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Post-Release Survival and Habitat Utilization of Juvenile Swordfish in the Florida Straits

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Abstract

The use of pop-up satellite archival tags (PSATs) eliminates many of the limitations associated with acoustic and conventional tags by using fishery-independent data collection and retrieval. Previous research techniques have provided information on longer-term movements, migrations, and behavior patterns, but there is still a need for additional tagging studies using tags with depth and light data and increased memory that will further define the short-duration activity patterns and habitat utilization of juvenile swordfish in the western North Atlantic. PSATs have been successfully used on other large pelagic fishes, but have yet to be used on juvenile swordfish. This study investigated two main topics: a) the post-release survival rates of juvenile swordfish after being released from the recreational rod-and-reel fishery and commercial swordfish buoy gear fishery in the Florida Straits, and b) the habitat utilization of juvenile swordfish following release. High-resolution PSAT technology was used to estimate the post-release survival of 16 individual juvenile swordfish captured with standard recreational or buoy fishing gear and techniques in the southeast Florida swordfish fishery. Analysis of release mortality estimates was done using the "Release Mortality" Program. Five of the fourteen reporting tags showed a mortality within 48 hours, for a release mortality rate of 35.7%. However, no common thread could be found among the five mortalities. Results of the Release Mortality program indicated that if the true mortality rate was 35.7%, approximately 1800 tags would have to be deployed to increase the precision of the mortality estimates to +/- 5% of the true value. The nine surviving fish varied in straight-line distance traveled and in direction, and could withstand a wide range of temperatures. A deterministic, periodic model was developed to fit to the data and describe the fishes' habitat utilization. This model identified both diurnal and lunar signals in the data, confirming that juveniles do move vertically based on the daily cycle of the sun and the lunar cycle of the moon and that their diurnal movements are much greater than their lunar movements. The results of this study can be valuable to management practices in future stock assessments and decisions regarding mandatory release of undersized fish.

Keywords: juvenile swordfish, post-release survival, habitat utilization, pop-up satellite archival tags

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1.0 Introduction

1.1 Biology and Ecology

The swordfish, *Xiphias gladius* Linneaus 1858 (Figure 1), is a monogeneric species (Family: Xiphiidae) that diverged from the istiophorid billfishes (marlin, sailfish, spearfish) approximately 3 million years ago (Fierstein and Stringer 2007). It is a solitary, pelagic, oceanadromous species found in tropical, subtropical and temperate waters worldwide from 45°N to 45°S, in temperatures from 5-27°C, and can function at extreme pressures and temperatures (Palko et al. 1981; Carey 1982; Nakamura 1985; Van den Burg et al. 2005; Abid and Idrissi 2006). Swordfish inhabit epipelagic and mesopelagic water masses (NMFS 2006) in zones of high food production and where major ocean currents meet (Sakagawa 1989). In the western North Atlantic, the Gulf of Mexico and the Straits of Florida in the Gulf Stream are primary spawning grounds for swordfish (Arata Jr. 1954; Arnold Jr. 1955; Markle 1974; Beardsley 1978; Taylor and Murphy 1992; Arocha and Lee 1996). Juvenile swordfish were frequently caught in the pelagic longline fishery along the Atlantic coast of Florida (NMFS 2006) until the closure of the area to the fishery in 2001. Adults are primarily found in pelagic waters warmer than 18°C and as deep as 500 meters (m) in Florida, from the 100 m isobaths to the EEZ boundary (NMFS 1999, 2006). Thus, the Gulf Stream is a primary habitat for swordfish (Sedberry and Loefer 2001; NMFS 2006). Juveniles range in size from 120 to 177 centimeters (cm) measuring from the tip of the lower jaw to the fork in the tail, abbreviated as the lower jaw-fork length or LJFL (SCRS 2000; Arocha et al. 2003).[1]

Swordfish feed in mesopelagic waters during the day and epipelagic waters at night (Clarke et al. 1995; Chancollon et al. 2006). However, longline catches indicate swordfish feed more often at night at the depths easily accessible by the fishery (De Sylva 1974). Individuals prey upon fish, cephalopods and crustaceans (Palko et al. 1981; Nakamura 1985; Heemsoth 2009). Dietary composition and prey size change with increasing age and size and regional variability, showing high individual plasticity in

[1] The literature states that juveniles range in size from 120 to 177 cm LJFL and that size at first maturity ranges from 156 to 179 cm LJFL. While the terms juvenile and undersized are not synonymous, those terms are interchangeable for the purposes of this study. To avoid the question of whether or not a fish at or larger than 156 cm LJFL is mature, the maximum size for this study is 150 cm LJFL.

foraging behavior (Chancollon et al. 2006; Heemsoth 2009). Evidence of large prey items in the diet of swordfish is also consistent with a solitary foraging strategy (Palko et al. 1981).

1.2 Management

Swordfish fall under the category of Highly Migratory Species in Annex I of the 1982 United Nations Convention on the Law of the Sea (UNCLOS 1982). On an international level, Atlantic fisheries for HMS species are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). ICCAT defines three separate stocks of swordfish within its Convention Area: the Mediterranean Sea, the North Atlantic and the South Atlantic. Some studies suggest that a mixing of populations across the North and South Atlantic stocks may take place (Matsumoto et al. 2003) and that the North Atlantic stock could be separated into western and eastern stocks (Neilson et al. 2009). However, the North Atlantic stock is currently treated as one unit for management purposes and the two stocks are divided at 5°N, based on biological, genetic (Kotoulas et al. 1995; Bremer et al. 1996; Chow et al. 1997; Kasapidis et al. 2006; Kotoulas et al. 2006), and tagging studies (Abid and Idrissi 2006). In the United States, the Highly Migratory Species Management Division of the National Marine Fisheries Service (NMFS), under the direction of the Atlantic Tunas Convention Act (ATCA) and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), is responsible for the management of all HMS species. As required by ATCA, the HMS Management Division domestically implements ICCAT recommendations and the MSFCMA guides the development of domestic fishery management plans.

The Standing Committee on Research and Statistics (SCRS) is the scientific body of the ICCAT Commission. In 1990, the SCRS scientific consensus indicated that if the levels of swordfish mortality remained, the stock would decrease (Anonymous 1995). ICCAT therefore approved a 15% decrease in fishing mortality from the 1988 levels for the North Atlantic swordfish stock (Anonymous 1995). Knowing the fishing mortality rates is vital to these assessments. In 1991, the United States established a total allowable catch (TAC) for swordfish in attempts to reduce mortality (Matlock 1995). A stock assessment was conducted in 1996 indicating the stock was still considered overfished.

Based on this assessment and due to the large number of juveniles being caught, NMFS closed the waters off the east coast of Florida to commercial pelagic longline fishing in 2001 (NMFS 2000). As of 2009, the North Atlantic stock was considered rebuilt (SCRS 2009).

The 1999 Final Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks (NMFS 2006) outlines the two primary management measures in the recreational fishery for Atlantic HMS: minimum size limits and bag limits. ICCAT minimum size options for the entire Atlantic are: 125 cm LJFL with a 15% tolerance for undersized fish or 119 cm LJFL with zero tolerance and evaluation of the discards. The recreational retention limit was established in 2003; it is one swordfish per person or three per vessel per day, whichever is less, regardless of trip length. Owners of vessels landing swordfish in the recreational fishery are required to report their catches to NMFS within 24 hours. This applies to both private and charter (headboat) vessels, but not those participating in a NMFS-registered tournament. All reported recreational swordfish landings count against the incidental swordfish quota (NMFS 1999, 2006). The NMFS HMS Management Division monitors all swordfish tournaments by requiring organizers to register their tournament with the NMFS Recreational Billfish Survey Program (RBS Program). Although only a fraction of the registered tournaments should be then "selected" by the RBS Program for complete reporting of tournament landings and angler participation, all registered tournaments are "selected" for such reporting in practice.

New ICCAT recommendations and resolutions were adopted for the conservation of North Atlantic swordfish at the 2011 Commission meeting (Meski 2011). ICCAT recalled two previous recommendations, the Supplemental Recommendation by ICCAT to Amend the Rebuilding Program for North Atlantic Swordfish [Rec. 06-02] and the Recommendation by ICCAT for the Conservation of North Atlantic Swordfish [Rec. 10-02], and made the determination that the total catch for all North Atlantic swordfish for any one year during the management period (2012-2013) will not exceed the TAC set at 13,700 metric tons (mt). The United States annual catch limit has been set at 3907 mt for the two-year period, 2012-2013. The transfer of a limited percentage of the annual catch limits between ICCAT member countries is also allowed. In instances where the annual TAC is exceeded, individual countries responsible for exceeding their limit must "pay back" their overharvest by a reduction in catch limit in following years. These 2011 recommendations and resolutions replace those in the Recommendation by ICCAT for the Conservation of North Atlantic Swordfish [Rec. 10-02].

1.3 Tagging

Traditional tagging of HMS like swordfish has provided some information on movements and growth (Beckett 1974), but other options are needed to determine residence times, short-term movements (Sedberry and Loefer 2001) and post-release survival. Reporting rates with traditional tags from pelagic species are low, however (approximately 2%; see Beckett 1974; Jones and Prince 1998; Ortiz et al. 1998). Low tag return from these species could be due to one or more of the following causes: high mortality resulting from capture and tagging, high rate of tag shedding, fouling organisms covering the tag, failure to report tag recoveries, and faulty tag mechanisms (Jolley Jr. and Irby Jr. 1979; Bayley and Prince 1994; Jones and Prince 1998).

Acoustic tracking studies on other billfish (e.g., sailfish *Istiophorus platypterus* by Jolley Jr. and Irby Jr. 1979; black marlin *Istiompax indica* by Pepperell and Davis 1999) indicate relatively high post-release survival for several hours to a few days after tagging. Acoustic telemetry has been used for short-term movement and vertical migration studies of swordfish (Carey 1990), but such methods are only good for assessing behavior for 24-48 hours (Sedberry and Loefer 2001; Horodysky and Graves 2005). However, acoustic tracking methods are not effective tools for estimating long-term post-release mortality. This method is labor-intensive and requires real-time tracking from a research vessel or fixed listening stations (Carey and Robinson 1981). Because of the high cost of ship and personnel time, relatively few animals have been studied using acoustic telemetry methods, and the variables between individual studies make cross-study comparisons difficult (Graves et al. 2002).

Electronic archival tags have also been used to study swordfish (e.g., Holdsworth et al. 2007). Archival tags have helped to provide understanding of migrations, behavior patterns, and environmental preferences (Luo et al. 2008). Archival tags sample and archive temperature, depth, and light and bin the data. The light level data can often be used to estimate longitude and latitude (Wilson et al. 1992; Hill 1994; Hill and Braun

2001), but archival tags have not been very effective at determining swordfish location in previous projects. In the best scenarios, solely light-based geolocation estimates are only accurate to ±0.2 - 0.9 degrees longitude and ±0.6 - 4.4 degrees latitude (Welch and Eveson 1999, 2001; Schaefer and Fuller 2002). Scientists have tried to use sea surface temperature (SST) data to increase position estimate accuracy (Domeier et al. 2004; Nielsen et al. 2006), but this method is only useful in areas with a significant horizontal temperature gradient (Domeier et al. 2004; Nielsen et al. 2006), and nearshore SST values are often not as accurate as those in the open ocean (Pearce et al. 2006). Since these types of tags must also be returned to recover the data, and return rates in mark-recapture studies are only around 1%, they are very inefficient when studying swordfish movement (Holdsworth et al. 2007).

Pop-up satellite archival tags (PSATs) were developed in the late 1990s to track large pelagic fishes (Arnold and Dewar 2001; Gunn and Block 2001). These electronic tags can collect environmental and physiological data over several days, months, or even years (Arnold and Dewar 2001; Gunn and Block 2001). PSATs vary in the features they offer: number of functions (temperature, pressure, tag inclination, light level), deployment period or length, amount of and format in which they store data, the format in which the data is transmitted, emergency releases and programming, and cost (Kerstetter et al. 2003). They record a variety of ambient environmental data including temperature, pressure (later converted to depth), tag inclination, and light level (later used in geolocation estimation). The tags then detach at a pre-programmed time, float to the surface, and transmit the stored data to an Argos satellite. With each pass of the satellite, more position, temperature, and pressure information is transferred and transmitted to a ground station and then to the investigator via the internet (Sedberry and Loefer 2001; Graves et al. 2002; Graves et al. 2003; Kerstetter et al. 2003; Grusha and Patterson 2005; Kerstetter and Graves 2008; Kerstetter et al. 2008). Data transmits early if premature detachment occurs or there is a lack of vertical movement. Mechanical and software-based release mechanisms free the tag if it reaches a depth where it could be crushed (Grusha and Patterson 2005).

Some types of PSATs “bin” the data into user-programmed summary histograms. However, this feature does not allow for reconstruction of short-duration movements within each pre-determined time period (Graves et al. 2003; Kerstetter et al. 2008). Data retrieval can be limited by data compression compensating for low data transfer rates, finite battery life, and high transmission errors (Arnold and Dewar 2001; Gunn and Block 2001). However, recovery rates of the stored data through the Argos system are as good as 90% in some cases (Block et al. 1998; Lutcavage et al. 1999).

The size of the PSAT and the size of the animal must be considered: if the bioenergetic cost of "towing" the tag changes the animal's behavior or survival, the information gained is therefore not representative of an untagged animal (Grusha and Patterson 2005). These tags have been successfully deployed on bluefin tuna *Thunnus thynnus thynnus* (Block et al. 1998, 3-14 days and 60-90 days; Lutcavage et al. 1999; Block et al. 2001), swordfish (Sedberry and Loefer 2001), blue marlin *Makaira nigricans* (Graves et al. 2002, 5 days), white marlin *Kajikia albida* (Kerstetter and Graves 2006, 43 days), sailfish (Prince et al. 2006, 18 days), and escolar *Lepidocynium flavobrunneum* (Kerstetter et al. 2008, 14 days).

The use of PSATs allows a researcher to overcome limitations associated with acoustic, conventional, or PAT type tags. Rather than needing to physically track an animal or wait for the return of a tag (Kerstetter and Graves 2008), the tag automatically detaches from the fish and transmits the data through an orbiting satellite system. Data collection with archival tags may be fishery independent but the data retrieval is fishery-dependent in the sense that the scientist is dependent on the fishery to catch the fish and return the tag. With PSATs, both data collection and retrieval are fishery-independent (Block et al. 1998).

1.4 Study Summary

Using the PSAT technology of the X-Tag designed by Microwave Telemetry Inc. (Columbia, MD, USA), this project investigated two topics: the post-release survival rates of 16 individual juvenile swordfish (size range limits, 50-150 cm LJFL) after being captured with standard recreational rod-and-reel fishing gear or buoy gear and techniques and released in the Florida Straits, habitat utilization of juvenile swordfish after resuming normal behavior following release.

This type of tag collects individual data points on the temperature, pressure (converted to depth) and light levels of the surrounding environment every 90 seconds for 9.5 days following capture and release, allowing for a more detailed reconstruction of the vertical and horizontal profiles of these fish. The tag functions and size of the Microwave Telemetry Inc. HR X-tag model pop-up satellite archival tag are optimal for this kind of study (Figure 2). Swordfish are capable of carrying tags for several months; however, the swordfish in this study will be much smaller than previous studies. Other work has shown that smaller individuals of other species (e.g., striped bass *Morone saxitilis* in Graves et al. 2009) of similar size have successfully carried these tags. This model tag is small enough that it does not add a substantial amount of bioenergetic costs to the fish carrying it as to interfere with the fishes' natural behavior. Calculations of bioenergetic costs with tags of this size show that fish as small as 11.3 kg could carry this tag with a bioenergetic cost of < 10%, the commonly accepted threshold for changing behavior (Grusha and Patterson 2005).

While post-release survival and habitat utilization of adult swordfish have been evaluated with pop-up satellite archival tags (Sedberry and Loefer 2001, 43 days; Canese et al. 2008, 4-120 days), no similar studies on juvenile swordfish have been conducted. Swordfish are both a commercially and recreationally significant species. The current minimum retention size for swordfish (119 cm LJFL) is lower than the scientific estimates for size at first maturity (Arocha and Lee 1996, 179 cm; Mejuto and Garcia-Cortes 2007, 156 cm; data from Table 3 in Abid and Idrissi 2006), suggesting that some juveniles are being retained in the U.S. recreational fishery. Not all juveniles are undersized, but all undersized swordfish are juveniles. Therefore, it is also important to know the habitat utilization of this species at this life stage.

2.0 Chapter 1: Post-Release Survival

2.1 Introduction

The recreational swordfish fishery began in the 1920s as an incidental overnight fishery to daytime yellowfin tuna *Thunnus albacares* trips from Massachusetts to New York (De Sylva 1974; NMFS 2006). Fishing was mostly done by handline or rod and reel (NMFS 1999, 2006). Angling for swordfish was primarily a sport for the wealthy due to the high cost of travel, boat time, and equipment (De Sylva 1974). Many early descriptions of the recreational swordfish fishery (e.g., De Silva 1974, Beardsley and Conser 1981) considered swordfish to fall under the category of "billfish" or used the two words interchangeably, as the same wealthy anglers targeting swordfish opportunistically during the early years of the fishery were also targeting istiophorid billfishes. The billfish fishery as a whole expanded geographically and demographically after World War II due to increased leisure time and affluence, better and cheaper air travel, and newer and better gear, vessels, and angling techniques (De Sylva 1974; Beardsley and Conser 1981). Advances such as faster sportfishing vessels, electronic navigation and depth-finding gear, and improved tackle increased the efficiency of fishing for swordfish. By the 1960s, about 50 swordfish were caught annually with rod-and-reel recreational fishing gear (NMFS 1999). Most fishing was done during the day and targeted large swordfish basking at the surface (Levesque and Kerstetter 2007).

The popularity of recreationally targeting swordfish grew in areas such as Florida, the Bahamas, and southern California (De Sylva 1974). Around 1976, it evolved into a year-round recreational rod-and-reel fishery off Florida with fishermen attracting swordfish with live or dead bait (NMFS 1999, 2006). Swordfish anglers began using gear and techniques adopted from Cuban pelagic longline fishermen and istiophorid billfish recreational fishermen; drifting baited lines at various depths at night (Levesque and Kerstetter 2007). The first recorded swordfish caught at night by a recreational fisherman were landed in Miami, FL in 1976 (Dunaway 1976). The world's first night-time swordfish tournament was held in Miami, FL in 1977; 27 vessels landed 86 swordfish (Levesque and Kerstetter 2007). Fishing success increased with this technique (25-30 swordfish were landed in 1976, while 400-500 were landed in 1977) and its use spread into the Gulf of Mexico and Atlantic coasts of the United States (Beardsley and Conser 1981; NMFS 1999, 2006). In the early 1980s, there were a large number of big-game fishing tournaments throughout the western North Atlantic Ocean and the Gulf of Mexico (Beardsley and Conser 1981). However, with a combination of declining catch rates and an increase in commercial fishing effort, the popularity of fishing for swordfish decreased in the early 1980s. The last swordfish tournament in southeast Florida during the early period of the fishery was held in 1983; no swordfish were landed at this event (NMFS 1999, 2006; Levesque and Kerstetter 2007).

While the recreational swordfish fishery has declined dramatically in the past twenty years, it is rebuilding off the east coast of Florida (NMFS 1999, 2006). The first tournament since 1983 was held in 2001 in Fort Lauderdale. Three fish were landed and twelve more released (Leech 2007). Three more tournaments were held in 2002 off the southeast coast of Florida (Levesque and Kerstetter 2007). As of 2007, the United States was one of only three (including Venezuela and New Zealand) nations to have a well-established recreational swordfish fishery (Levesque and Kerstetter 2007), although other locations (e.g., the Azores and the Cayman Islands) have since developed fisheries. Swordfish are still mainly recreationally targeted by anglers using rod-and-reel gear (NMFS 1999, 2006). Common billfish bait includes mullet, bonefish, balao, ballyhoo, mackerel, barracuda, dolphin, rainbow runner, jacks, tuna, bonito, squid, and flyingfish. Artificial bait includes rubber squids, sauries, mackerel, bonito, halfbeaks, and eels (De Sylva 1974). The amount of moonlight is thought to affect catch rates, with the best fishing considered to be on the brightest nights. A review of the former commercial pelagic longline fishery in the Florida Straits found a significant positive relationship between moon illumination and targeted fishing depth (Lerner et al. *in review*)[2]. A strong north or northeast wind is also thought to negatively affect catch rates in southeast Florida; local anglers prefer a light south or southeast wind (Levesque and Kerstetter 2007). In 2003, a Highly Migratory Species (HMS) Angling permit became a requirement to recreationally target any HMS species, including swordfish (NMFS 2006).

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[2] Lerner JD, Kerstetter DW, Prince ED, Talaue-McManus L, Orbesen ES, Mariano A, Snodgrass D, Thomas GL. Swordfish *Xiphias gladius* vertical distribution and habitat use in relation to diel and lunar cycles in the western North Atlantic. In review, Transactions of the American Fisheries Society.

The swordfish buoy gear (SBG) fishery originated around 2000 as an alternative to the closed pelagic long-line fishery in east coast Florida waters. This gear employs a J-hook attached to a 150-200 m length of monofilament (or braided nylon mainline) which is then attached to a large lighted inflatable float or a "hi-flyer" radar-reflecting buoy. This addition allows the gear to be monitored by the vessel during the nighttime fishing operations. Vessels can successfully deploy and monitor up to fifteen of these individual pieces, although the number deployed varies between vessels (pers. comm., D. Kerstetter). This set-up is deployed as an individual piece of gear; as such, each piece is believed to function more like a small, individual, segment of pelagic longline gear. SBG is currently classified as "handgear" under federal regulations, permitting the use of J-style hooks. SBG may prove to be an enticing alternative to pelagic longline gear for directed swordfish permit holders in Florida, given the rise in fuel costs of traveling great distances to reach open fishing grounds and the increased pressure on those fishing grounds.

The United States has long been an advocate for the release of small swordfish during international management discussions. Domestically, any swordfish that cannot be landed because of fishery regulations must be released (NMFS 2010). However, these juveniles need a reasonable probability that they will survive the catch-and-release experience for this management measure to be effective. Implementing recreational fishing methods with the lowest post-release mortality rates for swordfish under the minimum size limit is beneficial to both recreational and commercial fisheries. Despite the evidence of post-release survival of other large pelagic species (Graves et al. 2002; Kerstetter et al. 2003; Kerstetter and Graves 2008), international pelagic longline fisheries are resistant to accepting management practices requiring the release of live undersized swordfish. Implementing those management practices would mean less money to the fisheries and most individual fishers do not believe that small swordfish survive the release (D. Kerstetter, pers. comm.).

2.2 Materials and Methods

2.2.1 Tagging

Tagging was conducted as swordfish became available, during nighttime, aboard pre-arranged volunteer recreational rod-and-reel and commercial swordfish buoy gear fishing vessels in the Florida Straits. Tagging efforts were concentrated in U.S. federal waters (>3 nm from shore) from Marathon in the Florida Keys north to West Palm Beach. A total of sixteen tags were deployed, nine on swordfish caught by buoy gear and seven on swordfish caught by recreational rod-and-reel gear. Thirty-nine recreational fishing trips and three buoy fishing trips were conducted.

The fishing procedure was what is considered the “normal” fishing manner for recreational and buoy fishing vessels targeting swordfish. The “normal” fishing manner for recreational vessels is that in which vessels drift rod-and reel fishing gear from a single boat at multiple depths from sunset to after midnight (Levesque and Kerstetter 2007). The “normal” fishing manner for buoy vessels is that in which vessels deploy several individual buoys connected to a baited hook by monofilament approximately 150-200m long (Kerstetter and Bayse 2009). Bait was either dead squid or live or dead fish. The terminal tackle was an offset J-style hook ranging in size from 8/0 to 11/0.

Only live swordfish with a lower jaw fork length between 50 and 150 cm (19.7 to 59.1 inches) scoring higher than a 2 on a modified “ACESS” condition scale were eligible for tagging. All fish tagged in this study scored a nine or higher on the scale. The modified “ACESS” scale (see Kerstetter et al. 2003) was used to quickly evaluate the condition of the fish prior to tagging. The scale contains six different characteristics of a fish (activity, color, condition of the eyes, stomach eversion, general state of body musculature, and level of bleeding) and for each category a value of 0, 1, or 2 is assigned. A fish can score a maximum value of 12, indicating little damage and most likely survival, or a minimum value of 0, indicating severe damage and suggesting likely death (Kerstetter et al. 2003; Kerstetter and Graves 2006; Kerstetter et al. 2011). This method of evaluating the candidacy of a swordfish for tagging was implemented to qualitatively asses the fishes’ likelihood of survival and to remove assumptions or biases on the part of the researcher. The standard for determining live or dead was a lack of movement per Falterman and Graves (2002).

The fish were not removed from the water for tagging, rather they were held along side the vessel until calm. Each tag had an attachment leader with a modified tag head with “wings” of hydroscopic nylon (Figure 3). Activation of the tag was done by removing the magnet from the tag a minimum five minutes prior to attachment (Microwave Telemetry 2010). It was then inserted 5 cm below the midpoint of the anterior dorsal fin approximately 10-15 cm deep using a tagging applicator; this technique locks the wings in place behind the pterygiophore bones securing the tag. When possible, an additional NMFS streamer tag was attached posterior of the PSAT helping to further identify the fish to anglers as a research subject. When the hook was easily accessible, it was removed. If not, the leader was cut near the hook and the fish was released with the hook remaining in the animal. Additional data was collected on the following parameters: fish lengths, estimated weights, hooking location on the animal, time of day, geographic location, and surface water temperature. Once the fish was brought to the boat, the entire procedure lasted approximately two minutes.

To characterize the catch composition and disposition of the catch and bycatch, scientific personnel were aboard each recreational swordfish fishing trip and buoy fishing trip to record catch and bycatch information during the project. However, little empirical information is available on the catch composition of the recreational swordfish fishery. Therefore, standardized datasheets were created and used to obtain trip, environmental, gear, effort, and catch data (Appendix A).

The tag used was a Microwave Telemetry, Inc. (Columbia, MD, USA) HR X-Tag pop-up satellite archival tag. It weighs 40 grams, is 12 cm by 3.2 cm in size, and can sustain pressures up to 2500 m in depth. The tag sensors collected individual data readings of temperature, pressure (depth) and light levels. They were programmed to collect the data every 90 seconds and release from the fish after 9.5 days. Data was then transmitted to an Argos satellite using trademarked SiV technology that transmits only when a satellite is in view and able to receive transmissions, thereby saving the internal tag battery power and increasing data recovery rates. The data files were then retrieved from the Argos satellite and sent to the manufacturer, which decodes the raw data from transmitted hexadecimal code before sending it to the end-user scientist (Microwave Telemetry 2010).

The tags were programmed to detach in 9.5 days. The number of days for this study was determined based on previous research. Conventional tag recaptures of billfish a few days following release demonstrate a return to feeding behavior (Kerstetter and Graves 2008). Deployment period ranging from 5 to 10 days are considered appropriate when studying post-release mortality of billfishes; studies on blue, white, and striped marlin all suggest that if a mortality occurs, it happens within a few hours of tagging (Block et al. 1992; Brill et al. 1993; Kerstetter et al. 2004; Horodysky and Graves 2005) and most mortalities occur within 144 hours of release (Domeier et al. 2003; Horodysky and Graves 2005; Kerstetter and Graves 2006). Longer deployment periods increase chances of natural or fishing mortality, or tag malfunction or damage (Goodyear 2002; Kerstetter et al. 2004). Also, there is a direct and negative, relationship between data resolution and deployment length due in large part to limited data transmission capability through the satellite system (P. Howey, Microwave Telemetry, Inc., pers. comm.).

2.2.2 Data Analysis

Previous post-release survival studies with istiophorid billfish have used water temperature changes, depth utilization profiles, and net displacement distance to successfully infer survival of the tagged billfish (Kerstetter et al. 2003; Horodysky and Graves 2005; Kerstetter and Graves 2008). The same three attributes were used in this study. Temperature, depth and light data were retrieved from the tags by downloading the data from the ARGOS satellite system. Net displacement distance was calculated as the distance between the release location and the location of the first "good" transmission to the ARGOS satellite system (Horodysky et al. 2007; Kerstetter et al. 2008). Locations of transmitting tags are determined through a Doppler shift in the signal and labeled by Argos with a location accuracy code; "good" locations are those with an accuracy code of 1, 2, or 3[3]. In cases where the first transmission was not given a good accuracy code, the next transmission within the first three hours to be given a good accuracy code was used

[3] The precision of location estimates is based on the attitude of the receiving satellite, with transmissions through the ARGOS system categorized into seven location accuracy codes. Locations are considered "good" if the ARGOS system reported an accuracy code within 250 meters (code 3), 500 meters (code 2) or 1500 meters (code 1).

instead (Collecte Localisation Satellites 2010). Straight-line distances were calculated using Google Earth software (Google Inc. 2012).

Bootstrapping simulations were conducted using RELEASE MORTALITY to examine the effects of the low sample size on the estimated 90% confidence intervals of the release mortality estimates (Goodyear 2002; Horodysky and Graves 2005). Since it is unclear how mortality caused by the tagging experience might be separated from mortality caused by the catch-and-release experience, that variable was not included in the analysis. A total of 10,000 simulations were conducted (per Horodysky and Graves 2005). The "release mortality fraction" was determined by dividing the number of fish that died within 48 hours of release by the total number of fish tagged and released. The "days to full expression" was the number of days of tag deployment (9.5 days). The number of tags included in these simulations was 14 and the programmed pop-off day was the length of the tag deployment (9.5 days). Tag shedding and tag failure can bias the release mortality estimates upward. Due to the short duration of tagging deployment, tag failure, tag shedding, and natural mortality assumed to be unlikely to occur and were given a value of zero. The simulations started with the actual number of tags deployed in the study, the number was then exponentially increased, and the 90% confidence interval (the 5^{th} and 95^{th} percentile values) were plotted until the values were +/- 5% of the initial assumed true value.

There were two tag failures out of the 16 tags that were deployed. These tags were completely removed from the analysis based on the rationale of Goodyear (2002): "If the actual level of release mortality is low and the assumption is made that tag failures represent fish deaths, this can lead to overestimating the release mortality rate." This bias is completely removed when the tags that failed to report are eliminated from the analysis.

2.3 Results

In Figure 4, the data that was retrieved from each reporting tag is plotted, showing the vertical movement profile (depth) over time. Five out of the 14 fish whose tags reported died within about a day of tagging (Fig 4a-d, k; Table 1). Nine out of the 14 fish survived the full 9.5 days (Fig 4e-j, l-n; Table 1). The ratio of tags deployed versus number of tags that provided significant data in this study is comparable to or better than other similar studies (Matsumoto et al. 2003; Loefer et al. 2007; Canese et al. 2008; Neilson et al. 2009; Dewar et al. 2011).

The results of the Release Mortality program are presented in Figure 5, which shows the 5th and 95th percentile values plotted for each increase of the sample size. The true value, or release mortality fraction, is indicated by the middle, horizontal, dashed line. The upper and lower dashed horizontal lines indicate the 5th and 95th percentile values of the actual release mortality value for the given sample size (x axis values). The point at which the 5th and 95th percentile values are within +/- 5% of the true value determines the number of tags required to achieve a 90% probability that the estimate will be within +/- 5% of the true release mortality, assuming that no tags fail, no tags are shed, there is no tagging induced mortality, and no natural mortality occurs. By increasing the sample size, the estimate becomes more precise. With this model, the results of 10,000 simulated experiments with a true mortality rate of 35.7% indicated that approximate 90% confidence intervals for mortality estimates for an experiment deploying 14 tags on juvenile swordfish range from 14.3% to 57.1%, assuming that no tags fail, no tags are shed, there is no tagging induced mortality, and no natural mortality occurs.

2.4 Discussion

Two of the tags released on fish caught on recreational rod-and-reel gear did not report. This is not an uncommon occurrence and has been seen in other studies (Sedberry and Loefer 2001; Dewar and Polovina 2005; Holdsworth et al. 2007; Loefer et al. 2007). Failure to report can be the result of the tag antenna being damaged and therefore not able to communicate with the satellite. The tag could also become lodged underneath structure (including dense mats of floating *Sargassum)*, keeping it from reaching the surface prior to the depletion of the battery. The fish and the tag could have been consumed by a predator, destroying the tag. The fish could have also been captured by someone unfamiliar with tags that chose to keep the tag somewhere where it cannot transmit; since the tags require a seawater ground for transmission, even keeping a tag dry on a vessel cockpit would preclude reporting. Without the data from those tags, the fate of those two fish cannot be determined, and they were excluded from all analyses so as not to introduce a bias into the study.

Vertical profiles for the five fish that died during the study are presented in Figure 4. The fish in Figure 4a died within 6 hours of the catch, tag and release experience. This is a small enough window to speculate that death was related or due to the stress caused by that experience. This was the smallest fish seen throughout the study, measuring only 85 cm (LJFL) and caught on manual rod-and-reel gear (Table 1). This fish was not hooked, but wrapped in the lines of at least two rods for an undeterminable amount of time. It was only during haul-back that it was noticed that the fish was wrapped in the lines. The fish was determined to be in good enough condition to be included in the study, based on the ACESS scale. A few factors can be attributed to this fish's death. The fish was presumably unable to move about for a period of time, and it possibly was not in good enough condition to endure the stress of the catch, tag and release process (signs of which were not evident based on the ACESS scale).

In comparison, the fish in Figure 4b was the largest fish seen during the study, measuring 129 cm (LJFL). It was also caught on rod-and-reel. This fish only fought for 25 minutes and was tagged and released within two minutes. It was hooked in the jaw and the hook was removed. According to the ACESS scale, it was deemed viable enough to be included in the study. This fish survived for only 28 hours after release. The window between the tagging event and death is small enough that the stress of the tagging even could be the cause of death. However, not knowing what the fish experienced before or after the event, one can only speculate the true cause of death. All that is known for certain is that it exhibited abnormal behavior and died.

The fish represented in Figures 4c and 4d died immediately after the catch, tag and release experience. The fish represented in Figure 4k survived for approximately 24 hours after the catch, tag and release experience. All of these fish were caught on buoy gear, were approximately the same size, hooked in the jaw, and the hook was removed. All three of these fish also shared one other common factor, tagging outcome. The tag head and tether went through the fish with the tag head visible on the other side, a term referred to as "buttonholed" colloquially. The fish in Figure 4c went momentarily slack. Given this information, it is possibly a tagging related death. It is believed that the spine of the fish in Figure 4d may have been hit during tagging. This observation is based on the tagger being able to feel strong resistance when inserting the tag (that resistance most likely being bone) and a full body shudder from the fish at that moment. Based on the field observations, and the resulting data, it is also possible that this is a tagging related death. The fish in Figure 4k did not cease movement at any time, nor did it get hit in the spine and shudder. It also survived for a full day before dying. However, it was buttonholed during tagging. So while the fish in Figure 4k could have been preyed upon, it was showing abnormal behavior after being released and it was buttonholed during tagging. That may be the common thread to explain all three deaths.

Successful, complete deployments were achieved for nine of the tagged and released fish (Fig. 4e-j, l-n; Table 1). They were all tagged between June and December, and caught with both types of gear. Sizes ranged from 90 cm to 121 cm (LJFL). Hooking varied between dorsal fin, jaw, gut, and being wrapped in the line. In each case the hook was removed, except for the gut hook that was left in. Hook sizes ranged between 8/0 and 11/0, and fight time ranged between 5 and 18 minutes. When considering all parameters of the catch, tag and release experience, there is no clear common factor to explain the successful survival of these fish compared to the ones that died (Table 1).

Based on the data collected at the time of each tagging, it seems that all fish tagged in this study experienced similar conditions during the catch, tag and release experience (Table 1). There is no clear category in Table 1 that explains the cause of deaths or the survivals. The only common thread is a unique event during all but one of the tagging experiences that resulted in death. For one fish, it was being wrapped in fishing line and presumably not permitted to move and get enough oxygen flow. For three other fish, they all shared the common factor of being buttonholed. One of those same fish was mostly likely hit in the spine with the tagging applicator. Another of those same fish went momentarily slack during tagging. Conversely, while "buttonholing" those fish may have led to those deaths, there were two more fish that were buttonholed and survived the full deployment. Two fish were deemed in need of resuscitation by the scientist and captain; this determination was made if the fish showed little to no aggressive movement after tagging. Of the fish that were deemed in need of resuscitation, those that were resuscitated survived.

