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Evaluating Post-Release Survival and Distribution of Juvenile Swordfish (Xiphias gladius) Caught on Buoy Gear Within the Gulf of Mexico and the Florida Straits

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Submitted in Partial Fulfillment of the Requirements for the Degree of

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By
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Abstract:

Buoy gear used to target swordfish (Xiphias gladius) has become an increasingly popular commercial gear type throughout the United States fisheries in both the Atlantic and Pacific oceans. Buoy gear can be defined as a series of independent free-floating gear where each rig consists of at least one floatation device, a vertical mainline, and no more than two hooks. Because of the potential modifications to the component parts and deployment strategies, buoy gear has been hypothesized to decrease bycatch interaction and dead discard numbers by targeting specific depths of swordfish habitat throughout various times of the day. Under the *Deepwater Horizon* (DWH) Oceanic Fish Restoration Project (OFRP), commercial buoy gear fishing was analyzed through ecological and economic data collection. The DWH OFRP aimed to reduce fishing mortality of catch and bycatch of pelagic fish, through a six-month repose of pelagic longline (PLL) fishing by a portion of the Gulf of Mexico (GOM) PLL fleet. Although there have been studies evaluating swordfish post-release mortality (PRM) rates after commercial fishing gear interaction, little has been done to assess juvenile swordfish (<49in/119 cm LJFL) mortality rates after release from commercial buoy gear. Data collected by pop-off satellite archival tags (PSATs) was analyzed for PRM rates and vertical habitat utilization from 45 swordfish captured on buoy gear in the GOM and Florida East Coast (FEC). A suggested PRM from commercial buoy gear of 42.1% was found with a mortality rate of 60.5% of individuals who did not survive to the full 30-day tag expression. This suggest a survival rate of 57.9% of juvenile swordfish after post-release from commercial buoy gear. Management suggestions of potential gear modification is then suggested in order to increase the post-release survival rate of juvenile swordfish for the current regulations of the commercial buoy gear fishery in the Florida Straits.

Keywords: Juvenile swordfish, Post-release Mortality, Gulf of Mexico, Florida East Coast, Buoy Gear, Highly Migratory Species (HMS), Vertical Habitat Utilization

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Introduction

The Oceanic Fish Restoration Project

The Oceanic Fish Restoration Project (OFRP) is a voluntary, temporary, and low regulatory restoration initiative, managed by NOAA and partnered with the National Fish and Wildlife Foundation (NFWF). The OFRP aims to restore pelagic fish populations impacted by the 2010 Deepwater Horizon oil spill by reducing fishing mortality of bycatch and other non-target pelagic fish species caught in the Gulf of Mexico (GOM) pelagic longline (PLL) fishery with two separate, but complementary actions: a repose period and the encouraged use of alternative fishing gear. This restoration effort was approved in the Final Phase IV Early Restoration Plan and Environmental Assessments (DWH Trustees 2015) to offset injuries to pelagic finfish due to the DWH oil spill (Piko, 2021). During the voluntary repose, participating PLL vessels are compensated to not use PLL gear for six months (January through June, 2017-2022) in order to reduce discards in the fishery, thereby restoring biomass. For the alternative gear component, participants can fish for target species during the repose with non-PLL gear provided by the OFRP (greenstick, buoy gear, and deep-drop/rod-and-reel) to reduce the economic impacts to the vessel owners, fishers, and shoreside support industries caused by reduced catches of target species, as well as to evaluate the competitiveness of the alternative gears with PLL in regards to overall catch rates.

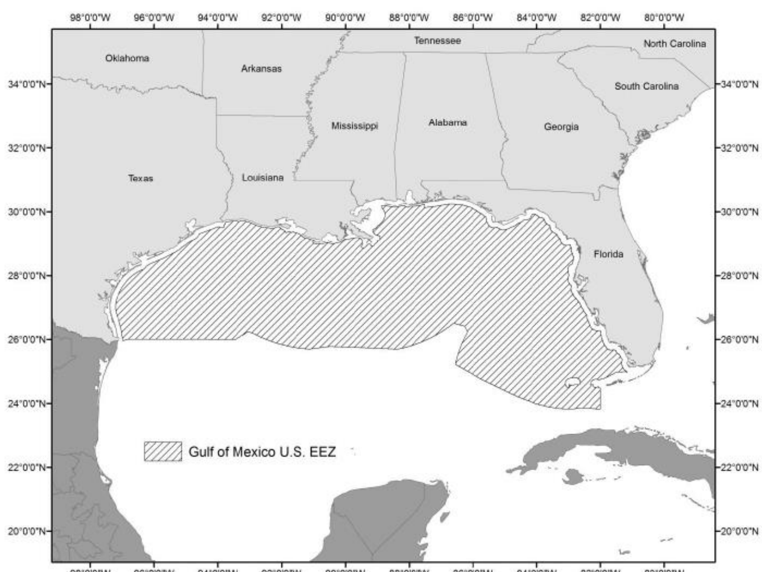


Figure 1. The Oceanic Fish Restoration Project location in the U.S. Exclusive Economic Zone in the Gulf of Mexico indicated by shaded area (Piko, 2021).

Fishing parameters for participants within the OFRP were initially constrained to the waters of the U.S. Exclusive Economic Zone of the Gulf of Mexico (Figure 1), but in 2018 the Atlantic Florida East Coast (FEC Statistical Zone described by NOAA SEFSC) was included within the scope of the project (Figure 2). All participants are required to have made at least one PLL set in the Gulf of Mexico in the previous two years, possess all limited access permits required to engage in PLL fishing in the Gulf, and possess the minimum Individual Bluefin Quota (IBQ) allocation for a vessel fishing in the GOM PLL fishery, consistent with 50 C.F.R. § 635.15(b)(3) (2014) (Piko, 2021). Selection of vessels was done by an application submission with a price quotation in a uniform-price reverse auction (Holzer & Byler, 2019).

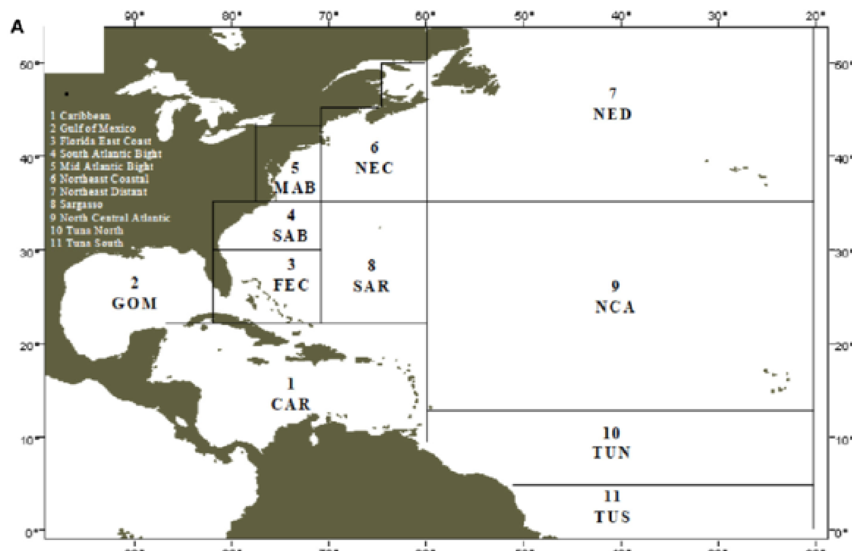


Figure 2. NOAA SEFSC map of North Atlantic statistical regions, including the two areas the OFRP participants practiced use of alternative gear. Statistical area #2 (GOM) and #3 (FEC) both had fishing and satellite tagging effort for this analysis.

To increase the probability success of the OFRP repose and alternative gear performance, a metric expectation of reducing dead discards by 11,600 discounted kilograms (dkg) of whole weight fish biomass per vessel per year was targeted. Based on preliminary analysis of OFRP data collected from 2017-2019, this target was exceeded every year (Piko 2021; Kerstetter & Garvey 2020). For the three recorded years, a total of 56,635 dkg of total biomass has been avoided per vessel. Table 1. shows a breakdown of dead discards avoided by year per vessel, catch avoided by year per vessel and total biomass avoided by year per vessel. For the overall restoration efforts, an estimated 23,259 individual fish (459,247 dkg) avoided being caught through the implementation of the three repose periods (Kerstetter & Garvey, 2020). Coincidingly, the participants that utilized alternative gears were successful, but they did not prove to be competitive to PLL gear in regard to number of target catches (Kerstetter & Garvey, 2020). Although the alternative gears were found to produce overall low catch rates, the dead discard rate associated with alternative gear is minimal (Kerstetter & Garvey, 2020). Four species are estimated for avoided catches and dead discards, yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), lancetfish (*Alepisaursus* spp.), and blackfin tuna (*Thunnus atlanticus*) in terms of count and discounted kilograms of biomass (Kerstetter & Garvey, 2020). Yellowfin tuna had the highest number of avoided catches, and the highest overall biomass of the avoided catch, with 234,244 dkg of tuna avoiding being caught across all repose periods. Swordfish contributed to the most biomass avoided dead discards with 18,583 dkg across all repose periods (Kerstetter & Garvey, 2020).

Table 1: Dead discards avoided by year per vessel, catch avoided by year per vessel, and total biomass avoided by year per vessel for 2017-2019 due to the OFRP restoration effort (Piko, 2021).

Dead Discards Avoided by Year per Vessel			
	2017	**2018**	**2019**
Weight in discounted kilograms (dkg)	1,882	2,492	2,419
Counts	208	278	278
Catch Avoided by Year per Vessel			
Weight in discounted kilograms (dkg)	13,057	18,664	18,121
Counts	681	925	925
Total Biomass Avoided by Year per Vessel			
Weight in discounted kilograms (dkg)	14,939	21,156	20,540
Counts	889	1,203	1,203

Based on preliminary data from avoided dead discards of swordfish across the three repose years, and a relatively high CPUE rates in comparison to other OFRP alternative gear types (2018-2021) based on observer data, buoy gear used to target swordfish is considered the most successful of the alternative gear types tested and was determined by OFRP to need further research (Figure 3). Coincidently, NOAA utilizes the *Atlantic Highly Migratory Species (HMS) Management-Based Research Needs and Priorities* list to publicize current research priorities that could provide insight for improving stock management of Atlantic HMS fishes. This list currently prioritizes as a near-term research need analyses regarding the feasibility of using alternative gears to reduce bycatch and discard mortality rates of HMS species while maintaining target catch and seafood quality (National Marine Fisheries Service [NMFS], 2020). To meet these goals, a further examination of avoided dead discard of swordfish associated with buoy gear use was needed. To produce an accurate representation of what the commercial buoy gear industry contributes to dead discards of swordfish will take many steps, but one necessity is to examine and quantify the fish released from buoy gear. Given this need, the OFRP further funded a project to examine the fate of juvenile swordfish release from swordfish buoy gear.

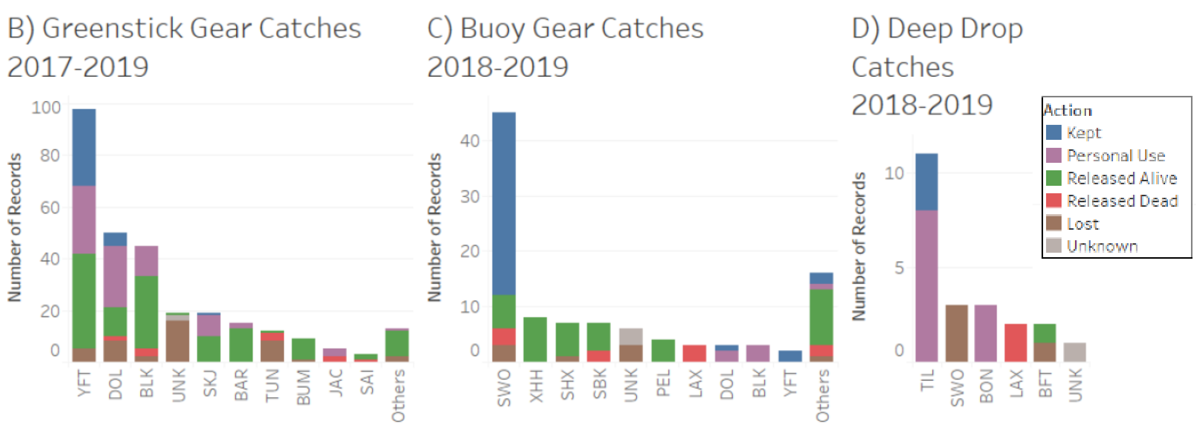


Figure 3. Overall catch composition of observed alternative gear deployments during 2017-2019 repose (Jan-June). B) Count species caught with greenstick gear, C) Count of species caught with buoy gear, D) Count of species caught with deep drop gear. Although this only accounts for two years of buoy gear data, versus three years of greenstick data, these catch rates show that buoy gear was assumingly more successful targeting swordfish and limiting bycatch throughout participants in the OFRP. From *OFRP Summary Monitoring Report 2017-2019*, Kerstetter & Garvey, 2020. https://www.gulfspillrestoration.noaa.gov/2022/01/its-final-year-early-project-data-show-fishermen-are-contributing-healthier-gulf-fisheries#monitoring%20results).

Swordfish Buoy Gear

Buoy gear is defined in NOAA regulations as hand gear consisting of one or more floatation devices supporting a single mainline to which no more than two hooks or gangions are attached (50 CFR §635.2) (Figure 4). A gangion is defined as a line that serves to attach a hook, suspended at a specific target depth, to the mainline (64 CFR § 635.1). Due to the classification of being a hand gear, J hooks are allowed to be used. From each buoy configuration, a vertical mainline contains hooks at variating depths to target swordfish and tuna. While fishers can monitor up to 15-35 buoy rigs at a time, each buoy "rig" is checked consistently by direct interaction with the gangions to inspect catch. Although PLL is prohibited for use in the FEC, buoy gear configuration can be seen as a smaller, individual, section of pelagic longline gear. Each "rig" constitutes an independent floating piece of buoy gear and thus must follow regulations of no more than two hooks or gangions. While buoy gear rigs used to target swordfish may legally contain two or three different flotation devices, regulations specify that a maximum of 35 total floats may be used, so it is common to see only one float being used per rig. Floats often contain surface lights, radar reflectors, and even GPS location devices for easier retrieval. All catch retrieval is required to be done by hand, unless a proper buoy gear federal Exempted Fishing Permit (EFP) is possessed by the vessel owner. Within the scope of OFRP, participants were given an EFP to allow the use of an electric power hauler for fish haul back.

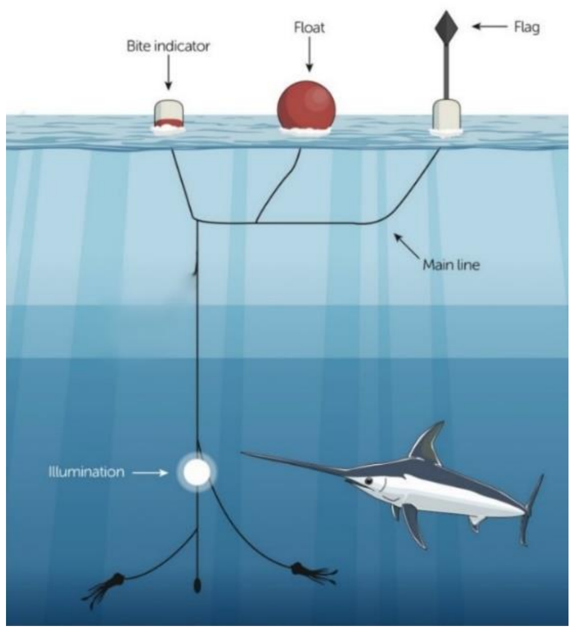


Figure 4. Basic configuration of buoy gear used to target swordfish at night. Buoy gear consist of one or more flotation device, a single mainline, and no more than two hooks. Adapted from Deep-Set Buoy Gear: A Better Way to Catch Swordfish, by The Pew Charitable Trusts, 2015 (https://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2015/11/deep-set-buoy-gear-a-better-way-to-catch-swordfish). Copyright 2015 The Pew Charitable Trusts.

Current regulations require fishers to obtain an HMS swordfish limited access permit including a Directed permit, a Handgear permit, or an open access HMS Commercial Caribbean Small Boat Permit (valid only in the U.S. Caribbean Region) to legally fish commercial swordfish buoy gear (SBG) (Highly Migratory Species Compliance Guide: Commercial Fishing

[HMS], 2022). SBG gear within the United states originated due to closures of PLL fishing grounds along the Florida East Coast in 2000 (Fenton, 2012). The addition of SBG allowed for continued commercial fishing within this area. At this time, there is not a commercial industry for buoy gear in the GOM outside of the scope of the OFRP, but interest has remained with an increase in popularity within the commercial fishing industry operating in the Florida East Coast (FEC) NOAA pelagic statistical area, which includes the whole of the Florida Straits (south of 28° 17’ 10” through the northwestern boundary of Monroe County in the Gulf of Mexico) (HMS, 2022). There is increased interest of buoy gear due to interaction with limited bycatch as well as allowable access to areas where PLL is prohibited, such as the Florida Straits and Desoto Canyon. Within the FEC, there is also increased interest due to the advantage of being able to deploy buoy gear with a smaller vessel and the ability to conduct shorter trips, sometimes returning to port in less than 24 hours. Within 2019 there were 60 vessels participating in commercial buoy gear with a total of 798 trips, while in 2020 there were a total of 63 vessels participating with a total of 819 completed trips (NMFS, 2021). There is also an established commercial buoy gear fishery in the eastern Pacific off California, which uses very similar buoy gear configurations (Sepulveda et al. 2014; Sepulveda et al. 2018). With one established commercial fishery off the U.S. west coast and one off the U.S. southeast coast, understanding the mortality rates of live swordfish released from buoy gear will be extremely important to the overall fisheries management implementations regarding protection of the swordfish populations. Results from this study will only be used for management suggestions for the Atlantic swordfish population and buoy gear fished within the Atlantic. Participants within the OFRP project who alternatively fished swordfish buoy gear were allotted EFP’s to commercially harvest swordfish and other target species in ways atypical to the current regulations enforced by HMS.

Buoy gear has become increasingly popular throughout the United States with a concentration seen in Southeast Florida and the Southern California coasts. Due to the minimal amount of gear needed for a successful buoy gear it has become economically intriguing to fishers. Due to the small amount of gear needed for the buoy gear type, smaller vessels can be used to deploy this gear. Smaller vessels in turn directly relate to shorter trip durations. Not only has buoy gear been considered economically pleasing due to these factors, but it is also hypothesized to lower bycatch interactions while simultaneously targeting swordfish

Buoy gear used to target swordfish is unique because it can transect the thermocline to specifically target swordfish habitat during certain times of day, while reducing interactions with other species of concern (Sepulveda et al., 2014). Typical buoy gear configurations target swordfish during the night reaching depths of 150 m, this is considered shallow water buoy gear. Deep set buoy gear is typically deployed at 150-370 m depth allowing fishermen to reach swordfish occupying depths beneath the thermocline during light hours (Sepulveda et al., 2018). Within the OFRP participants, deep set buoy gear has been recorded to target depths up to 800 m during the day time hours. It can be theorized that fishing at these depths are to follow target depths of swordfish similar to recreational deep-drop rod and reel fishing techniques (Kerstetter et al., 2017). Swordfish follow a daily vertical migration pattern occupying deeper waters during the day and more shallow waters at night. In theory, these DVM patterns are due to swordfish following the deep scattering layer (DSL) and seem to be a low light level preference species (Lerner 2009; Lerner et al. 2012). Although commercial swordfish targeting practices vary based on oceanic conditions, the buoy gear practices in the Pacific are structured similarly to those in the Atlantic. In comparison to the Pacific fishery, OFRP participants within the Atlantic and GOM have been setting deeper into the water column to bypass a deeper thermocline. Preliminary analysis has shown that at-vessel mortality of the average alternative gear deployment in the OFRP has a live release to dead discard ratio over 10 times higher the ratio for the average PLL gear deployment for all species. These numbers are representative of all three alternative gear types, and not just buoy gear (Kerstetter & Garvey 2020; Serafy et al., 2011).

