think the regulation should be changed; if you think no change needs to be made, check the corresponding box for no changes).

REGULATION	**INCREASE**	**DECREASE**	**NO CHANGES**
Size limit (47" lower jaw-fork length)			
Bag Limit (1 per person or 4 per vessel whichever is less)			

For catch reporting, check the box you feel appropriate and provide a short reason why you chose that box.

REGULATION	**CONTINUE MANDATORY REPORTING**	**DISCONTINUE MANDATORY REPORTING**
Catch Reporting		

IV. demographic

16. What is your ethnicity?
    a. African American
    b. Asian-Pacific Islander
    c. Hispanic
    d. Native American
    e. White (Non Hispanic)
    f. other

17. What is your occupation?
    a. self employed
    b. government worker
    c. education (K-12)
    d. College degree
    e. graduate degree
    f. Insurance
    g. communications
    h. retail
    i. transportation
    j. banking/finance
    k. healthcare
    l. hospitality
    m. other

18. What is your age?
    a. <10 years
    b. 11-20 years
    c. 21-30 years
    d. 31-40 years
    e. 41-50 years
    f. 51-60 years
    g. 61-70 years
    h. >70 years

19. What is your annual income?
    a. 0-30,000
    b. 30,000-60,000
    c. 60,000-100,000
    d. 100,000-150,000
    e. 150,000-200,000
    f. 200,000+

20. How many years have you been a recreational angler?
    a. 1-5 years
    b. 6-10 years
    c. 11-15 years
    d. 16-20 years
    e. 21-25 years
    f. 26-30 years
    g. 31-35 years
    h. greater than 35 years

21. How many years have you been swordfish fishing off South Florida?
    a. 1-5 years
    b. 6-10 years
    c. 11-15 years
    d. 16-20 years
    e. 21-25 years
    f. 26-30 years
    g. 31-35 years
    h. greater than 35 years

22. What recreational saltwater fishing license do you currently have (you can choose more than one)?
    a. resident
    b. non-resident
    c. HMS permit

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