While each fish did not have the same experience, they each suffered a unique event that could explain their death. This holds true for all but one of the fish that died (Fig. 4b). This was the largest fish tagged in the study at 129 cm LJFL. It was caught on rod-and-reel, jaw hooked, the hook was removed, the hook was size 9/0, and it fought for 25 minutes. The only factor that may explain the fish's death is: this fish had the longest fight time of all fish in the study. Adult swordfish are known to fight for hours, and the cause of mortality resulting from a long fight time is that their weakened state increases the probability of becoming prey. However, it is highly unlikely that a fight time of 25 minutes resulted in the fish being in such a weakened state that it did not survive. Considering nothing is known about its experiences and behavior prior to tagging, no concrete determination can be made.

Results of the Release Mortality program indicated that if the true mortality rate was 35.7%, approximately 1800 tags would have to be deployed to increase the precision of the mortality estimates to +/- 5% of the true value (Figure 5). Conducting an experiment on that scale is currently not plausible, given the costs of the tags and the immense effort required to deploy them. However, conducting these simulations can help to improve the estimates of total removals, which can subsequently be reflected in more accurate stock assessments (Goodyear 2002; Horodysky and Graves 2005).

In this particular use of the Release Mortality modeling tool, tag shedding, tag failure and natural mortality were assumed to be zero due to the short duration of the tag deployment. However, all three of these variables are likely to increase with a longer tag deployment and can all bias the release mortality estimate upward. Since there is no positive, efficient way to confirm a tag shedding, tag failure, or even natural mortality event in connection with a non-reporting tag, it is difficult to account for those in the model. Tag failures generate ambiguous results and should be minimized or eliminated from the analysis. To minimize the occurrence of these scenarios, it is recommended to set the duration of tag deployment no longer than required for the majority of mortality instances to be fully expresses when estimating release mortality rates (Goodyear 2002).

While this model is useful when estimating total removals from a population, there are some assumptions. Each tagged fish is assumed to have the same probability of dying due to the catch-and-release experience. In reality, many other variables factor into the probability of death from catch-and-release: species, size of the fish, type of gear, type of hook, type of bait, skill level of the fishermen and captains, and environmental conditions (Goodyear 2002). When designing a study, the researcher can control some of these variables (species, size of fish, type of gear, type of hook, type of bait), but some of the variables remain somewhat uncontrollable (skill level of the fishermen and captains, environmental conditions). When using this model, it is important to keep in mind the uncontrollable variables of fishing and how those variables may affect the release mortality fraction.

3.0 Chapter 2: Habitat Utilization

3.1 Introduction

Studies show North Atlantic swordfish exhibit three generalized migration patterns varying in distance and direction. They have been documented migrating northeastward in the summer and southwestward in the autumn, following the major currents in the North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico (Mather et al. 1975; Palko et al. 1981; NMFS 2006). Swordfish migrate westward toward the continental shelf in the summer and eastward into deeper water in the autumn (Palko et al. 1981). They also exhibit diurnal movement patterns, spending the daylight hours at depths between 200 and 800 m and the nighttime hours between 0 and 160 m, presumably following prey abundance and distribution (Palko et al. 1981; Sedberry and Loefer 2001; Matsumoto et al. 2003; Takahashi et al. 2003; Dewar and Polovina 2005; Loefer et al. 2007; Canese et al. 2008; Abascal et al. 2010; Sepulveda et al. 2010; Dewar et al. 2011). This diurnal movement can be referred to as an inverted U-shaped pattern of the depth distribution as their primary habitat is at depth. The deepest depth ever personally observed was by G.R. Harbison in the Bahamas in 1984, who encountered a swordfish at 628 m from a submersible (described in Harbison and Janssen 1987), although records of deeper depths have been obtained from archival tagging (e.g., 1448 m by Lerner 2009).

While previous research techniques have provided information on short-term movements, migrations, and behavior patterns, there is still a need for additional tagging studies with "second generation" tags with depth and light data and increased memory that will further define the activity patterns and migratory behavior of swordfish in the North Atlantic (Sedberry and Loefer 2001). PSATs have been successfully used on other large pelagic fishes (Block et al. 2001; Horodysky et al. 2007; Kerstetter et al. 2008), but have yet to be used on juvenile swordfish. Swordfish exhibit different habitat utilization and vertical movements than other large pelagic species, warranting a study of this nature.

The type of tag being used in this study does not "bin" the data as seen in previously used PSATs (e.g. Kerstetter et al. 2008, Graves et al. 2003), rather it logs individual linear data points (Figure 6) allowing for a more thorough profile of the swordfish's behavior and habitat preferences (Microwave Telemetry 2010). This type of data output directly leads to a more detailed description of swordfish behavior patterns. This is an increasingly important aspect of stock assessment modeling; more models are incorporating habitat preference data and this data can provide an experimentally-generated estimate of the recreational fishing mortality of juveniles.

3.2 Materials and Methods

3.2.1 Tagging[4]

Tagging was conducted as swordfish became available, at night, aboard pre-determined volunteer recreational and buoy fishing vessels in the Florida Straits. The tag used was a Microwave Telemetry, Inc. HR X-Tag pop-up satellite archival tag. Fishing procedure was what is considered the "normal" fishing manner for recreation and buoy fishing vessels targeting swordfish. Only live swordfish with a lower jaw fork length between 50 and 150 cm (19.7 to 59.1 inches) scoring higher than a 2 on the "ACESS" condition scale were tagged. The standard for determining live or dead was a lack of movement per Falterman and Graves (2002). The fish were not removed from the water for tagging, rather they were held along side the vessel until calm. Each tag had an attachment leader with a modified tag head with "wings" of hydroscopic nylon (Figure 3). Activation of the tag was done by removing the magnet from the tag a minimum five minutes prior to attachment (Microwave Telemetry 2010). It was then inserted 5 cm below the midpoint of the anterior dorsal fin approximately 10-15 cm deep using a tagging applicator; this technique locks the wings in place behind the pterygiophore bones securing the tag. When possible, an additional NMFS streamer tag was attached posterior of the PSAT helping to further identify the fish to anglers as a research subject.

The tags were programmed to detach in 9.5 days. When the hook was easily accessible, it was removed. If not, the leader was cut near the hook and the fish was released with the hook remaining in the animal. Additional data was collected on the following parameters: fish lengths, estimated weights, hooking location on the animal,

[4] The Materials and Methods, Tagging section in Chapter 2 is a condensed version of the same section in Chapter 1. This work will be submitted as two separate manuscripts for publication. Please refer to the same section in Chapter 1 for more information.

time of day, geographic location and surface water temperature. Net movement was estimated by determining the straight-line distance from the tagging location to the first location of reliable data transmission (Horodysky et al. 2007; Kerstetter et al. 2008) (Figure 7). These data were used to analyze behavioral interactions with the fishing gear, such as habitat utilization patterns. Data gathered by this study were also compared with other published descriptions of swordfish behavior for constancy.

3.2.2 Data Analysis

To analyze the habitat utilization patterns, a deterministic, periodic model has been developed to fit to the data. The model was validated using adult swordfish and sailfish data and fits a line to the data elucidating any diurnal and lunar signals (Figures 8-9). This model has for amplitude parameters, two each for the diurnal and lunar cycles, and a mean depth value (Equation 1). The amplitude of the diurnal signal is calculated from amplitude parameters 1 and 2 (Equation 2). The amplitude of the lunar signal is calculated from amplitude parameters 3 and 4 (Equation 3). When ***dep_t*** (Equation 1) is calculated for every time value and plotted with the time values, the resulting fit line shows the diurnal and lunar signals within the data. The model was constructed using Matlab R2006a (The MathWorks Inc. 2006). The time values were converted from the format Month/Day/Year, Hour:Minute:Second to decimal fractions of a day (i.e., 1.2 days from the start). The depth values were mathematically manipulated to be depth deviations from the mean.

Prior to using Equation 1, the amplitude parameters for the diurnal cycle (c1, c2, Equation 4) were calculated. This calculation was done for each time value, the end result being a matrix with two values in each row, and the number of rows equal to the number of time values in the data set. The least square regression command was applied to the data (Equation 5), producing two coefficient values that are the amplitude parameters for the diurnal cycle. Those coefficients were then used in Equation 6. That equation calculates ***dep_t*** for every time value. This gives the depth values that, when plotted with the time, give the diurnal signal. Equation 7 calculates the residual values. For every depth deviation value associated with a time value, removing the fit value (calculated from Equation 6) gives the residual value. This step removes this fit from the depth deviations to form a depth residual data set, thus allowing one to then look for patterns (i.e. a lunar cycle) in the residual data set. The same steps are then followed to calculate the coefficients (amplitude parameters) c3 and c4 for the lunar cycle from the residual data set (using Equation 8, then Equation 5). Once all four coefficients are calculated, they are entered into Equation 1. This equation calculates a ***dep_t*** value for every time value. Equation 7 is repeated, removing the fit values from the depth values to calculate the residual values from the model (to be used in further calculations). When the ***dep_t*** values are plotted with the time values and the original depth data, the resulting fit line shows the diurnal and lunar signals in the data (Figure 10).

dep_t = = c1*cos(omeg1*t(i)) + c2*sin(omeg1*t(i)) + c3*cos(omeg2*t(i)) + c4*sin(omeg2*t(i)) + c5 (1)

where: cos is cosine (periodic function)

sin is sine (periodic function)

t(i) is the 1^{st} value through the n^{th} value of t

omeg1 is angular frequency of the diurnal cycle ($\omega=2\prod/T$ where T = 1)

omeg2 is angular frequency of the lunar cycle ($\omega=2\prod/T$ where T = 28)

c1, c2, c3, and c4 represent the amplitude parameters of the diurnal (c1 & c2) and lunar (c3 & c4) cycles

c5 is the mean depth value

$$p1 = \sqrt{(c1^2 + c2^2)} \quad (2)$$

$$p2 = \sqrt{(c3^2 + c4^2)} \quad (3)$$

X = [cos(omeg1*t(i)) sin(omeg1*t(i))] (4)

x = lscov(A,b) (5)

dep_t = c1*cos(omeg1*t(i)) + c2*sin(omeg1*t(i)) (6)

res_t = dep_dev(i) - dep_t (7)

X = [cos(omeg2*t(i)) sin(omeg2*t(i))] (8)

The correlation between the fishes' movements was also analyzed. Theoretically, as time passes, there is less correlation between events, and is quantified by the integral time scale. The integral time scale is defined to be the integral of the correlation function over all positive temporal lags. This value is, relative to the fit, a measure of time (in hours) in which motion is correlated. The residual values calculated from Equation 1 in the model were used to calculate the integral time scale. These values were averaged in one-hour bins and an input matrix was created, where the rows represented days and the columns represented the hourly bins. In cases where gaps in the data were present, the available data was used to interpolate the missing values. A covariance matrix, which calculates the sample variance of the values of a matrix, was calculated for the input matrix using the Matlab command "nancov". The variance of the data about the trend at hours 0 through 12 (S_h) was calculated from the covariance matrix data (Equation 9). Each of these values was then divided by S_0 to calculate the autocorrelation value at each hour lag. Twice the integral time scale is a measure of the time for auto-correlated events to become independent. Estimates of the correlation function at discrete lags, tau, were calculated from residual depths using the best-fit harmonic model as the mean depth. A general three parameter correlation, form ***C(1)cos(2 PI tau/C(2))exp-(tau^2/C(3)^2)***, was fit to the correlation estimates by minimizing the mean-square fitting error using a brute force method. The integral time scale was calculated by integrating this best fit correlation function (see Garraffo et al. 2001 for details). These steps were carried out for every full deployment record. The integral time scale values were plotted against size, diurnal and lunar amplitude, mean depth, moon phase, and month of the year to determine a correlation. Diurnal and lunar amplitude, mean depth, moon phase, and month of the year were also plotted against individual fish size (Figure 11).

$$\Sigma X_{ij}/n = S_h \qquad \textbf{(9)}$$

where h=0:12 and

at hour 0: i=1:24, j=1:24, n=24

at hour 1: i=1:23, j=2:24, n=23

at hour 2: i=1:22, j=3:24, n=22

at hour 3: i=1:21, j=4:24, n=21

at hour 4: i=1:20, j=5:24, n=20

at hour 5: i=1:19, j=6:24, n=19

at hour 6: i=1:18, j=7:24, n=18

at hour 7: i=1:17, j=8:24, n=17

at hour 8: i=1:16, j=9:24, n=16

at hour 9: i=1:15, j=10:24, n=15

at hour 10: i=1:14, j=11:24, n=14

at hour 11: i=1:13, j=12:24, n=13

at hour 12: i=1:12, j=13:24, n=12

The depth over time profile was also plotted over temperature data collected from the tags from fish that survived release (Figure 12). The data from the two fish that died immediately are not included as their temperature data did not reflect survival and movement. The temperature data was binned in 30 minute and 5 m depth increments and structured in a matrix format, with the rows representing depth and the columns representing half-hour bins. The temperature data for the entire length of the deployment was interpolated from the temperature data given, and plotted with the depth and time data (original Matlab code courtesy of A. Bever, Virginia Institute of Marine Science, pers. comm.).

Two additional summary figures were created. Figure 13 is in 3D format, showing the mean, diurnal, and lunar amplitude values calculated by the model and the integral time scale values for each tag that reported data from a surviving swordfish (the two that died immediately are not plotted). The three markers without a paired integral time scale value represent the three fish that died within a day of being released, no correlation data could be ascertained from those short records. Figure 14 shows the diurnal and lunar amplitude around the mean for each surviving swordfish (the two that died immediately are not plotted).

Testing of the model with adult swordfish and sailfish data validated the model's output (Figures 8-9). The adult swordfish data used to test the model were shared from previous work by Lerner (2009). The tags used in that study were Mk10 PAT tags, programmed at a 30 second sampling interval and 1 hour bins, so the data points plotted are hourly binned data. The data is uneven in time, so the plot of the fit to the data is not purely periodic. The tagging was done in the Florida Straits. The adult sailfish data used to test the model were shared from Kerstetter et al. (2008, 2011). The tags used in that study were PTT 100 HR tags, programmed at a 95 second sampling interval, giving a 10 day record. The tagging was done in the Southeast Gulf of Mexico and the Florida Straits.

By conducting a sensitivity analysis with five sets of data from each species, it was determined that by removing the upper 20 m data points from the juvenile swordfish files and the 0 m data points from the sailfish files, a better, more enhanced periodic signal could be extracted from the data (Table 2). A sensitivity analysis evaluates how the output changes when the input is changed; in this case, it is how the diurnal and lunar signals and mean value change when a certain section of the input data is removed. The analysis was run for the following scenarios for sailfish: case 1= includes all data, case 2 = without 0 meter data, case 3 = without 0-5 meter data. The analysis was run for the following scenarios for swordfish: case 1= includes all data, case 4 = without 0-10 meter data, case 5 = without 0-20 meter data.

The 0-5 m data in the sailfish files composes an average of 63.65% of the data, while the 0 m data alone composes an average of 33.87% of the data. Removing 63.65% of the sailfish data could weaken the accuracy of the results from the model. However, the periodic signal in the sailfish data can be enhanced when the 0 m data is removed as compared to using the full data set. Based on those two observations, the decision was made to remove the 0 m data from the sailfish files when evaluating the vertical behavior with the model. The 0-10 m data in the swordfish files composes an average of 5.44% of the data, while the 0-20 m data composes an average of 12.63% of the data. The removal of the 0-30 m data was investigated, however, that would be a 16.37% removal of data, possibly weakening the accuracy of the results from the model, and was therefore considered not a reliable option. The periodic signal in the swordfish data is enhanced when the 0-10 m data is removed and when the 0-20 m data is removed; the difference in the fitting error values obtained from the model in either scenario is less than 10%. By removing the 0-20 m data points (only 12.63% of the data) the surface is not over-sampled, thus leading to larger lunar amplitudes. Based on these observations, the decision was made to remove the 0-20 m data from the swordfish files when evaluating the vertical behavior with the model.

3.3 Results

In this study, forty-two trips were conducted using recreational rod and reel gear and buoy gear from August 2010 to January 2012. A total of 16 tags were deployed on juvenile swordfish in the Florida Straits. All tagged fish were caught (and released in the same location) off the coast of South Florida, on the Florida shelf between Miami and Jupiter (Figure 7). Sizes ranged from 85 cm to 129 cm LJFL. Two fish died immediately, three showed erratic behaviors and died shortly after release, two tags never reported, and nine carried the tag for the full 9.5 days (Table 1). Results from several trips were no activity or only catching sharks.

Figures created from the model for all reporting tags on fish that survived release, showing movement in the water column and diurnal and lunar signals, are presented in Figure 10. Figures showing the depth over time profile of the fish with the water temperature are presented in Figure 12. Table 1 presents data on tag number, date tagged, platform, length, hook location on the fish, hook status (wrapped in line, left in or removed), hook sizes used in the study, fight time, survival, straight-line distance each fish traveled, sub-figure of Figure 7 that the track is in, diurnal amplitude, lunar amplitudes, mean depth, temperature range, and lunar phase for all tags deployed.

Testing of the model with adult swordfish and sailfish data validated the model's output (Figures 8-9). In tests run with adult swordfish data, a clear diurnal signal can be seen in the figures (Figure 8). In tests run with adult sailfish data, a clear diurnal and lunar signal can be seen in the figures (Figure 9). Proof of diurnal movements in adult swordfish has been demonstrated in other studies (Sedberry and Loefer 2001; Takahashi et al. 2003; Dewar and Polovina 2005; Loefer et al. 2007; Lerner 2009; Abascal et al. 2010; Sepulveda et al. 2010), confirming the validation of the model.

The three fish that died shortly after release all remained in the upper 140 meters of the water column and in waters 20-26°C until their deaths (Figures 4a,b,k; Figures 12a,b,i). The nine fish that survived the full deployment showed a wide range of depths encountered. Collectively, they spent the nighttime hours in waters 0-200 m in depth, with occasional nighttime depths of 200-350 m. Daytime depths ranges were 400-750 m, with occasional daytime depths of 250-400 m (Figures 4e-j, l-n). Temperatures encountered ranged from a maximum of 31°C at the surface to a minimum of 6°C at maximum depths (Figure 12c-h, j-l).

The calculations of the integral time scale for each record show that the amount of time in which the movements were correlated ranged from 2.8 to 10.5 hours (Figure 13). The limited analysis of a correlation between the integral time scale values and various variables shows a positive correlation between the integral time scale and size, lunar amplitude, month of the year and mean depth (Figure 11a, c, e, f). No clear trend was evident when comparing the integral time scale value to diurnal amplitude or moon phase

(Figure 11b, d). A positive correlation is indicated between size and lunar amplitude, month of the year and moon phase (Figure 11h, k, j), while a negative correlation is indicated between size and diurnal amplitude and size and mean depth (Figure 11g, i).

In five of the nine full tracks (Figure 4e, 4f, 4h, 4j, 4m), the swordfish rose to the surface during the day for a period of time and then descended again. In one case, the fish reached the surface (Fig 4m, delineated by 0 m depth data). The fish showed this behavior twice on day two for a total of approximately 1.85 hours or 0.81% (Figure 4m). In the other four cases the fish rose to shallow depths but did not reach a 0 m depth. Amount of time spent in surface waters during the day was 4.05 hours or 1.77% for the fish in Figure 4e, 3.41 hours or 1.5% for the fish in figure 4f, 6.66 hours or 2.91 % for the fish in figure 4h, 2.95 hours or 1.29% for the fish in figure 4j.

3.4 Discussion

3.4.1 Horizontal Movements

Research fishing trips were conducted throughout the year, but tagging was only conducted between June and January, possibly suggesting seasonality in residence time of the fish. The results of a study by Neilson et al (2009) demonstrated seasonal residence time in temperate and tropical waters. However, the tagging trips conducted in this study were done on an opportunistic basis, not regularly, so some months saw more trips than others, possibly biasing the suggestion of seasonality. Also, the short-duration tags used here do not provide enough information to assess the possibility of seasonality.

All tagging locations, pop-off locations, and a line indicating the straight-line distance traveled for all reporting tags were plotted in Google Earth and are presented in Figure 7. The straight-line distance traveled in kilometers (km) is presented in Table 1. All tagged fish were caught on the Florida shelf between Miami and Jupiter, off the coast of South Florida (Fig. 7a). Upon observation, the tags could be sorted into three categories. Three of the tagged fish remained in the area, and thus has the shortest tracks, residing in waters between Miami and West Palm Beach (Fig. 7b). Three of the fish moved away from the tagging area, heading in a mostly north direction (Fig. 7c). Eight of the fish moved away from the tagging area, heading in a north-east direction, more towards the open waters of the Atlantic (Fig. 7d).

When considering each case individually, and comparing the distance traveled to the survival time, a pattern appeared. The three fish with the shortest tracks (Fig 7b), shared one variable in common, they each survived for the full deployment period of the tag (Fig. 4i, 4l, 4n; Table 1). This indicates that the fish were not simply moving along with the current, they were exhibiting control over their movements and a choice to stay in the same location, most likely due to a sufficient food source.

Of the three fish that moved northward, only one survived for the full deployment period (Fig. 4j Table 1). It also had the shortest track of that group (Fig. 7c). The long straight-line distance of the two fish that died after being caught, tagged, and released show they traveled farther (Fig. 7c, Table 1). One explanation for that could be that while the fish didn't live very long after tagging, the tag sank with the fish, was still attached for a period of time after the fishes' death, and then it took some time for the tag to reach the surface, all while the fish and tag continued to be moved by the current until the tag reached the surface and was able to transmit it's first location (Fig. 4a, 4k). It is not believed that the fish were actually able to cover that amount of ground in the few short hours they lived after release.

Of the eight fish that moved northeast, three died immediately after tagging (Fig. 4b, 4c, 4d) and showed the longest tracks (Fig. 7d; Table 1). Five of the fish survived for the full deployment period (Fig. 4e-h, 4m) and showed significantly shorter tracks (Fig. 7d; Table 1). This is believed to be more examples of the same occurrences. Those fish that died show longer tracks because they were most likely caught in a fast moving current before the tag released. Those fish that lived were exhibiting a choice in their movements and distance traveled; most likely they were following prey.

Of the fish that survived the full deployment period, they showed a variety of movements, in terms of straight-line distance traveled and in direction. Three fish chose to stay in the general area they were caught and tagged in, only moving between 42.6 and 92.6 km. One moved in a mostly northward direction and covered 416.7 km, the longest track of the surviving fish. Five moved in a northeast direction, moving between 257.4 and 320.4 km (Table 1). This north/northeast movement of swordfish was also seen by Sedberry and Loefer (2001). The average speed of the fish varied from 2.16 km/day to 20.98 km/day with an average for all of 12.67 km/day (similar results were seen in

Canese et al. 2008). Size appeared to have no correlation to the distance the fish traveled (also noted in Sedberry and Loefer 2001). Two fish, both measuring 105 cm LJFL, showed a difference in their average speed of approximately 15 km/day. This was seen again in two fish both measuring 121 cm LJFL (Table 1).

3.4.2 Vertical Movements

A model has been developed to fit a curve to the data showing the diurnal and lunar cycles and to get amplitude data on the vertical movements of the fishes from that model. This model works for data collected on adult swordfish, sailfish and juvenile swordfish. This model serves as a way to characterize the vertical behavior/distribution of these fishes.

Data from all 14 reporting tags from the juvenile swordfish were analyzed using the new model developed. Figures from each data set are presented in Figure 10. The first two swordfish showed erratic behavior and died shortly after release, 6 hours (Fig. 10a; Table 1) and 28 hours (Fig 10b; Table 1), respectively. In each figure the abnormal behavior can be seen. Figure 4 shows those same two data sets depicting the points at which the fish died, sank, and remained at a constant depth until the tag released from the fish. The tags then floated to the surface and began to transmit. Given the abnormal behavior of these fish, short duration time and subsequent death, the information on diurnal and lunar movements the model provides helps to confirm the abnormal behavior seen in these cases. The third and fourth swordfish tagged in this study (Fig. 4c, d; Table 1) died immediately after release. The third fish simply floated at the surface while the forth fish sank and stayed at a constant depth until the tag release mechanism was activated. For the third fish, not enough data was available to run the model. For the fourth fish, the model does not give accurate information. One other fish died roughly 24 hours after release (Fig. 10i; Table 1) in this study, and the data shows it exhibited a similar vertical profile as the first two fish. Figure 4 also shows that data set depicting the points at which the fish died, sank, and remained at a constant depth until the tag released from the fish. In that case, the model also helped to confirm the abnormal behavior that fish exhibited before death.

Correlation data was also computed from the residual values produced by the model in attempts to analyze each fishes' individual movements in relation to previous movements. Those data were also compared to other variables. The analysis was limited by the small sample size of only nine fish, but correlations were seen between the integral time scale and lunar amplitude, mean depth, month of the year, and size and between size and diurnal amplitude, lunar amplitude, mean depth, month of the year and moon phase (Figure 11). An integral time scale of zero indicates no correlation between the variables at any time lag; while a large integral time scale implies that the motions are correlated over a long time. Twice the integral time scale is the average time it takes for the data to become independent of each other.

For the four cases where a positive correlation to the integral time scale is visible, this suggests that as the fish grows in size, changes its lunar amplitude or mean depth, or as the time of year changes, the fish's movements through time are more correlated to each other. Perhaps the fish are learning from their previous movements at depth as they age, over the course of the lunar cycle or over the course of the year. Correlations between size and diurnal amplitude and mean depth were negative; suggesting that as a fish grows (and therefore ages), it is showing less random motion in the water column. Correlations between size and lunar amplitude, month of the year and moon phase were positive. It is possible that as these fish age their movements are more influenced by the lunar cycle. The positive correlation between size and month of the year suggests that as the year progresses, larger fish are more likely to be caught. The positive correlation between size and moon phase suggests that larger fish are more likely to be caught during the last quarter of the lunar cycle. The small sample size limits the conclusions that can be drawn; however, an increase in the sample size may strengthen the correlations seen here.

3.4.3 Vertical Movements – Diurnal Signal

There were nine reporting tags showing full deployment and enough of the data was returned that the model was successfully applied to each record (Fig. 10c-h, j-k). In each record, a diurnal signal could be seen. The magnitude of change in each signal varied between fish. The range of the diurnal amplitude was from 217.63 m to 317.13 m.

Studies have shown that adult swordfish ascend around sunset and descend around sunrise, within an approximate two-hour window (Loefer et al. 2007; Abascal et al. 2010; Sepulveda et al. 2010; Dewar et al. 2011). Similarly, the diurnal movements seen in the juveniles are correlated with the daily cycle of the sun.

The time of day of descension and ascension were evaluated for each fish for each day. The group as a whole descended at approximately 10:09 (GMT) and ascended at approximately 23:06 (GMT). However, closer evaluation of these times reveals that these records can be broken down into three groups based on their descension and ascension times. The fish represented in figures 10j, 10k, and 10l all showed similar descension (average, 11:11 GMT) and ascension (average, 22:30 GMT) times, and were all tagged in December. The fish represented in figures 10g and 10h both showed similar descension (average, 10:14 GMT) and ascension (average, 22:41 GMT) times, and were both tagged in September. The fish represented in figures 10c, 10d, 10e and 10f all showed similar descension (average, 9:20 GMT) and ascension (average, 23:45 GMT) times, and were all tagged in June. The times of ascension and descension for all fish were compared to sunrise and sunset times. Each fish descended before sunrise each day (average 1.25 hours, range 0.33 -2.33 hours). During 73% of the days, the fish ascended before sunset (average 30 minutes). During 27% of the days, the fish ascended after sunset (average 13 minutes). The range of ascension around sunset was from 2 hours before to 31 minutes after sunset. The percent of days when ascension occurred after sunset increased from June (8.3%) to December (59.2%). These movements confirm that the fish are ascending around sunset and descending before sunrise. In addition, as the time of day of sunrise and sunset changes throughout the year, the fish adapt and change their descension and ascension times. In June, when the sun sets later in the day, the fish are ascending about two hours later than in December. The fish are also descending about an hour earlier in June than in December, as the sun rises earlier in the summer than in the winter.

These figures show that juveniles are moving vertically on a daily basis in conjunction with the rise and set of the sun (Figure 10). Most likely they are following prey as they move through the water column or are using the increase in sunlight during the day to search deeper depths until they find prey. This also suggests that they are following prey up in the water column at night or are limited by the amount of moonlight available to illuminate the water to search for prey. The difference in the magnitude of vertical movement in the water column shown by each fish could be related to the time of year the fish was tagged. There is a slight trend in that the maximum depths reached by the fish are deeper in the summer months than in the winter months. During certain times of the year, the sun is more directly overhead, thus possibly allowing for more sunlight to penetrate deeper into the ocean. The difference could also be related to the abundance of prey at any given time at any given depth in the water column. In other words, a particular fish might not have needed to move as much to find food that day or for the full deployment duration.

3.4.4 Vertical Movements – Lunar Signal

In each record, a lunar signal could be seen as well. The range of the lunar amplitudes was from 13.41 meters to 137.37 meters. The lunar signal seen in the juveniles' movements can be correlated with the lunar phases; by using the day and time information associated with the depth data, the lunar trend was determined for the deployed period of each tag. The fraction of the moon's visible disk illuminated by the sun (referred to here as moon illumination) for each night was ascertained. The lunar trends in Figures 10c-f and 10j-k were decreasing in moon illumination (Fig 10c, 62% to 0%; Fig 10d-f 53% to 1%; Fig 10j-l, 59% to 3%). The lunar trends in Figures 10g-h, 10l were increasing in moon illumination (Fig 10g-h, 11% to 92 %; Fig 10l, 40% to 100%). When comparing the lunar signal from the model to the moon illumination data the following patterns were visible. In Figures 10c-f, 10k the average depth of the lunar signal moves deeper in the water column as the moon illumination decreases. In Figures 10g-h, 10l the average depth of the lunar signal moves shallower in the water column as the moon illumination increases. In Figure 10j, the average depth of the lunar signal moves shallower in the water column as the moon illumination decreases.

Data from swordfish in other studies and areas have shown a positive correlation between average depth at night and visible moon fraction, with the fish remaining deeper during a full moon and shallower during a new moon (Loefer et al. 2007; Abascal et al. 2010; Dewar et al. 2011). It has been proposed that this movement in correlation to the lunar cycle is due to the movements of their prey organisms (Tont and Wick 1973; Linkowski 1996). At first appearance, it seems that only one of the fish in this study followed that same pattern (Figure 10j). However, closer observation of the fishes' average nighttime depths shows that seven of the nine fish are exhibiting the same correlation as seen in other studies, moving deeper as the moon illumination increases or shallower as the moon illumination decreases. Two of the fish do not show this correlation; increased moon illumination allows a swordfish the ability to move deeper in the water column but does not require it (Figure 15a-i).

There are several explanations for the discontinuity in the lunar signal. In other studies evaluating average nighttime depth and visible moon fraction, the deployment period for the tags lasted up to several months and included multiple repeats of the lunar cycle. The deployment length in this study only extended for approximately 1/3 of the full lunar cycle. The tags used in this study were also set for a more frequent sampling interval, therefore providing higher resolution data. In several of the records (Figures 10e-h, 10k-l), the maximum daily depth fluctuates, by up to 400 m in some cases. The model's output of the lunar signal is easily manipulated by the fish's daily maximum depths. In none of the records was 100% data transmission achieved, resulting in gaps in the data. All of these factors must be considered when evaluating the lunar signal produced by the model.

3.4.5 Summarizing Model Data

In Figure 13, the mean, diurnal and lunar amplitudes for each surviving fish are presented in a 3D plot. This figure does not include the two fish that died immediately following release. The integral time scale value is also presented next to each marker representing a fish that survived the full deployment period. The three markers without a value next to them represent the three fish that died within approximately 24 hours of being released. The clustering of the markers elucidates the similarities in the vertical movements in the groups of fish that did and did not survive the full deployment period. It also shows the innate variability of vertical movements in the fish that survived the full deployment period. Those that died shortly after release are closely plotted as are those that survived the full deployment, with the exception of two. Seven of the nine markers representing full deployment are loosely clustered together, indicating they showed similar vertical movements, while two of them are outliers. A review of Figures 10k and 10l shows the reason for the distance. Both fish showed truncated maximum daily depths at some point during the deployment period, causing their placement to be removed from the larger group.

Figure 14 shows the diurnal and lunar amplitudes around the mean as calculated by the model. Notice that the nine fish surviving the full deployment period all showed similar means and amplitudes. There is variability in the values, but the pattern of diurnal movements being greater than lunar movements is consistent. The three fish that died shortly after release all show similar means and amplitudes. Those values are not as large or as varied. This figure further elucidates the similarities among the fish in each group.

Figure 16 shows the average fish behavior over 28 days, the length of the lunar cycle. This figure was created by compiling the diurnal and lunar cycle amplitudes and average depth of all surviving fish and fitting that data in the model. This figure shows the vertical movement patterns of the fish as a whole for a full lunar cycle. The highest point in the signal (indicating the new moon phase) is approximately 14 days before the lowest point in the signal (indicating the full moon phase), clearly indicating a change in average vertical depth as the moon illumination fluctuates throughout a full lunar cycle.

Figure 17a shows the fit line produced by the model when evaluating the average depth over time data from the nine full deployment records. This shows that as a group, these juvenile swordfish are migrating to shallow waters (approximately less than 150 m) at night and deep waters during the day (approximately 350-750 m) with very little time spent at depths in between. Figure 17b represents a 24-hour period in the middle of the deployment. The diurnal signal and the depth data clearly show daytime maximum depths and nighttime minimum depths.

All depth data from these tags can also be analyzed for a maximum depth reached by each fish, and an average maximum reached by juveniles as a whole for this study. The deepest depth any one juvenile fish reached was 767.9 m, and the average maximum depth reached by juveniles during this study was 682.2 m. Based on the adult swordfish data used to validate the model, the deepest depth any one adult fish reached was 984 m, and the average maximum depth reached by adults was 847.6 m. The data showed that both juveniles and adults would reach the surface of the water column at night. This behavior could explain the number of juvenile swordfish that are encountered during nighttime fishing on either type of gear. This data also shows that while both adults and juveniles are remaining farther down in the water column during the day, they are stratifying out. Adults, on average, go deeper than juveniles. This could explain the lack of encounters with juvenile swordfish during daytime fishing, when anglers are known to target swordfish on the sea floor in a method now colloquially called "deep-dropping."

3.4.6 Temperature

Figures depicting the vertical movement profile in conjunction with the temperature data of the bodies of water the fish were moving through are presented in Figure 12. Figures from the two fish that died immediately are not included, as the temperature data from those tags was not sufficient and does not represent fish movement. Those fish that showed abnormal behavior and then died (Fig 12a, b, i) consistently stayed in warmer waters, 20°C or higher. Remaining in warmer waters could be part of the fish's attempts to recover from the catch, tag and release event or some other stress prior to that. For the nine fish that survived the full deployment, the temperature profiles vary daily and between fish as to the sea surface temperature and the depths at which the temperature changes. However, the fish are showing the same movement patterns, and seem to not be hindered by temperature changes at the surface or at depth (a similar observation was noted in Abascal et al. 2010). The variation in each record and between records could be due to the different fish moving to different locations and the changing temperatures of currents within the Gulf Stream (similarly suggested by Sedberry and Loefer 2001). The temperature profiles of the five fish that traveled in a north-east direction (Fig 7d, Fig 12c-f, k) showed an increase in temperature at depth during the deployment. This indicates those fish crossed the Gulf Stream and possible entered Bahamian waters.

These fish showed an average temperature of 17.49°C. They all stayed in waters with an SST of 24-30°C. Throughout their entire movements, these fish moved through bodies of water ranging from 6°C to 31°C. Data from swordfish tagged in other studies have shown similar ranges of temperatures (Sedberry and Loefer 2001; Matsumoto et al. 2003; Dewar and Polovina 2005; Abascal et al. 2010; Sepulveda et al. 2010; Dewar et al. 2011). This indicates a high tolerance for a wide range of temperatures. In each figure, the swordfish repeatedly went to depths with temperatures in the single digits, indicating that the first excursion into those temperatures was not arbitrary. This also indicates that their prey are also tolerant of these temperatures, as it is most likely that the swordfish are following or looking for their prey at these depths.

Figure 18 shows the average depth plotted against the average temperature of the nine records over the full deployment. While there is variation in the temperature at depth over time, there is a direct inverse relationship between depth and temperature. As depth increases, temperature decreases. There is a spread of temperatures, from 8°C to 15 °C, at depths greater than 500 m, again indicating that some of the fish possibly travelled to Bahamian waters. Figure 19 also shows the average depth over time vertical movement profile of the nine fish plotted on top of the average temperature data. This figure demonstrates the same direct inverse relationship in that as depth increases temperature decreases.