The main target commercial species for the U.S. PLL fishery are swordfish (*Xiphias gladius*) and the so-called "BAYS" tunas [bigeye tuna (*Thunnus obesus*), albacore (*T. alalunga*), yellowfin tuna (*T. albacares*), and skipjack tuna (*Katsuwonus pelamis*)]. Although current buoy gear regulations in the Atlantic only allow for retention of swordfish, buoy gear used by OFRP participants in the GOM and FEC can target PLL directed species under a federal EFP. It is hypothesized that buoy gear effectively reduces at-vessel mortality and post-release mortality of bycatch and regulatory discards when compared to PLL (Sepulveda et al., 2018). The post-release mortality rate of swordfish caught on PLL are relatively high, with previous studies showing an approximate 8% increase in survivability rate after the 2004 circle hook regulation, bringing the survivability of swordfish after post-release on PLL to 23-39% (Serafy et al., 2012).

Swordfish Ecology

Swordfish are a large, fast growing, pelagic, teleost species that are considered the most widely distributed billfish, inhabiting epipelagic and mesopelagic water masses from 45°N to 45°S (Dewar et al., 2011; Neilson et al., 2014; Palko et al., 1981; Rosa et al., 2022). Swordfish have been recorded to inhabit circumglobal temperatures from 5-27°C and reach depths up to 1000m during daily migrations, occupying tropical, subtropical, and temperate waters (Fenton, 2012; Griggs et al., 2005; Palko et al., 1981;). Swordfish are seen inhabiting areas with high food production where major ocean currents meet, often times experiencing extreme pressures and temperatures in the search for prey while following the DSL (Dewar et al., 2011; Fenton, 2012; Sakagawa, 1989). As an apex predator species, swordfish play a significant role in energy transfer between trophic levels within pelagic water marine ecosystems (Wetherbee et al., 2004).

Feeding ecology for adult and juvenile swordfish consist of mesopelagic teleost fish, cephalopods, and crustacean species. Dietary variability and prey size vary with age and size of individuals, as well as geographic variation, implying adult swordfish consume larger prey (Chancollon et al., 2006; Fenton 2012). Swordfish's natural diel vertical migration patterns and their resilience to high pressures and low surface and pelagic temperatures express behavior of a singular foraging feeding specialist. Satellite tagged swordfish are noted to have exhibited daily vertical migrations that are theorized to be influenced by the moon phases, as well as seasonal horizontal migrations in search of food and spawning grounds (Dewar et al., 2011; Logan et al., 2021, Sepulveda et al., 2019,). Swordfish undergo an extensive diel vertical migration, as seen by previous PLL data where fish can be seen at deeper depths (>500m) during the day time hours, while often seen at shallower depths (<90m) during the night hours (International Commission for the Conservation of Atlantic Tunas [ICCAT], 1991; ICCAT, 2019; ICCAT, 2022a). Swordfish spawn in western warm tropical and subtropical waters throughout the year, but there has been some seasonality reported, often sticking to the trend of inhabiting colder temperature waters during the summer and fall months (ICCAT, 2022a). The Gulf of Mexico and Straits of Florida that contain the Gulf Stream are notable year-round primary spawning habitat for Atlantic Swordfish, with peaks in December and June (Arocha & Lee, 1996; Fenton, 2012; Palko et al., 1981).

Juvenile swordfish can be recorded anywhere from 90-170 cm LJFL depending on regional stock differences. South Atlantic stocks have shown trends of reaching sexual maturity at smaller LJFL than the North Atlantic stocks (NMFS, 2022). It has been shown that about 50% of females are considered mature by age five, at a length of 180cm, but newer studies suggest lengths as small as 156cm can reach sexual maturity (DeMartini et al., 2000; De Metrio et al., 1989). Atlantic swordfish reproductive rate analyses have also shown that males mature faster than females (De Metrio et al., 1989; NMFS, 2022).

Swordfish Management

Atlantic swordfish have a complicated management strategy that requires international cooperation. Due to the migratory nature of swordfish, they are classified as a Highly Migratory Species in Annex 1 of the 1982 United Nations Convention on the Law of the Sea (Fenton, 2012; United Nations Convention of the Law of the Sea [UNCLOS], 1982). UNCLOS provide a regime of law and order pertaining to the world's oceans and seas that provide rules governing uses of the oceans and their resources. Internationally, swordfish are managed by the International Commission for the Conservation of the Atlantic Tunas (ICCAT). ICCAT is considered a regional fisheries management organization (RFMO) that collaborates with 17 international bodies to conduct lawful management and separation of the world's oceans resources (Neilson et al., 2013). Currently, ICCAT considers three distinct management units for assessing swordfish stocks: North Atlantic, South Atlantic, and Mediterranean Sea, and recent population genetics studies have shown genetic similarities within the singular stock units as well as genetic variabilities across the Atlantic and Mediterranean Sea stocks (Arocha et al., 2003; Neilson et al., 2013). ICCAT's conclusion of three separate stocks existing within the ICCAT convention area consisting of the North Atlantic, South Atlantic, and the Mediterranean Sea is evident due to the identification of specific spawning areas for the Atlantic Swordfish: three in the Mediterranean, and two more in tropical waters of the North and South Atlantic (Arocha, 2007; ICCAT, 1991; Neilson et al., 2013; Valerias et al., 2008). Although there are some genetic similarities between the North and South Atlantic stocks of swordfish, ICCAT manages these two stocks as two separate units. These two stocks are divided at the 5°N based on genetic, biological, and tagging studies (Fenton, 2012; Neilson et al., 2013).

In the United States, NOAA fisheries through the Atlantic Highly Migratory Species Management Division (HMS) of the National Marine Fisheries Service (NMFS), set regulations within the GOM and FEC for swordfish based on U.S. science, conservation and management, and recommendations from ICCAT (Fenton, 2012; Neilson et al., 2013; NMFS, 2022). HMS is mandated under the Atlantic Tunas Convention Act (ATCA) and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), to manage all highly migratory species within the United States oceans (Fenton, 2012). NMFS HMS develop and implement fishery management plans in cooperation with the HMS advisory panel, monitors commercial and recreational catches to ensure compliance with domestic and international quotas/catch limits, issues permits for commercial and recreational HMS fishing, as well as implements domestic requirements from ICCAT to support international negotiations as expressed in MSFCMA (Fenton, 2012).

Atlantic Swordfish have been a targeted commercial species since the early 1800’s, but it wasn’t until 1985 that the United States implemented the first Atlantic Swordfish Management Plan. This plan was set in action to reduce the harvest of small swordfish while simultaneously conduct monitoring research on the swordfish stock (National Oceanic & Atmospheric Administration [NOAA], 2019). By 1990, international collaboration began managing and implementing size regulations for North Atlantic stock of swordfish under recommendation of The Standing Committee on Research and Statistics (SCRS), the scientific body of the ICCAT Commission (Fenton, 2012). After a review of the initial stock assessment and yield of swordfish stocks, the SCRS determined that the yield of swordfish was not sustainable, and if the same levels of juvenile swordfish mortality remained, the population would persist in an overfished status (ICCAT, 1991; ICCAT, 2017). Consequently, ICCAT approved a 15% decrease in fishing mortality from the previous assessment levels in 1988. In 1996 another stock assessment was completed by ICCAT and the Atlantic Swordfish fishery stock was still considered overfished due to the large number of juveniles being harvested (ICCAT, 2017). To monitor the successfulness of the Atlantic Swordfish stock, ICCAT implemented a 10-year swordfish re-building plan. In 2001, NMFS enforced area closures to commercial PLL to help mitigate the amount of juvenile catches and by 2009 the Atlantic swordfish population was considered rebuilt (Fenton, 2012; ICCAT, 2017). In regards to this study, NMFS allocated hand gear permits, including buoy gear, for commercial Atlantic swordfish for 2013 (HMS, 2022).

Current ICCAT recommendations for retention size of swordfish include a LJFL of 125 cm with a 15% tolerance for undersized fish or 119cm LJFL with zero tolerance and evaluation of the discards (ICCAT 1991; NMFS, 1999; NMFS, 2006). This has been set forth based on ICCAT recommendations in 1991 that has been theorized to have contributed to an increase in the Atlantic swordfish population throughout the last three decades (ICCAT, 2022b). Although these recommendations have produced reduced landings and overall mortality of the Atlantic swordfish population, overall mortality for the population is very underrepresented for non-PLL gear types, attributing to only 1% of total estimation mortalities for all handline gear types (ICCAT, 2019). Estimates of fishing mortality rates are necessary for stock assessments, and incorporating post release mortality (PRM) rates of from all gear types, could provide insight on necessary management practices needed to produce an accurate status representation of the Atlantic swordfish stock.

Tagging

Tagging analysis of highly migratory species with traditional and electronic tags have become an integral portion of stock assessment modeling (Kerstetter et al., 2003; Marshall et al., 2023; Musy et al., 2011). There are generally three types of tagging experiments that prove useful to various individual biology and population analysis including: mark-recapture experiments, acoustic telemetry electronics, and electronic archival tagging experiments (Pine et al., 2011; Thornstad et al., 2013). Mark-recapture tagging studies can provide helpful insight on population levels and movements of a particular species or stock, but cannot provide an analysis for post-release survival, habitat preference, residence times, or short-term movements (Fenton, 2012; Jepsen et al., 2015). Acoustic telemetry experiments can prove useful when assessing short term movements within a designated spatial area, vertical habitat preference, short term post-release mortality, and 24-48-hour behavior studies, but do come with limitations (Thornstad et al., 2013). More recently, telemetry projects are often overlooked due to the highly intensive labor requirements of maintaining and deploying electronics, and the short-term estimation analyses that can be derived from reported data. In order to analyze long-term post-release mortality, movement, and habitat preference of individuals and species stocks, electronic archival tag data and analyses has been incorporated into ICCAT, NMFS, and international stock assessments (ICCAT, 2017). In 2017, ICCAT and the SCRS requested implementation of a tagging program to provide insight on habitat preferences, movements, and size and sex distributions for incorporation into ongoing stock assessments of the various swordfish populations (ICCAT, 2019). The need for this incorporation of tagging analysis in tandem with the increased demand for enhanced electronic technology has led way to a variety of electronic data analyses including: post release mortality, seasonal migration and behavior patterns, habitat preferences, and distribution of populations (Jepsen et al., 2015).

Electronic archival tags can be defined as § 635.2 “a device that is implanted or affixed to a fish to electronically record scientific information about the migratory behavior of that fish” (National Archives, 2023). The archival tag can either be placed internally or externally on an individual and have been used on numerous accounts for swordfish and Istiophorid billfish to analyze movements and post release mortality (Dewar et al., 2011; Hoolihan et al., 2011; Jepsen et al., 2015; Kerstetter & Graves, 2007; Kerstetter & Graves, 2008; Lerner et al., 2012). A Data

Storage Tags (DST) include archival tags that can be used in tandem with acoustic telemetry electronics that transmits a radio wave frequency that is picked up by a posted telemetry station. Other DSTs used simply accumulate data parameters associated with the movement and behavior of the individual until it has been recovered (Thorstad et al., 2013). Data parameters that can be recorded with DST's include pressure for water depth readings, temperature, light levels, salinity, magnetic field pull readings, latitude and longitude, and movements and behavior analyses based on accelerometer readings in predetermined 1-15 minute increments (Thorstad et al., 2013). DST's often become difficult in data analysis due to the high probability of non-recovered units and the limitedness of having one-way communication with reporting's (Akesson, 2002; Jepsen et al., 2015; Thorstad et al., 2013). Due to the daily migratory behavior and probability of the catch and recapture sequence, acoustic telemetry and DST's have been considered ineffective when studying swordfish (Fenton, 2012; Holdsworth et al., 2007).

Electronic archival tags that are considered one of the greatest advancements in understanding the behavior of large pelagic fish species is the use of pop-up satellite tags (PSATs) (Gunn & Block, 2001; Hoolihan et al., 2010). Rapid development in PSAT technology have given researchers the ability to collect a variety of physiological and environmental data parameters associated with the movements of various migratory species. PSAT tags accumulate these data parameters for a predetermined amount of time with the ability of days, months, or years providing a long-term approach to post release mortality, seasonal and behavioral migration patterns, and habitat preferences (Arnold & Dewar, 2001; Gunn & Block, 2001). PSAT's vary in terms of configuration and functionality, but the use of external tether and PSAT tags with an internal anchor, and ARGOS satellite communication have proved to be most successful when analyzing movements of billfish and swordfish (Fenton, 2012; Graves et al., 2002; Holdsworth et al., 2007; Kerstetter & Graves, 2008). Data parameters that are often collected with PSAT's include: mortality, temperature, tag inclination, pressure and depth, ambient light levels, salinity, and geolocation and pop-off location coordinates (Wildlife Computers, 2023). Once the tag has reached the predetermined time for dislocation, the satellite tag will "pop-off" the individual, rise to the surface, and begin transmitting to the ARGOS satellite systems (Fenton, 2012.) Tags are programmed to transmit data to satellites in various incremental "bins" or programmed summaries, which is then provided to the researcher via a manufacture database (Kerstetter et al., 2003). These tags are successful in detecting mortality of tagged individuals as they are programmed to prematurely dislocate from the individual if a consistent depth is maintained for a 12-24 hour time period, insinuating no vertical movement. (Wildlife Computers, 2023). Mortality can also be detected if the tag descends to a depth approaching the pressure that will crush the tag (>1400m) (Wildlife Computers, 2023). Due to the low temperatures and high-pressure depths that some species can reach during daily/annual migrations, PSAT tags are often pre-programmed to release itself if pressures or temperatures become high enough to compromise the tag's integrity (Wildlife Computers, 2023).

Given that PSAT technology providing fishery independent data to researchers remotely after tag deployments have been conducted, it allows scientist to overcome limitations associated with catch-recapture methods, acoustic telemetry, and DST type analyses (Fenton, 2012). PSAT tags have successfully been deployed on a variety of HMS species including: white marlin (Kerstetter & Graves, 2006), blue marlin (Kerstetter et al., 2003), sailfish (Kerstetter & Graves, 2007), swordfish (Fenton, 2012), bluefin tuna (Orbesen et al., 2018), yellowfin tuna (Hoyle et al., 2023), and various shark species (Whitney et al., 2021), but are faced with limitations of their own. Length and weight of the individual animal and size of external tag used needs to be considered for these types of studies. An individual subject to a tag too rotund could cause it to exceed the bioenergetic cost of living or alter the behavior of the individual (Fenton, 2012; Grusha & Patterson, 2005). Tag shedding, tag malfunction, and damage due to predation or elemental causes are also limitations to consider when conducting a PSAT data analysis.

Study Summary

Wildlife Computers Inc. (Seattle, Washington, USA) miniPAT and survival PATs were used, for this project to investigate two separate topics: the post-release survival rates of 45 individual swordfish (size range limits 60cm-120cm LJFL) after being captured with commercial buoy gear in the GOM or Florida Straits, and habitat utilization and horizontal movement patterns after resuming normal behavior following release. The implementation of a tagging study to assess post-release mortality of fishes discarded from alternative gear would further clarify the restoration benefit that the OFRP provides to pelagic fishes, as well as inform regulatory policy for the use of these gears. There have been multiple studies of post-release mortality of large pelagic fishes caught on PLL gear (e.g., Kerstetter et al., 2003 for blue marlin *Makaira nigricans*, Kerstetter and Graves (2008) for sailfish *Istiophorus platypterus*, Orbesen et al., (2019) for bluefin tuna *Thunnus thynnus*, but the study of the post-release mortality of fish caught on non-PLL alternative gears is limited. For example, a 37% post-release mortality of swordfish from buoy gear was reported by Fenton (2012), but data were collected from only 14 individuals and also included fish caught on traditional rod-and-reel gear. A similar post release survival study was done in Australia for deep-drop rod and reel, producing a 85.6% survival rate but included 26 individual swordfish greater than or equal to the United States retention size (Wolfe & Tracey, 2023). There have been numerous adult and legally sized swordfish post-release survival and habitat utilization analyses using pop-off satellite tags, however, there has been only one evaluating juveniles specifically (Fenton, 2012). Conducting an analysis specifically on post release mortality for swordfish buoy gear can aid in an overall understanding of undersized swordfish mortality rates associated with fishing interactions of all encompassed commercial and recreational fishing gears (Fenton, 2012; Wolfe & Tracey, 2023).

Due to the multifactor variables used in order to produce stock assessments when evaluating highly migratory species, horizontal and vertical movement behaviors play a critical role in management implications. Understanding time-at-depth and habitat preference of juvenile swordfish can allows researchers to provide management suggestions that can limit the catch and potential mortality of undersized fish. Analyzing the vertical movements after release on buoy gear aids in determining mortality and can suggest how quickly juveniles potentially return to normal feeding behavior after live release on commercial buoy gear. Horizontal movement analysis on juvenile swordfish within the GOM and Florida Straights can provide further evidence for the current theories of typical North Atlantic swordfish migrations.

Results from this study are likely to prove significant due to the increase in potential use of buoy gear fishing outside of the scope of the OFRP project. Due to the attractiveness of small bycatch numbers, smaller vessels being able to participate, and allowable access to areas otherwise closed to commercial PLL, properly managed buoy gear fishing has potential to provide a commercial swordfish-targeting fishing industry outside of PLL gear. With an increase in commercial popularity, an analysis of juvenile swordfish mortality was chosen due to the theorical assumption that adult swordfish would be more resilient than juveniles, and thus provide management implementations for both age groups. Producing PRM rates for adult swordfish can be considered a moot point due to the retention and the commercial value of legal sized swordfish. Knowing the mortality rates of juvenile swordfish on a gear type that is underrepresented in stock analyses counts, can provide insight into overall mortality rates of the commercial fishing industry in its entirety, thus providing the most accurate stock assessment management implementations needed to keep our stock of Atlantic swordfish in a not-overfished status.

Methodology

Tagging and Data Collection

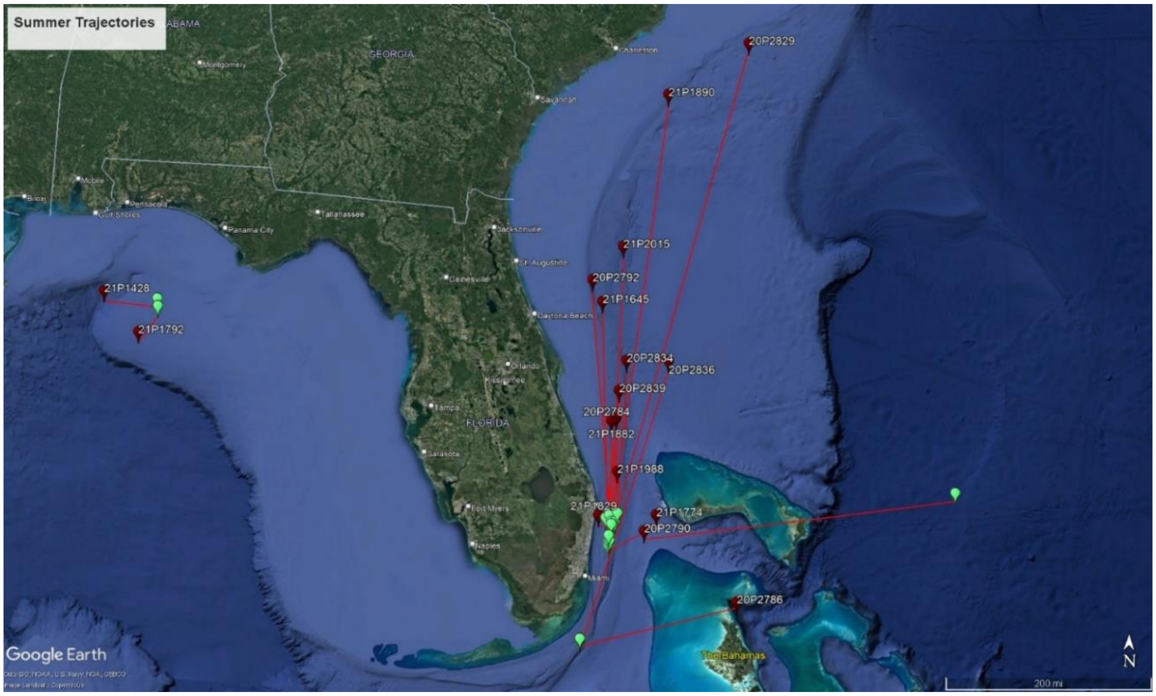
All tag deployments for this study were conducted aboard commercial swordfish buoy gear vessels participating in the experimental alternative gear restoration portion of the OFRP. Tagging effort was conducted by federal NMFS trained observers from May 2021 through June 2023 on juvenile swordfish caught on buoy gear as they became available during night and day time hours. Although OFRP participants are permitted to fish in PLL closure areas, use of an electric power back hauler for hand gear, and the ability to retain BAYS tuna, permit SWO-EFP-21-36 was acquired to allow participants to fish under the same regulations during the non-repose months (July-December, 2021-2023) with implication that an observer has to be on board. Due to the scope of the OFRP, all tagging effort was contained to the U.S. federal waters of the Gulf of Mexico and the Florida Straits where OFRP participants encountered successful fishing. Two different models of Wildlife Computer Inc. PSAT tags were used, creating a sum total of forty-five tag deployments on juvenile swordfish caught by commercial buoy gear. In this analysis 40 survivorship PSAT tags (sPAT-407) were deployed and five miniPAT PSAT tags (miniPAT-390) tags were deployed on juvenile swordfish. Through the entirety of this project, thirty OFRP buoy gear trips were completed with tag deployments.

Of the forty-five tag deployments, deployments between the GOM and Florida Straits varied due to participant catch successfulness. There was a total of seven tags deployed within the GOM, and thirty-eight tags deployed within the Florida Straits. Figure 5 shows deployment locations of all tags deployed within the scope of this project in a seasonal format. Although there are only seven deployments of tags within the GOM, these tags are the first deployments on juvenile swordfish capture on buoy gear within the GOM. Although there is no commercial fishery for buoy gear in the GOM, the gear specifications of OFRP participants follow typical buoy gear configurations that are fished in the Atlantic East Coast, including the Florida Straits. Typical swordfish buoy gear can be described as individual buoy "rigs" that contain 1-2 mainline floats attached to 90-150m long monofilament ending with 1-2 baited hooks (Bayse & Kerstetter, 2010). Hooks used for the purpose of this tagging project include EAGLECLAW model: L2048LM 16/0 circle hooks and 9/0 to 10/0 J hooks. Bait includes whole, dead, dethawed, mackerel and squid. Both chemical and electronic light sticks were used on gear during all tag deployments. The vessels that participated in swordfish buoy gear within the scope of the OFRP project contained porting locations in Panama City, FL (F/V ORION) and Destin, FL (F/V MISS

SHANNON) for the GOM deployments, and Pompano Beach, FL (F/V KRISTIN LEE, F/V OUTLAW, and F/V TROUBLE) for the deployments in the Florida Straits.

For each observed trip, environmental, gear configuration, and catch data was collected for each gear deployment completed. Standardized data sheets were created to encompass all environmental conditions at the beginning and end of each deployment, as well as gear interaction and catch data throughout the entirety of the gear deployment. Data fields include: buoy gear composition of lengths, sizes, and materials used, deployment locations, sea surface temperature (SST), weather conditions, maximum hooks used, maximum buoys used, and species, lengths, sex, and release status of all catch. For the tag deployments, data specific to each tag deployment was collected. A swordfish specific data form was created in order to encompass all environmental conditions, gear deployment data (date, time, location, tag ID), and condition of the individual being tagged (Appendix A). Geographic location of capture, time at haul back, fish lengths, estimated weights, hooking location, hook type, and tag location are all collected during each tag deployment. Data collection followed NMFS Observer protocol and can be seen included in the OFRP final report (Kerstetter & Garvey, 2020).

Observers were instructed to tag swordfish as OFRP participants conducted "normal" fishing operations. "Normal" fishing operations can be defined as techniques executed as they would normally be done if an observer was not on board. Not interfering with the fishing practices can be theorized to limit bias in regards of mortality rates reflecting what actually takes during interactions with catch-and-release fish. If a fisher would normally bring a fish on deck to confirm legality, then this practice was maintained while observers were on the vessel and conducting tag deployments. Individual swordfish were tagged both boated and boat side depending on vessel buoy gear practices.


Summary Trajectories
20P2829
21P1890
21P2015
20P2792
21P1645
21P1428
21P1792
20P2834
20P2836
20P2839
20P2784
21P1882
21P1988
21P1774
20P2790
20P2786
Google Earth
200 mi
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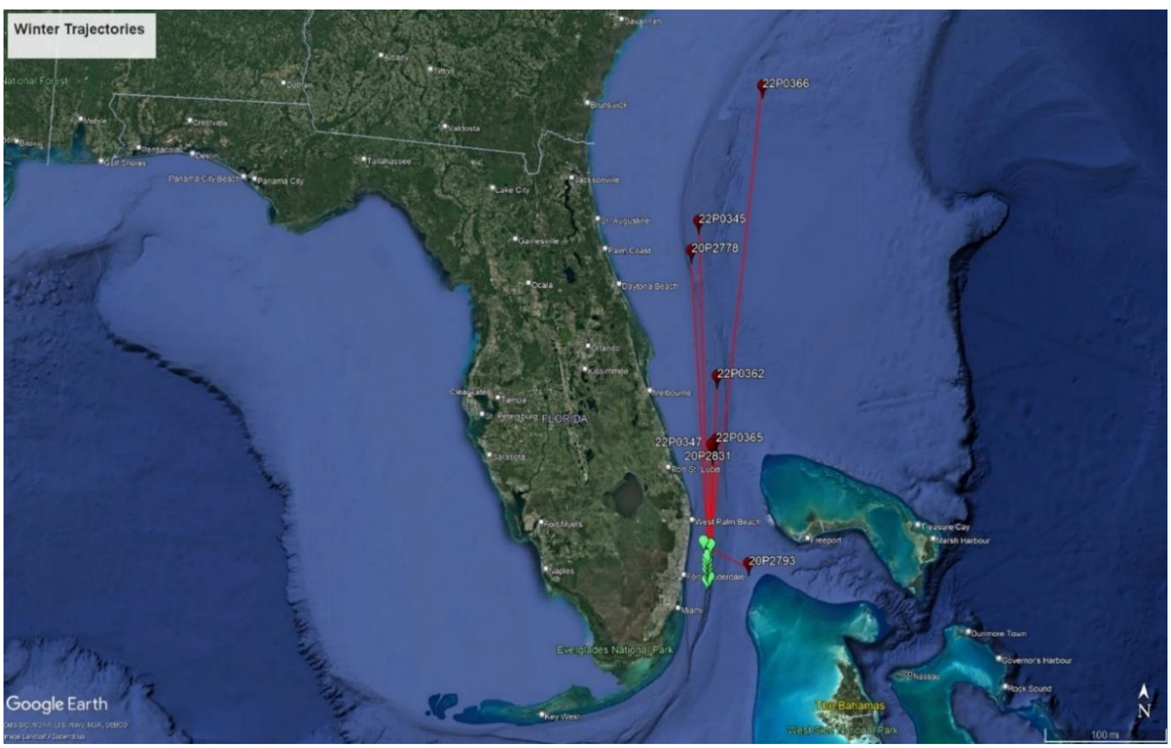
Winter Trajectories
22P0366
22P0345
20P2778
22P0362
22P0365
22P0347
20P2831
20P2793
Google Earth
100 mi
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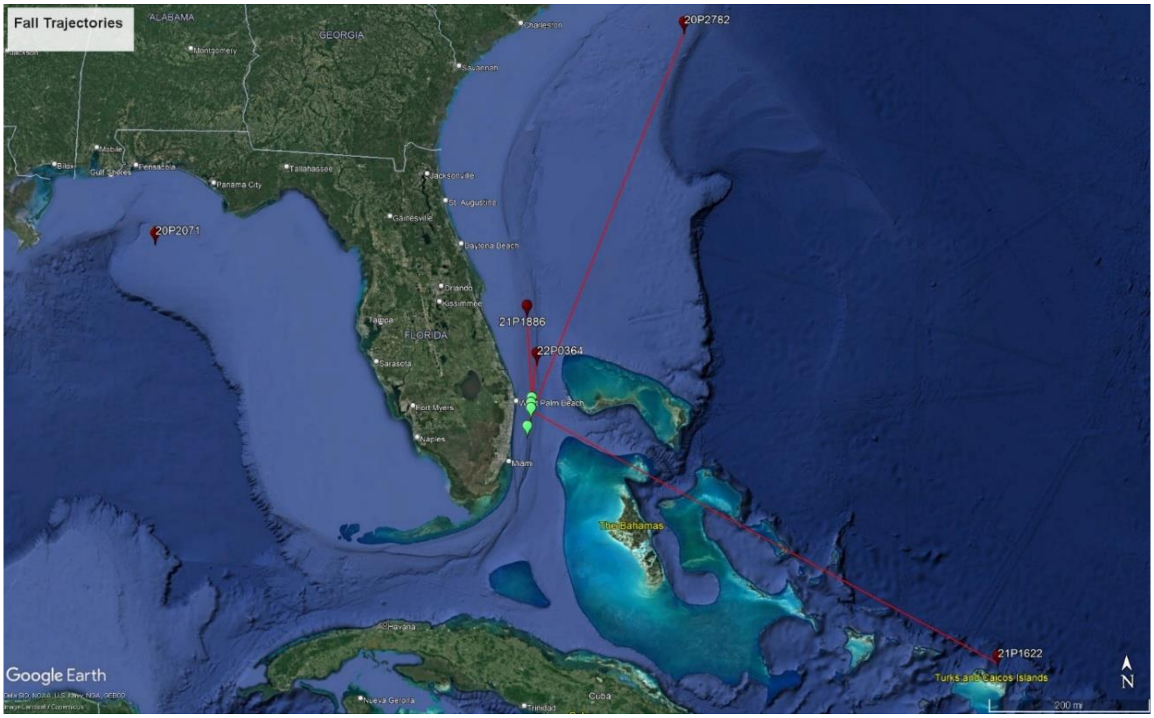


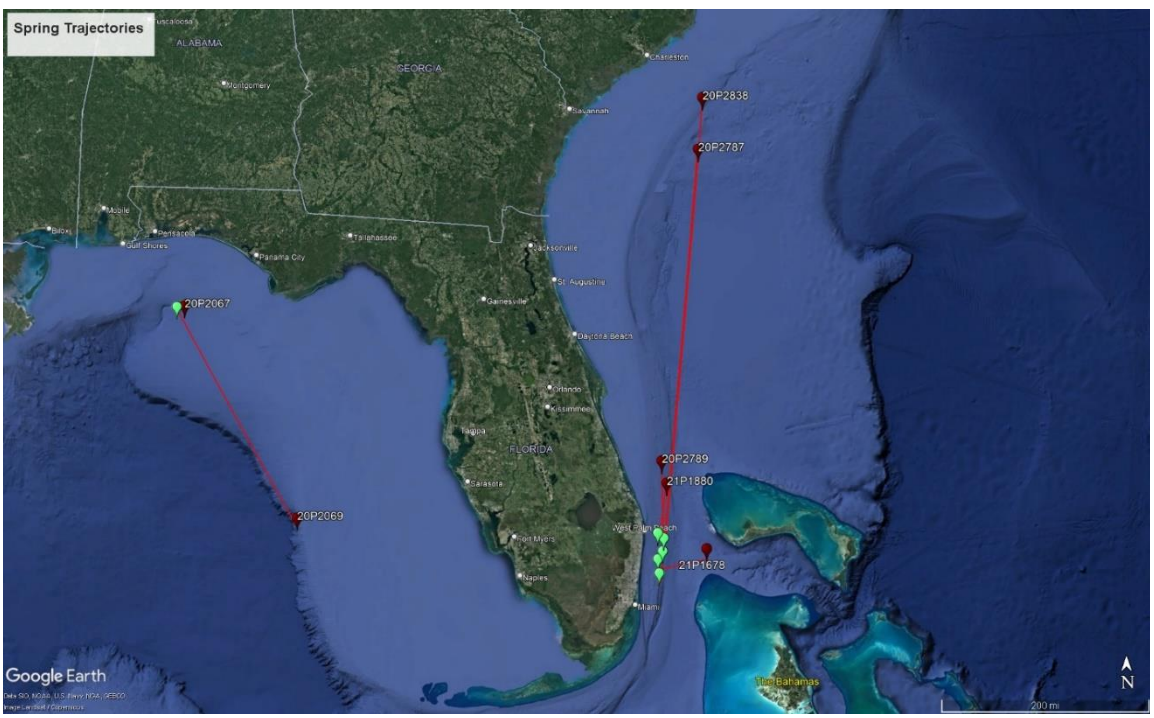


Figure 5. All reporting tag deployments for this analysis in a seasonal format: Summer (June-August), Winter (December – February), Fall (September – November), and Spring (March-May). All tag deployments took place during 2021-2023. Deployment locations are indicated by the green pin, while the red is representative of the first transmission location.

A total of 45 live juvenile swordfish were tagged after being caught on buoy gear, ranging from measured and estimated lengths of 60-120cm LJFL. Estimations were done with a tape measure device floating on the surface next to an individual swordfish, or with a tape measure on deck for boated individuals. Individuals 60cm or smaller were typically avoided due to concern of tag size influencing movement and behavior, although one individual was tagged at 60cm LJFL. Tag size can create drag, which is theorized to create substantial metabolic costs for small individuals and could influence swimming ability, and thus predation or mortality. (Grusha & Patterson, 2005). It has also been observed first hand that swordfish 80 cm or less do not have large amounts of musculature and that could also inhibit placement of the tag anchor. A modified "ACESS" condition scale was used for observers to quickly evaluate the condition of the swordfish (Kerstetter et al., 2003). The modified scale used in this study includes seven characteristics of the fish condition in order to asses if the fish is taggable. Movement of the individual, color, eye condition, level of bleeding, overall state of body, gill condition, and an injury assessment were all characteristics included in this assessment. Each characteristic had three levels of severity with each level receiving a value of 1, 2, or 3. A value of 1 is considered to be of high concern, and a value of 3 is considered no concern. A fish can score a minimum value of 7, suggesting certain mortality, or a maximum of 21, suggesting no damage and thus a likely survival (Fenton 2012; Kerstetter et al 2003; Kerstetter et al., 2011; Kerstetter and Graves, 2006). All tagged individuals in this project received a value of 13 or higher on this scale, but any fish receiving an 8 or higher would have been eligible for tagging. Individuals receiving a 1 in the category assessing activity level would not be considered eligible for tag placement due to the display of lack of movement being the standard of determination of a live or dead (Falterman & Graves, 2002). After the tag was placed the hook was removed if accessible, or left on the fish with no more than 1 foot of monofilament line remaining. All tags were targeted for placement along the posterior section of the dorsal fin, approximately 3 inches below the skin in order to anchor between the pterygiophore bones. Tagging applicator needles were used in tandem with a rubber stopper to ensure proper anchor depth.

Two types of tags were used in this study, both manufactured by Wildlife Computers Inc. (Seattle, WA, USA), the miniPAT-390 and SurviorshipPAT-407 (sPAT). Both satellite tags are approximately 61 grams and have a length and diameter of 124 mm by 38 mm and can withstand pressures of up to 2000m depth. The tags are anchored with a large Domeier style tether that has a 31 mm by 16 mm length and diameter. Before deployments, tags were stored in the off-mode, turned into auto-detect mode by observer coordinator staff, and then sent to the observer. Once in auto-detect mode, the tags use a wet/dry sensor to detect whether the tag has entered the water. This detection automatically switches the tag into start mode, where data collection begins. If tags were exposed to water before deployment on an animal, the observer is able to toggle the mode back to stop or auto-start mode with use of a magnet (Wildlife, 2023).

Although the two types of tags used are similar in size, weight, and deployment techniques, the data parameters collected by each vary significantly. The sPAT model can solely be used for detection of mortality. These tags contain light, depth, and temperature sensors that store a complete record of daily minimums and maximum values throughout the duration of the tag deployment. In the event of a mortality or the release of a tag due to the threshold being surpassed, the tag will transmit data via ARGOS satellite systems for the last 5 days of the deployment. The data is collected in intervals of ten minutes and monitoring durations are customizable of up to 30, 45, or 60 days. Once the data has been received by the satellite, it is sent to the manufacture where it is decoded into various .csv files for the end-user scientist.

These tags are successful when trying to detect mortality due to their minimum and maximum temperature and depth readings, Delta light-levels for each UTC day, and the 10-minute time series depth data for the last 5 days of the deployment. Geolocation of the first satellite transmission is also included, this can be portrayed as the satellite tag “pop-off” location from the animal. Using the first satellite transmission location in combination with tag deployment coordinates, a net horizontal displacement can be calculated, described as the distance in kilometers between the two locations (Kerstetter & Graves, 2008). For this study, sPAT tags are programmed to release at 30 days. This time length was chosen to give clear delineation of post release survival and to examine if normal behavior is still exhibited after being caught and released on buoy gear. Including a 30-day tag duration was also chosen, in part, to test the assumption that 8 days was a sufficient duration to capture the rate of post release mortality resulting from interaction with commercial swordfish buoy gear (Kerstetter et al., 2003). Since the sPAT’s main functionality feature is to express mortality events, a tag duration period longer than 30 days did not seem necessary for a PRM study, and extended monitoring could introduce natural mortality events.

Data parameters associated with the miniPAT tags can be considered a little more complex. These tags exhibit the same functionality as the sPAT tags but include data transmission for the entirety of the tag deployment. Data summaries of the following can be included in the storage with miniPAT tags: daily depth, temperature and light values, daily light-level geolocation, acceleration and tag orientation data, activity time series, depth time series, temperature time series, mixed layer time series, and summary histogram plots of time-at temperature and time-at depth (Wildlife, 2023). MiniPAT tags are successful when determining mortality events, tracking long-scale horizontal and vertical movements, and deterring time at depth for specific individuals. By using a combination of light level data and pressure at depth data, daily geolocation coordinates are derived and summarized from the transmitted data. This allows for approximated daily tracks to be made on movements throughout the tag deployment. Tag duration for miniPAT tags is customizable for up to two full years (Wildlife, 2023). For this study, the five miniPAT tags deployed are programmed for release at 120 days after deployment. There have been minimal studies on juvenile swordfish movements within the GOM and Florida Straits, so this time length was chosen to evaluate long term movements.