3.4.7 Irregular Post-Release Behavior

Some studies have suggested that, after a fish has been released with a satellite tag, the first few/several days are not indicative of that fish's normal behavior due to the need for recovery time (Hoolihan et al. 2011). In Hoolihan et al. (2011), four out of the sixteen fish studied showed apparent irregular post-release behavior (IPRB). The authors speculate that detection of irregular post-release behavior would increase with the use of high-resolution archival data. The authors suggest that by not considering these behavioral changes, researchers may be introducing biases into their analyses. They suggest a level of post-release behavioral modification due to capture and handling that may extend for long periods of time. Contact with fishing gear, internal hooking, improper tag-and-release procedures, and acclimating to the tag can all be causes of behavioral modification. Other studies have noted changes in behavior of swordfish following release (Abascal et al. 2010) and some authors have begun to exclude early portions of the data from their analyses (Hoolihan et al. 2009; Leroy et al. 2009; Dewar et al. 2011). However, this is not yet a universal practice among studies as some have noticed little post-tagging change in dive behavior and have not excluded data from analyses (e.g., Sepulveda et al. 2010).

The possibility of irregular post-release behavior in the juvenile swordfish dataset was examined. The fish represented in Figures 4a, 4b, and 4k could be categorized as showing IPRB as they did not resume common diurnal movements and died shortly after release. The fish in Figures 4e, 4f, 4h and 4l returned to the common diurnal movements after release and the maximum depths reached were consistent throughout the deployment period, indicating no IPRB. The fish in Figures 4g, 4i, 4j, 4m and 4n returned to the common diurnal movements after release. However, in Figures 4g and 4m, the fish did not reach the same maximum depths the first two days compared to the rest of the deployment, and in Figures 4i, 4j and 4n the maximum depth was shallower and more varied for the second half of the deployment. The daytime surfacing behavior exhibited in Figure 4e was sparse and several days after release. The fish in Figures 4f, 4h, 4j each displayed daytime surfacing behavior within the first 24 hours of being released. The fish in Figure 4m showed daytime surfacing behavior on the second day. The fish in Figures 4g, 4i, 4l, 4n did not show any daytime surfacing behavior.

The wide variability among the fish in this study with regards to consistency in maximum depths reached and occurrence of daytime surfacing behavior further divides a small sample size. Figure 13 elucidates the variability in the vertical movements seen in this group. Therefore, no definite statement can be made from these results as to the behavior of juvenile swordfish being a factor of IPRB or simply behavioral variability.

3.4.8 Basking and Daytime Surfacing Behavior

Basking behavior, common in other studies, is classified as any daytime ascent to the surface from depth followed by a descent back to depth prior to sunset (Holdsworth et al. 2007; Canese et al. 2008; Abascal et al. 2010; Sepulveda et al. 2010; Dewar et al. 2011). The number of times this occurs can range from none to multiple in a given data set and can happen at any time of the day and during all moon phases (Sepulveda et al. 2010). Dewar and Polovina (2005) suggested that these basking events are influenced by feeding events, stating that feeding adds to thermal stress and physiological requirements.

Possibly, the warm surface waters aid in digestion by minimizing thermal stress, as it is common to find full stomachs in those that are harpooned while basking (Dewar and Polovina 2005; Dewar et al. 2011). Alternatively, Carey and Robinson (1981) suggested this behavior allows for recovery after foraging in oxygen-poor waters.

Only one fish (Figure 4m) in this study exhibited basking behavior (reaching a 0 m depth), while four other fish rose to shallow surface waters during the day. These occurrences will therefore be referred to as daytime surfacing behavior because the fish did reach shallow or surface waters. Two of the fish showing daytime surfacing behavior only did so once on day one (Figure 4f, 4j). One showed this behavior three times on day one (Figure 4h). One fish showed this behavior once on days three, four, and five (Figure 4e). These daytime surfacing and basking events appeared to be sporadic, as not all fish showed the behavior (Figures 4g, 4i, 4l, 4n), nor were there consistent patterns in those that did show the behavior. It is unknown why some of these fish rose to shallow depths but did not reach the surface. However, the same explanations of what would cause a fish to bask at the surface could also explain the causes of a fish rising to shallow waters during the day. While exact reasons are currently unknown, some juveniles in this study showed daytime surfacing behavior and basking behavior similar to those in other studies, suggesting this behavior is consistent throughout the species, and is neither population nor size specific.

4.0 Conclusions

No definitive statement can be made as to the common thread among the five mortalities or among the nine fish surviving full deployment, exemplifying the variability within the species to sustain stress. Considering the mortalities were evenly distributed between the two fishing methods, it is reasonable to conclude their mortality rates are approximately equivalent. The results of the Release Mortality program indicated a necessary sample size of approximately 1800 tags to be 95% confident in the experimental mortality rate. A study of this size is simply not plausible. While there are some assumptions that should be taken into consideration when interpreting the results from this model, these simulations can help improve estimates of total removals in stock assessments.

The model developed to analyze vertical movements of juvenile swordfish aided in quantitatively confirming behavioral patterns; juvenile swordfish do correlate their movements with the daily cycle of the sun and the lunar cycle of the moon. While it is evident when visually comparing the data between the fish that died shortly after release and the fish that survived the full deployment that the former were exhibiting abnormal vertical movements, the model data results confirm this finding. Close observation of the fishes' nighttime depths in conjunction with the lunar phases shows they are descending deeper as the moon illumination increases or shallower as the moon illumination decreases. Swordfish as a species show great variability in their vertical movements and the depths they reach, but their individual diurnal movements remain much greater than their lunar movements.

The nine fish that survived the full deployment varied their movements, in terms of straight-line distance traveled and in direction. Some stayed close to shore, one moved north, and several moved out toward the open Atlantic. Regardless of the direction and distance traveled, it is most likely that each was basing its movements on prey availability. Comparing the descension and ascension times with sunrise and sunset revealed that the fish are descending before sunrise and ascending around sunset. They are also adjusting the times at which they show this behavior in conjunction with the sunrise and sunset changes throughout the year. While both adults and juveniles descend deeper in the water column during the day, adults may be descending deeper, thus stratifying out the population at depth. Juvenile swordfish show a high tolerance for a wide range of temperatures, reaching depths where the temperature is in the single digits. However, they may also choose to stay in shallow, warmer waters as a recovery mechanism.

Analysis of the integral time scale data indicated that as the fish grows in size, changes its lunar amplitude or mean depth, or as the time of year changes, the fish's movements through time are more correlated to each other. The negative correlation between size and diurnal amplitude and mean depth suggest that as a fish grows (and therefore ages), it is showing less random motion in the water column. It is possible that as these fish age their movements are more influenced by the lunar cycle. The positive correlation between size and month of the year and moon phase suggests that as the year progresses larger fish are more likely to be caught and that larger fish are more likely to be caught during the last quarter of the lunar cycle.

While there were five mortalities in this study, a 37.5% mortality rate, a significant part of the study was to investigate the fishery practices. Therefore, this study was very inclusive in the fish that were tagged, by choosing a low ACESS scale score as the minimum score a fish must have to be included. This was done so as not to impose a bias on the fish that were chosen. A 35.7% mortality rate signifies a 64.3% survival rate, so the majority of the released fish survive, suggesting that release is still warranted. Since the release mortality is 35.7%, management bodies might consider lowering the legal retention size in order to account for the mortalities of those smaller swordfish in quotas and stock assessments. The consequences to that action would be that even more juveniles would be landed before the opportunity to spawn and replace themselves in the population; enough of which could wipe out the population. The ideal situation would be increased research efforts in minimal time that investigate changes in gear that could result in a decrease in the mortality rate of those smaller fish, thereby lessening the negative impact on the population.

This research can serve as a foundation for future studies. Those could include studies that increase the number of fish tagged. This would allow for continued comparisons among time of year, size, mean depth, diurnal and lunar amplitudes, moon phase and the addition of comparisons between gear types. This would help to clarify any correlations between these variables and may help to determine the variables that are most influential on the fishes' habitat utilization. An increase in tags deployed would also refine the post-release mortality estimate. Studies with longer duration tags would allow for further investigation of the lunar cycle's impact on movement and also aid in further adjustments to the model. Application of the model to more swordfish and other billfish data would allow for comparisons between juvenile movements and adult movements and comparisons among other billfish species. This would help to refine the model and provide a common analysis of habitat utilization across those species.

The results of this study have provided information on post-release survival rates of juvenile swordfish, information that remains lacking in the scientific literature. The knowledge of post-release survival rates may aid in determining better management practices in terms of the efficacy of mandatory release of undersized fish. The data from the tags, providing experimentally-generated estimates of fishing mortality, can be used in ICCAT stock assessments.

This research could lead to better management practices in both the commercial and recreational fisheries to maximize post-release survival, both domestically and internationally. Through mandatory individual angler call-ins and tournament reporting, the United States is one of few countries that aggressively monitors its recreational fishery, including monitoring against anglers landing undersized fish. The ability to maximize post-release survival could be useful in ICCAT negotiations by demonstrating a lower fishing mortality (F) on the undersized component of the stock. The United States recognizes the need and benefits of implementing a minimum retention size; there is also the understanding that due to the swordfishes' migratory nature, this management measure is not very effective if other nations are simply retaining what is being released here. With post-release survival data on swordfish to show other nations that releasing swordfish is not a waste and that there are monetary benefits to releasing undersized swordfish, the United States can continue to promote the implementation of international measures for releasing undersized fish to other countries and ICCAT. An international consensus on minimum retention size could result in substantial monetary benefits to Atlantic coast countries and a continued stability of the stock.

References

Abascal FJ, Mejuto J, Quintans M, Ramos-Cartelle A (2010) Horizontal and vertical movements of swordfish in the southern Pacific. *ICES Journal of Marine Science* 67:466-474

Abid N, Idrissi M (2006) Chapter 2.1.9: Swordfish. ICCAT Manual, International Commission for the Conservation of Atlantic Tunas (ICCAT), Madrid, Spain, Last Update: Nov. 13 2006,

Anonymous (1995) Report for biennial period 1994-1995 ICCAT pt 1 (1994) 69-90

Arata Jr. GF (1954) A contribution to the life history of the swordfish, *Xiphias gladius* Linnaeus, from the south Atlantic coast of the United States and the Gulf of Mexico. *Bull Mar Sci Gulf Caribb* 4:189-243

Arnold G, Dewar H (2001) Electronic tags in marine fisheries research: a 30-year perspective. In: Sibert JR, Nielsen JL (eds) Electronic tagging and tracking in marine fisheries. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp7-64

Arnold Jr. EL (1955) Notes on the capture of young sailfish and swordfish in the Gulf of Mexico. *Copeia* 1955:150-151

Arocha F, Lee DW (1996) Maturity at size, reproductive seasonality, spawning frequency, fecundity and sex ratio in swordfish from the northwest Atlantic. *Col Vol Sci Pap ICCAT* 45:350-357

Arocha F, Moreno C, Beerkircher L, Lee DW, Marcano L (2003) Update on growth estimates on swordfish, *Xiphias gladius*, in the northwestern Atlantic. *Col Vol Sci Pap ICCAT* 55:1416-1429

Bayley RE, Prince ED (1994) A review of tag release and recapture files for Istiophoridae from the Southeast Fisheries Center's Cooperative Game Fish Tagging Program, 1954 to Present. *Col Vol Sci Pap ICCAT* 41:527-548

Beardsley GL, Conser RJ (1981) An analysis of catch and effort data from the U.S. recreational fishery for billfishes (Istiophoridae) in the western north Atlantic ocean and Gulf of Mexico, 1971-78. *Fishery Bulletin* 79

Beardsley JL (1978) Report of the swordfish workshop held at the Miami laboratory southeast fisheries center, National Marine Fisheries Service Miami Florida. June 7-9. *Col Vol Sci Pap ICCAT* 7:149-158

Beckett JS (1974) Biology of swordfish, *Xiphias gladius* L., in the northwest Atlantic ocean. In: Shomura RS, Williams F (eds) Proceedings of the International Billfish Symposium, part 2 Review and contributed papers (NOAA Tech Rep NMFS SSRF-675) US Government Printing Office, Washingtion, DC, pp 103-106,

Block BA, Booth D, Carey FG (1992) Depth and temperature of the blue marlin, *Makaira nigricans*, observed by acoustic telemetry. *Marine Biology* 114:175-183

Block BA, Dewar H, Farwell C, Prince ED (1998) A new satellite technology for tracking the movements of Atlantic bluefin tuna. *Proc Natl Acad Sci USA* 95:9384-9389

Block BA, Dewar H, Blackwell SB, Williams TD, Prince ED, Farwell CJ, Boustany A, Teo SLH, Seitz A, Walli A, Fudge D (2001) Migratory movements, depth preferences, and thermal biology of Atlantic Bluefin tuna. *Science* 293:1310-1314

Bremer JRA, Mejuto J, Greig TW, Ely B (1996) Global population structure of the swordfish (*Xiphias gladius* L.) as revealed by analysis of the mitochondrial DNA control region. *Journal of Experimental Marine Biology and Ecology* 197:295-310

Brill R, Holts D, Chang R, Sullivan S, Dewar H, Carey FG (1993) Vertical and horizontal movements of striped marlin (*Tetrapturus audax*) near the Hawaiian Islands, determined by ultrasonic telemetry, with simultaneous measurement of oceanic currents. *Marine Biology* 117:567-574

Canese S, Garibaldi F, Relini LO, Greco S (2008) Swordfish tagging with pop-up satellite tags in the Mediterranean sea. *Col Vol Sci Pap ICCAT* 62:1052-1057

Carey FG (1982) A brain heater in swordfish. *Science* 216:1327-1329

Carey FG (1990) Further acoustic telemetry observations of swordfish. In: Planning the future of billfishes Proceedings of the Second International Billfish Symposium, part 2 Contributed papers National Coalition for Marine Conservation, Savannah, Ga, pp103-122

Carey FG, Robinson BH (1981) Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. *Fishery Bulletin* 79:16

Chancollon O, Pusineri C, Ridoux V (2006) Food and feeding ecology of northeast Atlantic swordfish (*Xiphias gladius*) off the Bay of Biscay. *ICES Journal of Marine Science* 63:1075-1085

Chow S, Okamoto H, Uozumi Y, Takeuchi Y, Takeyama H (1997) Genetic stock structure of the swordfish (*Xiphias gladius*) inferred by PCR-RFLP analysis of the mitochondrial DNA control region. *Marine Biology* 127:359-367

Clarke MR, Clarke DC, Martins HR, Da Silva HM (1995) The diet of the swordfish (*Xiphias gladius*) in Azorean waters. Arquipelago. *Life and Marine Sciences* 13:53-69

De Sylva DP (1974) A review of the world sport fishery for billfishes (Istiophoridae and Xiphiidae). Proceedings of the International Billfish Symposium Kailua-Kona, Hawaii, 9-12 August 1972 Part 2 Review and Contributed Papers

Dewar H, Polovina J (2005) Deploying satellite tags on swordfish using the California harpoon fleet. *Pelagic Fisheries Research Program* 10:3

Dewar H, Prince ED, Musyl M, Brill R, Sepulveda CA, Luo J, Foley D, Orbesen ES, Domeier ML, Nasby-Lucas N, Snodgrass D, Laurs RM, Hoolihan JP, Block B, McNaughton LM (2011) Movements and behaviors of swordfish in the Atlantic and Pacific oceans examined using pop-up satellite archival tags. *Fisheries Oceanography* 20:219-241

Domeier M, Dewar H, Nansby-Lucas N (2003) Mortality rate of striped marlin (*Tetrapturus audax*) caught with recreational tackle. *Marine & Freshwater Research* 54:435-445

Domeier M, Kiefer D, Nasby-Lucas N, Wagschal A, O'Brien F (2004) Tracking Pacific bluefin tuna (*Thunnus thynnus orentailis*) in the northeastern Pacific with an automated algorithm that estimates latitude by matching sea-surface-temperature data from satellites with temperature data from tags on fish. *Fish Bull Wash DC* 103:292-306

Dunaway V (1976) Swordfish premiere: a grand entrance on the angling stage. *Florida Sportsman* October/November 1977:4p

Fierstein HL, Stringer GL (2007) Specimens of the billfish *Xiphiorhynchus*, Van Benden, 1871, from the Yazoo clay formation (late Eocene), Louisiana. *J Vertebr Paleontol* 27:226-231

Garraffo ZD, Mariano AJ, Griffa A, Veneziani C, Chassignet EP (2001) Lagrangian data in high resolution numerical simulation of the North Atlantic I: Comparison with in-situ drifter data. *J of Mar Sys* 29:157-176

Goodyear CP (2002) Factors affecting robust estimates of the catch-and-release mortality using pop-off tag technology. *American Fisheries Society Symposium* 30:172-179

Google Inc. (2012) Google Earth [Software]. Available from http://earth.google.com

Graves JE, Luckhurst BE, Prince ED (2002) An evaluation of pop-up satellite tags for estimating postrelease survival of blue marlin (*Makaira nigricans*) from a recreational fishery. *Fishery Bulletin* 100:134-142

Graves JE, Horodysky AZ, Latour RJ (2009) Use of pop-up satellite archival tag technology to study postrelease survival of and habitat use by estuarine and coastal fishes: an application to striped bass (*Morone saxatilis*). *Fishery Bulletin* 107:11

Graves JE, Kerstetter DW, Luckhurst BE, Prince ED (2003) Habitat preferences of istiophorid billfishes in the western north Atlantic: Applicability of archival tag data to habitat-based stock assessment methodologies. *Col Vol Sci Pap ICCAT* 55:594-602

Grusha DS, Patterson MR (2005) Quantification of drag and lift imposed by pop-up satellite archival tags and estimation of the metabolic cost to cownose rays (*Rhinopera bonasus*). *Fishery Bulletin* 103:63-70

Gunn J, Block B (2001) Advances in acoustic, archival, and satellite tagging of tunas. In: Block BA, Stevens E (eds) Tuna: physiology, ecology, and evolution. Academic Press, San Diego, CA, pp167-224

Harbison GR, Janssen J (1987) Encounters with a swordfish (*Xiphias gladius*) and sharptail mola (*Masturus lanceolatus*) at depths greater than 600 meters. *Copeia* 2:511-513

Heemsoth A (2009) Diet composition of swordfish, *Xiphias gladius*, within the Straits of Florida. Nova Southeastern University, p79

Hill RD (1994) Theory of geolocation by light levels. In: LeBoeuf BJ, Laws RM (eds) Elephant seals: population ecology, behavior, and physiology. University of California Press, Berkeley, CA, pp227-236

Hill RD, Braun MJ (2001) Geolocation by light level, the next step: latitude. In: Sibert JR, Nielsen JL (eds) Electronic tagging and tracking in marine fisheries. Kluwer Academic Publisher, Dordrecht, pp315-330

Holdsworth J, Sippel T, Saul P (2007) An investigation into swordfish stock structure using satellite tag and release methods. Western and Central Pacific Fisheries Commission Scientific Committee Third Regular Session 13-24 August 2007, Honolulu, United States of America WCPFC-SC3-BI SWG/WP-3

Hoolihan JP, Luo J, Richardson DE, Snodgrass D, Orbesen ES, Prince ED (2009) Vertical movement rate estimates for Atlantic istiophorid billfishes derived from high resolution pop-up satellite archival data. *Bulletin of Marine Science* 83:257-264

Hoolihan JP, Luo J, Abascal FJ, Campana SE, DeMetrio G, Dewar HD, M.L., Howey LA, Lutcavage ME, Musyl MK, Neilson JD, Orbesen ES, Prince ED, Rooker JR (2011) Evaluating post-release behavior modification in large pelagic fish deployed with pop-up satellite archival tags. *ICES Journal of Marine Science* 68:880-889

Horodysky AZ, Graves JE (2005) Application of pop-up satellite archival tag technology to estimate post-release survival of white marlin (Tetrapturus albidus) caught on circle and straight-shank ("J") hooks in the western North Atlantic recreational fishery. *Fishery Bulletin* 103:84-96

Horodysky AZ, Kerstetter DW, Latour RJ, Graves JE (2007) Habitat utilization and vertical movements of white marlin (*Tetrapturus albidus*) released from commercial and recreational fishing gears in the western North Atlantic Ocean: inferences from short duration pop-up archival satellite tags. *Fisheries Oceanography* 16:240-256

Jolley Jr. JW, Irby Jr. EW (1979) Survival of tagged and released Atlantic sailfish (*Istiophorus platypterus*: Istiophoridae) determined with acoustical telemetry. *Bulletin of Marine Science* 29:155-169

Jones CD, Prince ED (1998) The Cooperative Tagging Center Mark Recapture Database for Istiophoridae (1954-1995) with an analysis of the West Atlantic ICCAT Billfish Tagging Program. *Col Vol Sci Pap ICCAT* 47:311-321

Kasapidis P, Mejuto J, Tserpes G, Antoniou A, Garcia-Cortes B, Peristeraki P, Oikonomaki K, Kotoulas G, Magoulas A (2006) Genetic structure of the swordfish (*Xiphias gladius*) stocks in the Atlantic using microsatellite DNA analysis. *Col Vol Sci Pap ICCAT* 61:89-98

Kerstetter D, Bayse SM (2009) Characterization of the catch by swordfish buoy gear in southeast Florida. NOAA Cooperative Research Program 1-25

Kerstetter DW, Graves JE (2006) Survival of white marlin (*Tetrapturus albidus*) released from commercial pelagic longline gear in the western North Atlantic US. *National Marine Fisheries Service Fishery Bulletin* 104:434-444

Kerstetter DW, Graves JE (2008) Postrelease survival of sailfish caught by commercial pelagic longline gear in the southern Gulf of Mexico. *North American Journal of Fisheries Management* 28:1578-1586

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

Kerstetter DW, Luckhurst BE, Prince ED, Graves JE (2003) Use of pop-up satellite archival tags to demonstrate survival of blue marlin (*Makaira nigricans*) released from pelagic longline gear. *Fishery Bulletin* 101:939-948

Kerstetter DW, Rice PH, Snodgrass D, Prince ED (2008) Behavior of an escolar *Lepidocynium flavobrunneum* in the Windward Passage as determined by pop-up satellite archival tagging. *Gulf and Caribbean Research* 20:97-102

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

Kotoulas G, Magoulas A, Tsimenides N, Zouros E (1995) Marked mitochondrial DNA differences between Mediterranean and Atlantic populations of the swordfish, *Xiphias gladius*. *Molecular Ecology* 4:473-482

Kotoulas KG, Mejuto J, Antoniou A, Kasapidis P, Tserpes G, Piccinetti C, Peristeraki P, Garcia-Cortes B, Oikonomaki K, de al Serna JM, Magoulas A (2006) Global genetic structure of swordfish (*Xiphias gladius*) as revealed by microsatellite DNA markers. *Col Vol Sci Pap ICCAT* 61:79-88

Leech M (2007) "Status quo?" *Marlin* February 2007:5p

Lerner JD (2009) Swordfish vertical distribution and recreational fishery in the Florida Straits. University of Miami, p87

Leroy B, Itano DG, Usu T, Nicol SJ, Holland KN, Hampton J (2009) Vertical behavior and the observation of FAD effects on tropical tuna in the warm-pool of the western Pacific ocean. In: Nielsen JL, Arrizabalaga H, Fragoso N, Hobday A, Lutcavage M, Sibert J (eds) Tagging and Tracking of Marine Animals with Electronic Devices. Springer, London, pp161-179

Levesque JC, Kerstetter DW (2007) First observations on the re-established southeast Florida recreational swordfish tournament fishery. *Florida Scientist* 70:284-296

Linkowski TB (1996) Lunar rhythms of vertical migrations coded in otolith microstructure of North Atlantic lanternfishes, genus *Hygophun* (Myctophidae). *Marine Biology* 124:495-508

Loefer JK, Sedberry GR, McGovern JC (2007) Nocturnal depth distribution of western north Atlantic swordfish (*Xiphias gladius*, Linnaeus 1758) in relation to lunar illumination. *Gulf and Caribbean Research* 19:6

Luo J, Ault JS, Larkin MF, Barbieri LR (2008) Salinity measurements from pop-up archival transmitting (PAT) tags and their application to geolocation estimation for Atlantic tarpon. *Marine Ecology Progress Series* 357:101-109

Lutcavage M, Brill R, Skomal G, Chase B, Howey P (1999) Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: Do north Atlantic bluefin tuna spawn in the mid-Atlantic? *Can J Fish Aquat Sci* 56:173-177

Markle GE (1974) Distribution of larval swordfish in the northwest Atlantic ocean Proceedings of the International Billfish Symposium Kailua-Kona, Hawaii, 9-12 August 1972 Part 2 Review and Contributed Papers. NOAA

Mather FJ, Clark III HJ, Mason Jr. JM (1975) Synopsis of the biology of the white marlin, Tetrapturus albidus Poey (1861). Pp. 55-94: Proc. Internat. Billfish Symp.; Kailua-Kona, Hawaii, 9-12 August 1972, Part 3: Species synopses (Shomura, R. S. and F. Williams, eds.) NOAA Tech. Rep. NMFS SSRF-675

Matlock G (1995) Options for establishing an interim permit moratorium and eligibility criteria for the Atlantic swordfish and shark fisheries. Fed Regist 27 July, 1995 50 CFR pt 630-678

Matsumoto T, Saito H, Miyabe N (2003) Report of observer program for Japanese tuna longline fishery in the Atlantic ocean from September 2001 to March 2002. *Col Vol Sci Pap ICCAT* 55:40

Meski D (2011) Recommendations and resolutions adopted at the 2011 commission meeting. International Commission for the Conservation of Atlantic Tunas, Istanbul, Turkey

Microwave Telemetry I (2010) Microwave Telemetry, Inc., Columbia, MD

Nakamura I (1985) Billfishes of the world. *FAO Fish Synop* 125:58p

Neilson JD, Smith S, Royer F, Paul SD, Porter JM, Lutcavage M (2009) Investigations of horizontal movements of Atlantic swordfish using pop-up satellite archival tags. In: Neilson, et al (eds),*Tagging and Tracking of Marine Animals with Electronic Devices,* Reviews: Methods and Technologies in Fish Biology and Fisheries 9,

Nielsen A, Bigelow K, Musyl M, Sibert JR (2006) Improving light-based geolocation by including sea surface temperature. *Fisheries Oceanography* 15:314-325

NMFS (1999) Final Fishery Management Plan For Atlantic Tuan, Swordfish, and Sharks. Office of Sustainable Fisheries. Highly Migratory Species Management Division

NMFS (2006) Final Consolidated Atlantic Highly Migratory Species Fishery Management Plan. Office of Sustainable Fisheries. Highly Migratory Species Management Division

NMFS (2010) Final Amendment 3 to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan. Office of Sustainable Fisheries. Highly Migratory Species Management Division

Ortiz M, Rosenthal DS, Venizelos A, Farber MI, Prince ED (1998) Cooperative Tagging Center annual newsletter: 1998. NOAA Tech Memo NMFS-SEFSC-423:1-23

Palko BJ, Beardsley GL, Richards WJ (1981) Synopsis of the biology of the swordfish, *Xiphias gladius* Linnaeus NOAA Tech Rep NMFS Circ 21p

Pearce A, Faskel F, Hyndes G (2006) Nearshore sea temperature variability off Rottnest Island (Western Australia) derived from satellite data. *Int J Remote Sens* 27:2503-2518

Pepperell JG, Davis TLO (1999) Post-release behavior of black marlin, *Makaira indica*, caught off the Great Barrier Reef with sportfishing gear. *Marine Biology* 135:369-380

Prince ED, Holts D, Snodgrass D, Orbesen ES, Luo J, Domeier M, Serafy JE (2006) Transboundary movement of sailfish, *Istiophorus platypterus*, off the Pacific coast of Central America. *Bulletin of Marine Science* 79:827-838

Sakagawa GT (1989) Trends in fisheries for swordfish in the Pacific ocean. In: Stroud RH (ed) Planning the Future of Billfishes: Research and Management in the 90s and Beyond Proceedings of the Second International Billfish Symposium, Kailua-Kona, Hawaii, August 1-5, 1988, Part 1: Fishery and Stock Synopses, Data Needs and Management. National Coalition for Marine Conservation, Inc., Savannah, Georgia 61-79

Schaefer K, Fuller D (2002) Movements, behavior, and habitat selection of bigeye tuna (*Thunnus obesus*) in the eastern equatorial Pacific, ascertained through archival tags. *Fish Bull Wash DC* 100:765-788

SCRS (2000) Detailed report on swordfish. Report of the ICCAT swordfish stock assessment session (Madrid, Spain, September 27-October 4, 1999). *Col Vol Sci Pap ICCAT* 51:1001-1209

SCRS (2009) Report of the 2009 Atlantic Swordfish Stock Assessment Session. International Commission on the Conservation of Atlantic Tunas, Madrid, Spain

Sedberry GR, Loefer JK (2001) Satellite telemetry tracking of swordfish, *Xiphias gladius*, off the eastern United States. *Marine Biology* 139:355-360

Sepulveda CA, Knight A, Nasby-Lucas N, Domeier ML (2010) Fine-scale movements of the swordfish *Xiphias gladius* in the Southern California Bight. *Fisheries Oceanography* 19:11

Takahashi M, Okamura H, Yokawa K, Okazaki M (2003) Swimming behavior and migration of a swordfish recorded by an archival tag. *Marine and Freshwater Research* 54

Taylor RG, Murphy MD (1992) Reproductive biology of the swordfish *Xiphias gladius* in the Straits of Florida and adjacent waters. *Fishery Bulletin* 90:809-816

The MathWorks Inc. (2006) MATLAB, Natick, Massachusetts

Tont SA, Wick GL (1973) Response of the deep scattering layer to the 1972 solar eclipse. *Deep-Sea Res* 20:769-771

UNCLOS (1982) United Nations Convention on the Law of the Sea, Oceans and Law of the Sea, Division for Ocean Affairs and the Law of the Sea

Van den Burg EH, Peeters RR, Verhoye M, Meek J, Flik G, Van der Linden A (2005) Brain responses to ambient temperature fluctuations in fish: reduction of blood volume and initiation of a whole-body stress response. *J Neurophysiol* 93:2849-2855

Welch D, Eveson J (1999) An assessment of light-based geoposition estimates from archival tags. *Can J Fish Aquat Sci* 56:1317-1327

Wilson RP, Ducamp JJ, Rees WG, Culik BM, Neikamp K (1992) Estimation of location: global coverage using light intensity. In: Priede IG, Swift SM (eds) Wildlife telemetry: remote monitoring and tracking of animals. Ellis Horwood, London, pp131-134

Figures

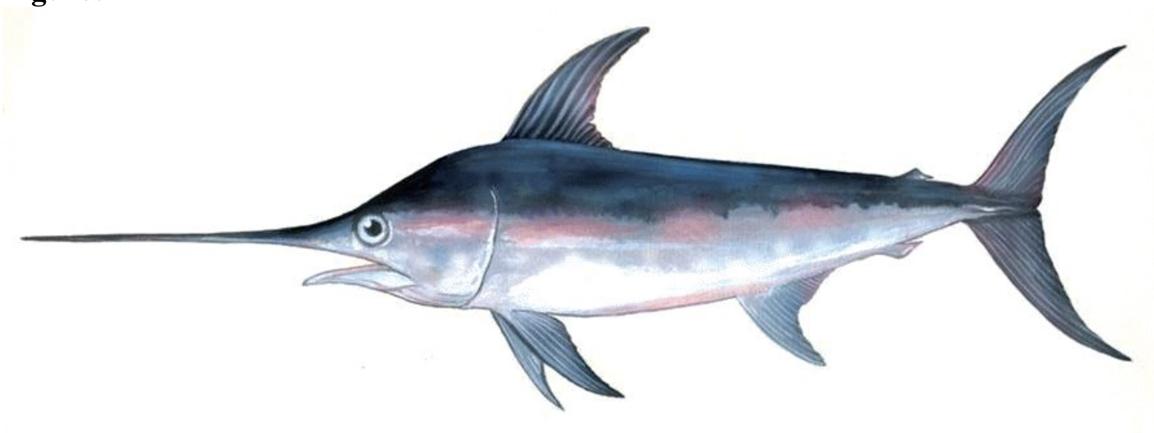


Figure 1: Drawing of an adult swordfish. (Credit: Wendy Williams, Fisheries and Oceans, Canada; Taken from ICCAT Manual 2006 Chapter 2.1.9.)

Figure 2: Relative sizes of Microwave Telemetry, Inc. X-Tag (top) and standard model (bottom) pop-up satellite archival tags (PSATs) next to a 72 cm fork-length mount of a blackfin tuna (*Thunnus atlanticus)*. The targeted swordfish individuals will be less than 150 cm lower jaw-fork length. (Photo courtesy D. Kerstetter, NSU OC)

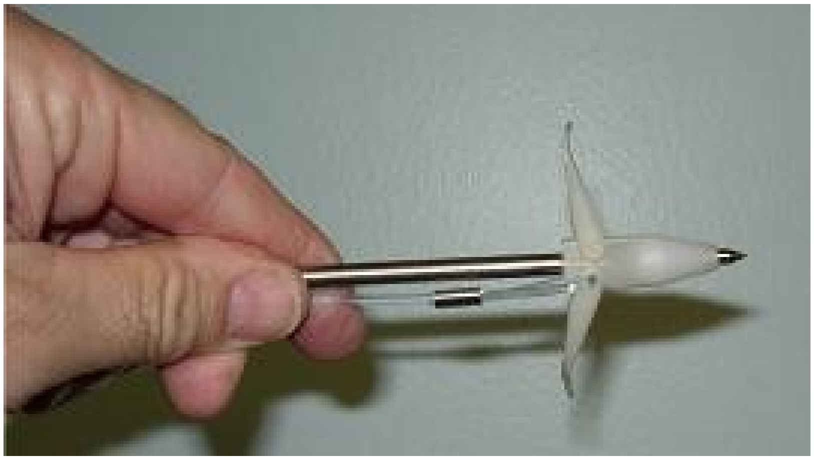
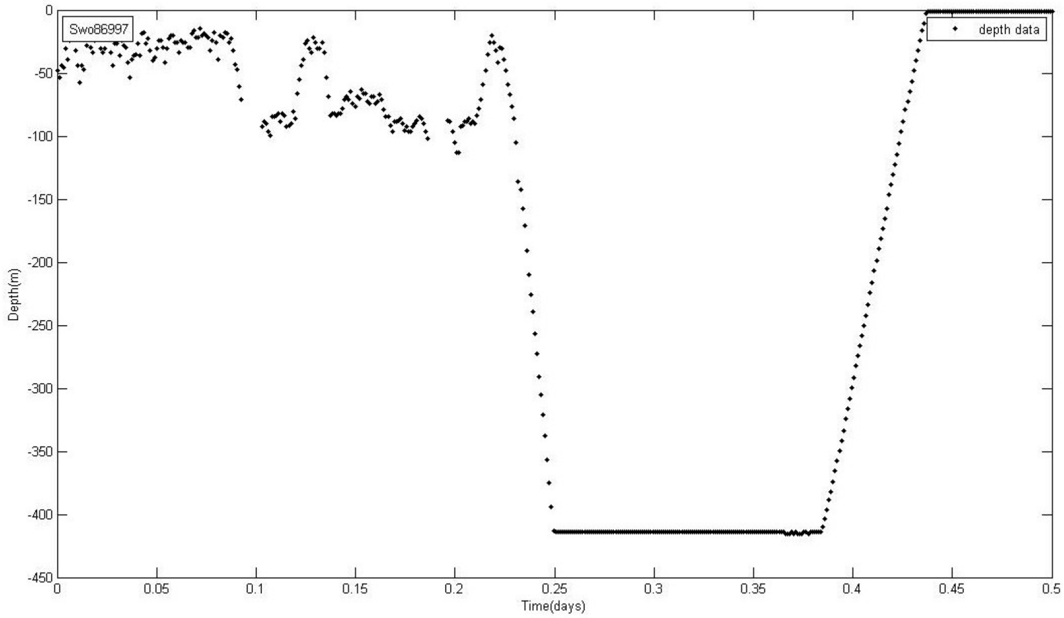


Figure 3: Design of nylon tag head incorporating “wings” for increased retention of tag by anchoring through inter-pterygiophore spaces. (Photo and tag head design courtesy of E. Prince, NOAA-NMFS SEFSC.)