Even though the two different tag models contain various data parameters and deployment durations, both were used to analyze mortality and survival rates of juvenile swordfish after live release. Since the projected goal for this analysis was to determine a PRM rate for juvenile swordfish released from commercial buoy gear, a majority of the tags used were sPAT tags due to their ability to detect mortality, and their cost effectiveness compared to the miniPAT tags. For this study, any mortality event that was inferred eight or less days (<192 hours) after tag deployment would be considered a mortality event associated with the catch and release interaction of swordfish buoy gear. Any swordfish surpassing the 30-day tag duration for sPAT tags and the 120 day duration for miniPAT tags, it is automatically assumed that survival has occurred. It has been noted in several studies that post release mortality is estimated to occur shortly after release ($\leq$ 144 hours) due to injury and physiological stress (Fenton, 2012; Horodysky & Graves, 2005; Kerstetter et al., 2004). It is also widely recognized that delayed mortality can occur days or weeks after post release due to inability to feed, predation events caused by morphological and behavioral changes, and infection (Burns & Froeschke, 2012; Orbesen et al., 2018;). Consequently, tags with longer deployment durations are subject to be influenced by mortality events unassociated with post release, including natural and fishing mortality and tag malfunction (Fenton, 2012; Goodyear, 2002; Kerstetter et al., 2004; Orbesen et al., 2018). In billfish and swordfish, most researchers tend to limit their most release mortality to the first 5-10 days after tag deployments (Fenton, 2012; Graves et al., 2002; Horodysky & Graves, 2005; Kerstetter et al., 2003; Marcek & Graves, 2014; Orbesen et al., 2018). To encompass all true post release mortality events while simultaneously limiting the probability of the inclusion of non-buoy gear interaction mortalities, the eight-day post release mortality value has been chosen. Table 2 shows all tag deployment information for this study including: Tag ID, Deployment Date, Deployment location, Pop-off location, tag model, estimated sized, programmed duration, and actual days at liberty. Table 3 lists release conditions for each individual tag, under the assumption that all fishing practices and handling are conducted under the normal configurations of the commercial buoy gear industry.

Data Analysis: Post Release Mortality

Post-release mortality of swordfish and other large pelagic fish can often be determined through tag reported data by analyzing three types of environmental data: ambient light levels, water temperature changes, and depth changes (Fenton 2012; Hoolihan et al., 2011; Kerstetter & Graves, 2008). For both tag models used in this study, depth time series, temperature time series, and light level values are produced and used to estimate mortality events for each individual fish. Out of 46 total tags deployed (40 sPAT and five miniPAT), eight of them did not report and one was lost due to a failed tagging event. One tag did not report properly, but it was recovered, so tag data was not lost and had the ability to be included within analysis. As tag technology has advanced over the years, there has been debate on whether nonreporting tags should be included within the post-release mortality analysis (Goodyear, 2002; Orbesen et al., 2018). The fate of a fish with a non-reporting tag is unknown, and the failed reporting could be caused by numerous issues including tag malfunction, or a predation event. Including the non-report tags as assumed mortality events could result in overestimated mortality rates, but they can be used to provide a range to consider when implicating management suggestions (Goodyear, 2002). For the purpose of this study, non-reporting tags are not included in the overall analysis for post-release mortality rates of juvenile swordfish to limit the bias associated with overestimating post-release mortality rates. However, due to the eight-day post-release value chosen for this analysis and the 30-120 day tag duration period, a post-release mortality range associated with commercial buoy gear and a mortality rate of full tag expression range will be provided.

Post-release mortality rates (R) can be estimated as described in Goodyear 2002., with the following equation:

$$R = \frac{D}{N}$$

Where D is the number of fish that have died prior to tag release and N is the total number of fish tagged. Two PRM rates were analyzed, one value associated with the capture event of commercial buoy gear, and another mortality rate associated with survivability past 30 full days representing a fully expressed tag duration. Once post-release mortality values were examined, a bootstrapping simulation was performed using "Release Mortality" to analyze the potential influence of having a relatively small sample size on the estimated 90% confidence intervals (5^{th} and 95^{th} percentiles) of the post-release mortality rates (Fenton, 2012; Goodyear, 2002; Horodysky & Graves, 2005). The computer program developed to implement these findings allowed for consideration of a very large number of parameter combinations for different possible conditions (Goodyear, 2002). Both buoy gear post-release mortality and mortality rates associated with fully expressed satellite tags were analyzed under this method by running a total of 10,000 simulations (Horodysky & Graves, 2005). These simulations can provide insight on how having a low sample size of tags can deviate the true post-release mortality values by 5-25% of the true value (Fenton, 2012; Goodyear, 2002). The following variables for the simulation are listed as either a Process Variable, Experimental Variable, or Decision Variable.

These variables used in this simulation are: Release Mortality Fraction: 0.421 & 0.605 based on the estimated post-release mortality rates, Days to Full Expression: 8.00 days chosen to represent mortality associated from PRM, Tagging Mortality Fraction: 0.00 chosen on assumption of no mortality caused due to tagging experience, Tag Failure Probability: 0.00 due to the exclusion of non-reports in this study, Natural Mortality Rate: 0.20 chosen based on (Griggs et al. 2005), Number of tags: 38, Program Pop-off Day: 30 focusing on sPAT tagging, Tags Reporting Normally: Included as survivor, Tags Not Reporting: Excluded from Analysis, and No Data Trends: Excluded from Analysis. For each the buoy gear post-release mortality rate and mortality rates associated with fully expressed satellite tags, the 90% confidence intervals were plotted until the values were +/- 5% of the initial assumed true value.

Table 2: Tag deployment information for 45 tag deployments including tag ID, deployment date and location, first transmission location, estimated size (cm), estimated weight (lbs), tag model (sPAT or miniPAT), programmed duration (30 or 120), and actual days at liberty.

Tag ID	Deployment Date	Deployment LAT	Deployment LON	Pop Off LAT	Pop Off LON	Estimated Size (cm)	Estimated Weight (lb)	Tag model	Programmed Duration (days)	Days at liberty
20P2836	06/16/21	24 45' N	80 12' W	28 28' N	79 02' W	115	25	sPAT	30	27
20P2786	06/16/21	24 44' N	80 12' W	25 16' N	78 00' W	95	18	sPAT	30	30
20P2792	06/11/21	26 27' N	79 50' W	29 31' N	80 09' W	100	15	sPAT	30	7
20P2834	06/12/21	26 20' N	79 45' W	28 28' N	79 38' W	100	22	sPAT	30	2
20P2790	05/26/21	26 41' N	74 51' W	26 13' N	79 20' W	110	30	sPAT	30	30
20P2784	06/17/21	26 01' N	79 50' W	27 40' N	79 50' W	100	18	sPAT	30	1
20P2778	12/27/21	26 03' N	79 49' W	29 27' N	80 06' W	115	25	sPAT	30	8
20P2832	12/27/21	26 05' N	79 50' W	Non-report	Non-report	115	25	sPAT	30	Non-report
20P2830	01/15/22	26 04' N	79 46' W	Non-report	Non-report	115	20	sPAT	30	Non-report
20P2831	01/18/22	25 58' N	79 47' W	27 18' N	79 47' W	120	30	sPAT	30	1
20P2793	01/20/22	26 21' N	79 52' W	26 07' N	79 19' W	110	15	sPAT	30	5
20P2787	02/11/22	26 00' N	79 49' W	31 23' N	79 10' W	105	15	sPAT	30	30
20P2066	02/21/22	28 40' N	86 48' W	Non-report	Non-report	115	15	miniPAT	120	Non-report
20P2789	02/19/22	26 17' N	79 46' W	27 26' N	79 46' W	100	20	sPAT	30	10
20P2838	02/28/22	26 27' N	79 45' W	32 03' N	79 05' W	120	30	sPAT	30	30
20P2067	04/27/22	29 20' N	86 39' W	29 19 N	86 39' W	115	20	miniPAT	120	2
21P1880	04/29/22	26 31' N	79 50' W	27 09' N	79 42' W	90	15	sPAT	30	30
21P1829	05/04/22	26 25' N	79 48' W	26 25' N	79 59' W	90	15	sPAT	30	30
21P1678	05/12/22	26 11' N	79 50' W	26 18' N	79 09' W	90	15	sPAT	30	4
21P1882	05/13/22	26 23' N	79 53' W	27 42' N	79 46' W	90	15	sPAT	30	30
21P1774	05/15/22	26 05' N	79 49' W	26 26' N	79 10' W	120	20	sPAT	30	30
20P2069	05/21/22	29 18' N	86 46' W	26 39' N	84 54' W	105	15	miniPAT	120	9
20P2071	05/28/22	29 08' N	86 41' W	29 07' N	86 40' W	115	25	miniPAT	120	120
21P1890	05/29/22	26 20' N	79 48' W	32 00' N	79 05' W	60	10	sPAT	30	30
21P2015	05/31/22	26 25' N	79 50' W	29 58' N	79 43' W	90	20	sPAT	30	3
20P2788	06/15/22	28 54' N	86 39' W	Non-report	Non-report	115	25	sPAT	30	2
21P1792	06/25/22	28 54' N	86 32' W	28 32' N	86 48' W	90	25	sPAT	30	12
21P1428	06/26/22	29 00' N	86 33' W	29 03' N	87 23' W	90	25	sPAT	30	30
21P1645	08/02/22	26 04' N	79 50' W	29 14' N	80 00' W	110	25	sPAT	30	7
20P2829	08/16/22	26 18' N	79 48' W	32 43' N	77 52' W	110	25	sPAT	30	11
20P2839	08/26/22	26 27' N	79 43' W	28 04' N	79 44' W	100	25	sPAT	30	1
20P2840	08/26/22	26 33' N	79 43' W	Non-report	Non-report	100	25	sPAT	30	Non-report
21P1886	10/24/22	26 34' N	79 44' W	28 01' N	79 48' W	90	25	sPAT	30	1
21P1828	10/25/22	26 29' N	79 45' W	Non-report	Non-report	90	20	sPAT	30	Non-report
21P1622	10/25/22	26 29' N	79 45' W	21 58' N	71 37' W	120	25	sPAT	30	30
20P2065	10/25/22	26 31' N	79 45' W	Non-report	Non-report	110	25	miniPAT	30	Non-report
20P2782	10/28/22	26 24' N	79 45' W	32 32' N	76 48' W	90	15	sPAT	30	30
22P0345	11/27/22	26 06' N	79 49' W	29 46' N	80 01' W	90	20	sPAT	30	8
22P0364	11/27/22	26 07' N	79 49' W	27 16' N	79 38' W	90	20	sPAT	30	2
22P0347	12/06/22	26 12' N	79 49' W	27 23' N	79 48' W	100	25	sPAT	30	1
22P0366	12/07/22	26 09' N	79 49' W	31 15' N	79 14' W	110	25	sPAT	30	30
22P0362	12/07/22	26 19' N	79 47' W	28 07' N	79 45' W	100	20	sPAT	30	13
20P2791	12/08/22	26 33' N	79 45' W	Non-report	Non-report	110	25	sPAT	30	Non-report
22P0365	12/12/22	25 56' N	79 49' W	27 26' N	79 45' W	110	15	sPAT	30	2
21P1988	06/03/23	26 09' N	79 50' W	27 00' N	79 44' W	120	35	sPAT	30	30

For this study, an assumption was made for a tagging mortality fraction and a tag shedding value to be zero. This is most likely not true given that satellite tags often can be shed from the animal due to environmental conditions or survivable predation attempts, and tagging mortality could have occurred due to the placement of a tag on an individual. Due to these two events potentially taking place throughout this study, a sensitivity analysis was completed in order to evaluate how the estimated PRM is influenced with different values of our independent variables (tagging mortality and tag shedding). A value of 0.2 was given for both tagging mortality and tag shedding within the "Release Mortality" program and the 90% confidence intervals were plotted using the new values of these variables being included with a comparison of the estimated true value of the 0.421 PRM.

Table 3: Individual release information for each juvenile swordfish tagged with a satellite tag in this analysis. Release information includes: Satellite tag number, LJFL Estimation (cm), if the leader was cut, fight time estimation (seconds), remaining leader length (inches), Hook size, Hook location, If hook was removed, release condition, activity, color, eye outcome, bleeding status, body status, gill status, observation of injuries, and if resuscitation occurred. These categories and data collection methods were an alteration of the ACESS method as described by Kerstetter et al. 2003.

SATELLITE TAG #	FORKLENGTH ESTIMATED	LEADER CUT?	FIGHT TIME ESTIMATED (S)	REMAINING LEADER (in)	HOOK SIZE	Hook location	HOOK REMOVED?	Release condition	Activity	Color	Eyes	Bleeding	Body	GILLS	INJURIES	RESUSCITATION OCCUR?
20P2790	110	Yes	180	10	9/0	Throat/deep	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2792	100	Yes	120	4	9/0	Lower jaw	NO	Strong	Slight movement	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	YES
20P2834	110	Yes	180	5	9/0	In mouth	NO	Strong	Active	Bright silver/blue		None obvious	Intact	INTACT	NO	NO
20P2786	95	No	120	0	9/0	Lower jaw	YES	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	UK	NO
20P2836	115	Yes	120	5	9/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	UK	NO
20P2784	100	Yes	120	8	9/0	Upper jaw	NO	Weak	Slight movement	Bright silver/blue	Both intact	None obvious	Intact	INTACT	UK	YES
20P2778	115	Yes	120	6	10/0	Throat/deep	NO	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	NO	NO
20P2832	115	No	120	0	10/0	Upper jaw	YES	Strong	Slight movement	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2830	115	No	180	0	10/0	In mouth	YES	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2831	120	Yes	120	1	10/0	Throat/deep	NO	Weak	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2793	110	No	180	0	10/0	Bill	YES	Weak	Slight movement	Patchy blue-grey	Both intact	None obvious	Intact	INTACT	NO	YES
20P2787	105	No	120	0	10/0	Tail	YES	Weak	Slight movement	Patchy blue-grey	Both intact	None obvious	Intact	INTACT	NO	NO
20P2789	100	Yes	120	3	9/0	Ventral	NO	Weak	Active	Patchy blue-grey	Both intact	Minor	Shallow cuts	INTACT	YES	NO
20P2838	120	Yes	180	4	9/0	In mouth	NO	Weak	Slight movement	Bright silver/blue	Both intact	Minor	Intact	INTACT	YES	NO
20P2066	115	Yes	120	0.5	16/0	Throat/deep	NO	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	YES	NO
20P2067	115	Yes	120	0	16/0	Lower jaw	NO	Weak	Active	Bight sliver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1880	90	No	540	0	10/0	In mouth	YES	Strong	Active	Brigt silver/blue	Both intact	Minor	Intact	INTACT	NO	NO
21P1829	90	No	240	0	10/0	In mouth	YES	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	UK	NO
21P1678	90	Yes		0.5	10/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	NO	NO
21P1882	90	Yes	120	1	10/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1774	120	No	360	0	9/0	In mouth	YES	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2069	105	Yes	120	2	16/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2071	115	Yes	240	1	16/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1890	60	Yes	120	0.5	10/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P2015	90	No	300	0.5	10/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	YES	NO
20P2788	115	Yes	120	0.5	16/0	Throat/deep	NO	Weak	Slight movement	Patchy blue-grey	Both intact	None obvious	Intact	INTACT	UK	YES
21P1792	90	Yes	120	3	16/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1428	90	Yes	180	1	16/0	Bill	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1645	110	Yes	180	1	9/0	In mouth	NO	Weak	Active	Bright silver blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2829	110	Yes	120	3	9/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2839	100	Yes	120	3	9/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2840	100	No	60	0	9/0	Unk	YES	Strong	Active	Bright silver/blue	Both intact	Minor	Shallow cuts	INTACT	YES	NO
21P1886	90	Yes	180	2	10/0	Lower jaw	NO	Strong	Active	Patchy blue-grey	Both intact	Minor	Intact	INTACT	NO	NO
21P1828	90	Yes	120	4	10/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	UK	NO
21P1622	120	Yes	120	4	10/0	In mouth	YES	Strong	Active	Bright silver/blue	Both intact	Minor	Intact	INTACT	YES	NO
20P2065	110	Yes	90	3	10/0	Lower jaw	NO	Strong	Active	Patchy blue-grey	Both intact	None obvious	Intact	INTACT	NO	NO
20P2782	90	Yes	60	0.5	9/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	UK	NO
22P0345	90	No	120	0	10/0	Lower jaw	YES	Weak	Slight movement	Patchy blue-grey	Both intact	Minor	Obvious deep cuts	INTACT	YES	NO
22P0364	90	No	120	0	10/0	Lower jaw	YES	Strong	Active	Patchy blue-grey	Both intact	None obvious	Intact	INTACT	NO	NO
22P0347	100	Yes	120	3	10/0	Lower jaw	NO	Strong	Active	Bright silver blue	Both intact	None obvious	Intact	INTACT	NO	NO
22P0366	110	Yes	120	3	10/0	Lower jaw	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
22P0362	100	Yes	300	4	10/0	In mouth	NO	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
20P2791	110	Yes	180	3	10/0	In mouth	NO	Weak	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
22P0365	110	No	90	0	9/0	Upper jaw	YES	Strong	Active	Bright silver/blue	Both intact	None obvious	Intact	INTACT	NO	NO
21P1988	120	Yes	120	12	9/0	Lower jaw	NO	Strong	Active	Bight sliver/blue	Both intact	None obvious	Intact	INTACT	NO	NO

Data Analysis: Horizontal and Vertical Movements

Due to the highly migratory nature of North Atlantic swordfish, there have been numerous studies analyzing the horizontal and vertical movements of swordfish in different regions throughout their range. Results from these analyses have aided in international management collaboration to restore the North Atlantic swordfish and other swordfish populations from over-fished, to restored. Having a thorough understanding of animal movements and habitat use can be critical for formulating reliable stock assessments (Braun et al., 2019). Between the three general Atlantic swordfish populations: the North Atlantic, South Atlantic, and the Mediterranean stocks, horizontal migration between them have recently been recorded (Schirripa et al., 2017; Sedberry & Loefer, 2001), but it is currently still recognized by ICCAT that this is not normal migration behavior and the North Atlantic and South Atlantic can be abruptly bounded by the 5°N latitude mark. However, recent genetic studies suggest that there are observed movements consistent with potential population structure within the North Atlantic, so revision of the boundary line may be needed. Past studies show typical migration patterns of the North Atlantic population following the movement of temperate waters, along the major ocean currents of the North Atlantic Ocean and the Gulf of Mexico, including the Gulf Stream (Braun et al., 2019). Horizontal movements associated with following seasonal temperate water conditions suggest swordfish can be seen migrating northeast in the summer months following productive foraging grounds in coastal areas, and then migrate southwest in the fall to more subtropical -tropical waters for spawning grounds and optimal larval growth conditions (Braun et al., 2019). The GOM and Florida East Coast are considered highly prioritized spawning and foraging grounds for swordfish and other billfish, so seasonal horizontal migrations are theorized to take place due to spawning opportunities and food availability (Rooker et al., 2012). Although there have been few studies to analyze juvenile swordfish movements within the GOM and Florida Straits, there has been research that shows juveniles follow similar seasonal migration patterns to adults (Rooker et al., 2012), but it is suggested that these seasonal movements are more likely not as large scale (Braun et al., 2019). It has been suggested that juveniles may typically occupy a more thermally-stable habitat due to a lower thermal plasticity, rather than having to require warmer water for spawning like adults (Braun et al., 2019). It has also been theorized that juvenile swordfish remain in areas such as the Desoto Canyon (GOM) and off the FEC where there are warmer temperature waters, thus precluding them from long range movements to feeding grounds in the Northeast, which have a wide range of temperatures (per. comm. Eric Orbesen, 2023).

Swordfish also exhibit evidence of a diurnal movement pattern influenced by light levels. They can be seen occupying surface waters from 0-160m during night time hours, while diving to depths of 200-800m during night hours, presumably to mimic targeted prey vertical movements (Braun et al., 2019; Fenton, 2012; Wolfe & Tracey, 2023). As adult swordfish tend to follow a daily diel-vertical migration (DVM) patterns, juvenile swordfish are seen to exhibit this same behavior, but not as consistently. Juveniles have been recorded to spend less time-at-depth when compared to adults, and this behavior is theorized to take place due to the physiological abilities to withstand acute changes in temperature and pressure (Braun et al., 2019). It has also been suggested by previous studies that the juvenile's lower resilience to changes in environmental conditions are influenced by an ontogenetic component influencing DVM patterns, which include extraocular musculature and vascular systems that warm the eyes and brain and the development of specific cardiac functions that aid in withstanding higher pressures and lower temperatures during DVM movements (Braun et al., 2019).

To examine the horizontal movements of juvenile swordfish after capture on buoy gear a net displacement of deployment location and pop-off location of each reported tag was conducted. Net displacements were done using the great circle distance formula for the distance in kilometers. The formula reads: =(6371*3.1415926*SQRT((LAT2-LAT1)*(LAT2-LAT1) + COS(LAT2/57.29578)*COS(LAT1/57.29578)*(LON2-LON1)*(LON2-LON1))/180). Maps of each tag were then created to compare differences in potential seasonal movements and differences between juvenile swordfish occupying the Gulf of Mexico versus the Florida Straits. Due to the limitations associated with the data collected by the sPAT tags, a net displacement analysis is the only form of geolocation analysis that can be done.

MiniPAT tags collect more intricate daily geolocation data associated with pressure and temperature, so a more detailed analysis can be reported. Geolocation tracks on the two longer attached miniPAT tags were constructed using the HMMoce package (Braun et al., 2019) for R studio (R Development Core Team, 2015). This model predicts likely movements based on combined measurements of light-levels, SST, and depth-temperature profiles reported by archival tags (Braun et al., 2019). There are four separate likelihood combinations used to derive the probable daily locations, these include: an SST likelihood, a light-based longitude likelihood, depth temperature profiles, and ocean heat content (OHC). For the purpose of this study, three separate combinations were tested to determine which would be the most significant when describing these likelihoods. The three combinations tested were: (i) light level data + SST + OHC, (ii) light level data + SST + depth temperature profiles, and (iii) a combination of all four likelihoods. The likelihood combination that proved to be most significant would be the first combination incorporating light level data, SST and OHC. These location likelihoods are then conducted under a Markov model that computes posterior probability distributions to estimate the most likely state (position and behavior) of the animal at each time point (Braun et al., 2019). A map showing movements of one 120-day miniPAT tag is shown based on these predictions produced by the Markov model.

For analysis on vertical movements, time series data on all miniPAT and sPAT tags were created from reported tag data, while time-at-depth histograms for the three miniPAT tags were made using the histogram data produced by each archival tag. Both the time-series graphs and time-at-depth histograms were made using Microsoft Excel 2019. Time series depth graphs were then used to compare vertical behavior between individuals caught and released in the GOM and Florida Straits. Individual swordfish were also analyzed for any irregular diving behavior and directional movement comparisons (i.e. movement from south to north). For time-at-depth analysis, percentages of each depth occupancy, in intervals of 100m, were analyzed and compared to previous studies in order to suggest typical juvenile swordfish habitat preference within the GOM. Three miniPAT tag data sets were examined for occupancy at depth ranging from tag deployment lengths of 2-120 days. Three daily time period categories were assigned to separate depth occupancy: Crepuscular, pure day, and night time, so each tag produces three separate bar graphs. Out of the 38 tags that reported, only two tags did not produce usable time series depth data. However, these two tags did report daily data, and thus were still viable for the post-release mortality assessment.

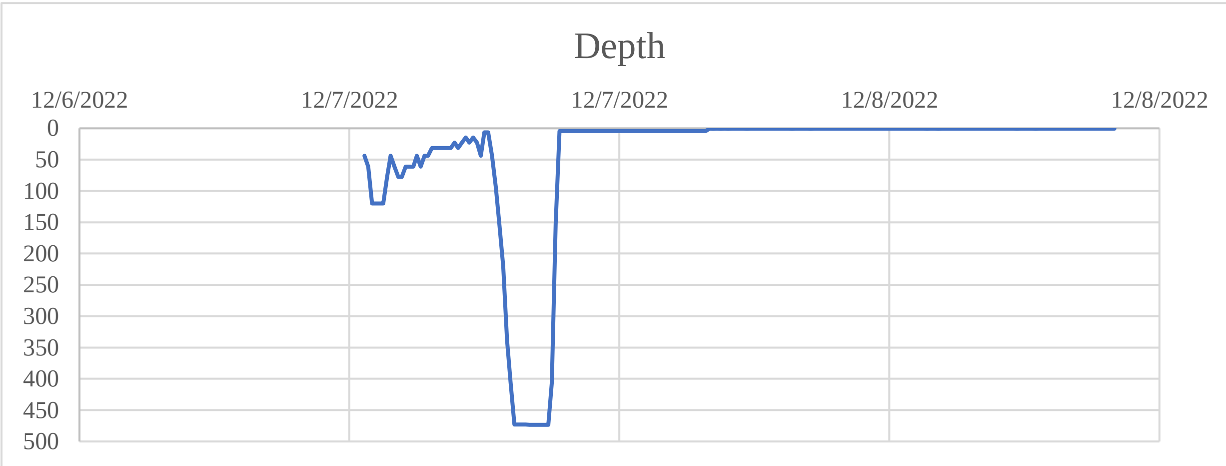
Results

Post-Release Mortality

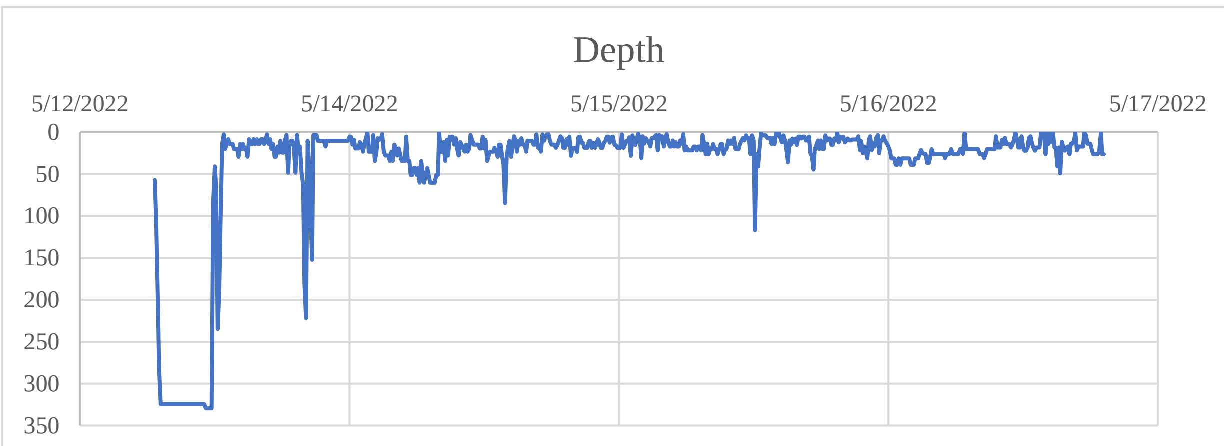
Figures 6, 7, and 15-19 are all examples of time-series depth plots used to analyze mortality events for all 38 reporting tags. Out of the 38 reporting tags, 22 fish survived past the 8-day post-release mortality event time period for the post-release analysis. For the mortality analysis associated with fully expressed satellite tags, 15 fish survived through the full tag expression period. Figure 6 shows examples of a time series depth plot that represents mortality events that took place 8 days or less after post-release from commercial buoy gear, and Figure 7 represents the 15 swordfish vertical profiles who survived to the fully expressed 30 day sPAT tag duration. The ratio produced by post-release mortality associated with the capture event was predicted to be 42.1% while the mortality rates of individuals that reached their fully expressed satellite tag duration was predicted at 60.5%. There were two instances in which tag data was not properly transmitted in the correct time series format, but the daily maximum and minimum data for delta-light levels, temperature, and depth were reported (Figure 8). These plotted values were used to determine potential movement and thus considered for post-release mortality events. Both of these tags remained on the swordfish through the duration of 30 days, and due to the light, temperature, and depth variability throughout time, they were considered individuals who did not represent a mortality event.

The results of the "Release Mortality" program can be seen in both Figure 9a-b for the post-release mortality and for mortality related to fully expressed tagged individuals, which represents the 5^{th} and 95^{th} percentile values plotted for an increase of sample sizes. In both of these plots, the solid lines represent the 5^{th} and 95^{th} percentile values of the actual release mortality value for each given sample size (x values). The dashed line between each of these plotted values represents the release mortality fractions produced from this analysis. These figures are representative of the 90% probability that the estimates will be within +/- %5 of the true post-release mortality. The results of 10,000 simulations with a post-release mortality rate associated with the capture event of 42.1% predict that approximate 90% confidence intervals for mortality estimates for an experiment containing 38 tagged individual juvenile swordfish range from 28.9%-57.9%. The results of 10,000 simulations with a post-release mortality rate associated with fully expressed tags of 60.5% predict that approximate 90% confidence intervals for mortality estimates for an experiment containing 38 tagged individual juvenile swordfish range from 50.0%-73.4%. In both instances, it is assumed that no tags are shed, there is no tagging induced mortality, no tags fail, and no natural mortality occurs.

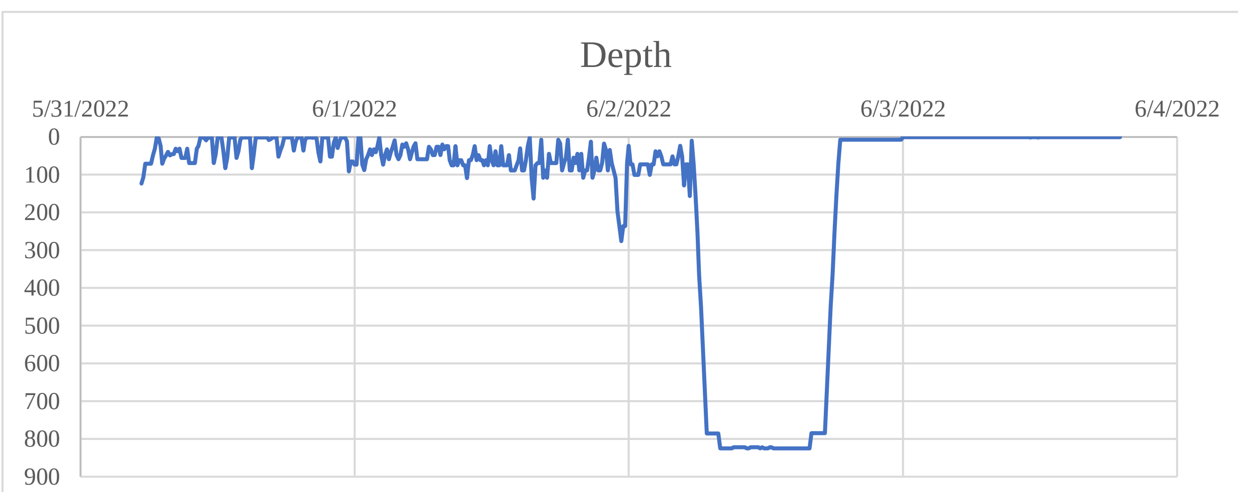
To understand how independent variables such as tag shedding and tagging induced mortality could potentially affect the outcome of our estimated mortality probability, a sensitivity analysis was conducted and can be seen in Figure 10. For the estimated PRM of 0.421, both tagging induced mortality and tag shedding were given probability values of 0.2 and compared to the results of the previously ran "Release Mortality" simulation. Results show that including these two variables within the analysis increase the mortality probability range, and thus should be considered when conducting a PRM study with satellite tag techniques.



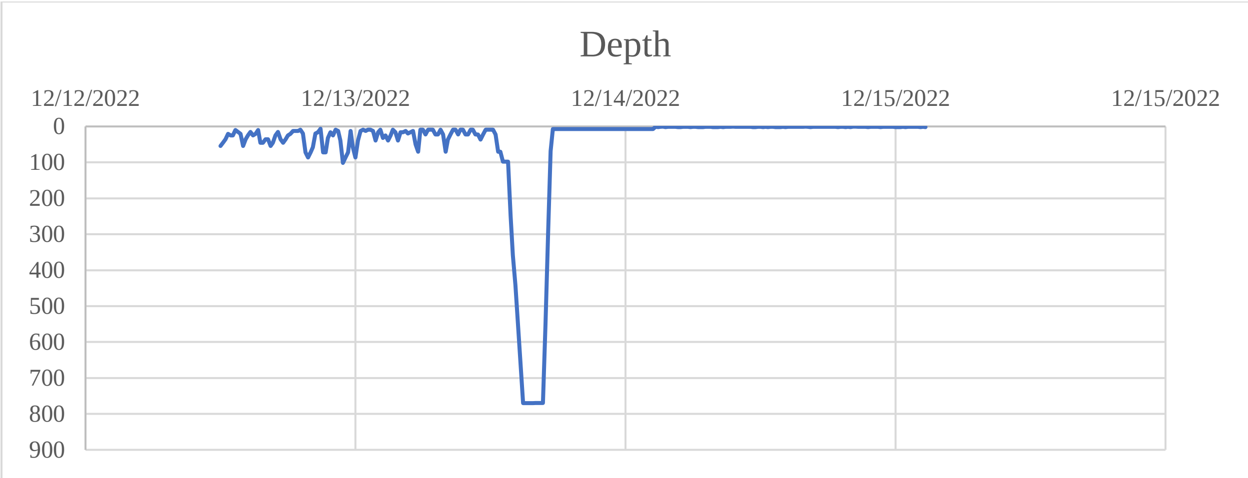
a) 22P0347



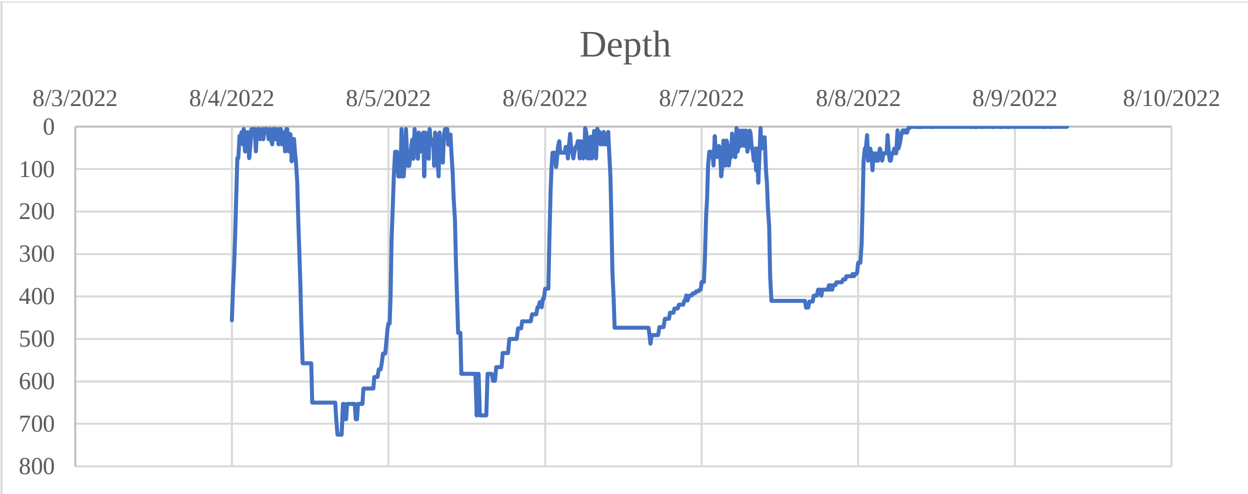
b) 21P2015



c) 21P1678

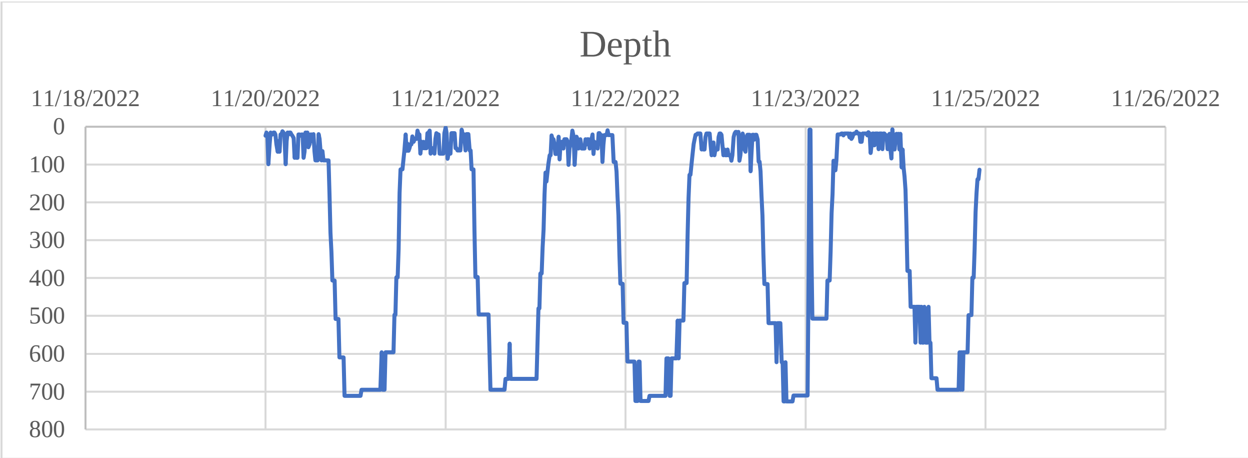


d) 22P0365

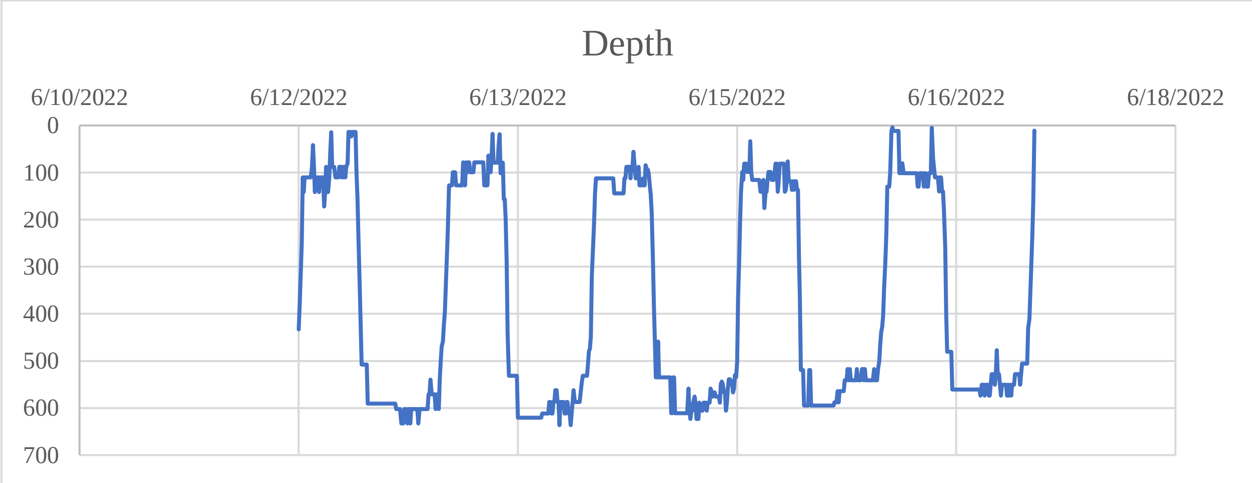


e) 21P1645

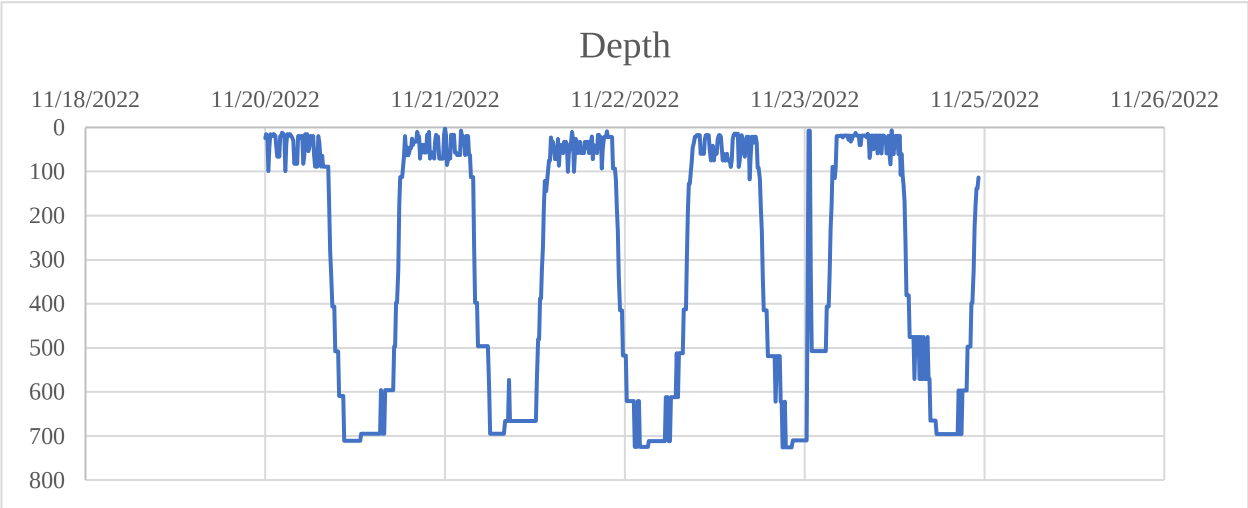
Figure 6. Depth Time series plots of five archival tags that show a mortality event presumed to be associated with the catch and release experience of commercial buoy gear. d) is an example of depth time series data that represents numerous attempts at dives and stayed within the surface waters, followed by one deep dive where mortality occurred, with the tag returning to the surface, most likely due to a scavenging event. e) This is a 7 day tag deployment and the individual completes shallower dives each day, this could represent the fish going through physiological stress that could have subject it to a predation event at night by a nocturnal shark species.