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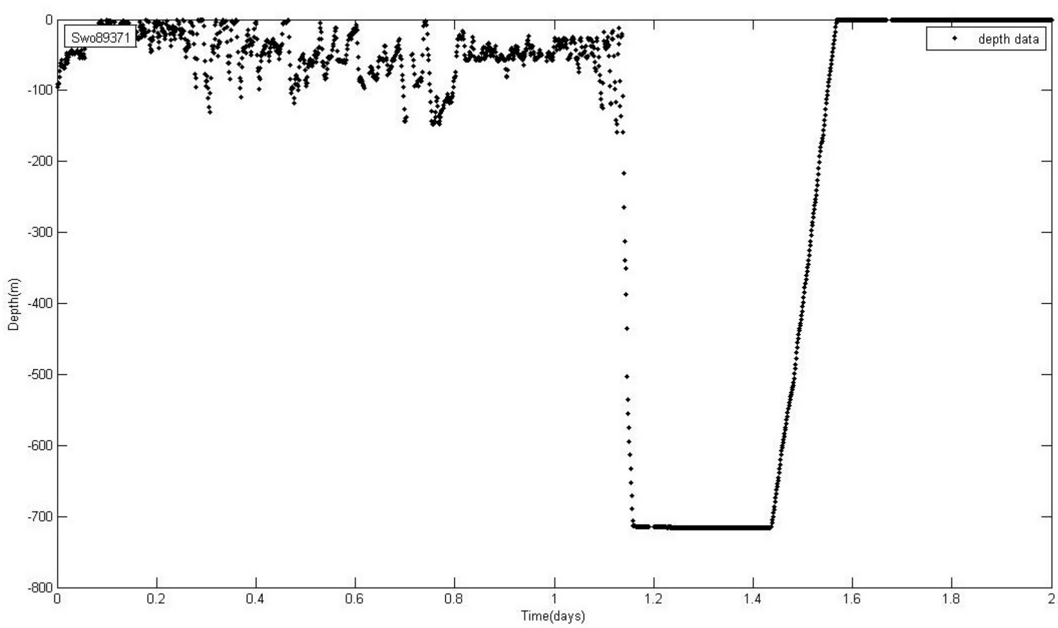

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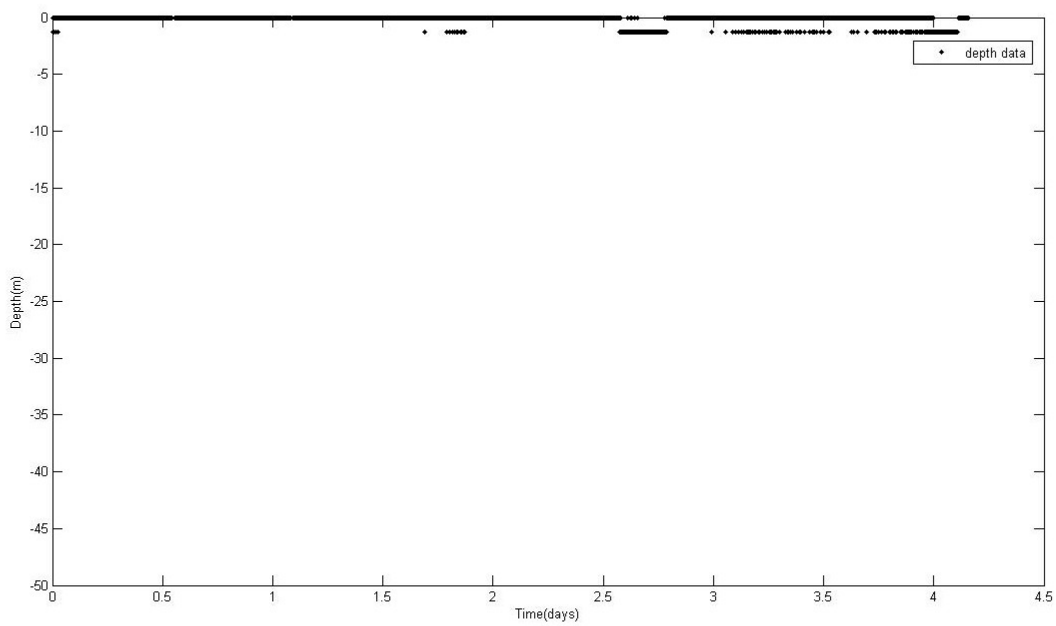

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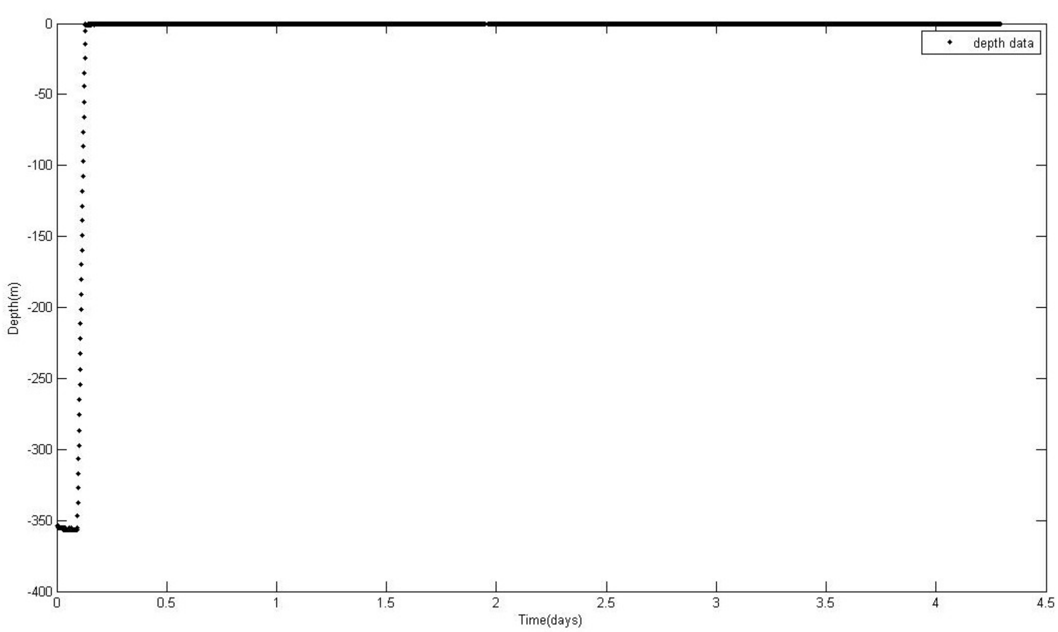

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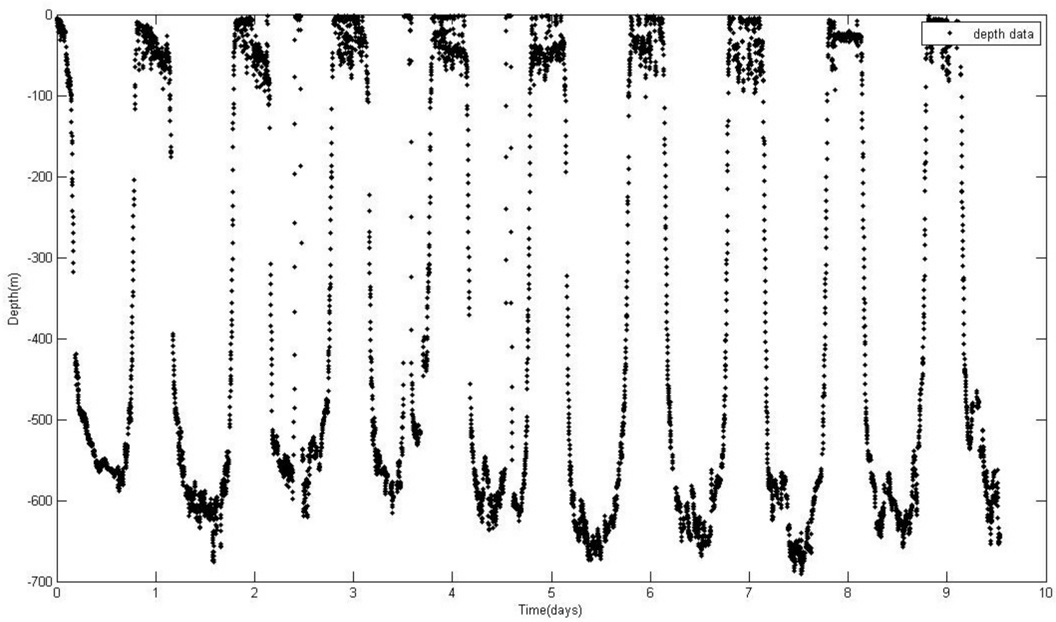

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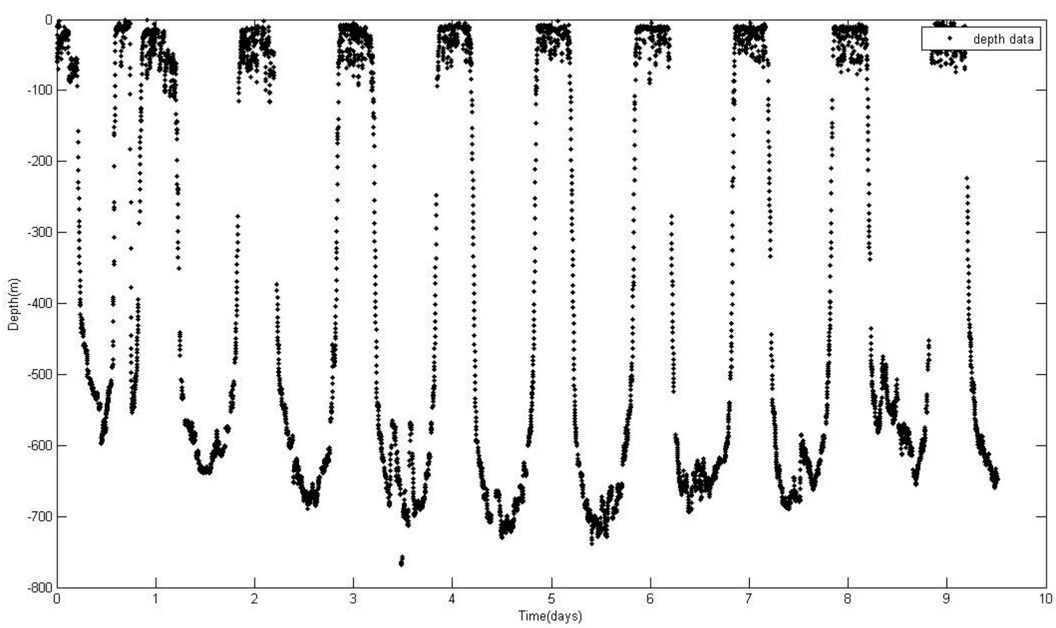

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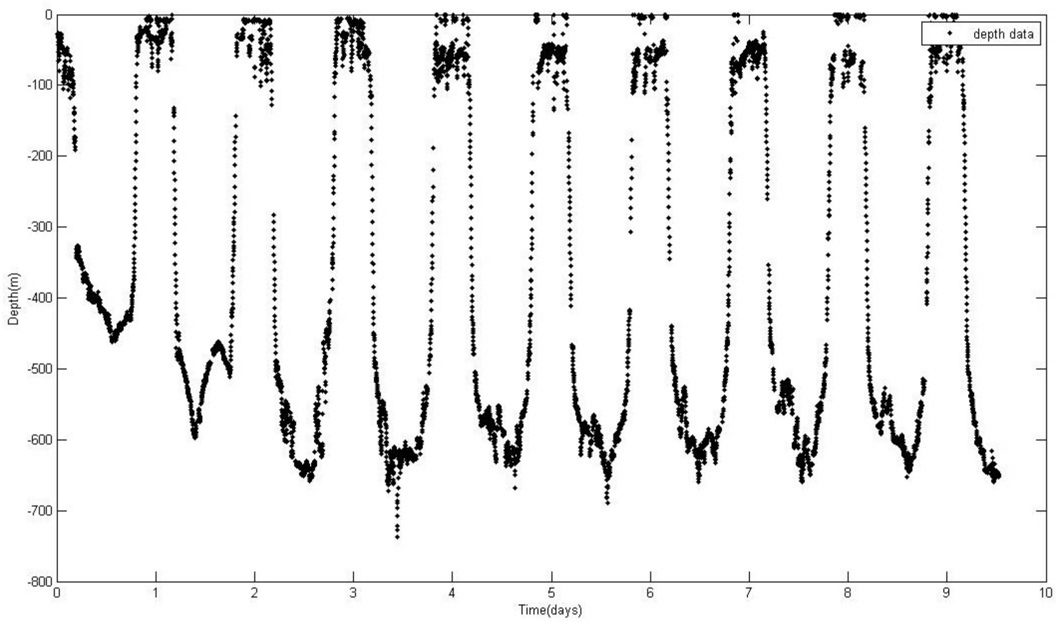

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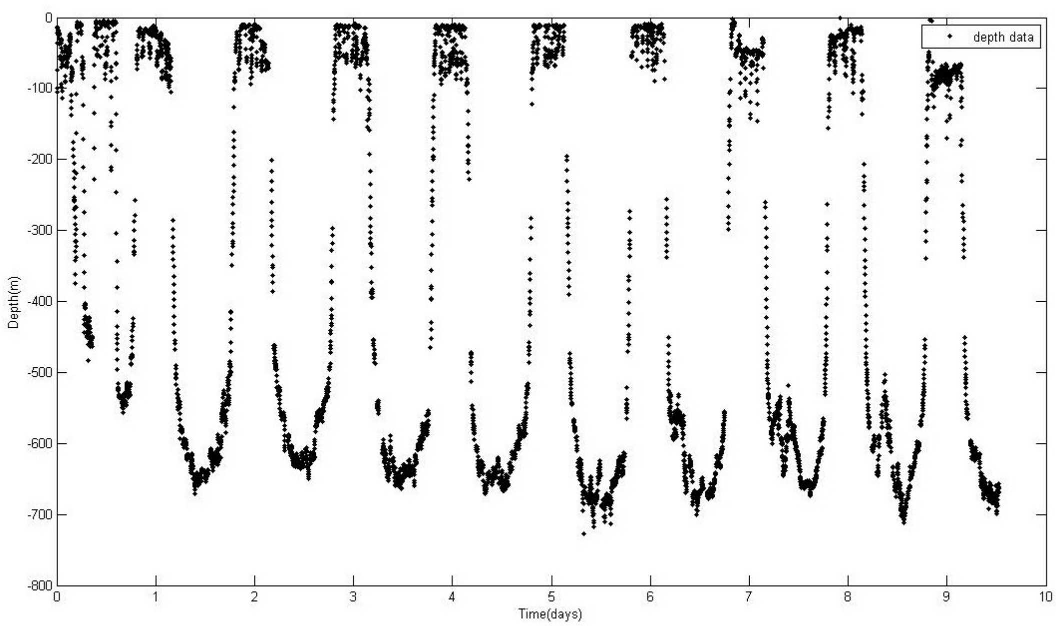

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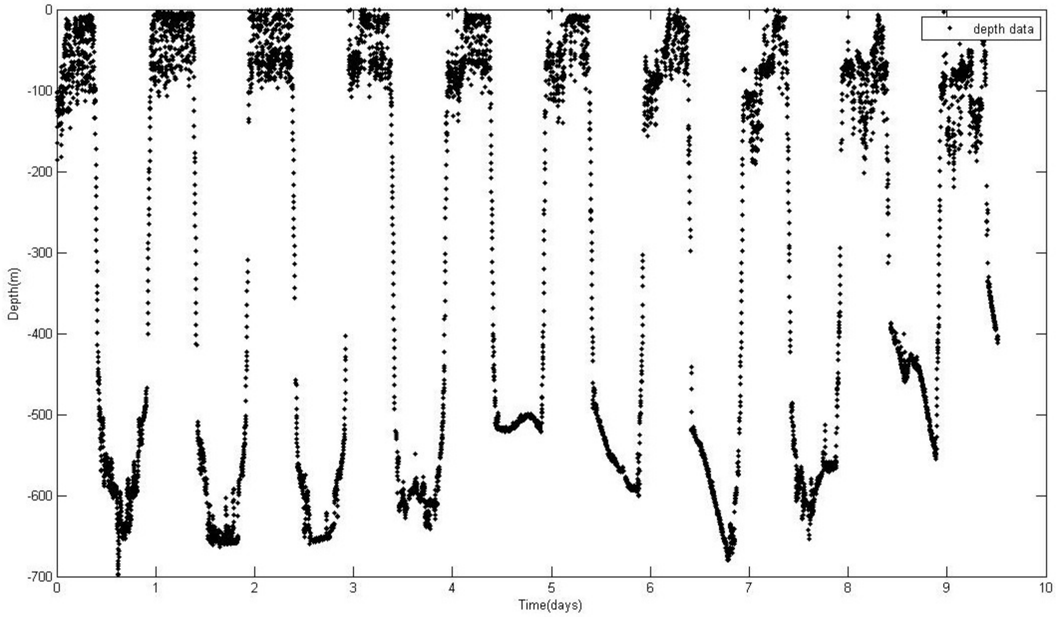

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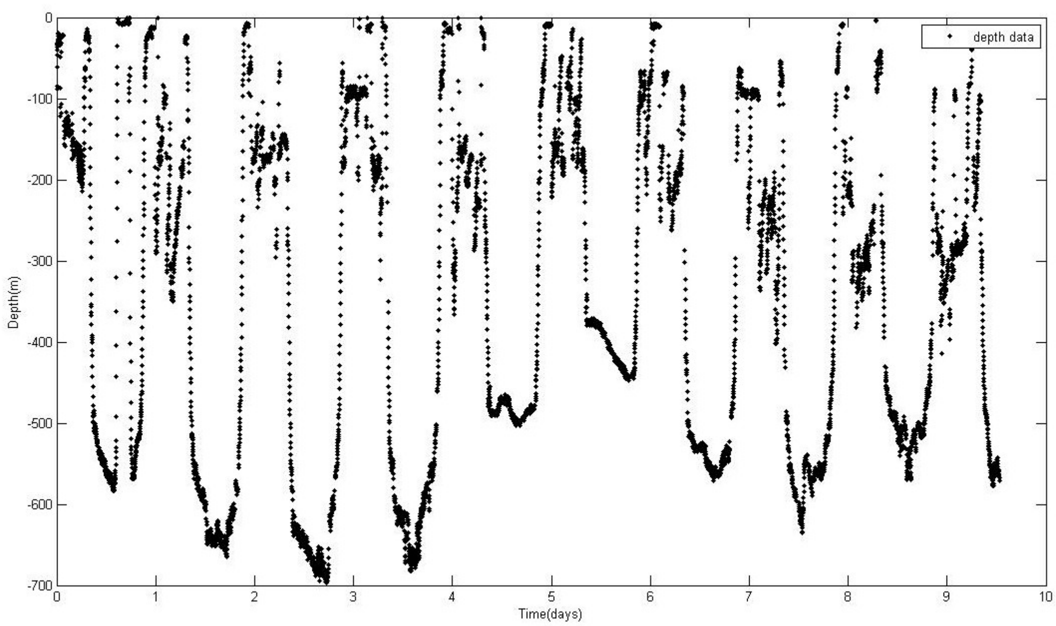

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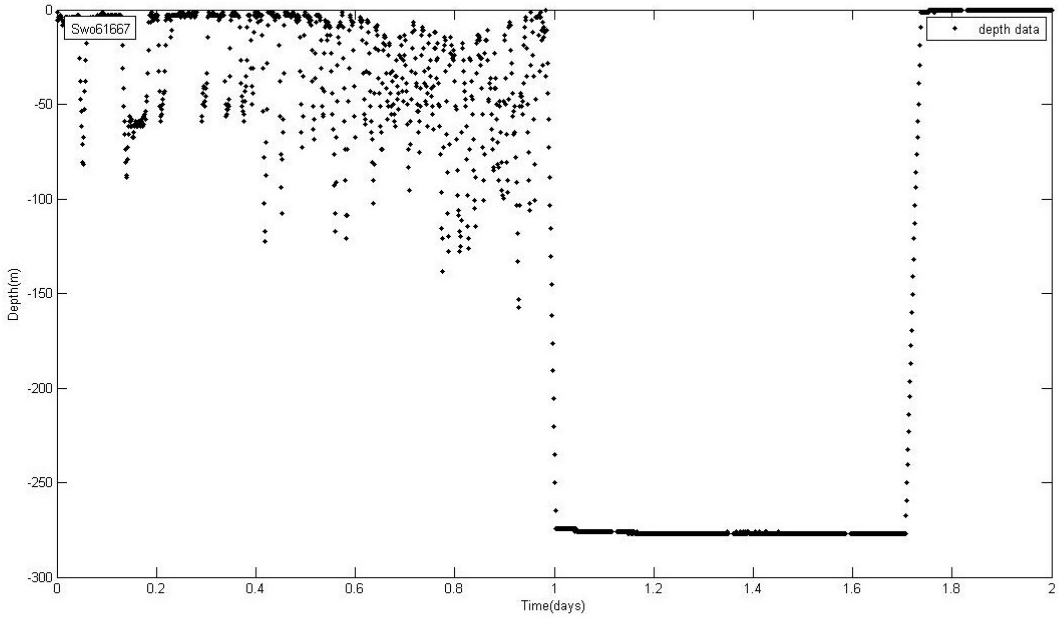

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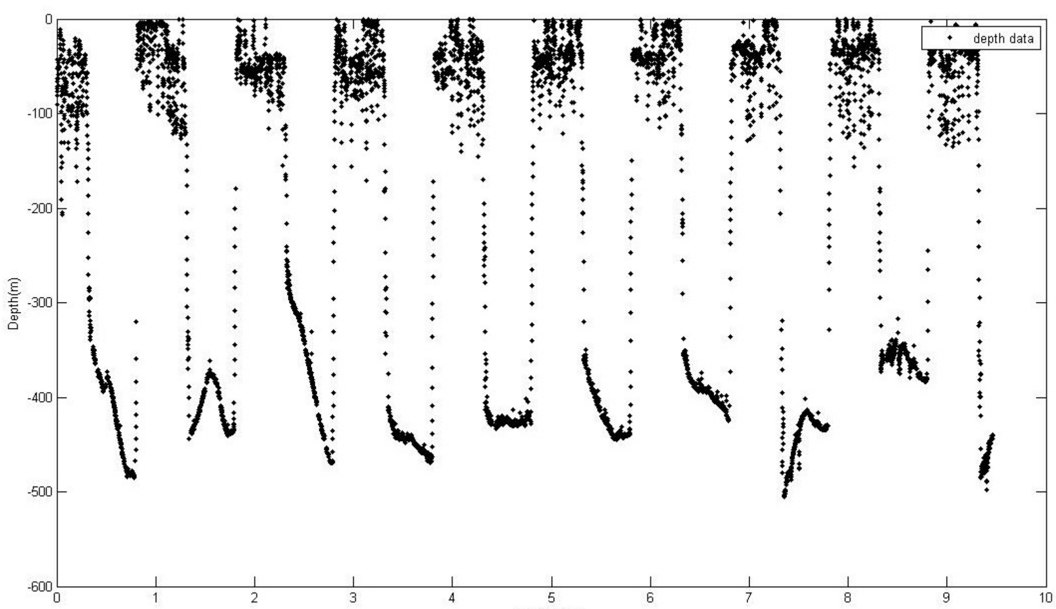

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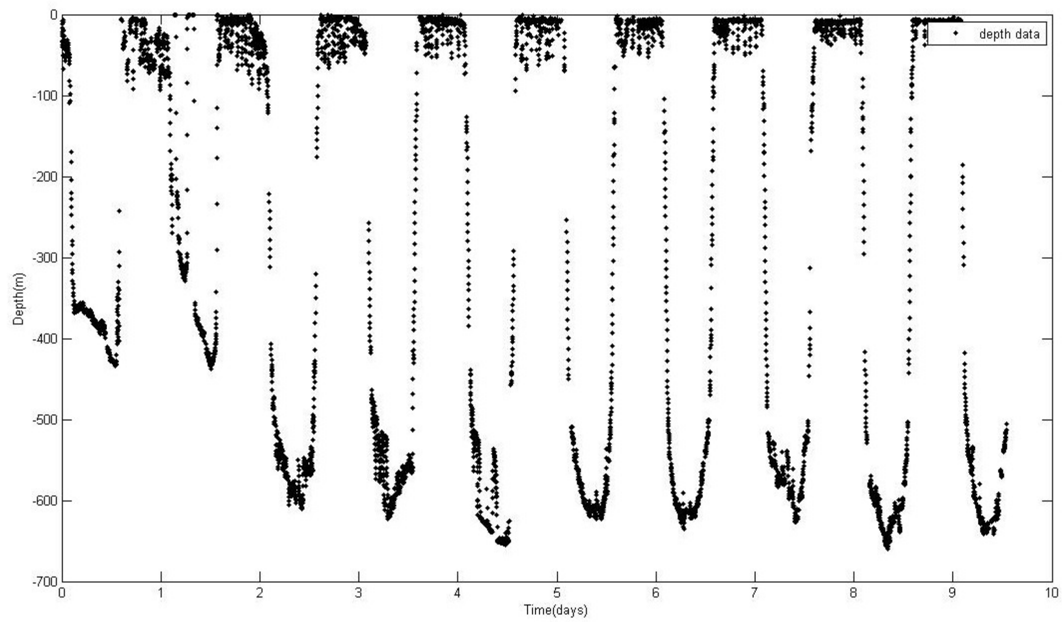

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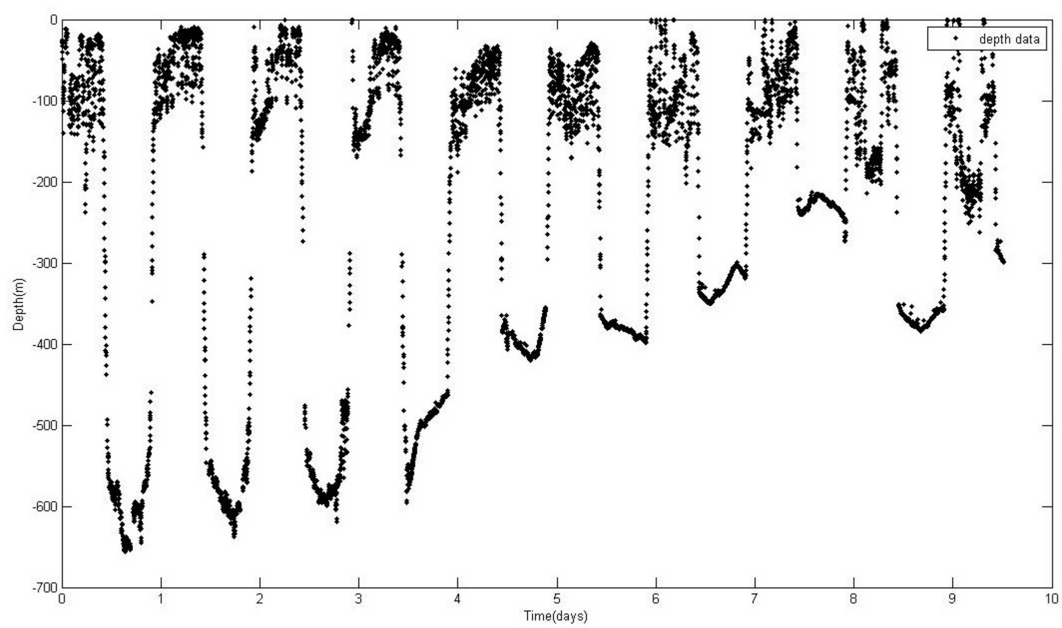

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Figure 4: Figures from all 14 reporting juvenile swordfish tags showing vertical movements over time and, when available, the point at which the tag released from the fish.

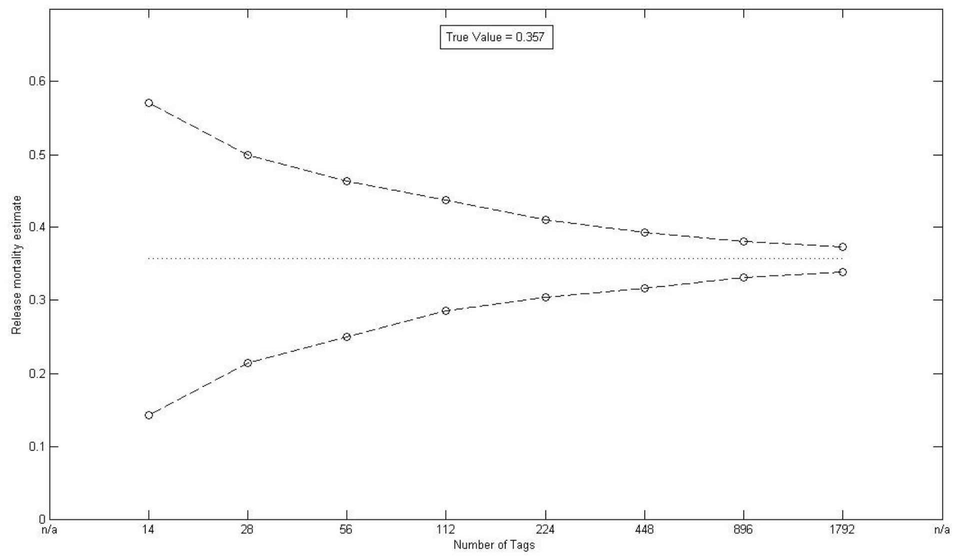


Figure 5: The 5th and 95th percentile values for each increase of the sample size and the true value.

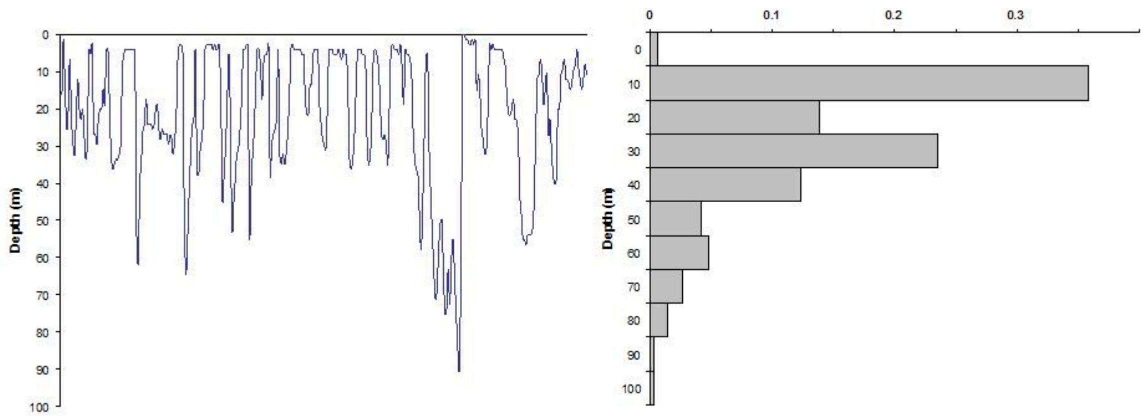
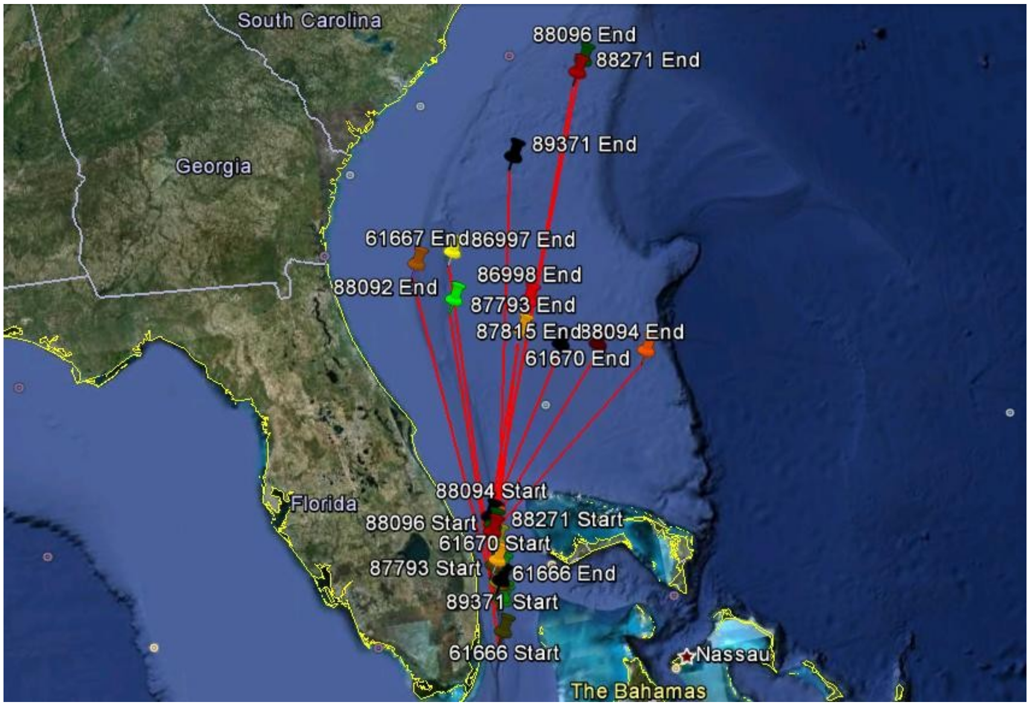
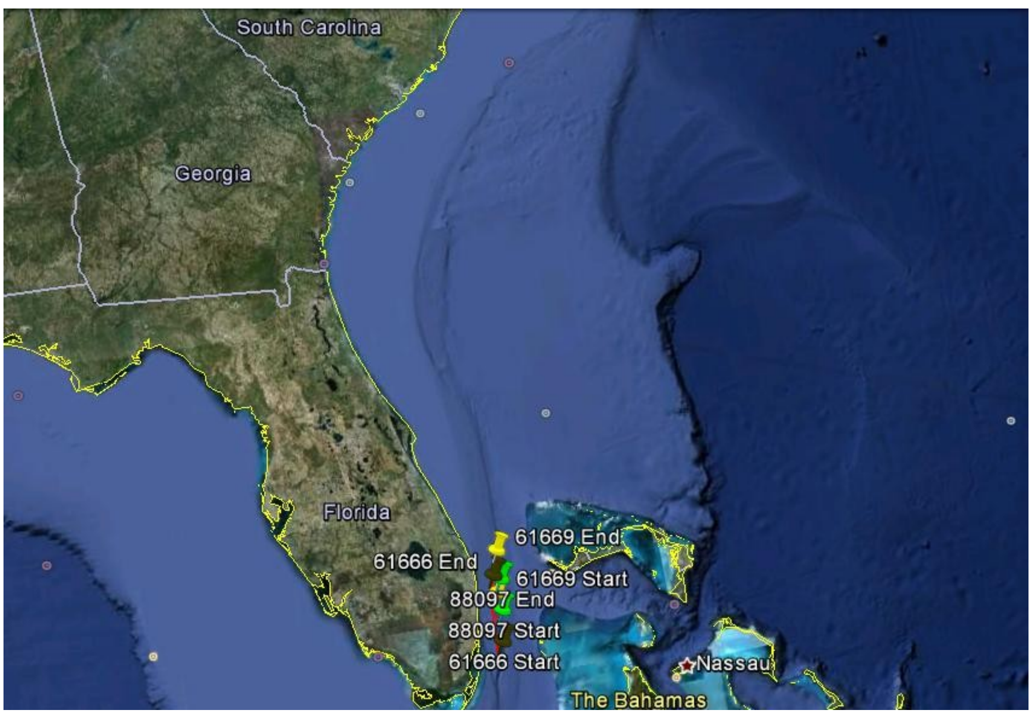


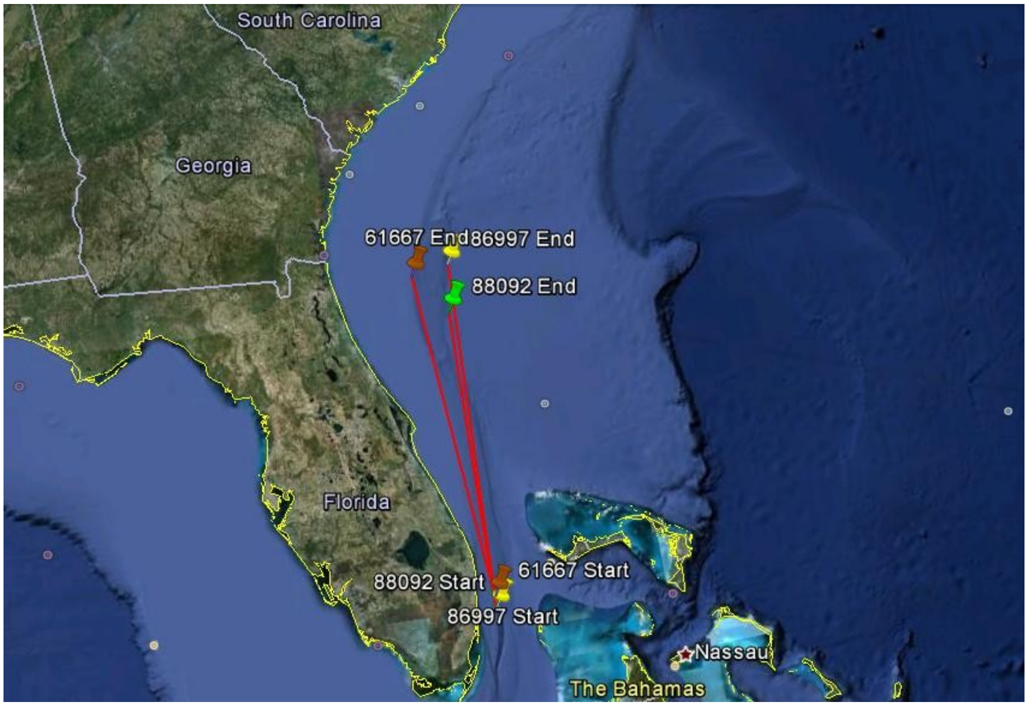
Figure 6: Graphic comparison between data returned for two types of PSAT tags, based on 12 hours of data on June 17, 2007, from a sailfish tagged off the Lower Florida Keys, Florida Straits. The left graph is the plot of the HR point data, while the right graph is a simulated example of summary data based on 10 m bins.



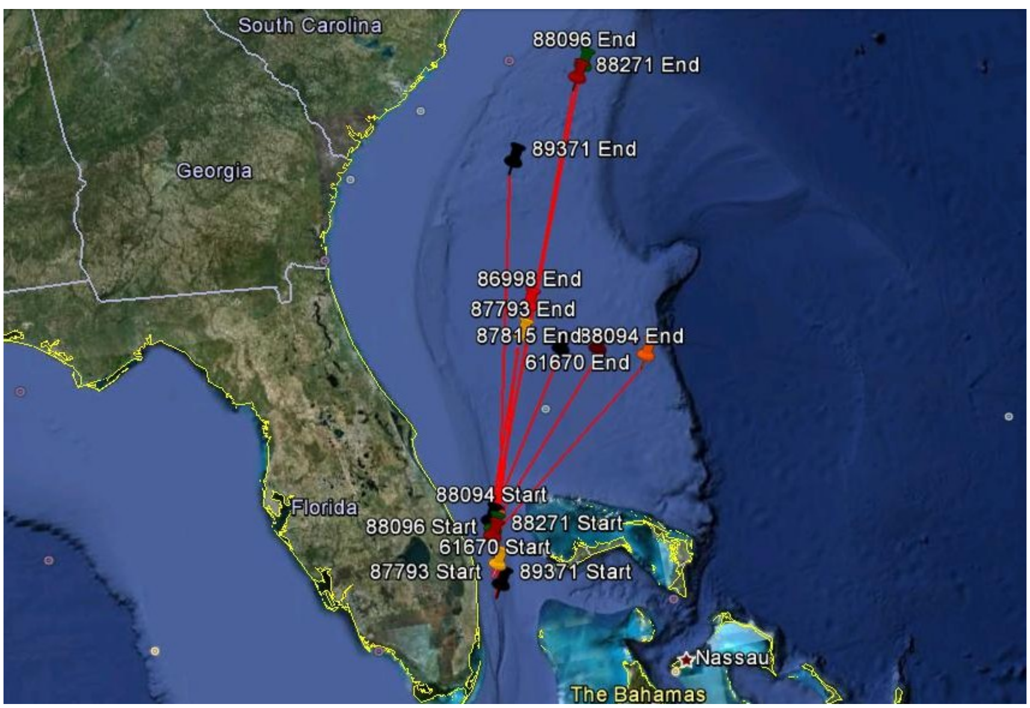
a) all tracks plotted together



b) fish with the shortest tracks

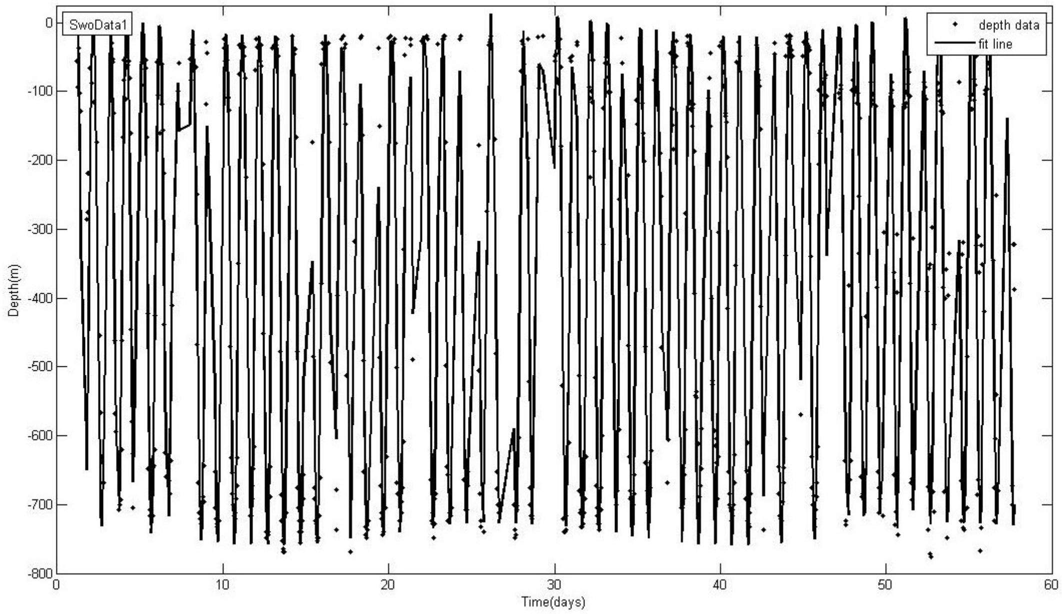


c) fish with tracks heading north

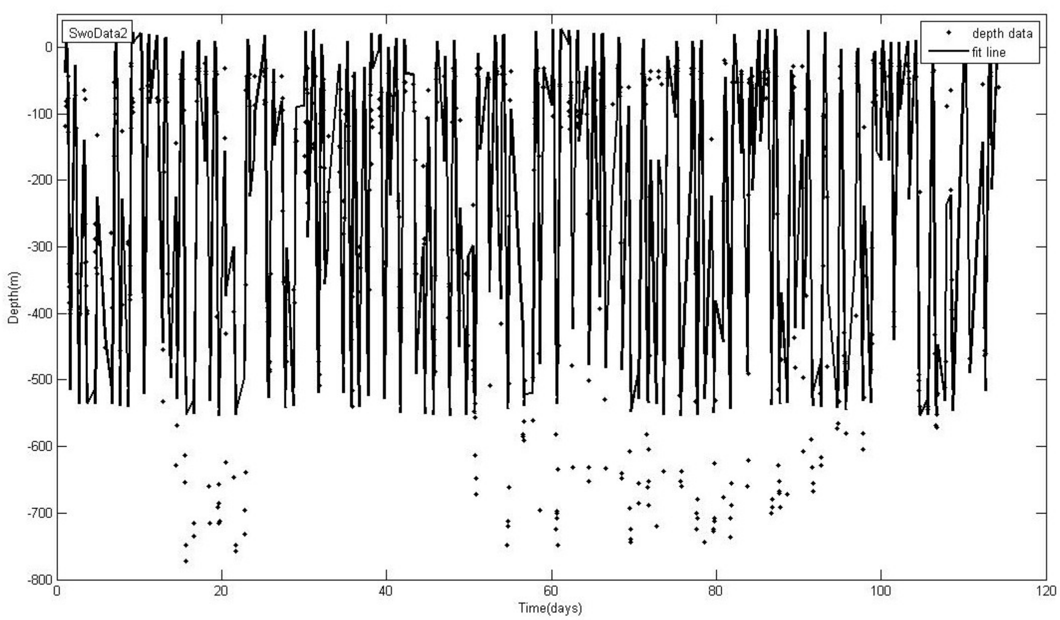


d) fish with tracks heading northeast

Figure 7: Google Earth images showing where all fish were tagged and where the tags popped off: (a) all tracks plotted together, (b) fish with the shortest tracks, (c) fish with tracks heading north, (d) fish with tracks heading northeast.



a) Data1



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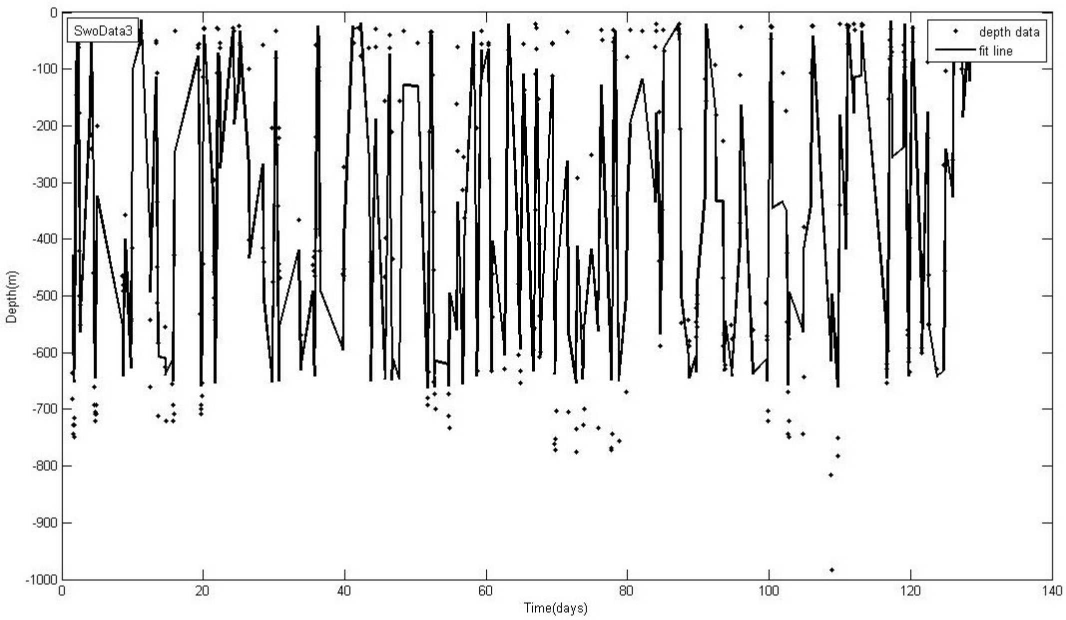
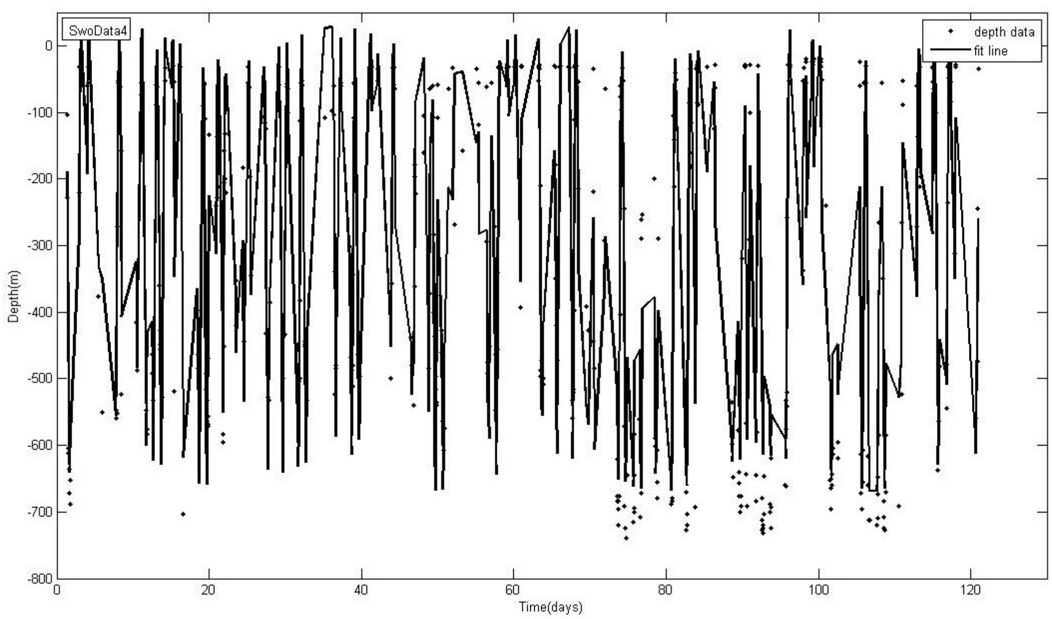
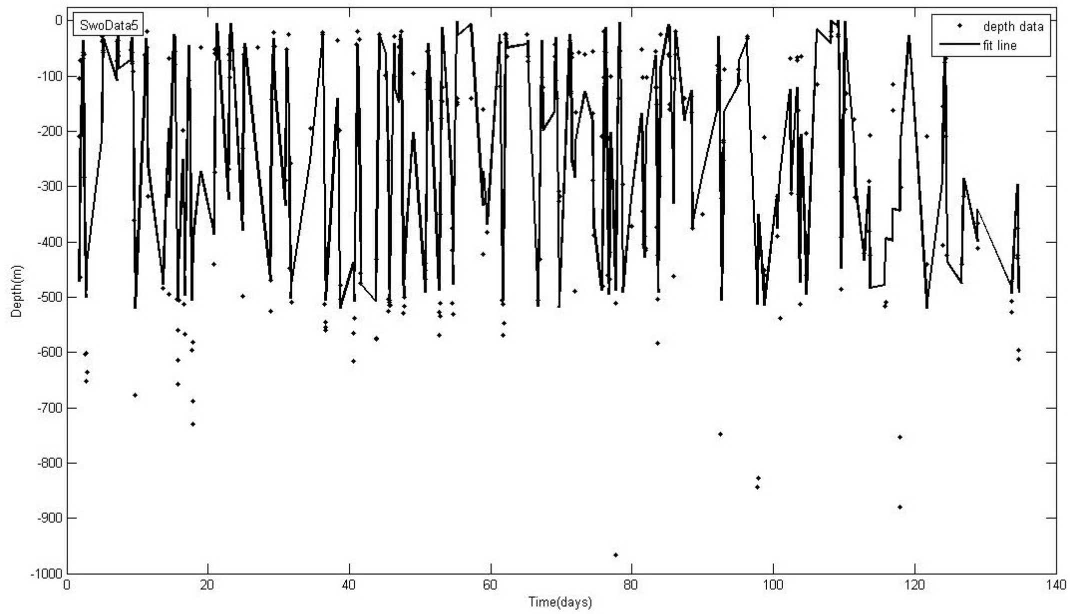


c) Data3

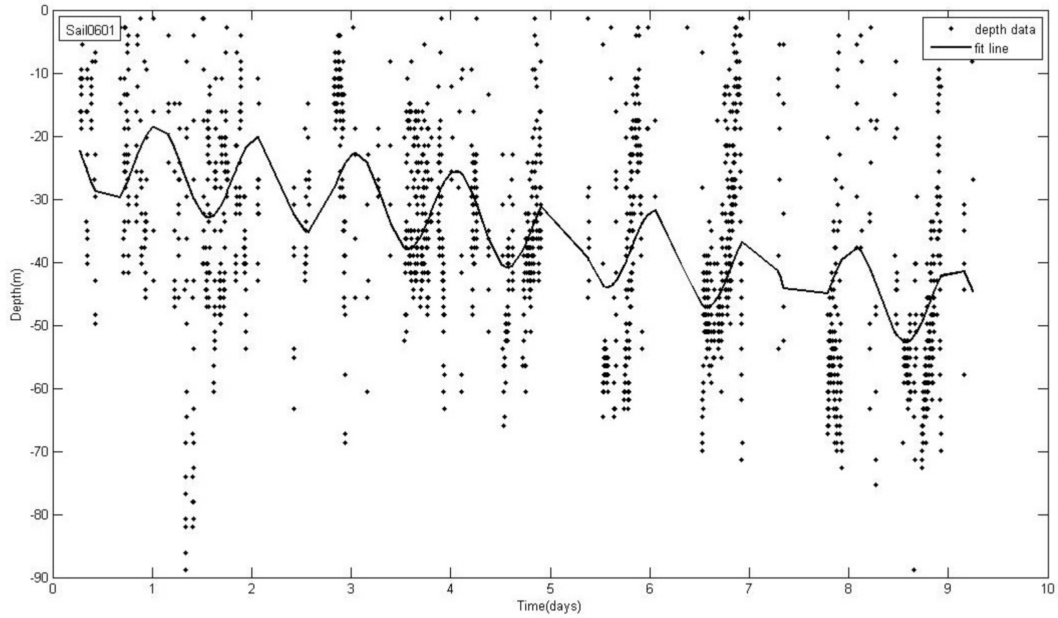


d) Data4



e) Data5

Figure 8: Adult swordfish data showing diurnal signal, denoted by reference number.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depth data
fit line
Depth(m)
Time(days)
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-10
-20
-30
-40
-50
-60
-70
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0
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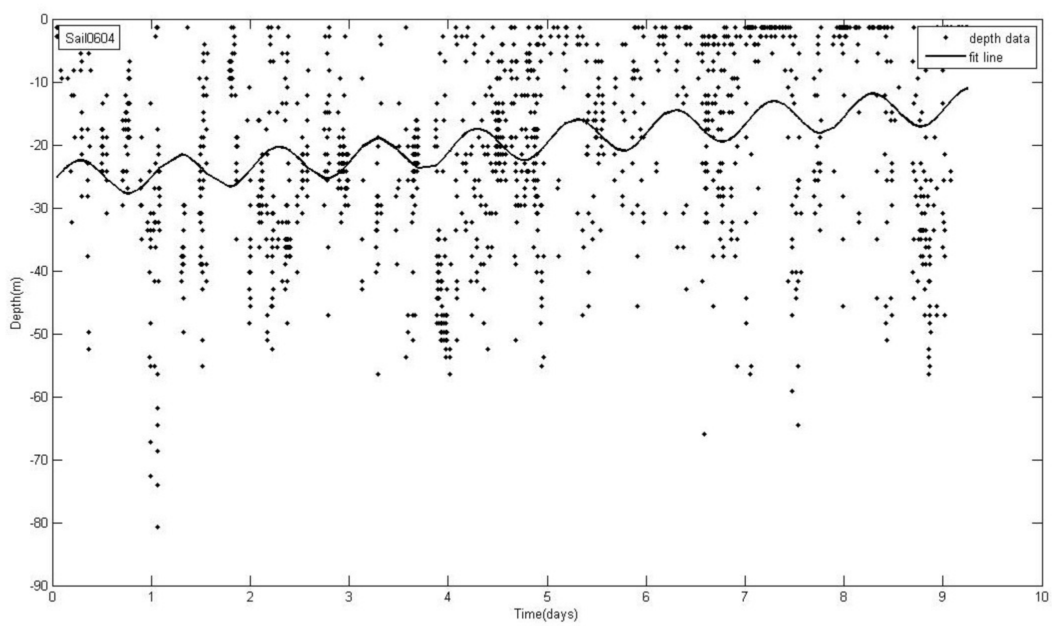
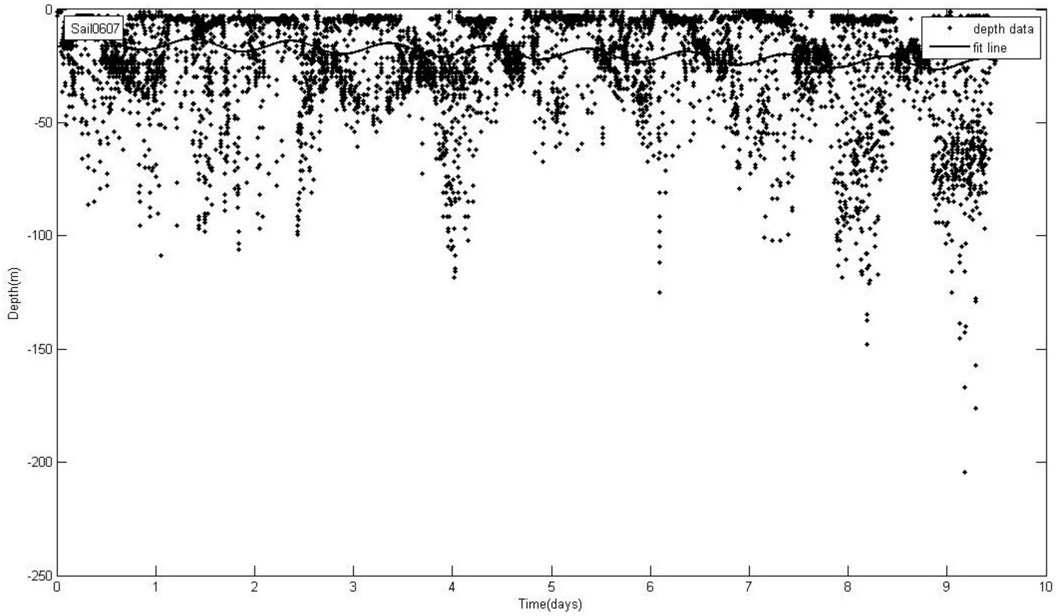
4
5
6
7
8
9
10

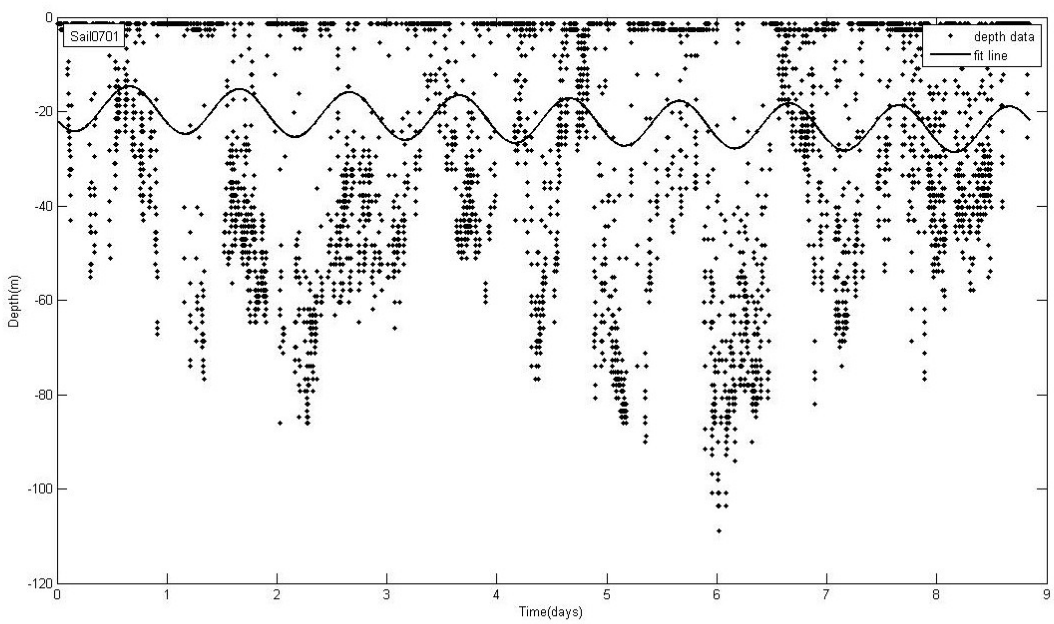
a) 0601


Sail0604
depth data
fit line
Depth(m)
Time(days)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
1
2
3
4
5
6
7
8
9
10

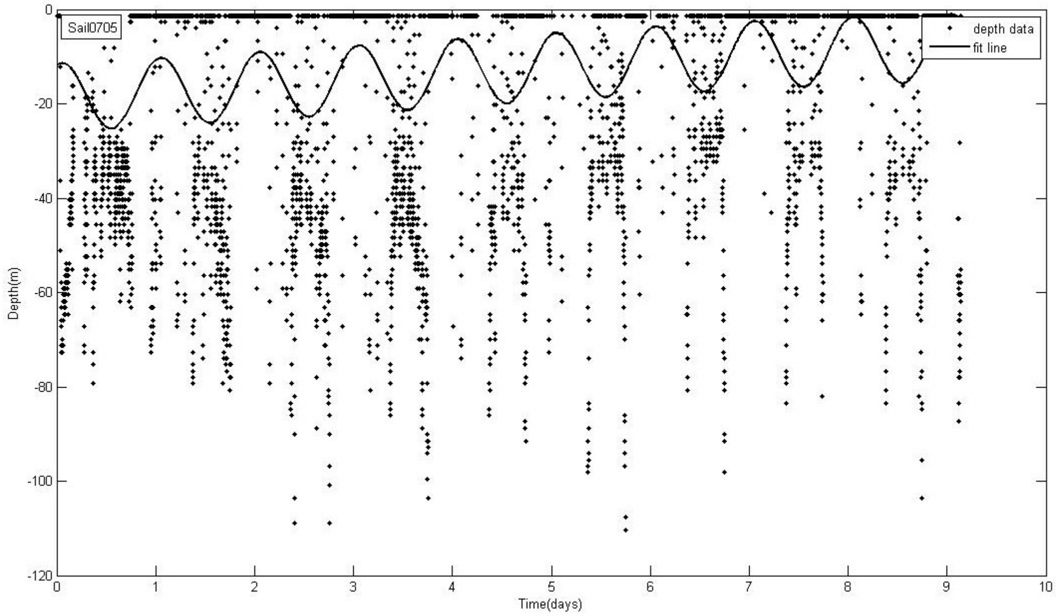
b) 0604


Sail0607
depth data
fit line
Depth(m)
Time(days)
0
-50
-100
-150
-200
-250
0
1
2
3
4
5
6
7
8
9
10

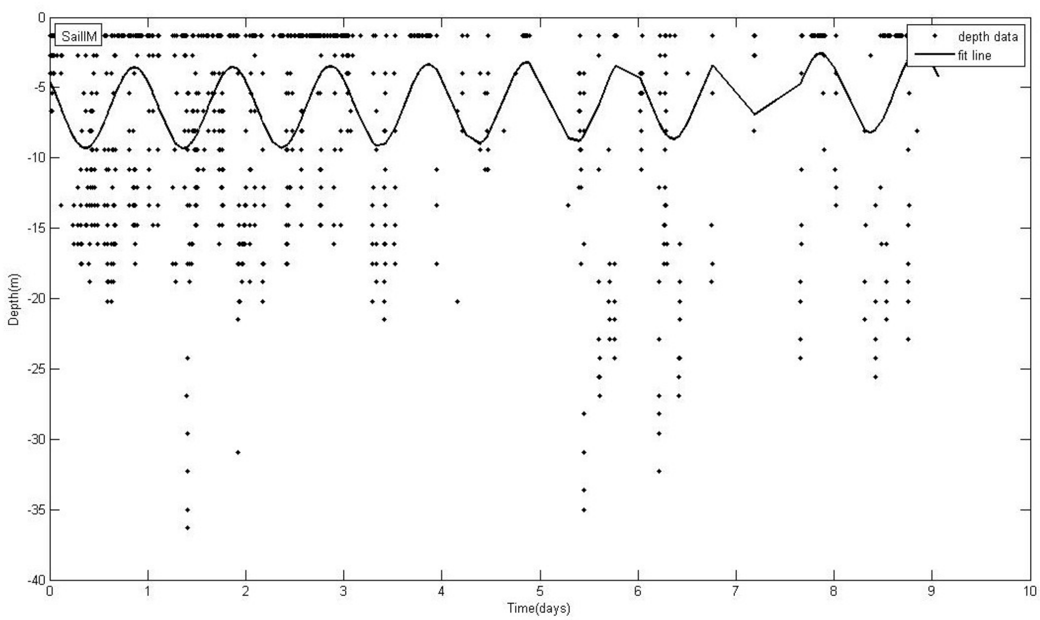
c) 0607


Sail0701
depth data
fit line
Depth(m)
Time(days)
0
-20
-40
-60
-80
-100
-120
0
1
2
3
4
5
6
7
8
9

d) 0701

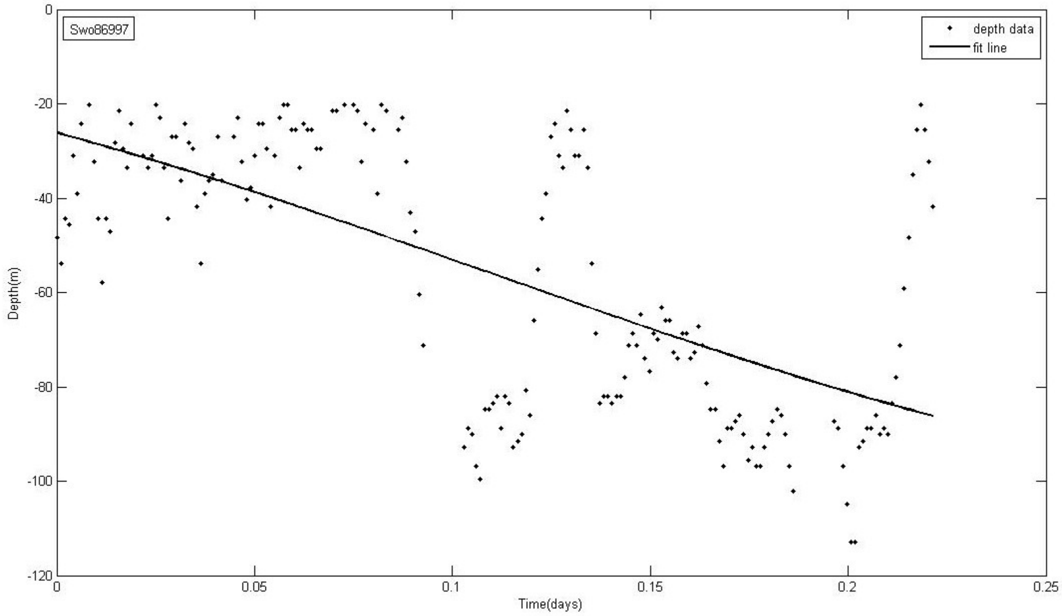


e) 0705

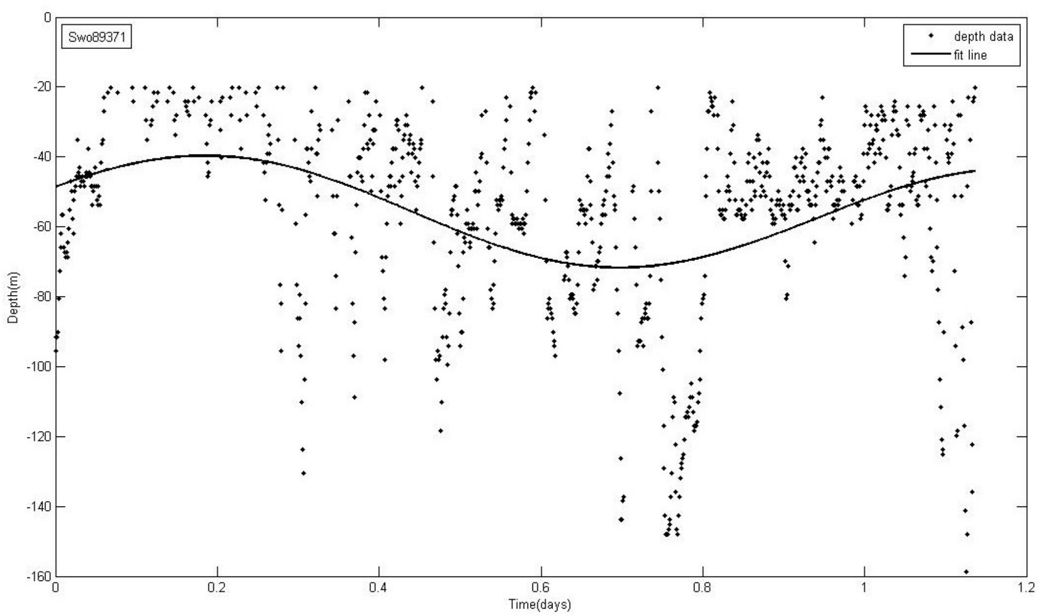


f) Isla Mujeres

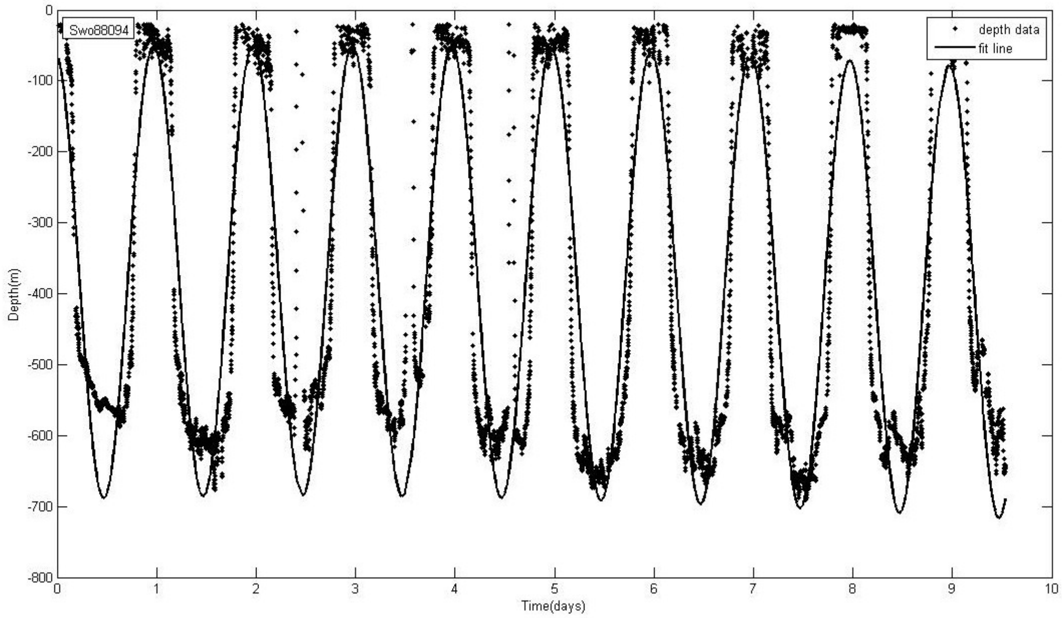
Figure 9: Adult sailfish data showing diurnal and lunar signals, denoted by reference number.