a) 21P1622

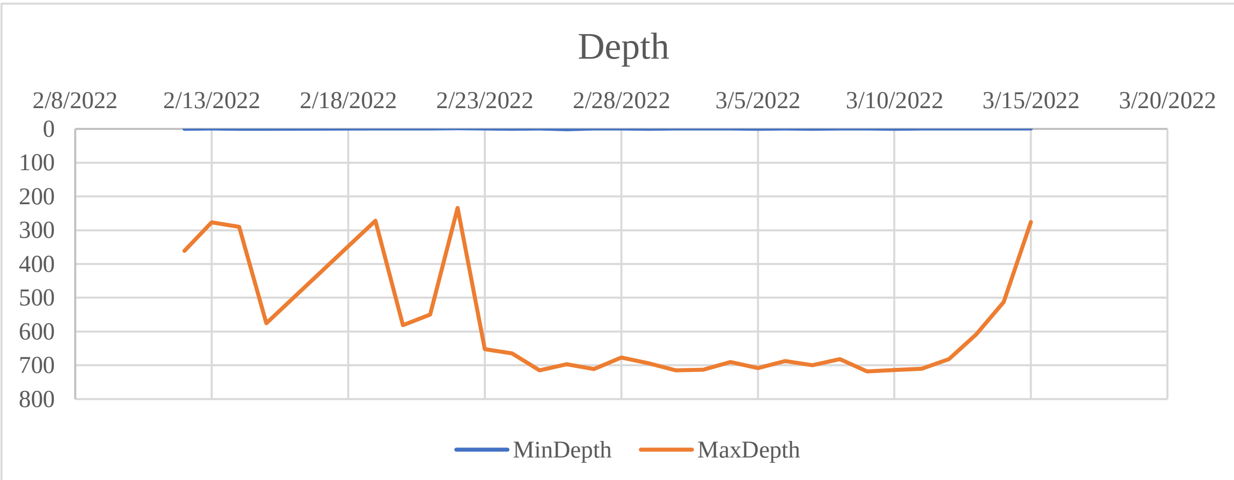


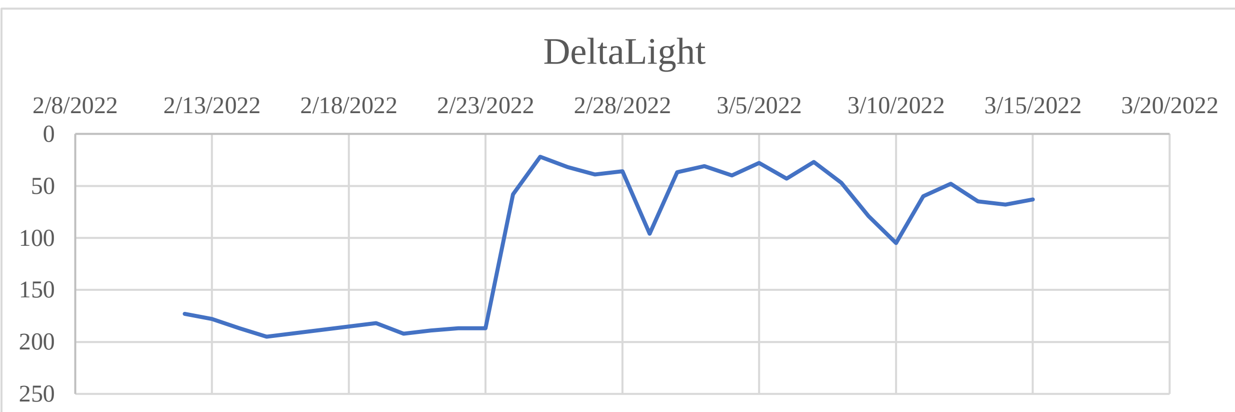
b) 21P1774

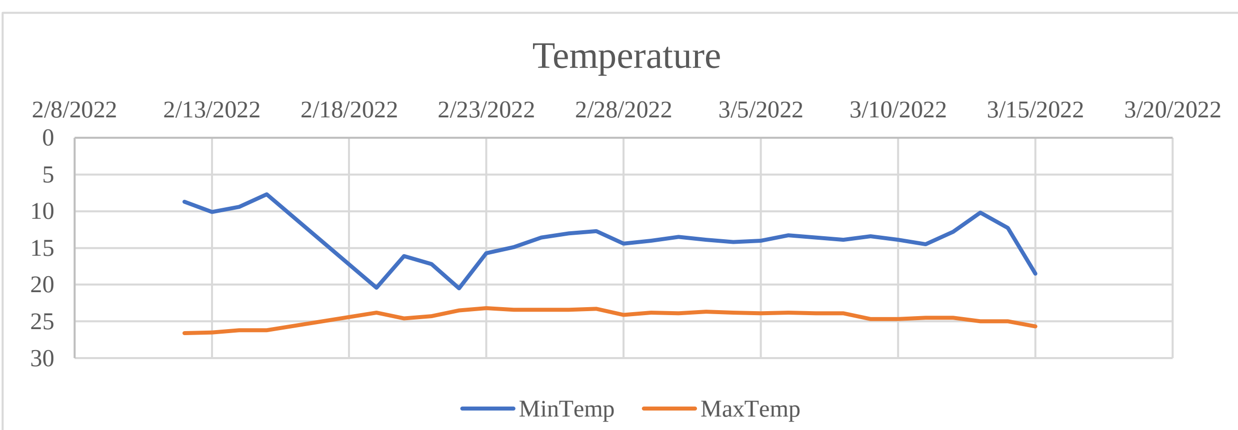


c) 21P1622

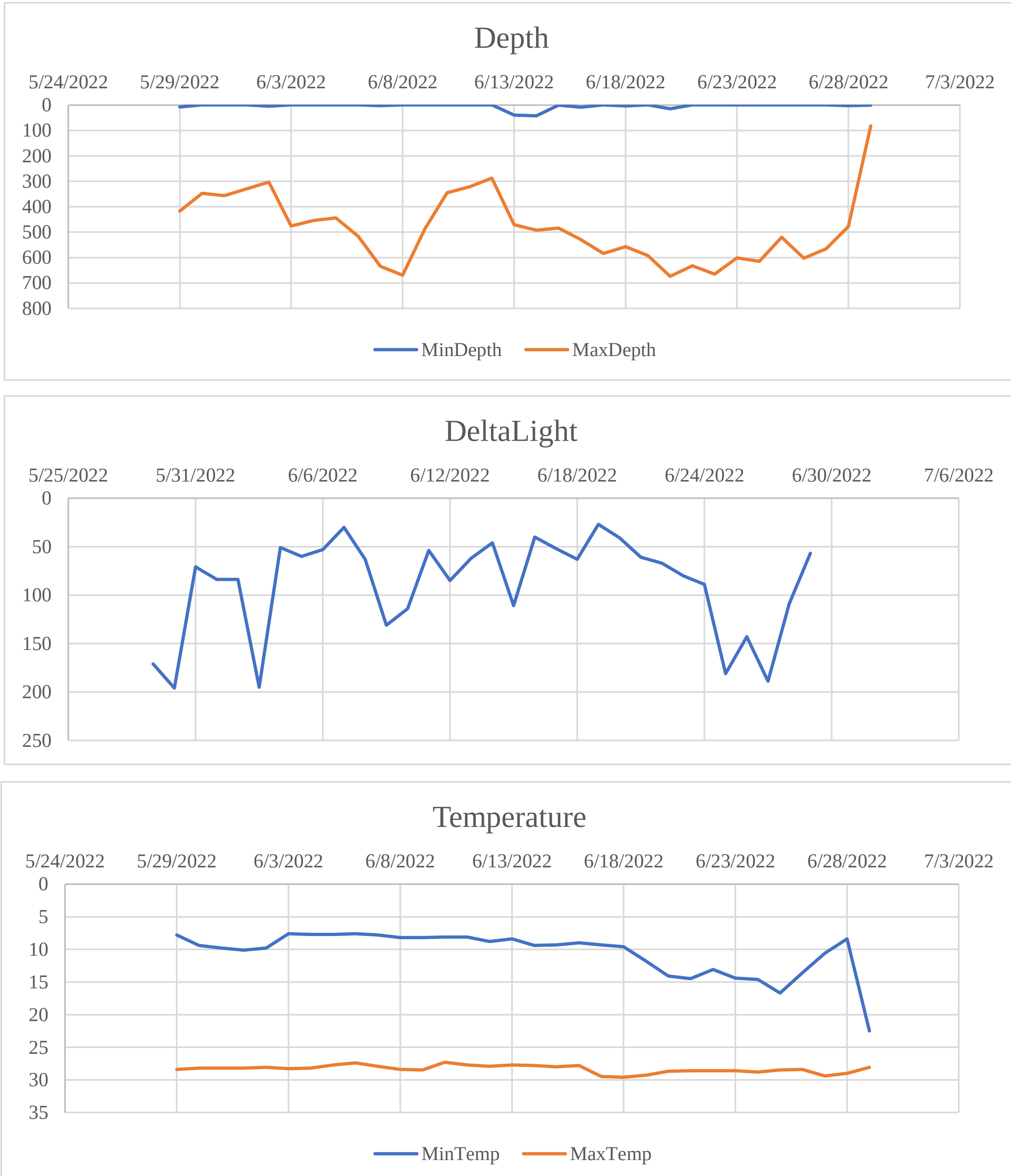
Figure 7. Three time series reporting's for fully expressed 30 day tags. These time series plots show the movements of the last five days of tag duration and represent typical movements of swordfish with occupancy at shallow surface waters at night time, and occupancy at deep waters below the thermocline during the day. c) This particular tag is also the individual who traveled the longest distance predicted by the straight-line distance calculation (Figure 11)





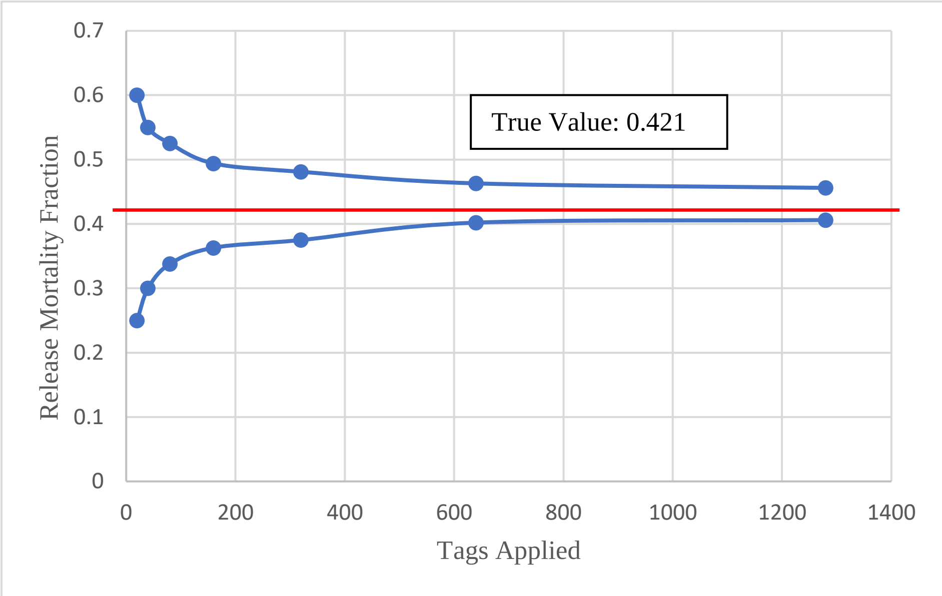


a) 20P2787



b) 21P1890

Figure 8. Two reporting tags that did not report series data, but did report daily data. Daily minimum and maximum temperature levels, depths, and light levels were analyzed for mortality events.



a) True Post Release mortality rate of 0.421 or 42.1%

b) Overall Post Release mortality rate of 0.605 or 60.5%

Figure 9. The 5th and 95th percentile values for each increase of the sample size and the true value. In both of these plots, the solid lines represent the 5th and 95th percentile values of the actual release mortality value for each given sample size (x values). The dashed line between each of these plotted values represents the release mortality fractions produced from this analysis. These figures are representative of the 90% probability that the estimates will be within +/- %5 of the true post-release mortality.

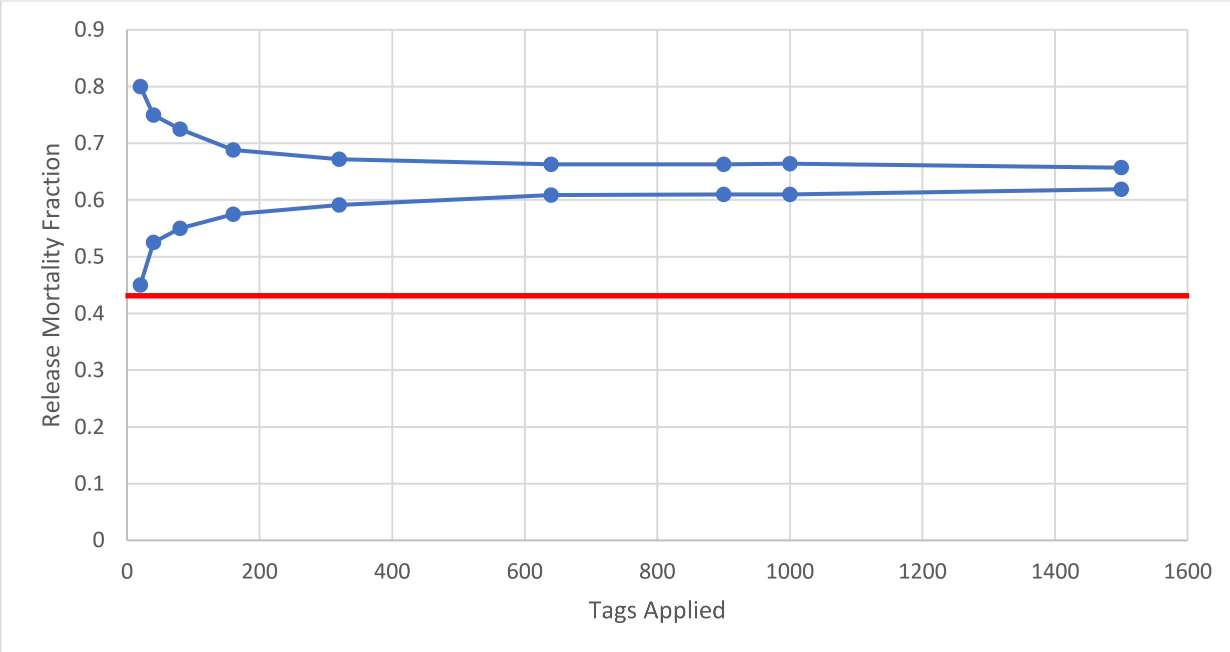


Figure 10. Sensitivity analysis using two variables that were not included within the original analysis. These variables include tag shedding and tagging induced mortality. Both variables were given a value of 0.2 and tested against the PRM rate of 0.421. Results show an increase in potential PRM rates once these variables are added, and thus should be included when analyzing PRM rates of juvenile swordfish. With the addition of these two variables, a PRM range of 45%-80% is now possible, with an approximate 1000 tags needed to be applied to reach within +/- 5% within the actual true PRM value.

Horizontal and Vertical Movements

In this study, both horizontal and vertical movements were analyzed by using a combination of time-series depth data, time-at-depth histogram data, straight line net displacement calculations, and geolocation likelihood modeling. For horizontal movement analysis, sPAT tags derived only straight—line net displacement calculations, while miniPAT tags provided a likelihood modeling possibility for potential movements and location occupancy ratios (Figure 5). Straight line net displacements ranged from 18 km to 945 km with a predominant south to north trajectory (Figure 12a and Figure 13). Out of the three reporting miniPAT tags, only one of them provided enough data to provide track geolocation estimates. One tag duration only lasted 10 days, so it had limited movement and did not provide much insight on likelihood movements, however Figure 11 provides possible movements based on the likelihood estimates done with the geolocation HMMocce package for one tag that fully expressed its programmed 120 days.