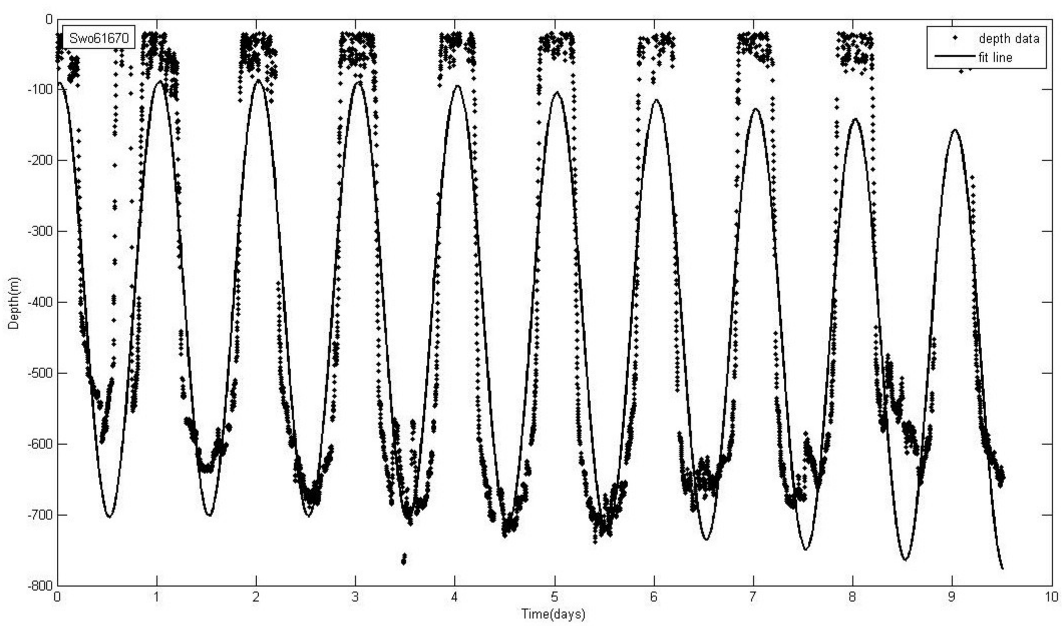
a) 86997



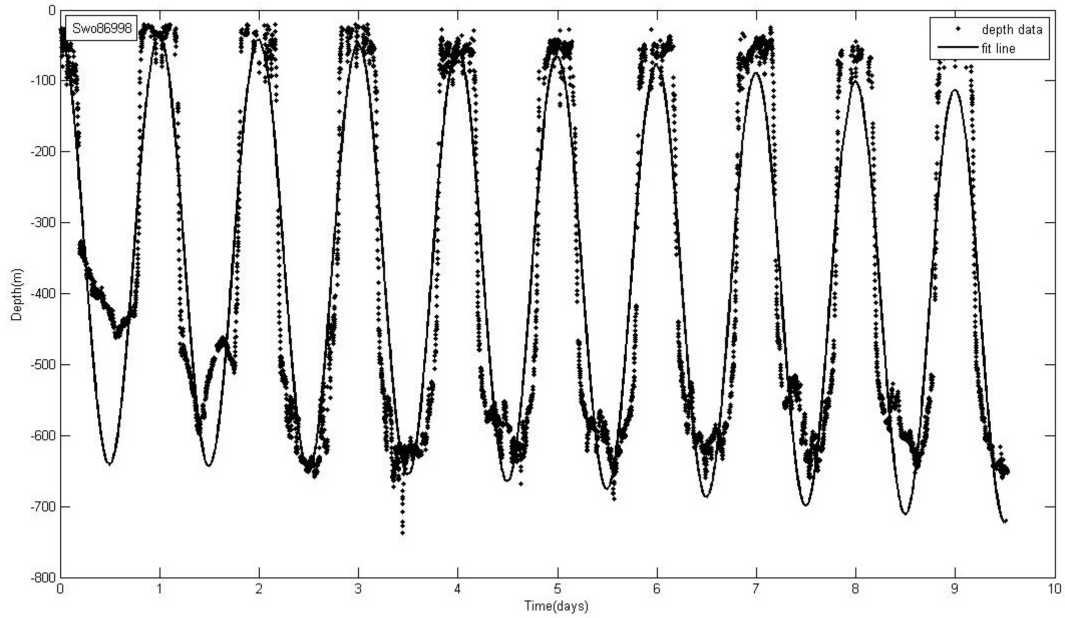
b) 89371



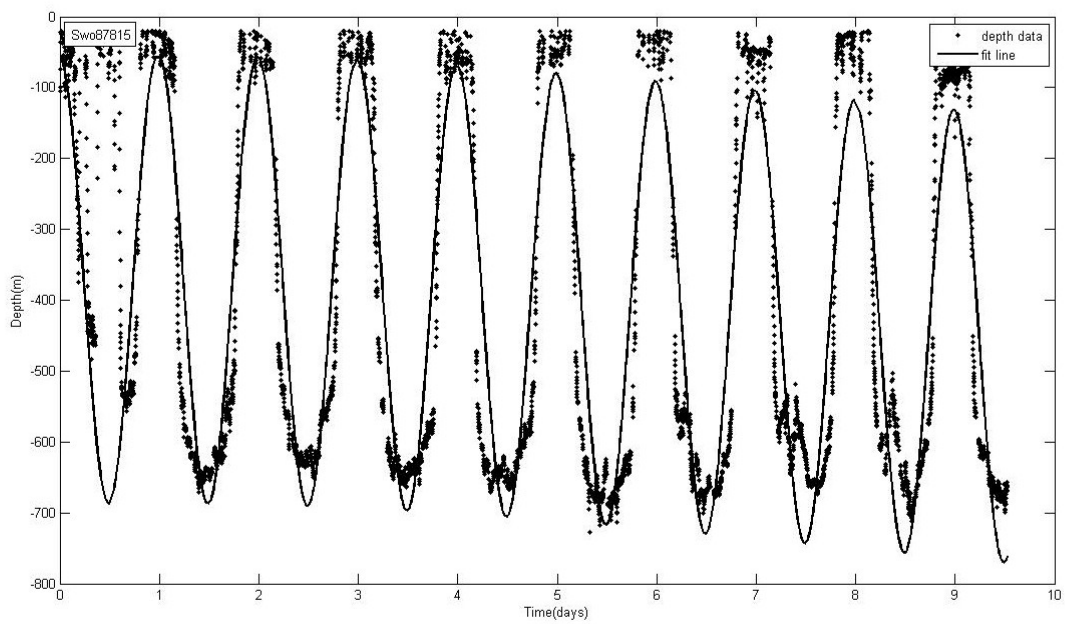
c) 88094



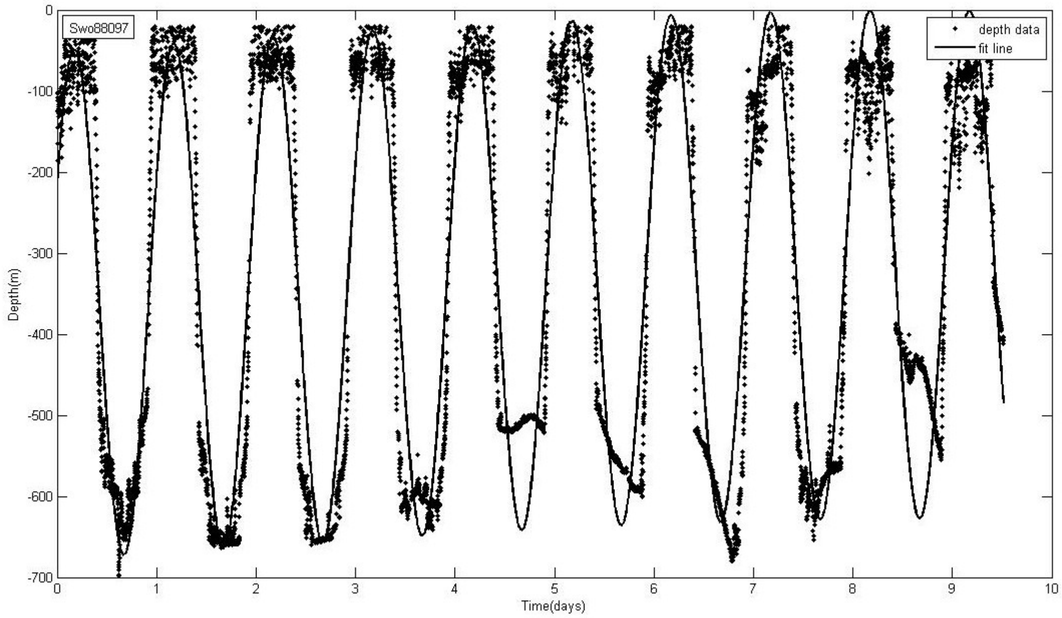
d) 61670



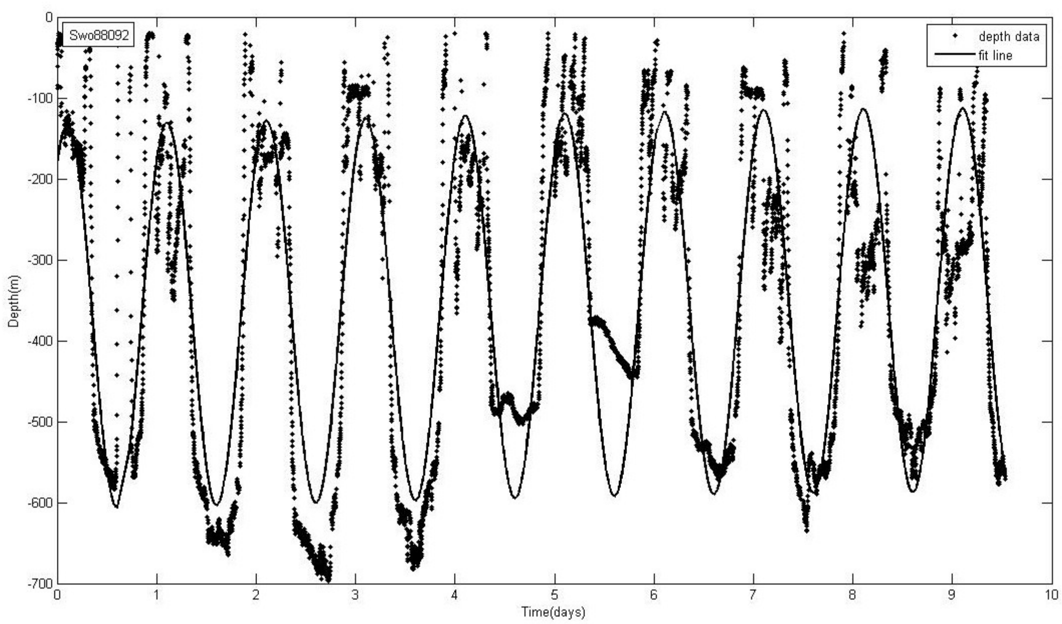
e) 86998



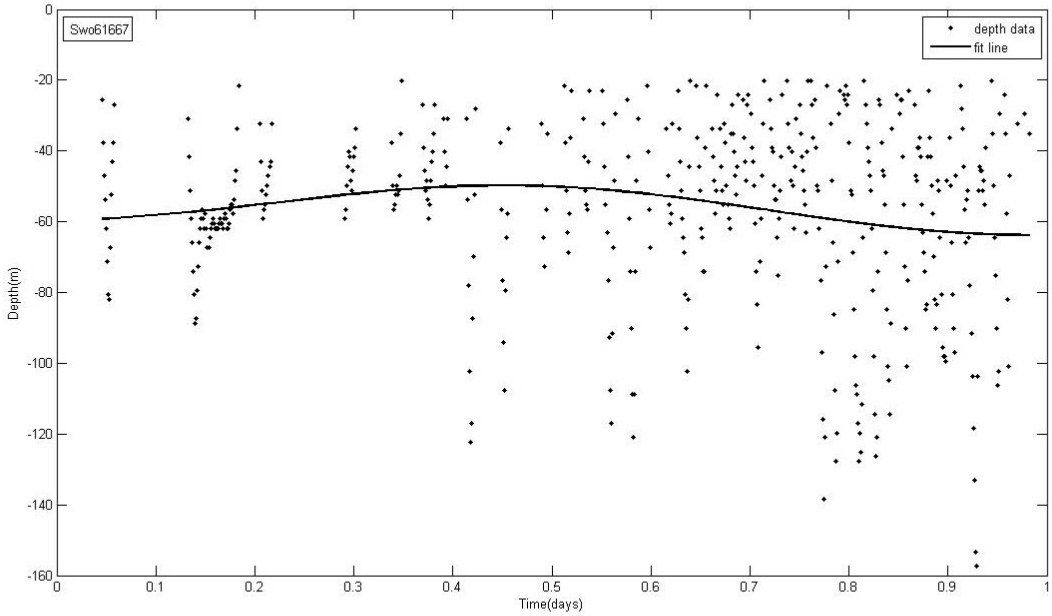
f) 87815



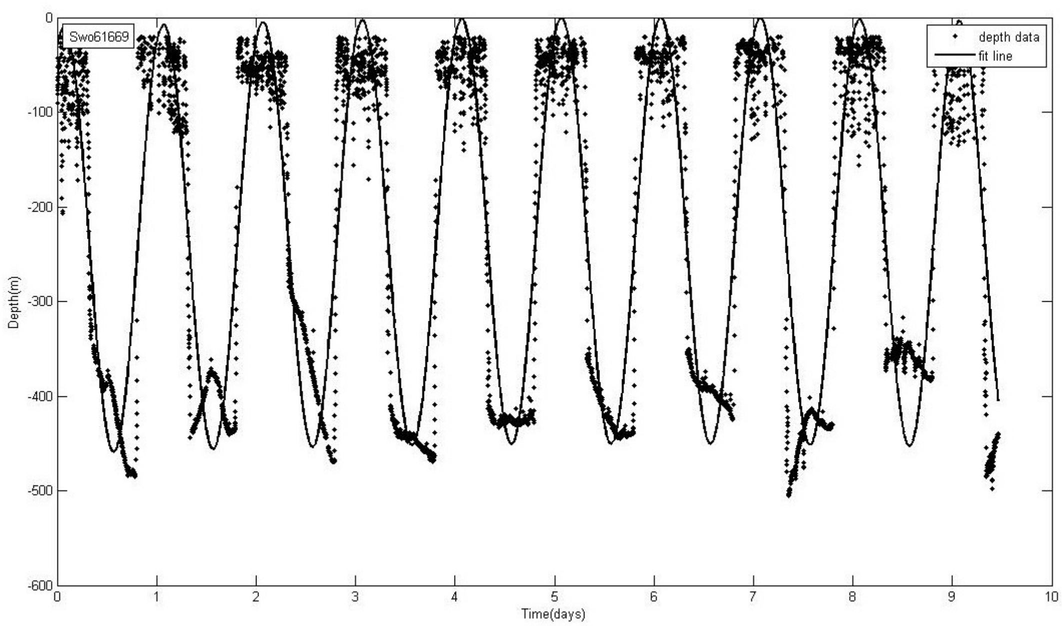
g) 88097



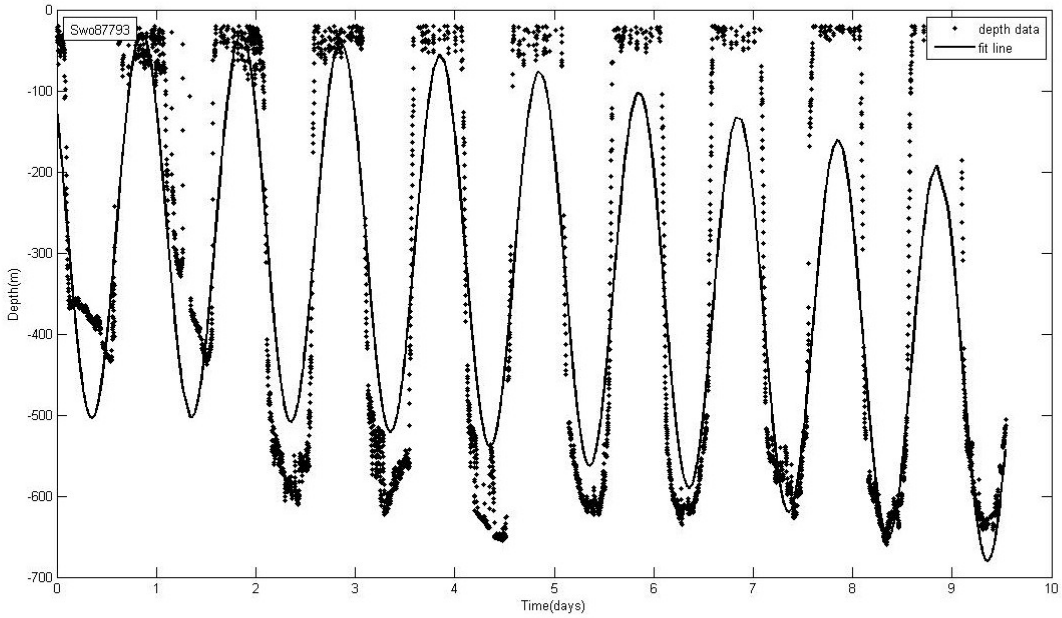
h) 88092



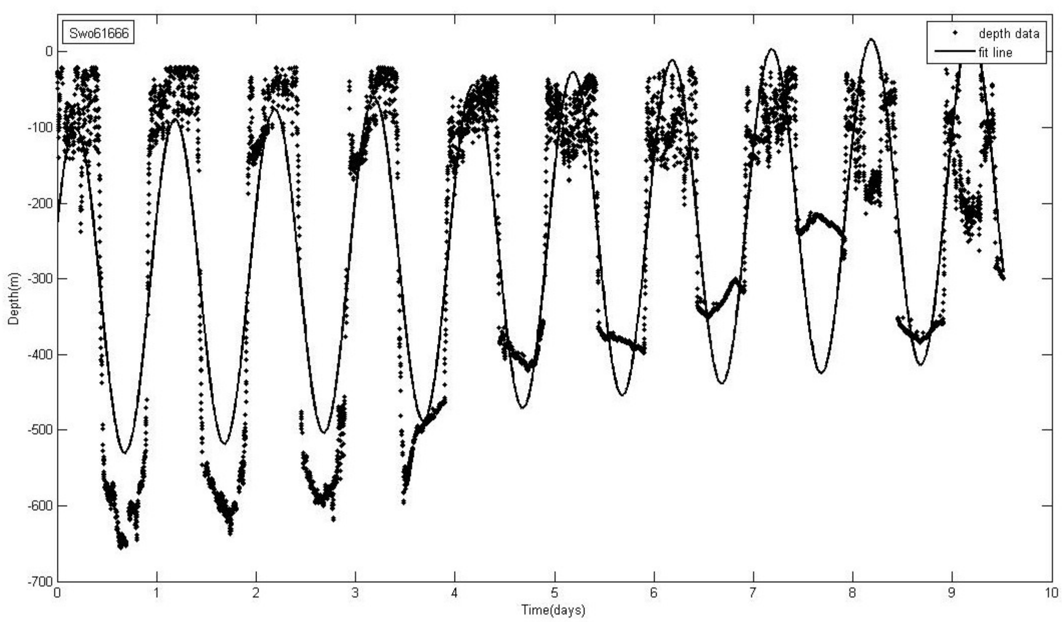
i) 61667



j) 61669

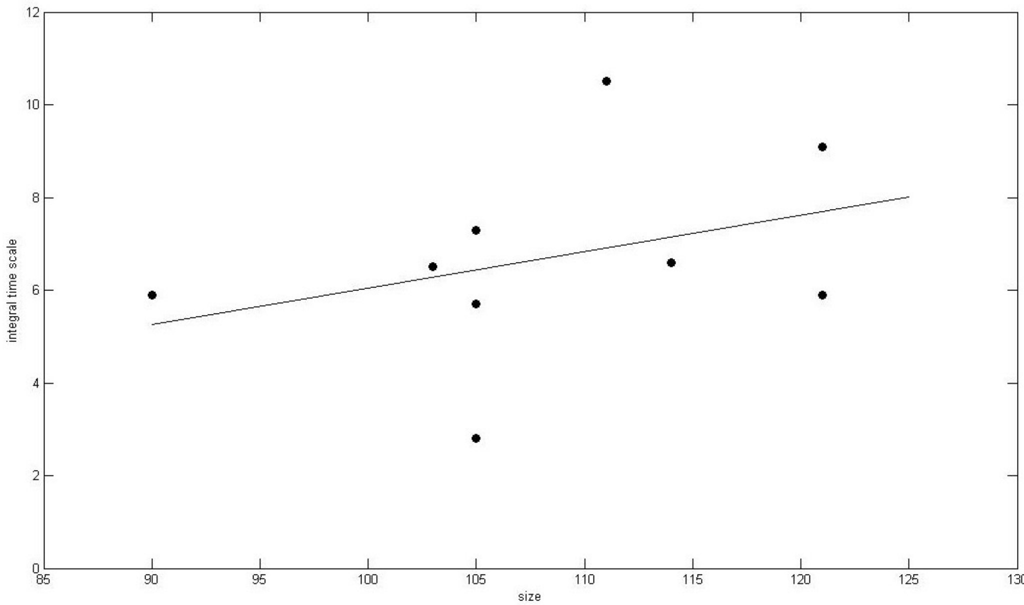


k) 87793

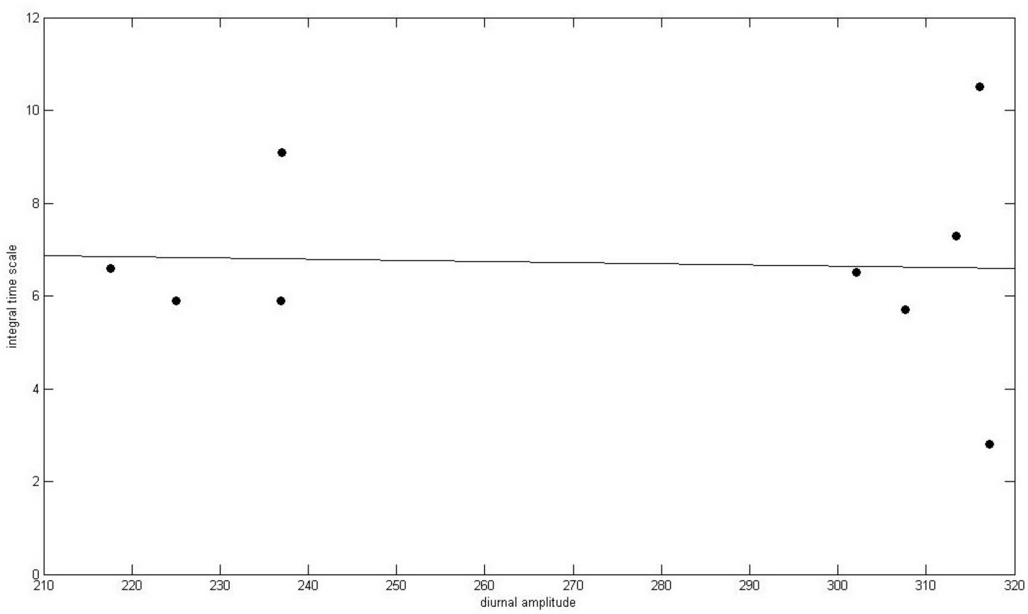


l) 61666

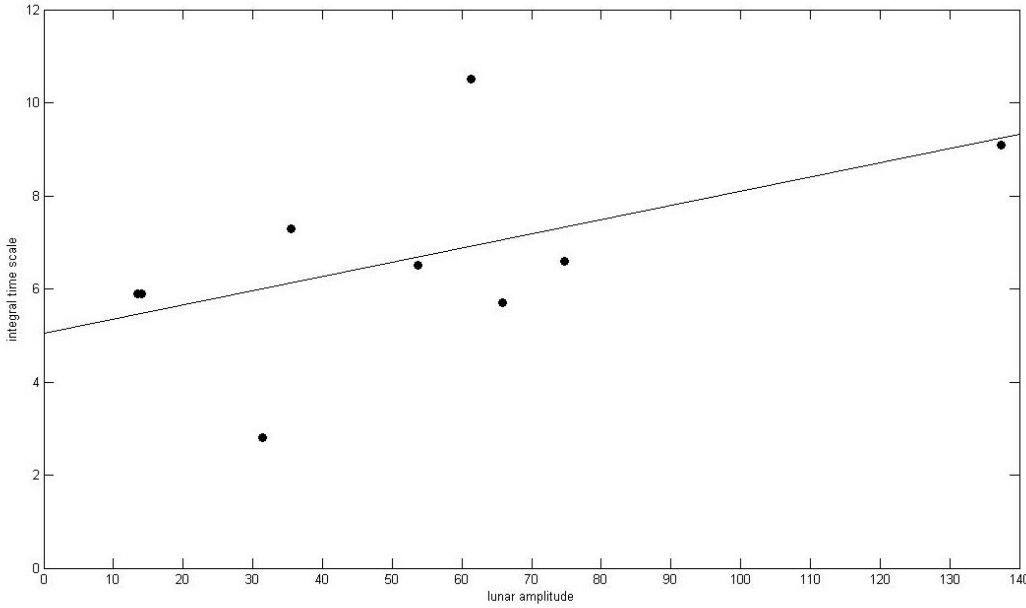
Figure 10: Figures from all 12 juvenile swordfish tags for those that survived release, denoted by tag ID number, showing vertical movements over time and any diurnal or lunar signals in the data.



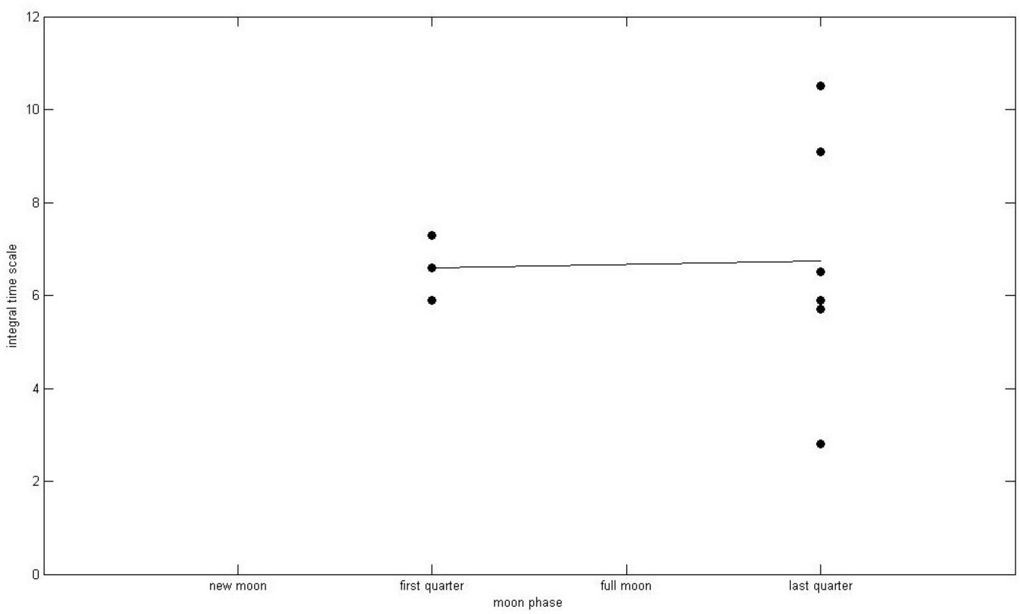
a) Integral time scale value vs. size



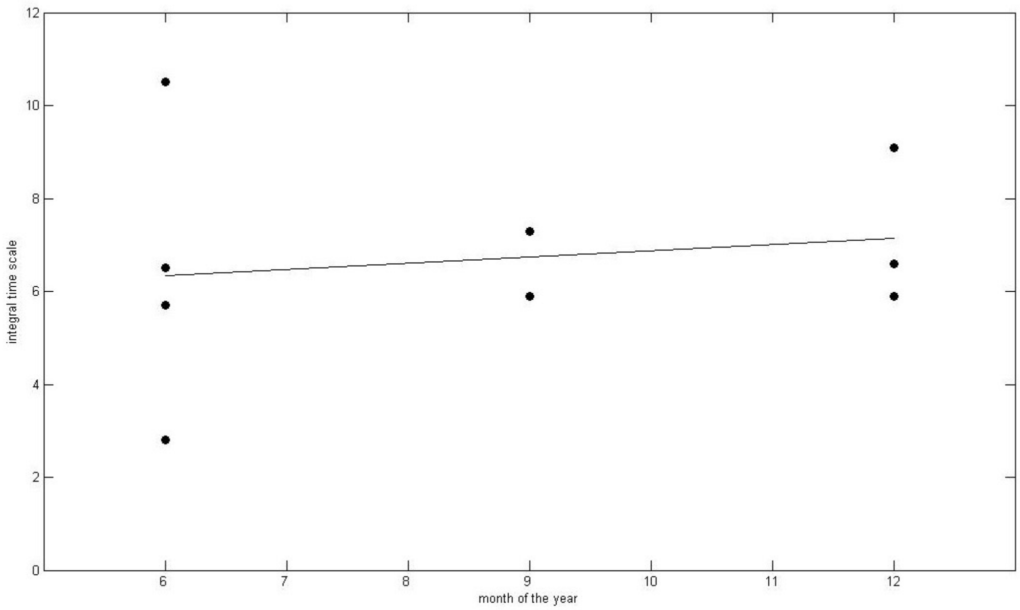
b) Integral time scale value vs. diurnal amplitude



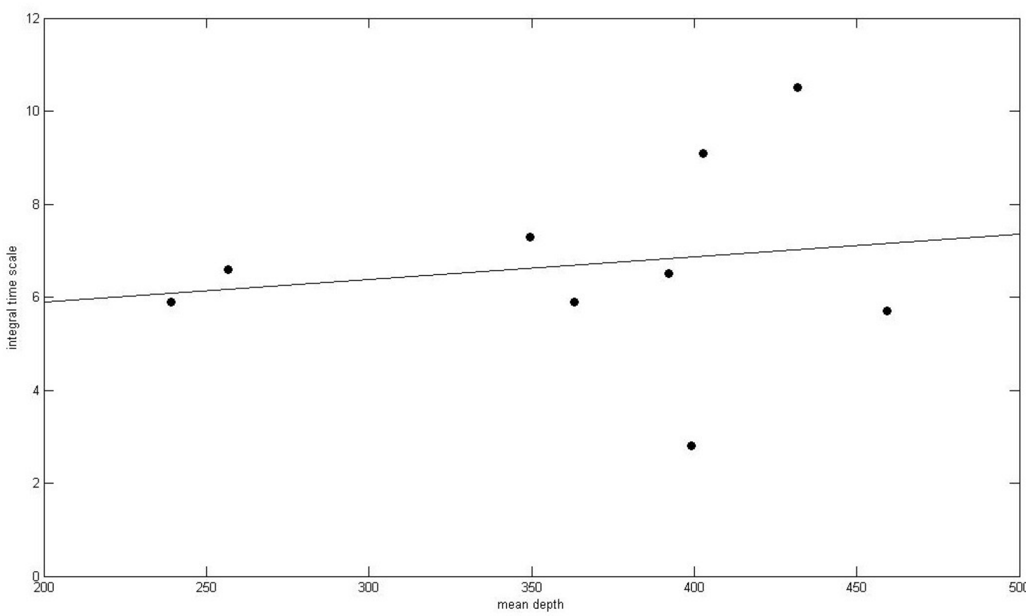
c) Integral time scale value vs. lunar amplitude



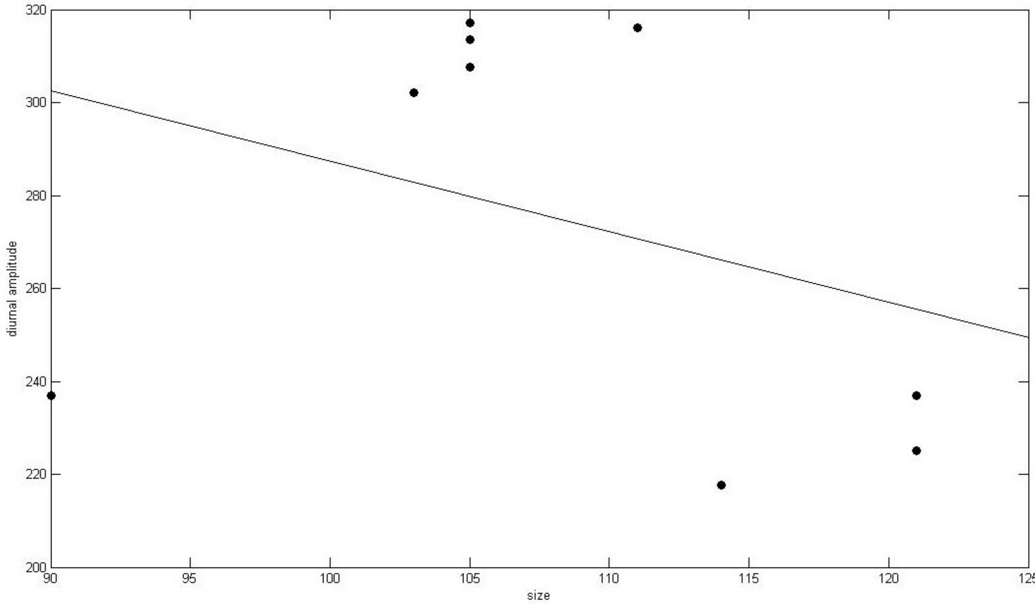
d) Integral time scale value vs. moon phase



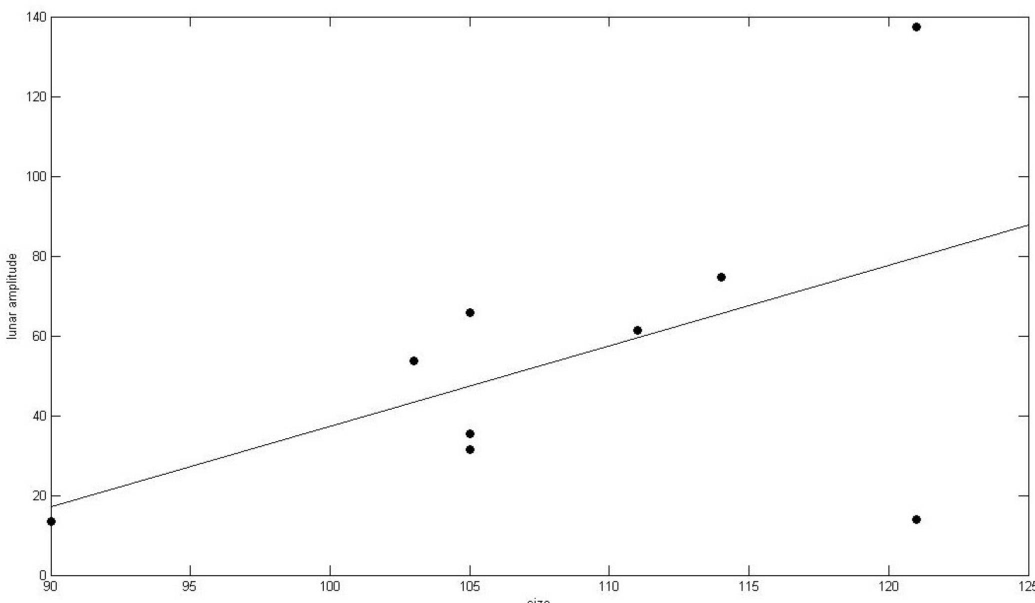
e) Integral time scale value vs. month of the year



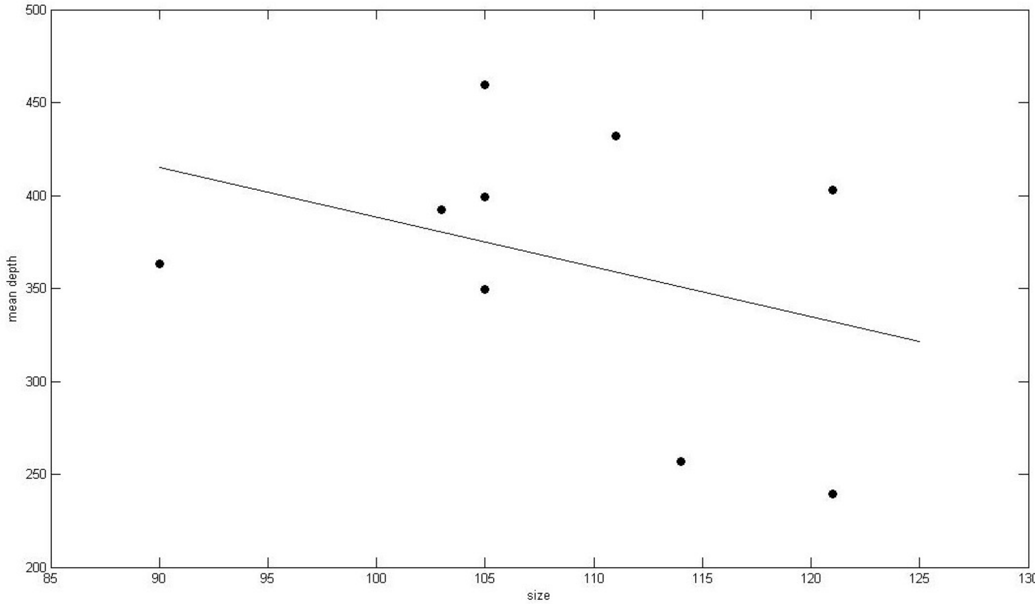
f) Integral time scale vs. mean depth



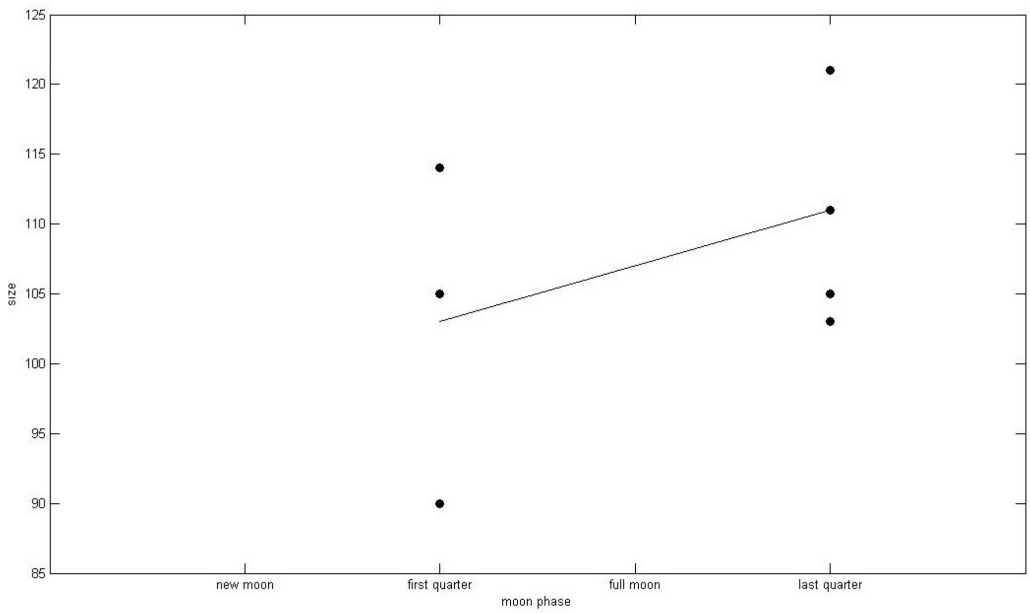
g) Size vs. diurnal amplitude



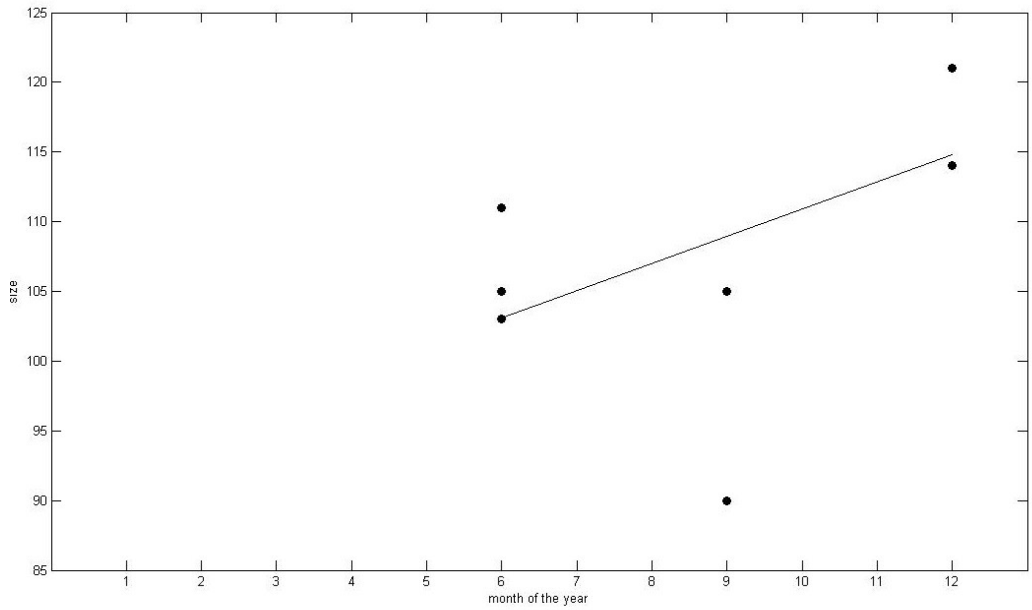
h) Size vs. lunar amplitude



i) Size vs. mean depth

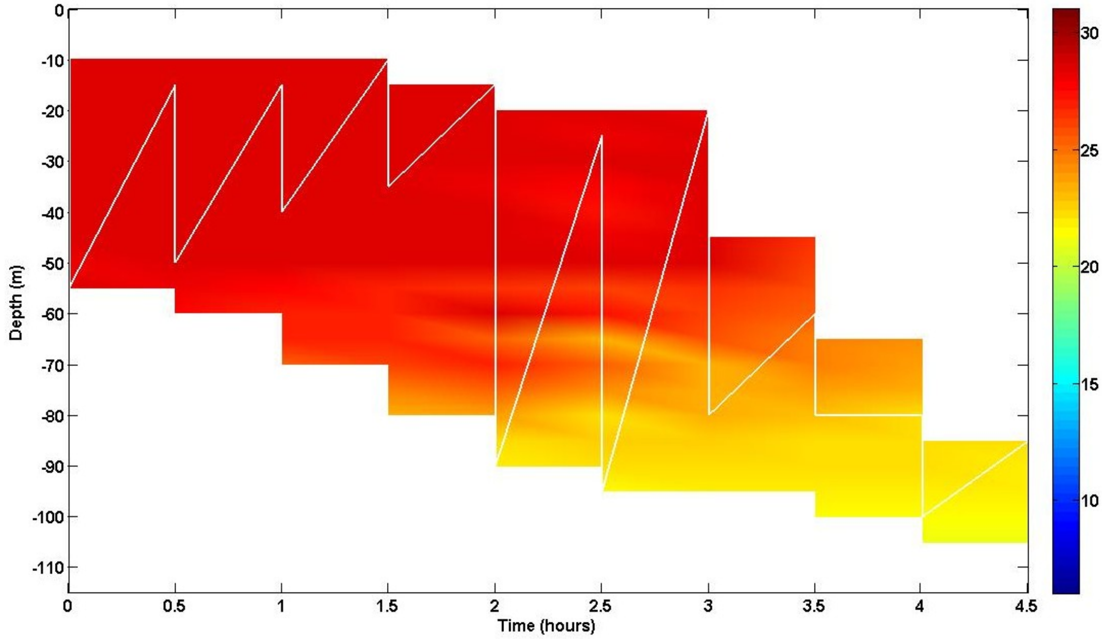


j) Size vs. moon phase

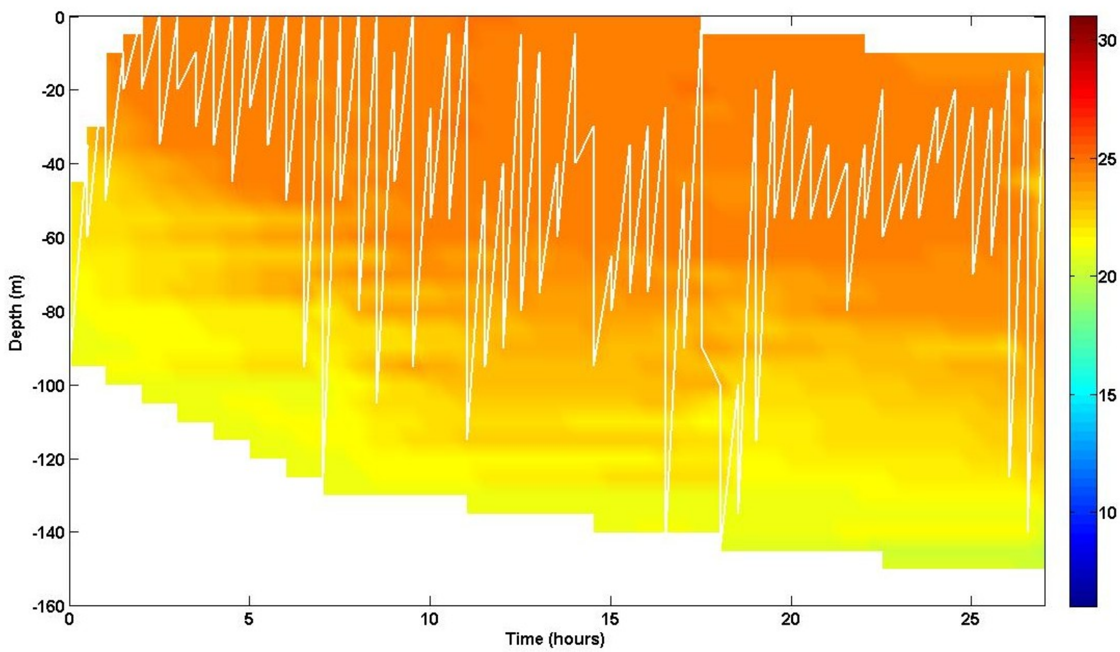


k) Size vs. month of the year

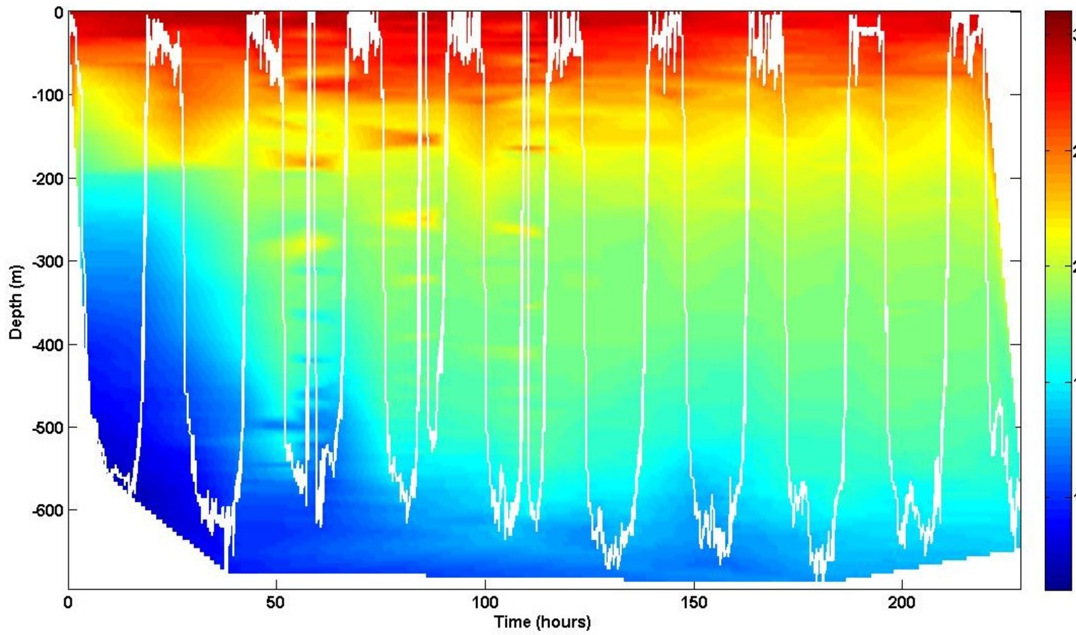
Figure 11: Integral time scale value and size vs. variables (size, diurnal amplitude, lunar amplitude, mean depth, moon phase, and month of the year).



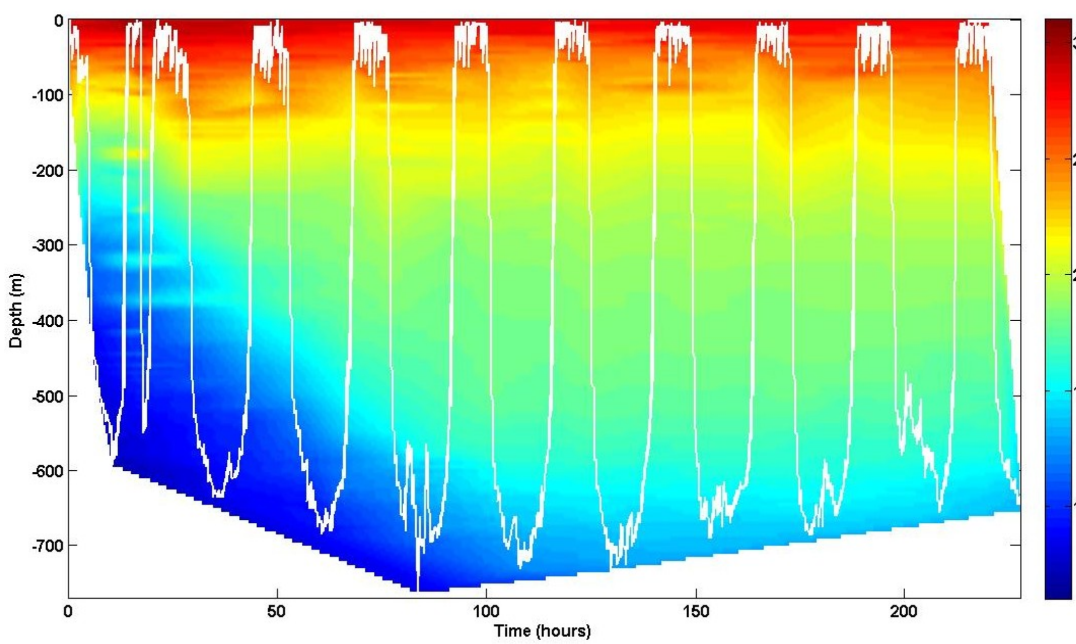
a) 86997



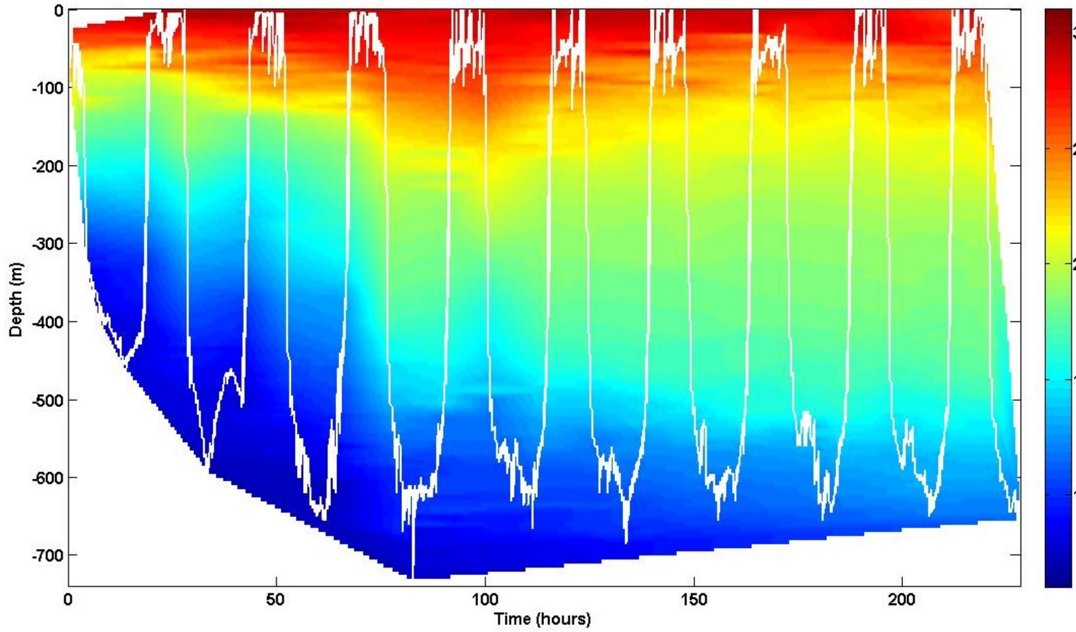
b) 89371



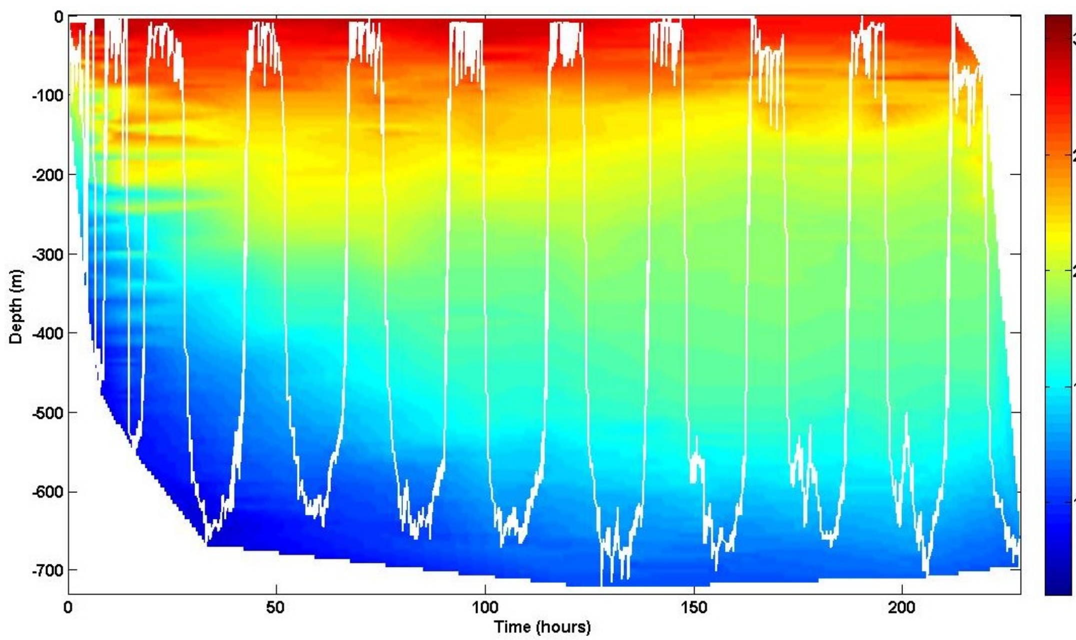
c) 88094



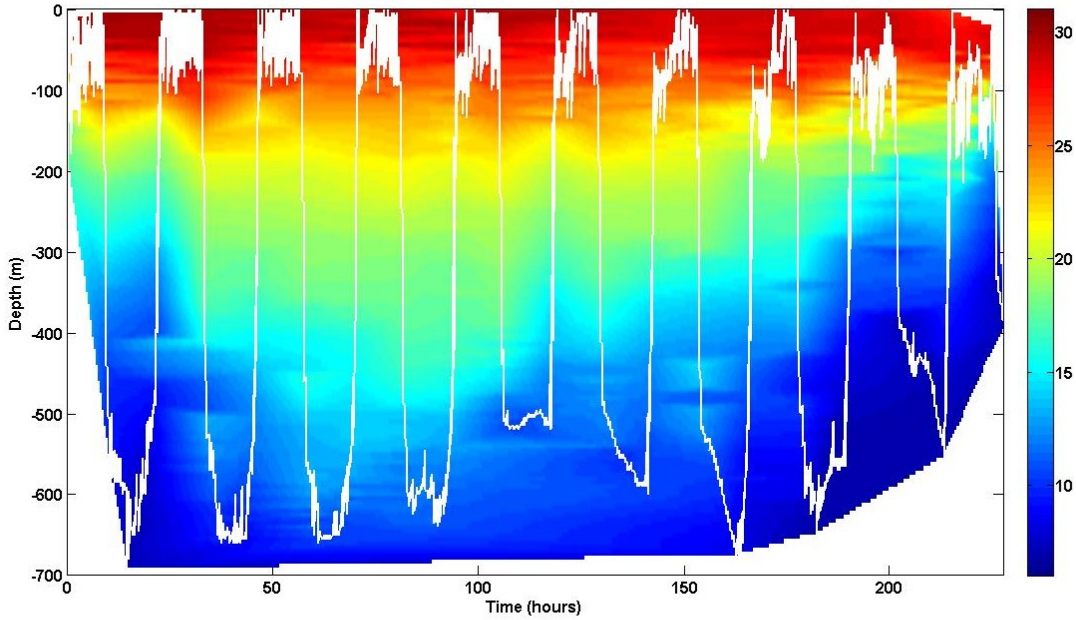
d) 61670



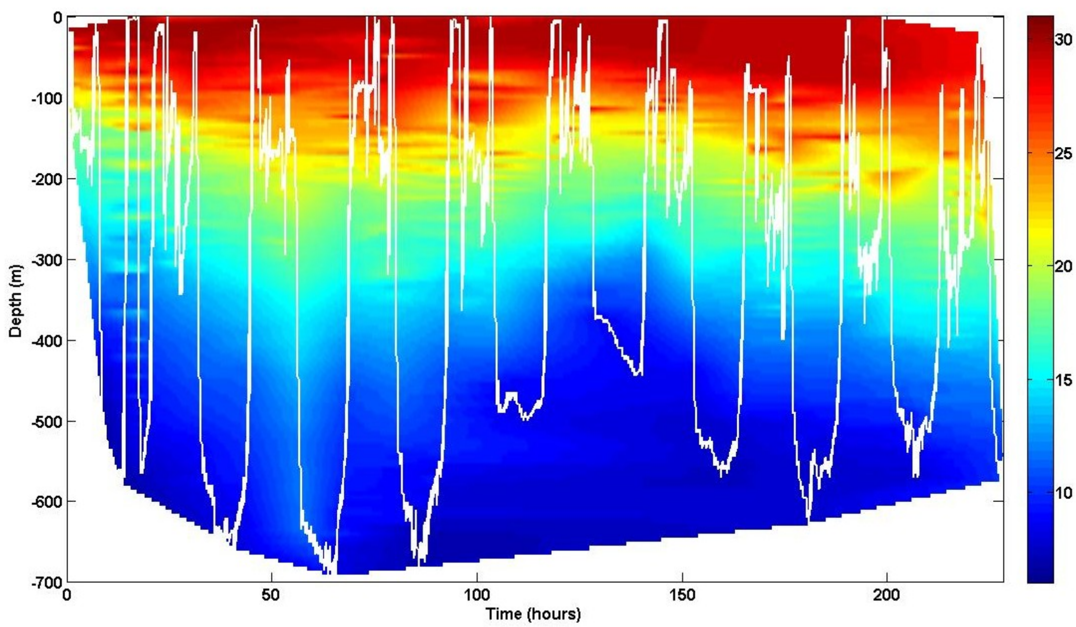
e) 86998



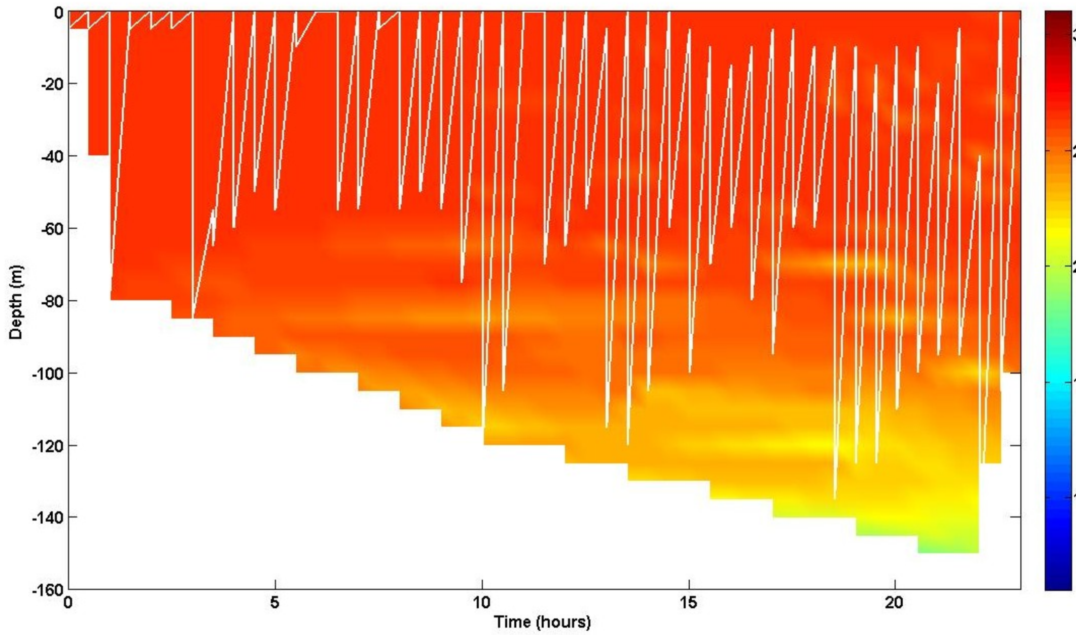
f) 87815



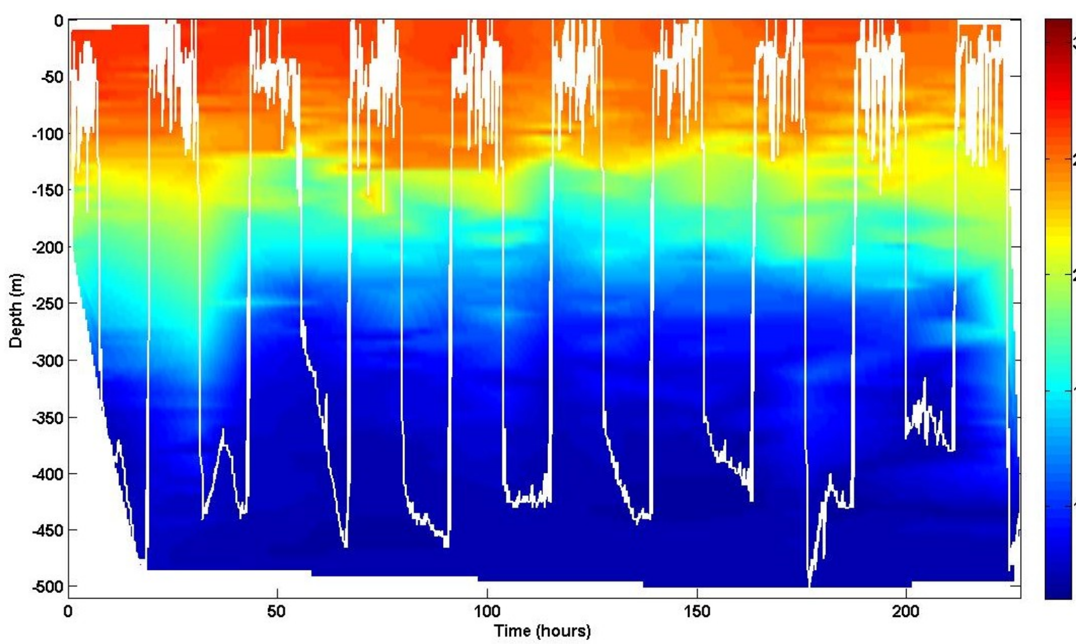
g) 88097



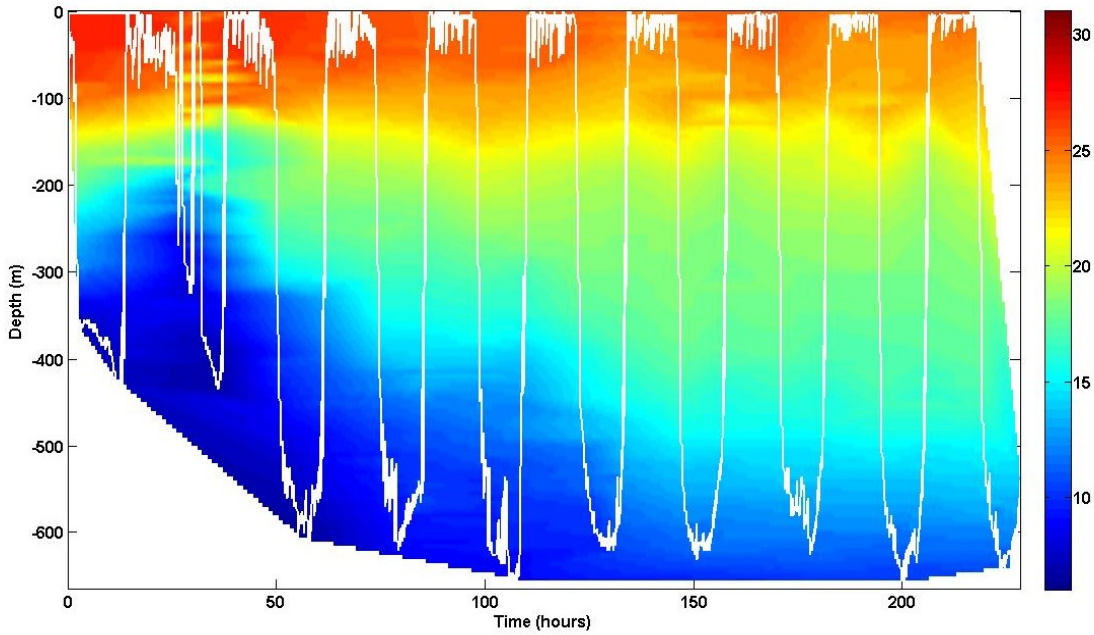
h) 88092



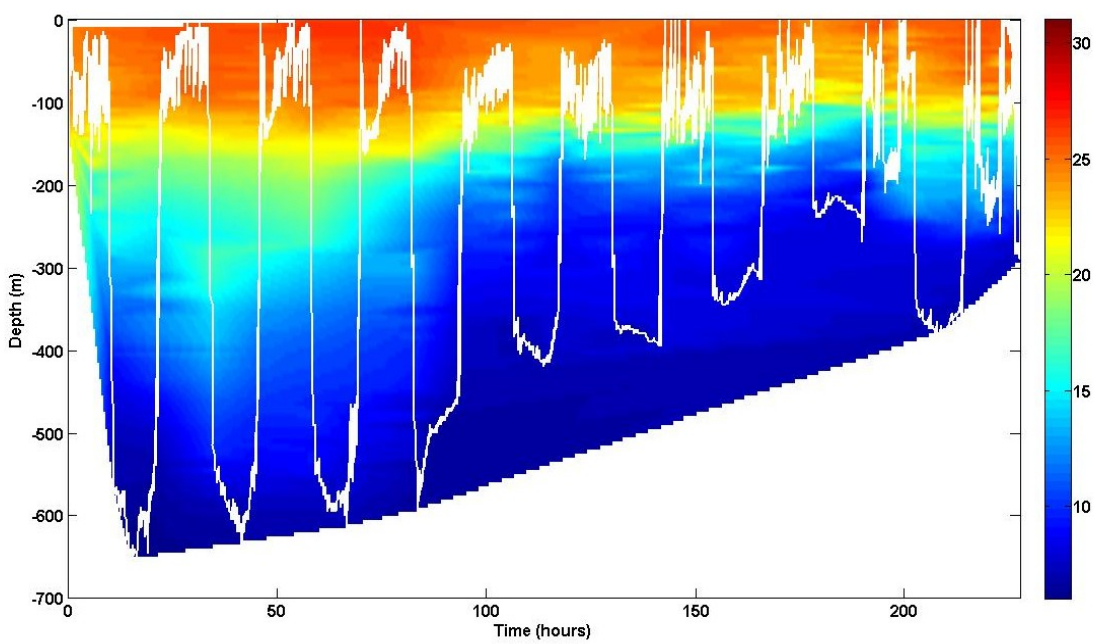
i) 61667



j) 61669



k) 87793



l) 61666

Figure 12: Figures from 12 reporting juvenile swordfish tags, denoted by tag ID number, showing the depth over time profile with the water temperature data.

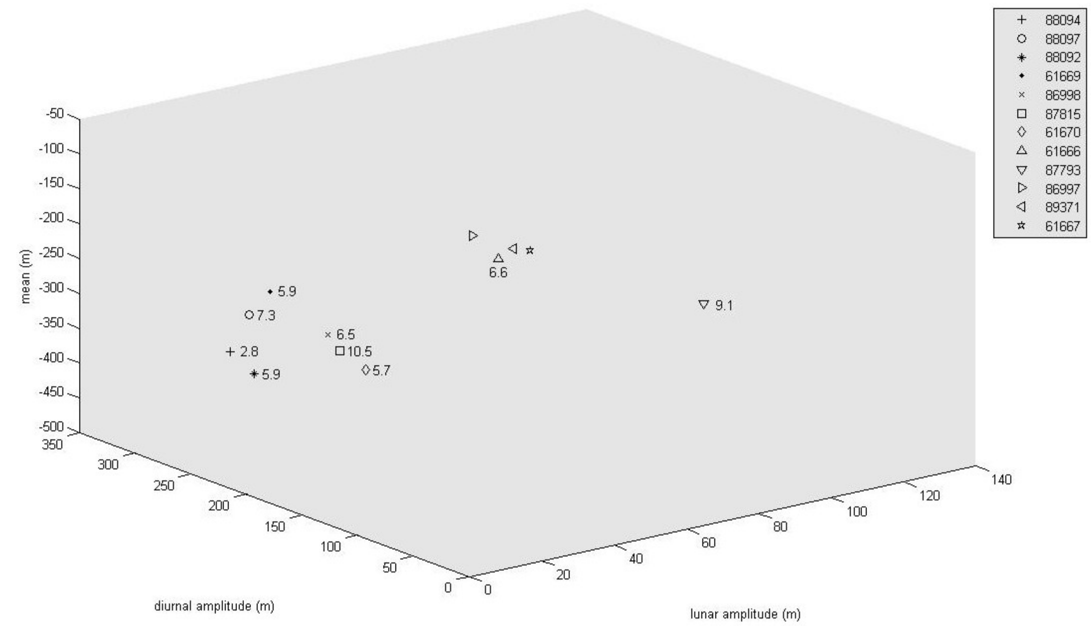


Figure 13: 3D plot showing the mean, diurnal amplitude, and lunar amplitude calculated by the model and the integral time scale value.

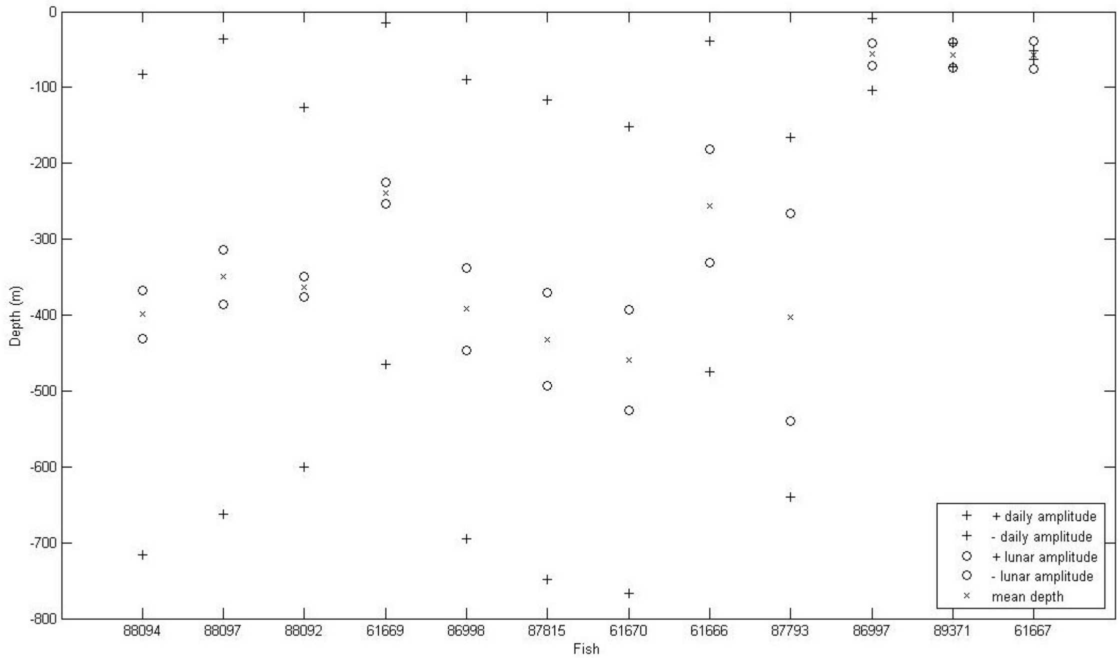
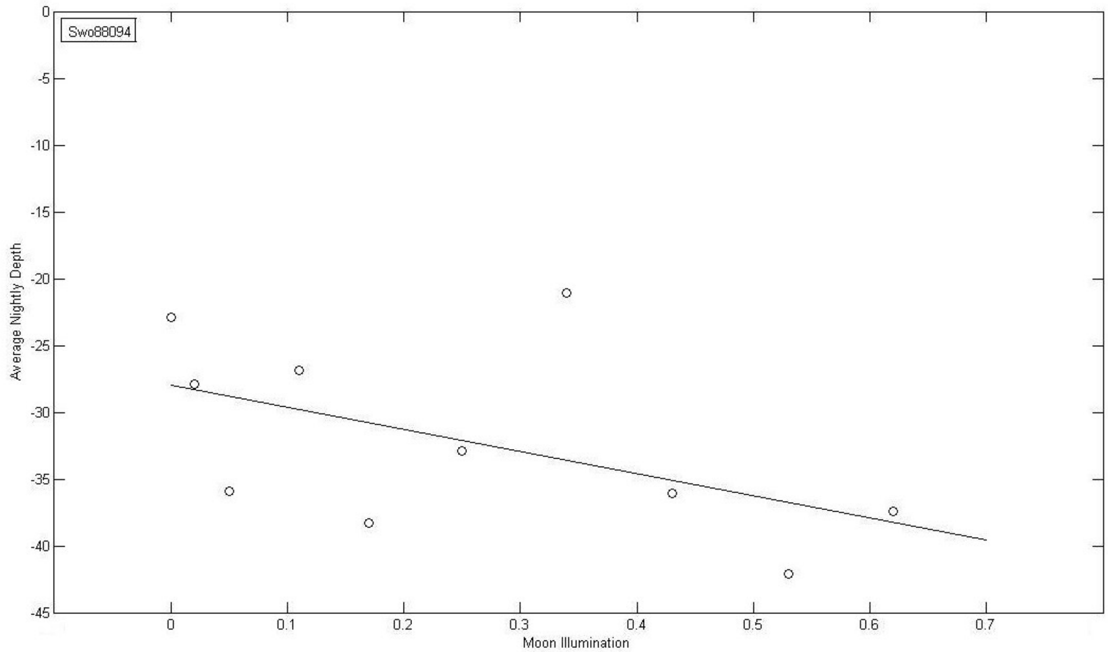
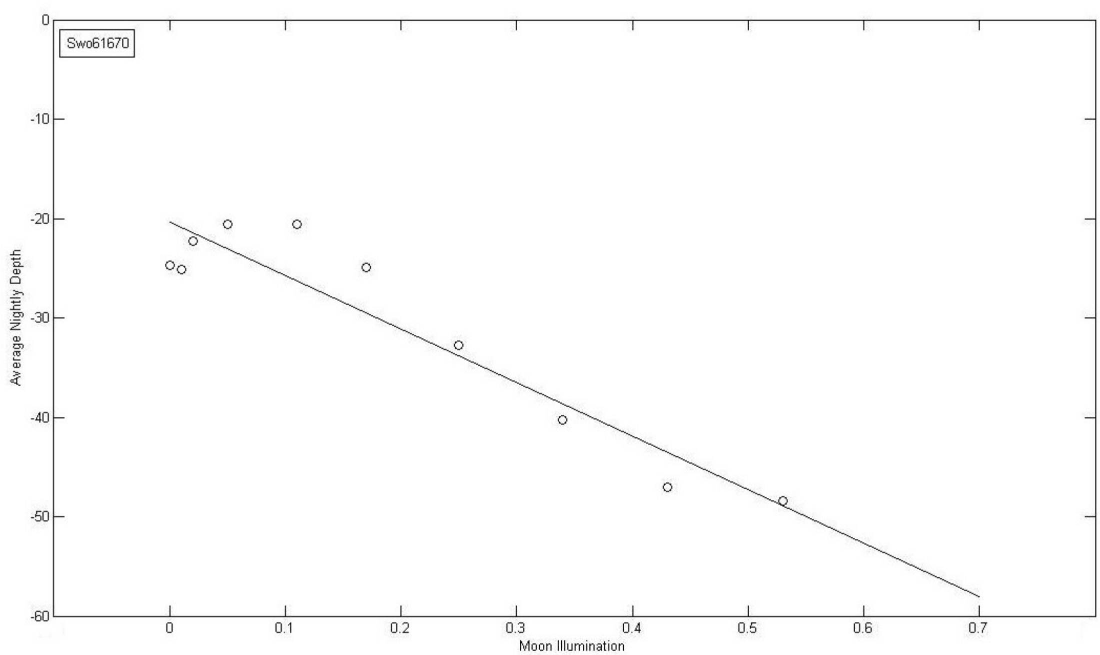


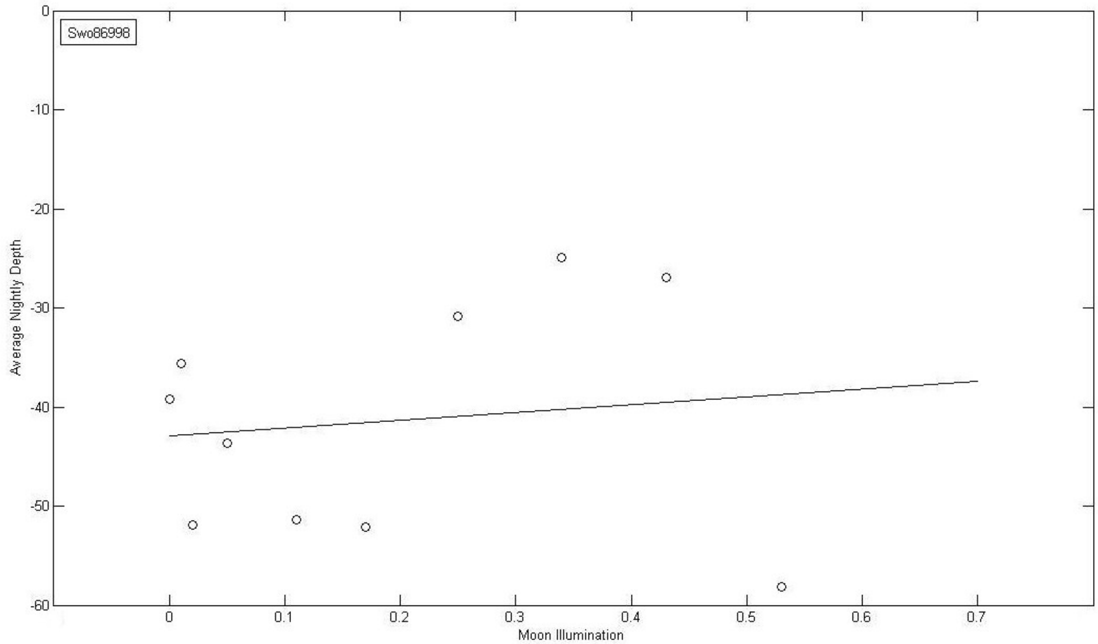
Figure 14: Diurnal amplitude and lunar amplitude around the mean calculated by the model.