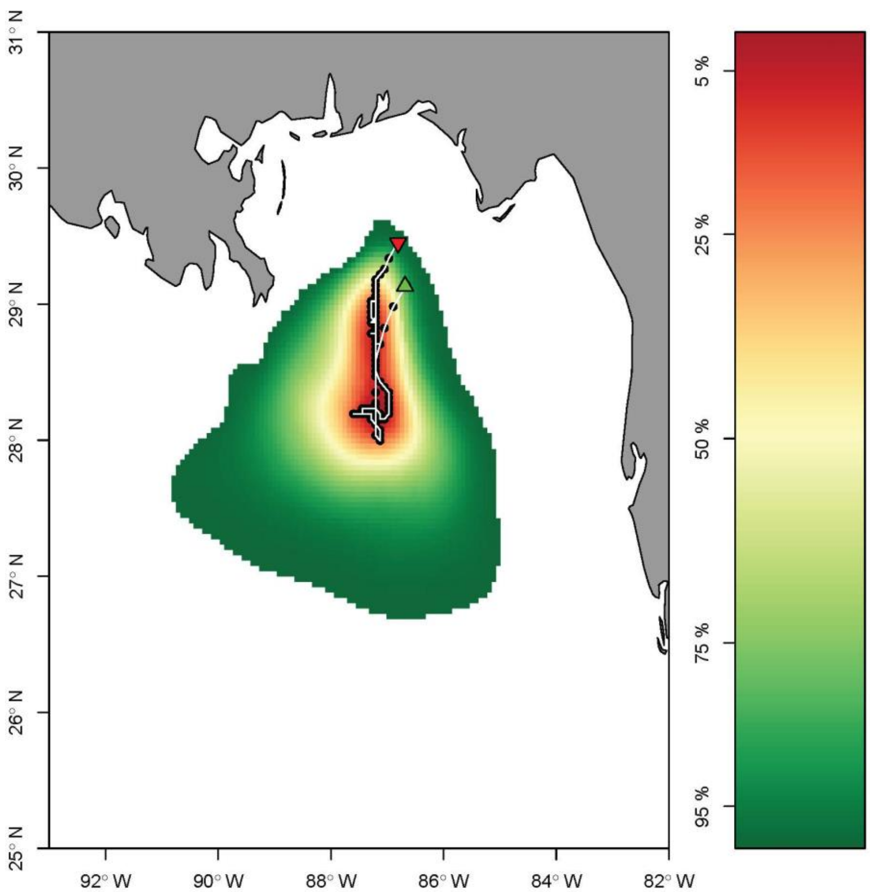
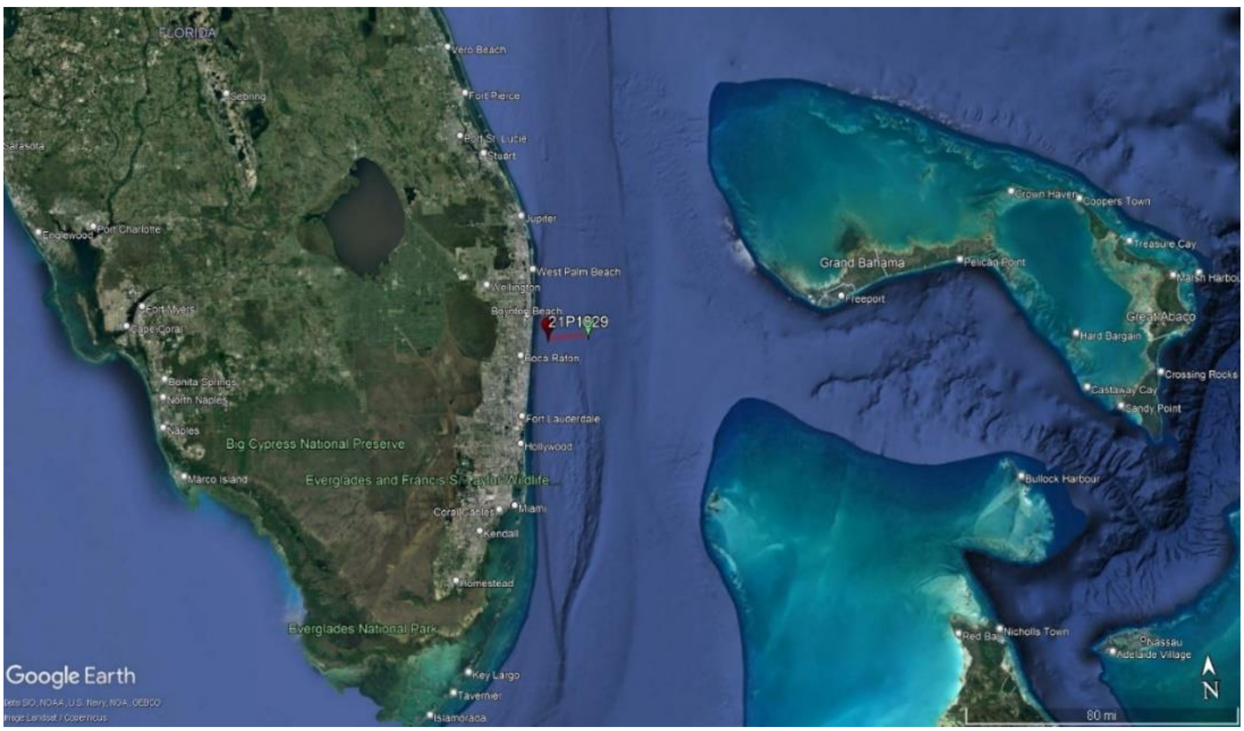
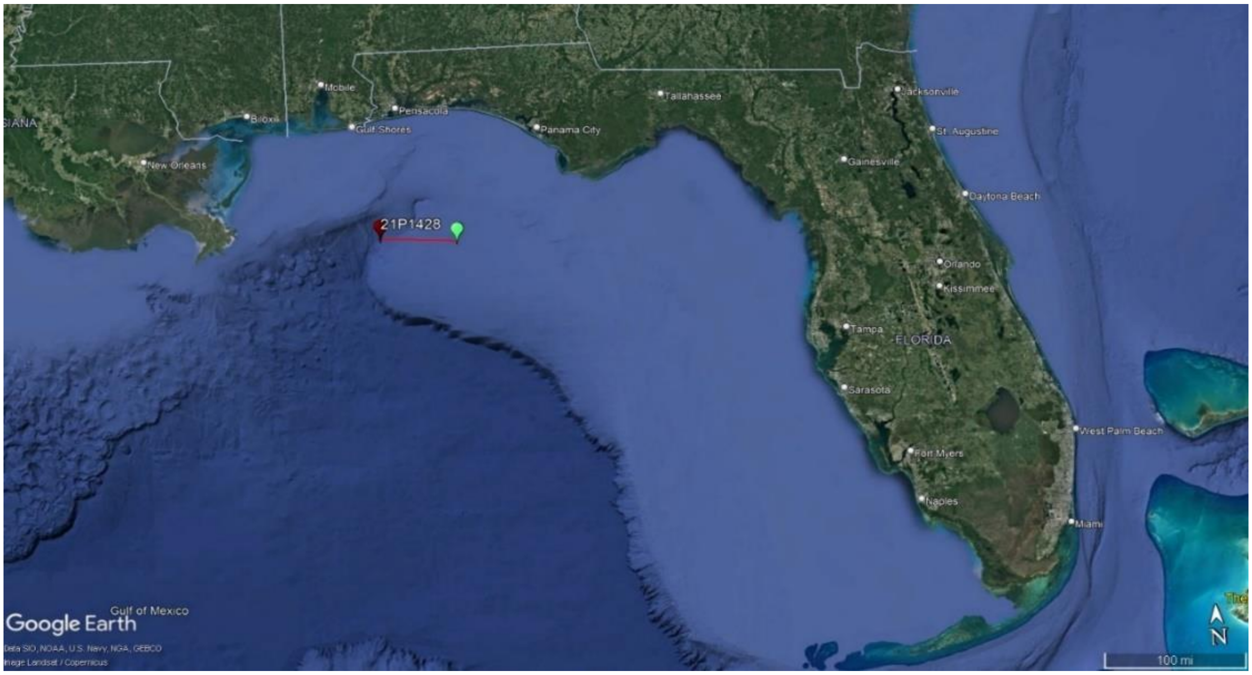


Figure 11. Possible track movements of miniPAT tag 20P207. This tag was fully expressed at 120 days. Green pin represents tag deployment, and the red pin represents the first tag transmission location. The track line shows possible movements based on ocean bathymetry, ocean heat content, and SST reporting's while the shaded area represents possible occupancy likelihoods.

Figure 5 represent all straight-line net displacement calculations by season done for both sPAT and miniPAT tags that produced data. The majority (27) of the straight-line net displacements were seen following a south to north trajectory but there are observed movements of two eastward, three southward, and three westward movements. There are five instances of fully expressed tag deployments (30 days) that produce small straight-line distances. Figure 12 provides examples of these estimated acute distances (18 km and 81 km) over a month time period. Since these estimates are produced from the deployment and first transmission locations, this could be a display of short distance movements due to forage ground preference. There is evidence of this in individuals tagged in both the GOM and Florida Straits. Even though there were only 3 tags that produced straight line net displacements deployed in the GOM, none of the tags reported northward movements, only southward and westward trajectories along the Gulf shelf break are predicted. For individuals tagged in the GOM, all trajectories show that they remained within the GOM, and furthermore did not leave the West Florida continental shelf. Coincidently, there were only five tags deployed in the Florida Straits that produced movements other than south-to-north, including one southwestward trajectory, two eastward, and two westward (Figure 5). The longest straight-line trajectory was estimated to be 945 km, and is one of three eastward predicted trajectories (Figure 13). This particular track exhibits a straight line across the continental shelf from southeast Florida to the islands of Turks and Caicos. Although it is highly unlikely that this individual swordfish moved in a straight—line direction, it could be representative of exhibiting foraging behavior between a continental shelf and a small island chain.



a) 21P1829 – 18 kilometers

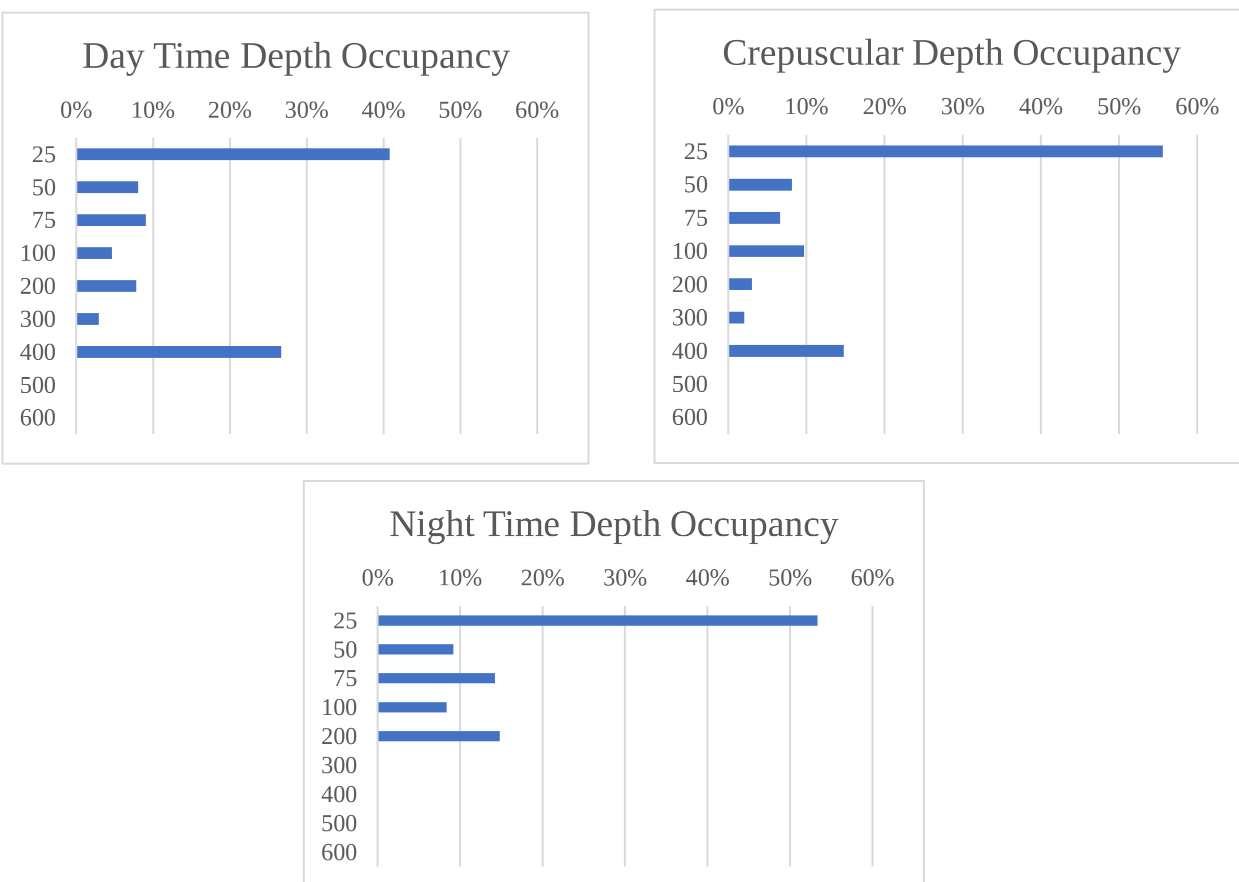


b) 21P1428 – 81 kilometers

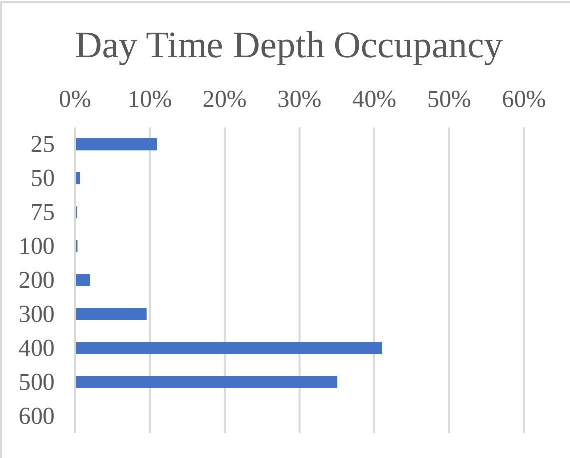
Figure 12. Two instances of fully expressed 30 day tag deployments that show small movements. a) is a 18 km prediction traveling in a eastward trajectory and b) is a 81 km prediction traveling in a westward trajectory, both potentially representative of foraging behavior along the shelf break for a 30 day period. Green pins represent tag deployment locations, red pins represent pop-off locations.

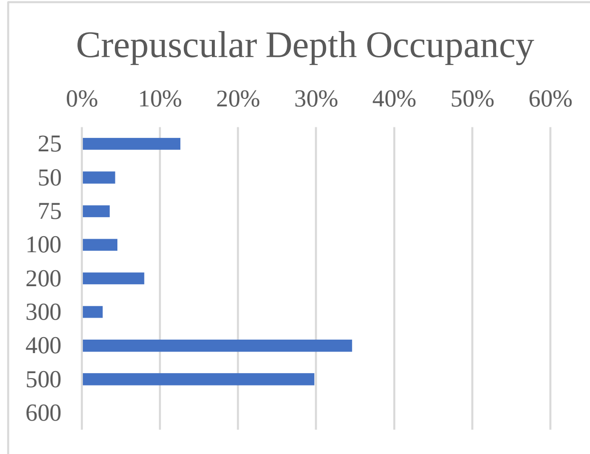
Figure 13. Tag 21P1622 predicts the longest straight-line trajectory at 945 km predicted to move in an eastward direction. Tag was deployed off the Coast of southeast Florida represented by the green pin, and the first pop-up transmission location was off the northern coast of Turks and Caicos Islands and is represented by the red pin.

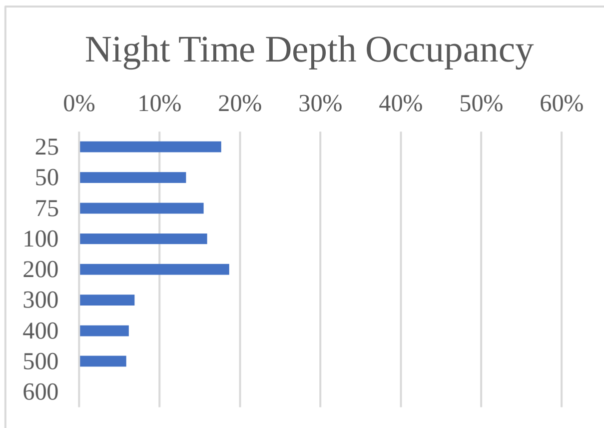
To analyze vertical movement patterns of each tag deployment a combination of depth time-series plots and occupancy at depth histograms were used. Figure 7 represents examples of the time-series depth data for each tag used to infer mortality events, but can also be useful when estimating vertical movements within the last five days of tag deployment for sPAT tags, and total deployments for miniPAT models. Figure 14 show time-at-depth histograms for depth occupancy at crepuscular, day, and night time periods for all three miniPAT tags used in analysis. Although one tag is subject to a mortality event after two days of deployment, two tags produced normal behavior depth occupancy patterns exhibited by swordfish, spending night time in shallower surface waters, while migrating to deeper waters during the day. Figure 14a depth occupancy histograms show majority of occupancy at near surface waters, this can be representative of a mortality event following a two-day tag deployment. There were two sPAT tags that did not properly report daily time series data, so only daily minimum and maximum depths, delta light, and temperature were analyzed and found to be representative of normal swordfish diving behavior (Figure 8).