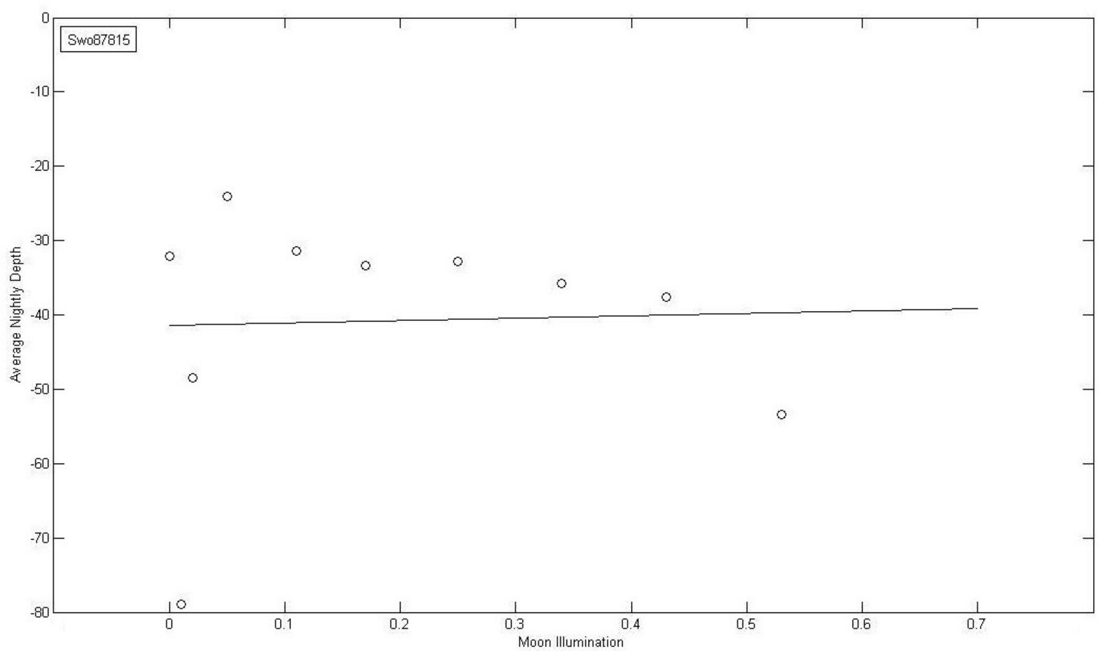
a) 88094



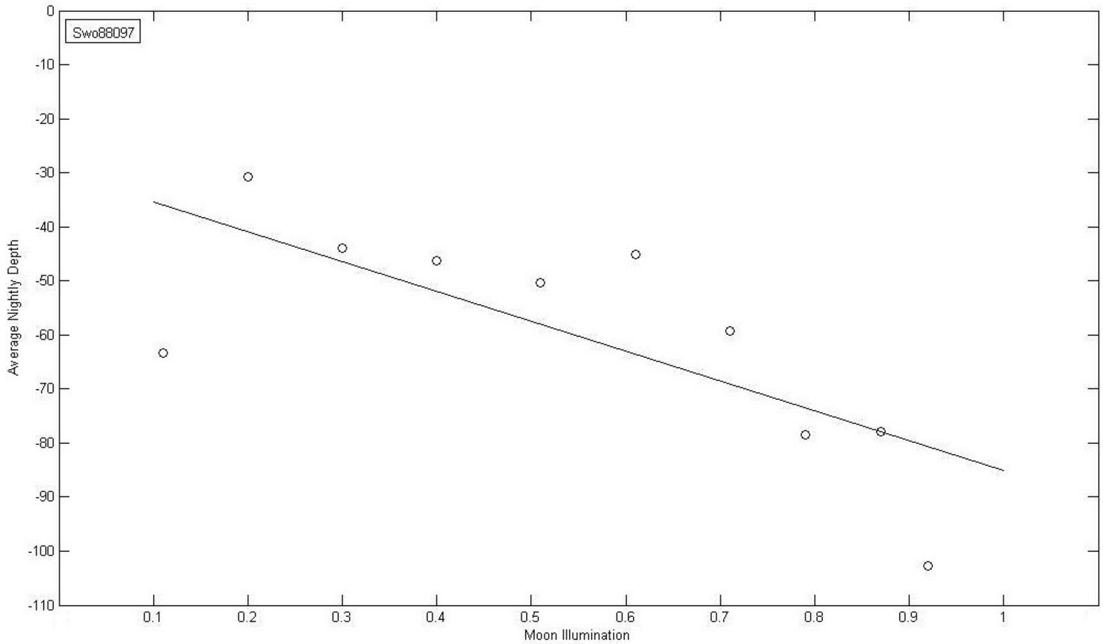
b) 61670



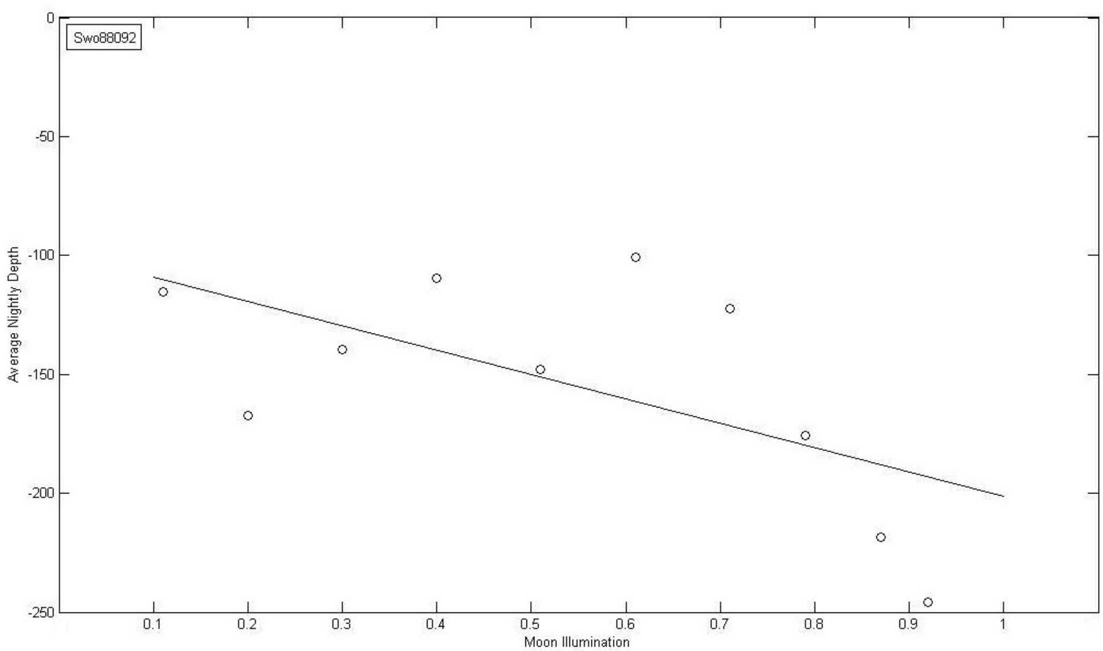
c) 86998



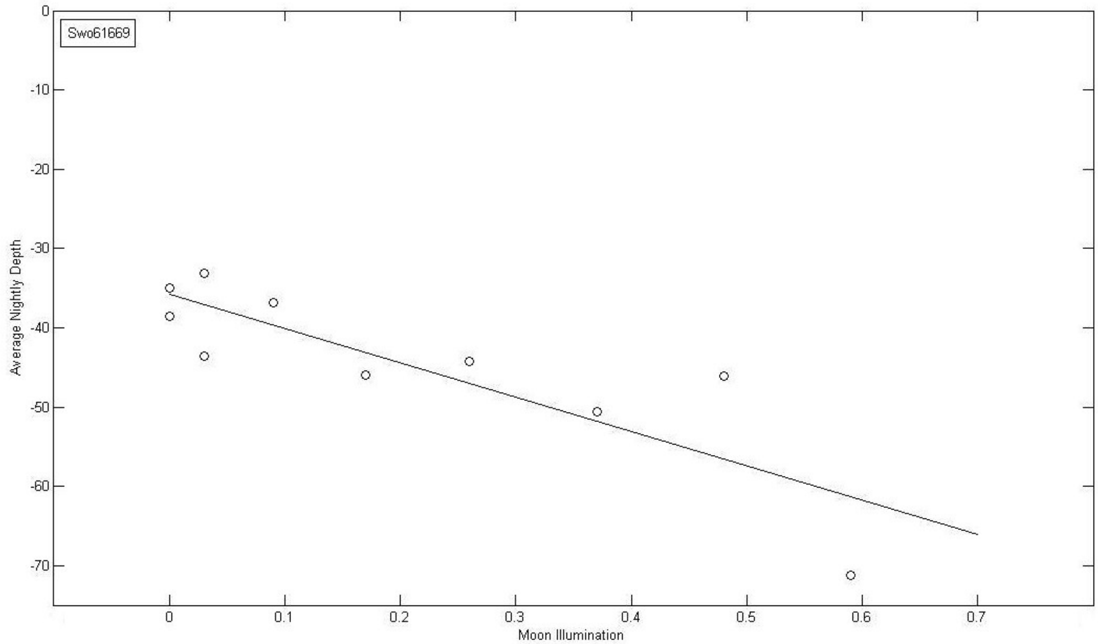
d) 87815



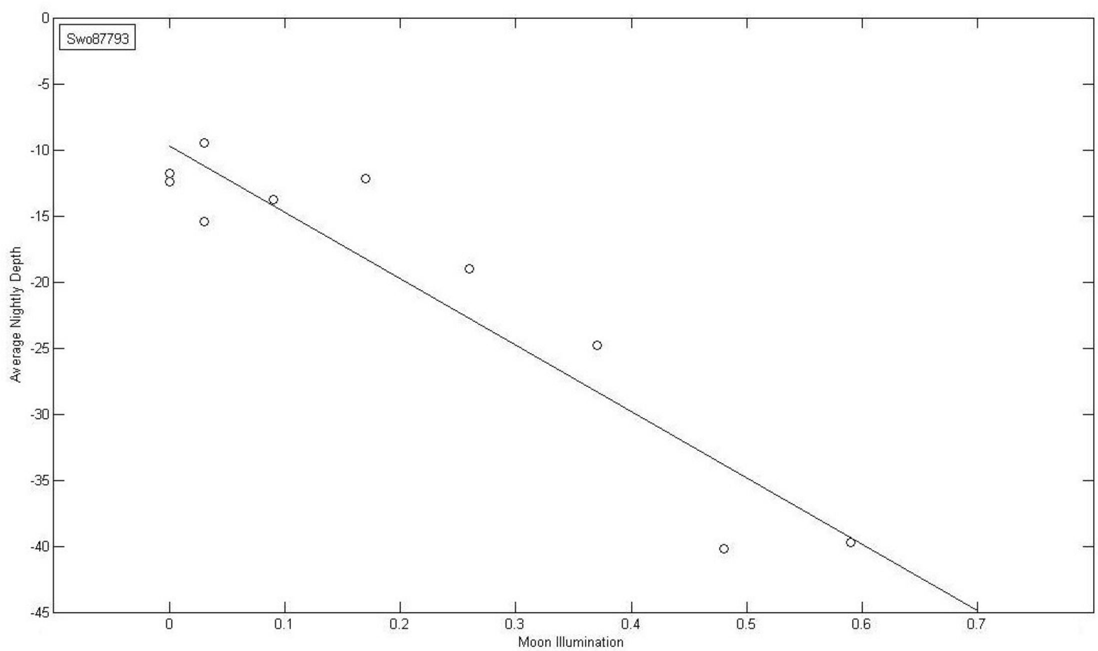
e) 88097



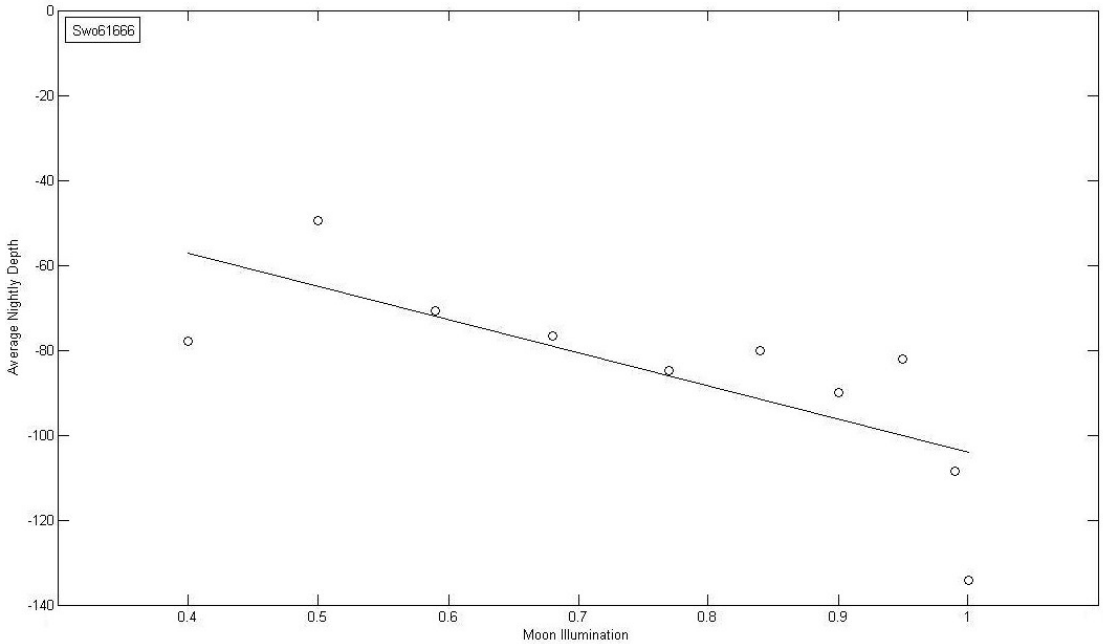
f) 88092



g) 61669



h) 87793



i) 61666

Figure 15: Correlation between average nightly depth and moon illumination.

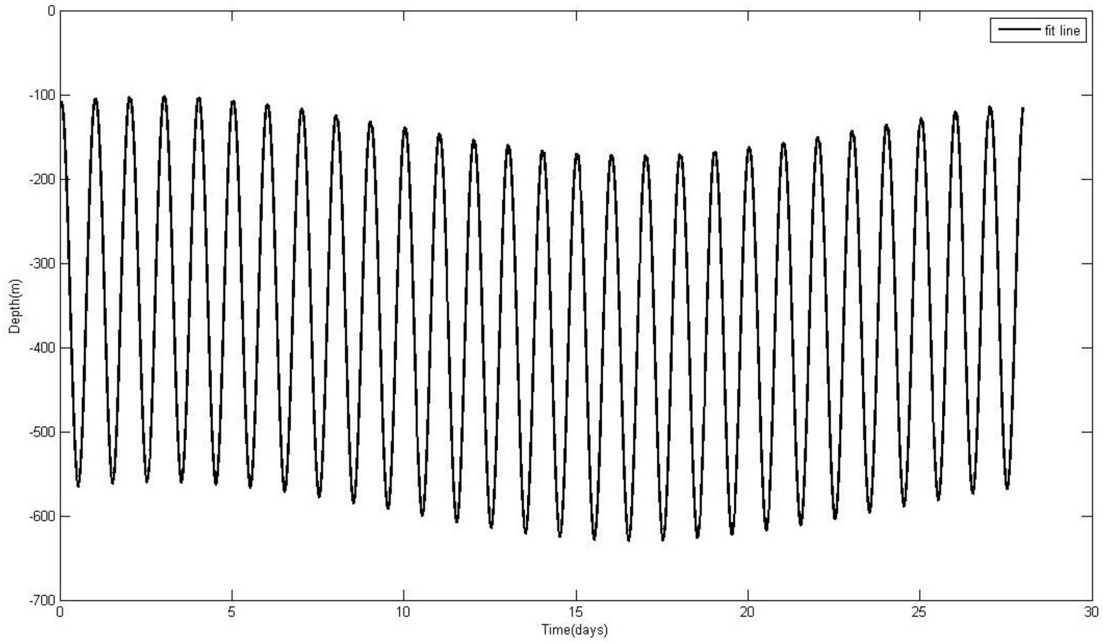
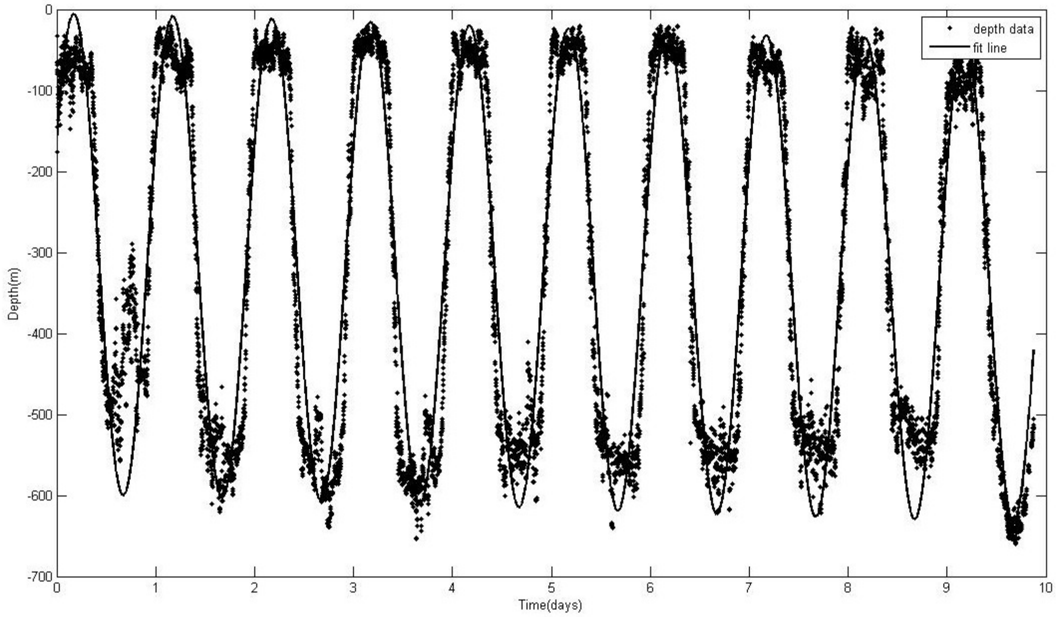
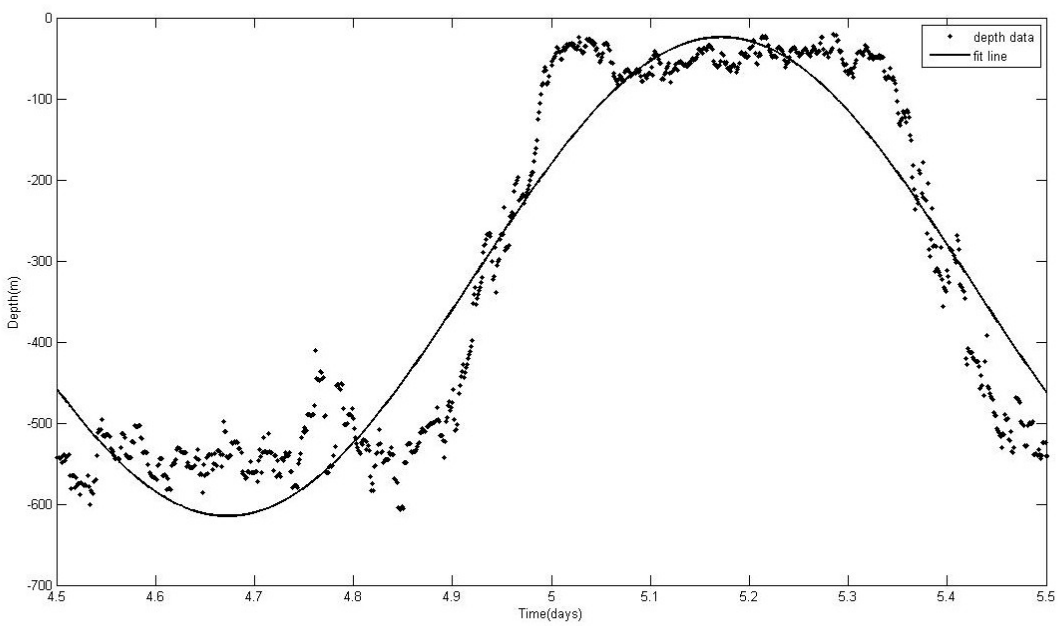


Figure 16: The average fish behavior over 28 days, the length of the lunar cycle.



a) full deployment



b) one day, mid-deployment

Figure 17: Average depth of all nine records of full deployment plotted over time with the fit calculated from the model, (a) full deployment, (b) one day, mid-deployment.

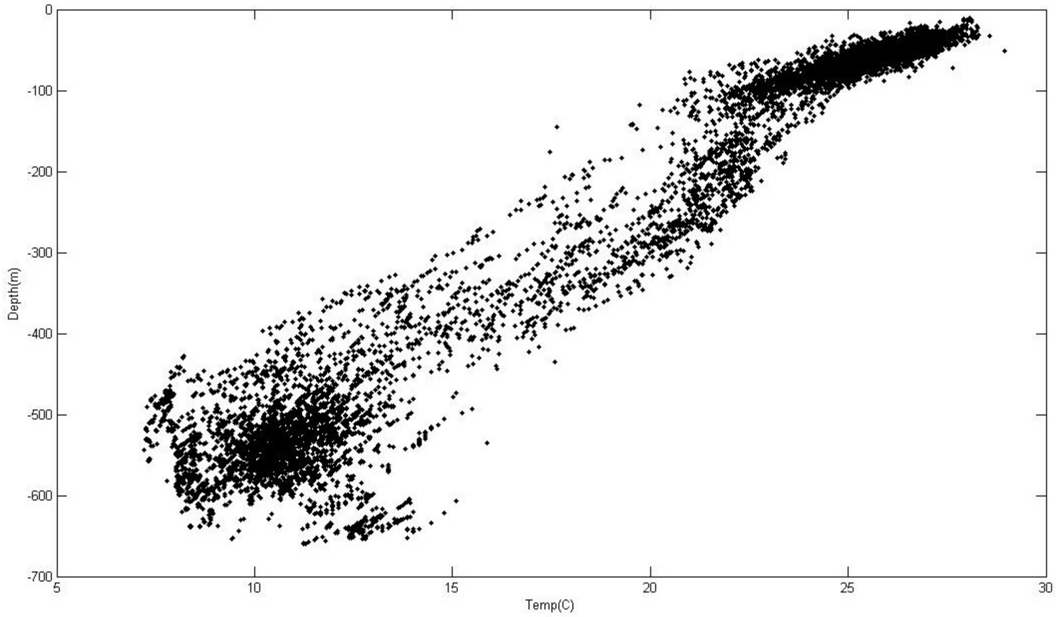


Figure 18: Average depth vs. average temperature for the full deployment period.

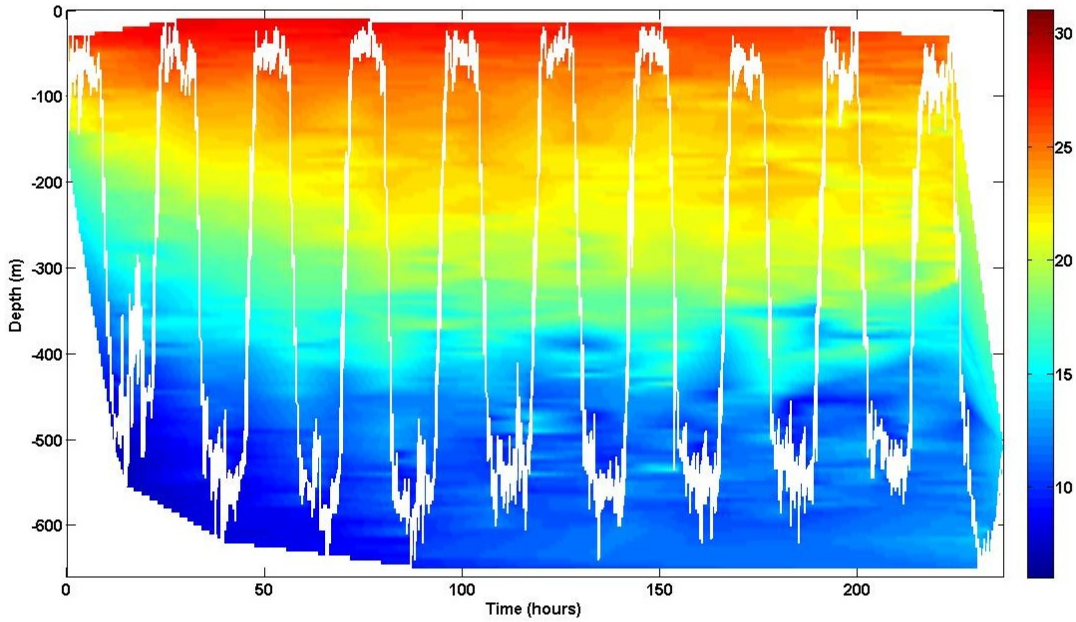


Figure 19: Average depth of all nine records for the full deployment period plotted over the temperature data.

Tables

Table 1: Tag ID number, date tagged, platform (R & R = rod and reel, BG = buoy gear), length (in cm LJFL), hook location on the fish, hook status (left in or removed), hook size, fight time (in min), resuscitation (Res.), buttonholed (BH), survival, strait-line distance each fish traveled (in km), average speed (km/day), sub-figure of figure 7 that the track is in, diurnal amplitude (in m), lunar amplitudes (in m), mean depth (in m), depth range (in m), mean temp (in °C), temperature range (in °C), and lunar trend (new moon = nm, first quarter = fq, full moon = fm, last quarter = lq) for all tags deployed.

Tag ID	86997	89371	88271	88096	88094	61670	86998	87815
Date Tagged	10/15/10	01/29/11	06/21/11	06/21/11	06/21/11	06/22/11	06/22/11	06/22/11
Platform	R & R	R & R	BG	BG	BG	BG	BG	BG
Length	85	129	115	120	105	105	103	111
Hook Location	Wrapped in line	Jaw	Jaw	Jaw	Dorsal fin	Gut hooked	Jaw	Jaw
Hook Status	NA	removed	removed	removed	removed	Left in	removed	removed
Hook Size	10/0	9/0	8/0	8/0	8/0	9/0	9/0	9/0
Fight Time	23	25	15	8	5	10	5	6
Res.	no	no	no	no	yes	yes	no	no
BH	no	no	yes	yes	no	no	no	yes
Survival	6 hours	28 hours	Fish died	Fish died	9.5 days	9.5 days	9.5 days	9.5 days
Distance	484.35	591.1	652.5	661.87	258.48	318.95	307.86	281.49
Avg Speed	N/A	N/A	N/A	N/A	14.31	17.74	17.12	15.66
Sub-figure	8c	8d	8d	8d	8d	8d	8d	8d
Diurnal Amplitude	47.42	15.08	N/A	N/A	317.13	307.62	302.11	316.07
Lunar Amp	15.35	16.76	N/A	N/A	31.45	65.82	53.75	61.32
Mean Depth	56.33	57.05	N/A	N/A	399.18	459.41	392.19	431.83
Depth Range	9-113	0-159	N/A	N/A	1.3-691.3	1.3-767.9	1.3-737	1.3-727.6
Mean Temp	25.96	24.09	N/A	N/A	19.14	18.78	17.32	18.06
Temp Range	20-29	20-25	N/A	N/A	7-30	7-30	7-30	7-30
Lunar Trend	N/A	N/A	N/A	N/A	fm to nm	fm to nm	fm to nm	fm to nm
Tag ID	76997	88097	88092	61667	61669	87793	88093	61666
Date Tagged	8/4/11	9/29/11	9/29/11	12/16/11	12/16/11	12/16/11	12/29/11	12/30/11
Platform	R & R	R & R	R & R	BG	BG	BG	R & R	R & R
Length	117	105	90	122	121	121	92	114
Hook Location	jaw	jaw	Wrapped in line	jaw	jaw	Jaw	Wrapped in line	Wrapped in line
Hook Status	Left in	removed	N/A	removed	removed	removed	N/A	N/A
Hook Size	11/0	11/0	11/0	8/0 or 9/0	8/0 or 9/0	8/0 or 9/0	9/0	9/0 - 11/0
Fight Time	7	13	8	8	8	12	12	18
Res.	no	no	no	no	no	no	yes	no
BH	no	no	no	yes	no	yes	no	no
Survival	NR	9.5 days	9.5 days	24 hours	9.5 days	9.5 days	NR	9.5 days
Distance	N/A	43.3	416.01	459.78	57.76	320.88	N/A	93.21
Avg Speed	N/A	2.17	20.98	N/A	3.19	17.69	N/A	5.18
Sub-figure	N/A	8b	8c	8c	8b	8d	N/A	8b
Diurnal Amplitude	N/A	313.45	236.86	5.93	225.07	236.96	N/A	217.63
Lunar Amp	N/A	35.55	13.41	18.69	14.03	137.37	N/A	74.75
Mean Depth	N/A	349.68	363.16	56.87	239.29	402.85	N/A	256.65
Depth Range	N/A	0-698	0-696.6	1-158	0-505.7	0-660.3	N/A	0-656.3
Mean Temp	N/A	18.01	15.95	26.27	16.52	18.02	N/A	15.58
Temp Range	N/A	6-30	6-31	17-27	6-27	6-27	N/A	6-27
Lunar Trend	N/A	nm to fq	nm to fq	N/A	fm to nm	fm to nm	N/A	nm to fm

Table 2: Sensitivity Analysis; case 1= includes all data, case 2 = without 0m data, case 3 = without 0-5m data, case 4 = without 0-10 m data, case 5 = without 0-20 m data

Fish ID	Diurnal Amplitude	Lunar Amplitude	Mean	% removed
Sail0603(1)	2.059871	0.371328	-4.63563	0
Sail0603(2)	3.506753	1.21287	-12.3645	62.51
Sail0603(3)	2.593007	1.037281	-18.3704	76.07
Sail0605(1)	4.600567	14.32164	-16.3721	0
Sail0605(2)	12.17759	23.30974	-26.4188	38.03
Sail0605(3)	20.39323	18.1313	-33.1742	51.47
Sail0606(1)	2.509998	4.390406	10.4504	0
Sail0606(2)	2.399783	4.210811	-10.864	3.81
Sail0606(3)	13.8974	10.68771	-39.3254	77.83
Sail0607(1)	2.655154	5.603508	-19.9155	0
Sail0607(2)	2.65581	5.608488	-19.9177	0.01
Sail0607(3)	7.152176	6.332105	-29.3389	36.25
Sail0608(1)	0.639668	0.070455	-4.47767	0
Sail0608(2)	1.981685	1.256034	-12.7943	65.00
Sail0608(3)	4.012381	2.642531	-18.0689	76.62
Swo61670(1)	348.805	42.56372	-375.782	0
Swo61670(4)	351.0618	29.87759	-386.759	2.90
Swo61670(5)	307.6157	65.82062	-459.414	18.71
Swo86998(1)	324.1958	41.08299	-349.408	0
Swo86998 (4)	306.5309	52.71861	-385.941	9.60
Swo86998 (5)	302.1118	53.74599	-392.198	11.10
Swo87815(1)	331.1941	70.60455	-375.32	0
Swo87815(4)	343.1128	52.09875	-380.911	1.50
Swo87815(5)	316.074	61.32024	-431.827	13.49
Swo88092(1)	236.3133	12.24655	-341.28	0
Swo88092(4)	243.7466	5.68808	-352.121	3.15
Swo88092(5)	236.8676	13.40949	-363.164	6.21
Swo88094(1)	315.1993	26.95349	-345.814	0
Swo88094(4)	325.6907	21.70917	-383.953	10.07
Swo88094(5)	317.132	31.45341	-399.185	13.62

Appendix A – Sample Data Sheet

Swordfish Tagging Research
Jenny Fenton – Thesis Project

Date:___________

Vessel Name: ______________________________
Captain Name: ______________________________
Scientific Crew Name(s): ____________________

Wind Speed: __________________
Sea Conditions: ________________
SST: __________________________

Drift #1:
Start Location: _______________________
End Location: _______________________
Time Lines In: _______________________
Time Lines Out: ______________________

Drift #2:
Start Location:________________________
End Location: ________________________
Time Lines In: _______________________
Time Lines Out: ______________________

Drift #3:
Start Location:________________________
End Location: ________________________
Time Lines In:________________________
Time Lines Out:_______________________

Number of Rods:______________________

Angler: _____________________

Hook Type:_________________
Hook Location:_______________
Hook Depth:________________

Bait Type: ___________________
Light Type:_________________
TDR #: _____________________

Time Hooked:________________
Time Tagged:________________
Time Released:_______________

Species: ____________________
Length: _____________________
Weight: _____________________
Sex:_________________________
X-Tag Number:_______________
RF Tag Number:______________

ACESS scale

Category	Level 0	Level 1	Level 2	Score
Activity	inactive	slightly moving	very active	
Color	grey	blue-grey	bright blue	
Eye Status	both eyes lacerated	one eye lacerated	both eyes intact	
Stomach Eversion	everted and lacerated	everted, no lacerations	not everted	
State of Body Musculature	obvious deep lacerations	some lacerations, none deep	no obvious lacerations	
Bleeding	extensive bleeding	light bleeding	no/almost no bleeding	

Notes: ____