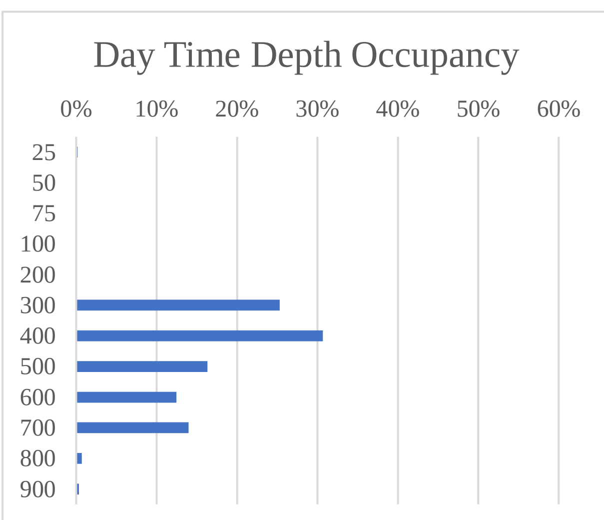
a) 20P2067 – 2 day tag duration

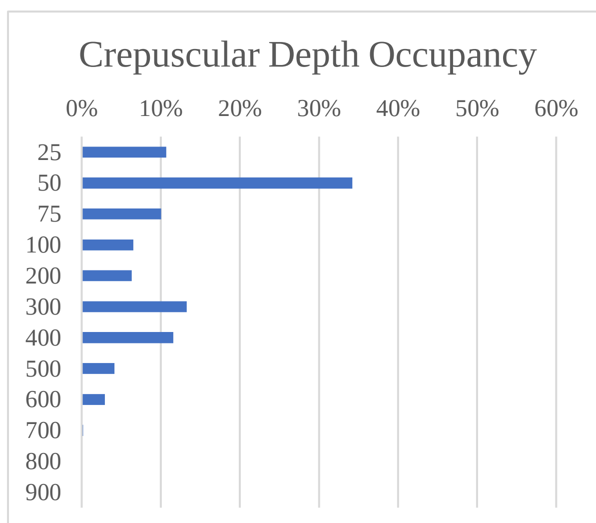


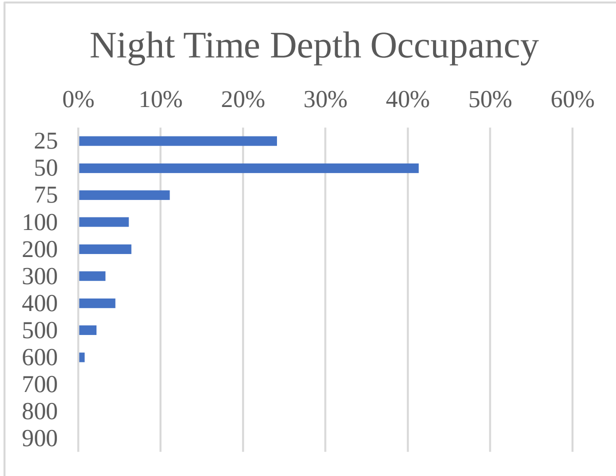




b) 20P2069 – 10 day tag duration



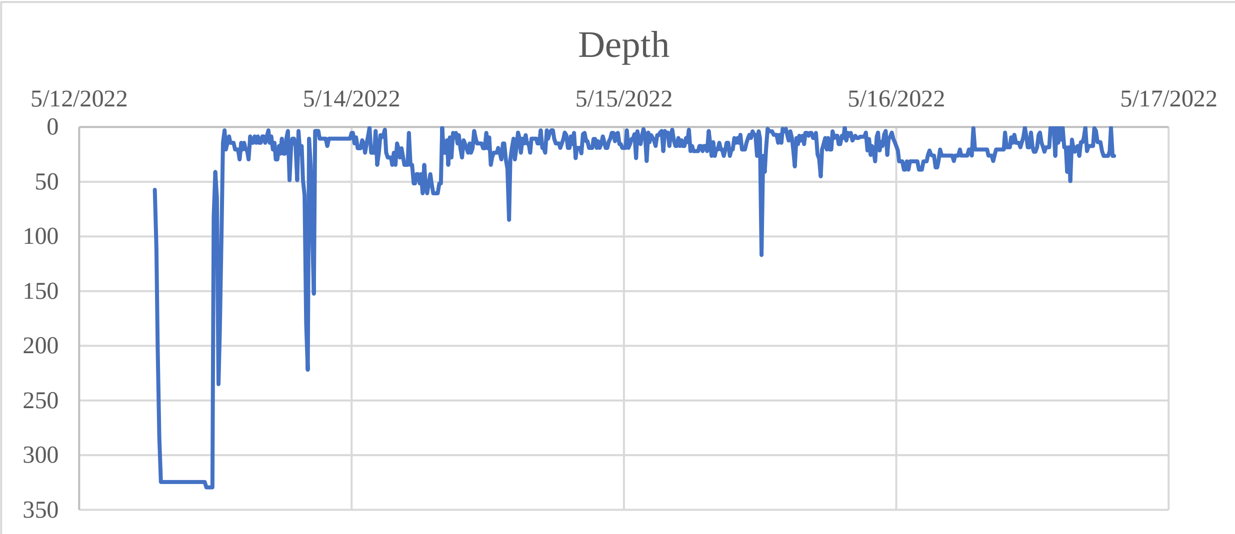


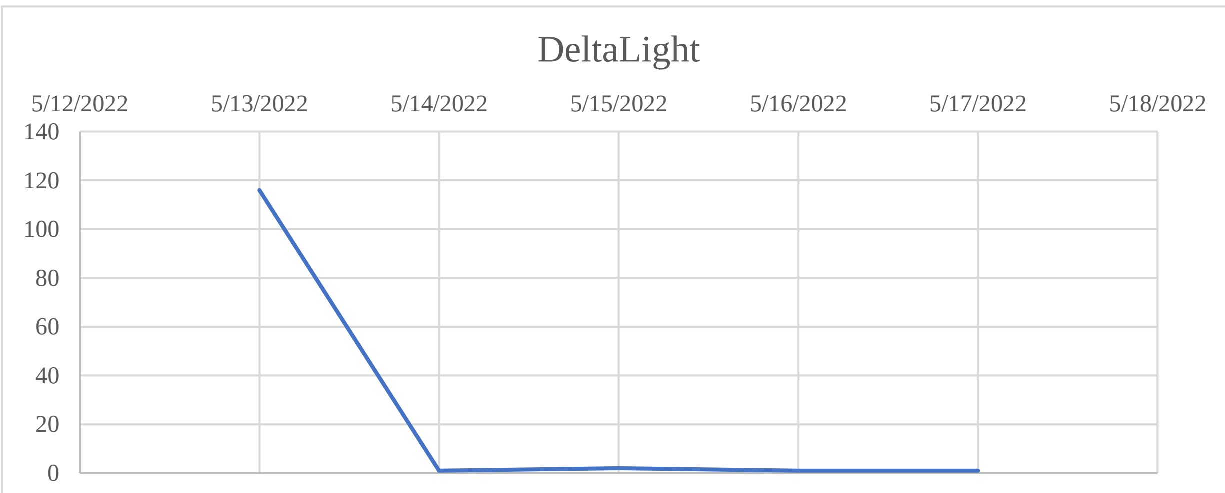


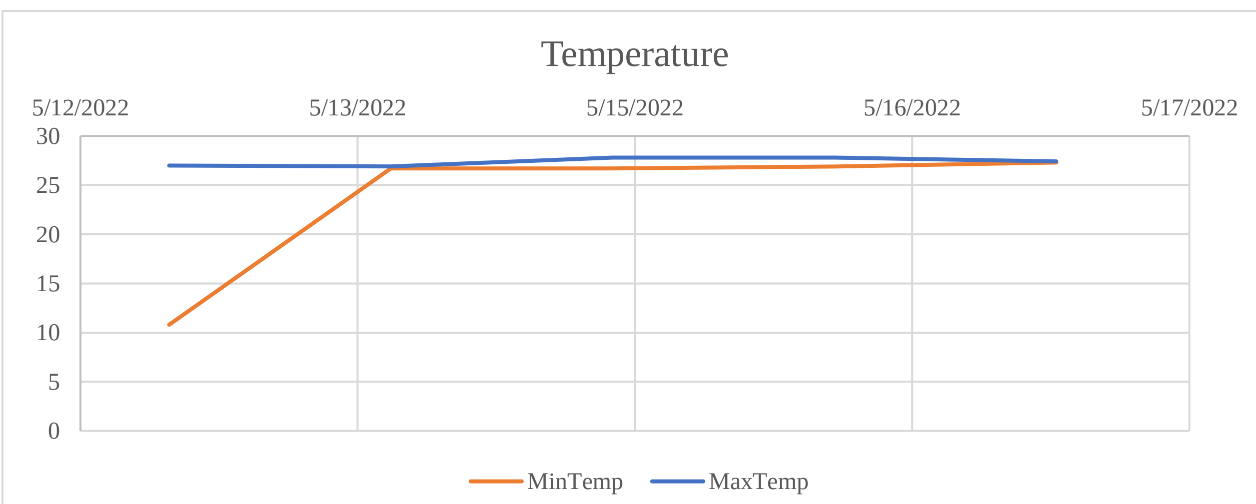
c) 20P2071 – 120 day tag duration

Figure 14. Time at depth Occupancy histograms for three miniPAT tag reporting's. a) shows a two day tag duration with most occupancy in shallow waters due to a mortality event and the individual floating at surface. B) shows a 10 day tag duration that shows normal crepuscular and day time occupancy, but night time occupancy has variance due to a mortality event. C) shows a 120 fully expressed tag movement and reflects normal swordfish depth occupancy for all three day periods.

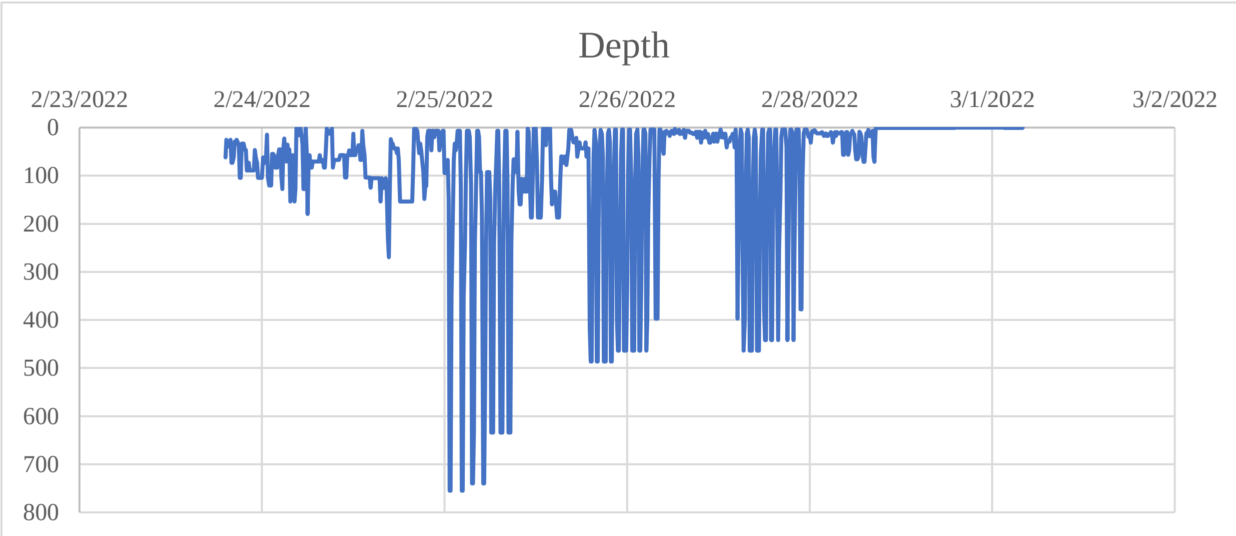
Normal swordfish dive behavior, as described in previous studies, were predicted for the majority of tags surviving post-release mortality behavior. Figure 7 shows examples of three fully expressed tag reports that represent typical diving behavior of swordfish. However, three individual tags exhibited vertical behavior that was not consistent with normal vertical diving behavior typical of swordfish (Figure 15). To understand why these irregular movements can be seen being exhibited by a juvenile swordfish, tag consumption possibility was analyzed. It has been noted in previous studies that tag consumption can be hard to detect, but with Daily temperature, light level data, depth profiles, consumptions can be inferred to evaluate tag outcome (Kerstetter et al., 2004). It was hypothesized that both of these individuals were predated on and the tags consumed due to consistent low light levels coupled with a constant change in vertical movement throughout the water column. Other instances of irregular vertical depth profiles can be associated with mortality events. Figure 16 and Figure 18 are examples of "erratic" behavior exhibited directly after post-release with numerous attempted shallow dives ending in one deep where mortality occurs. Figure 6b is the opposite effect, where one deep dive is made directly after post release, and then shallow surface dives were made until mortality occurred.

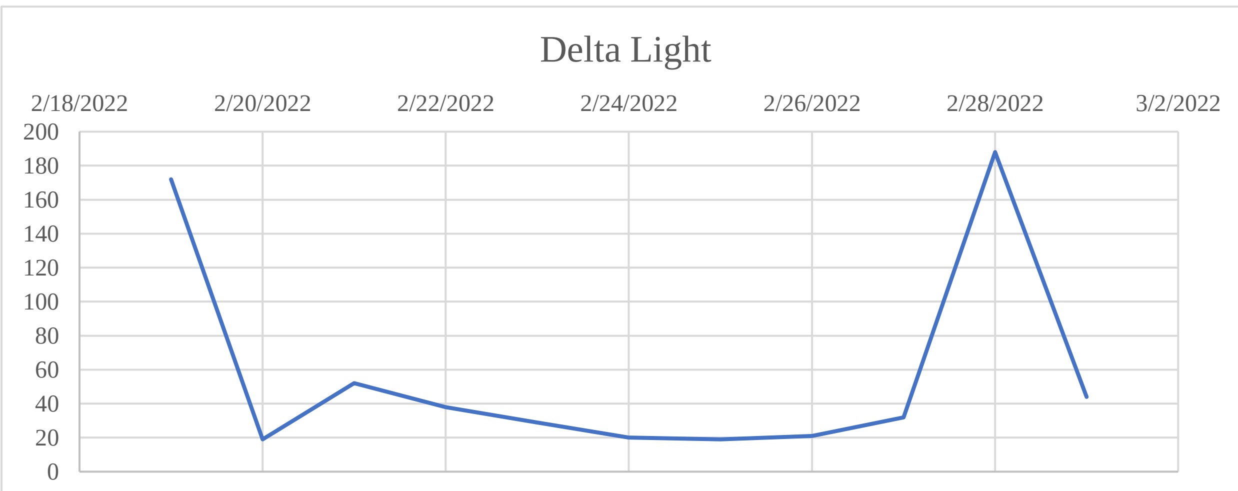


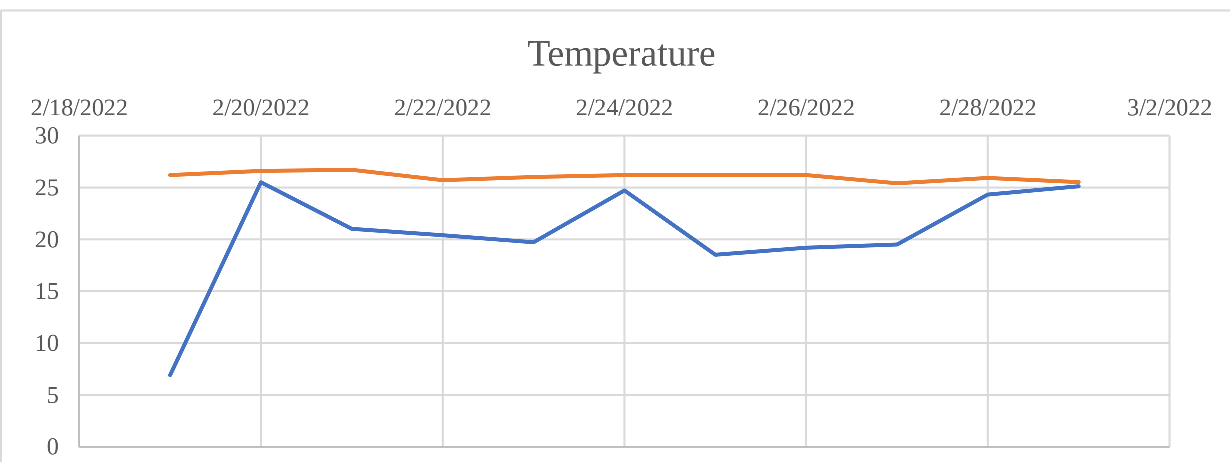




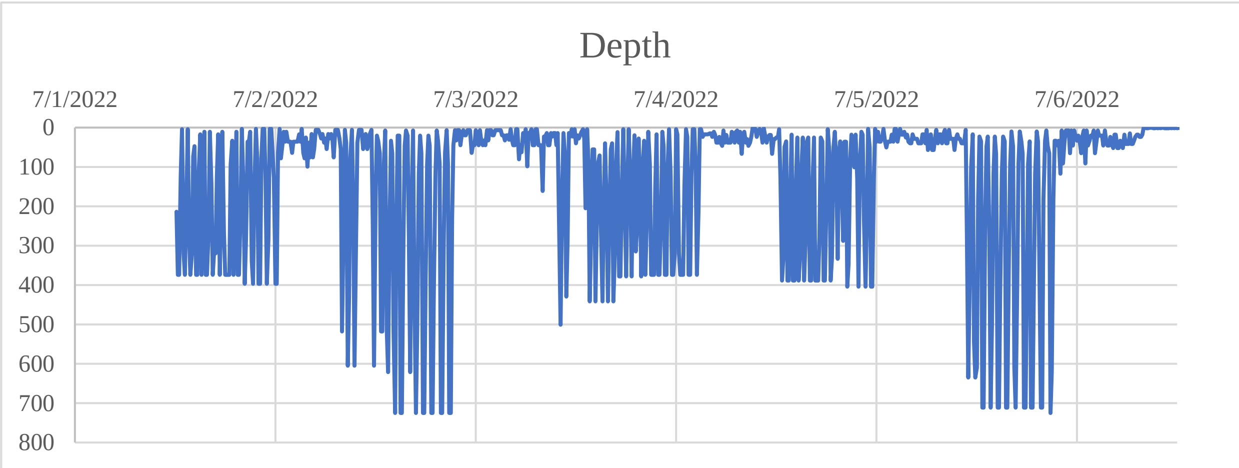
a) 21P1678 – 4 day tag duration

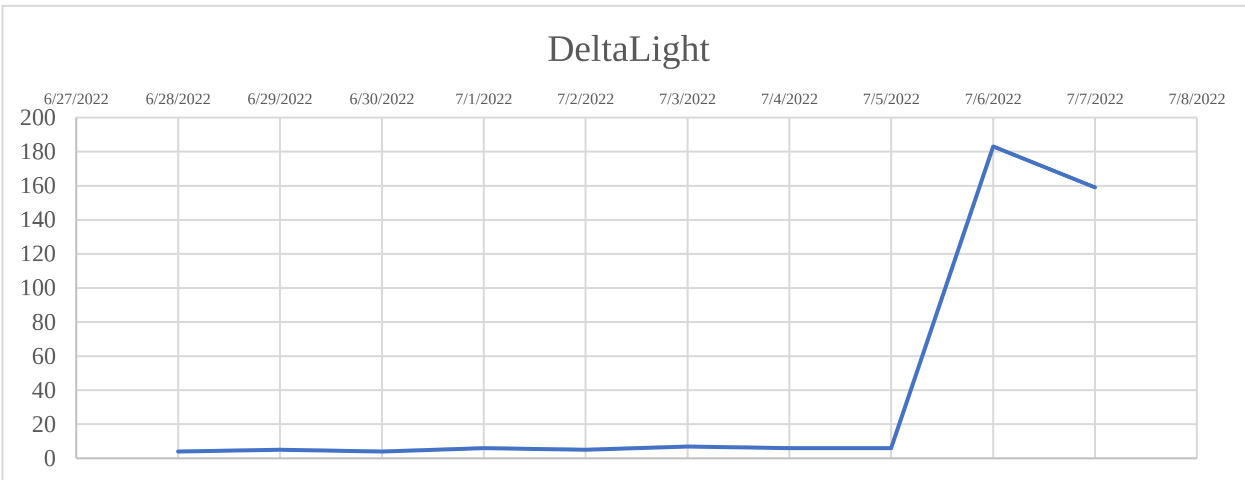


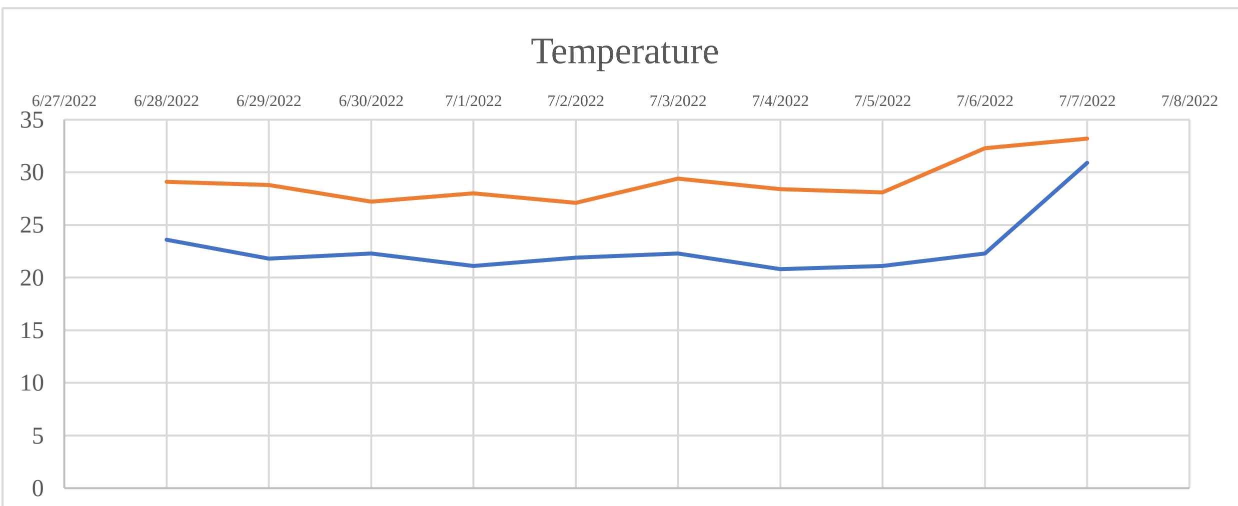




b) 20P2789 – 10 day tag duration







c) 21P1792 – 12 day tag duration

Figure 15. Three sPAT tag reporting's that showed irregular swordfish behavior. A Depth time series plot, a daily light reading plot, and a min/max temperature plot were used to analyze outcome of these individuals. a) Predation by an endothermic shark species (Shortfin Mako or Thresher Shark) were suggested for these movements and b) and c) predation by an ectothermic shark species (Silky Shark) were suggested for these tags.

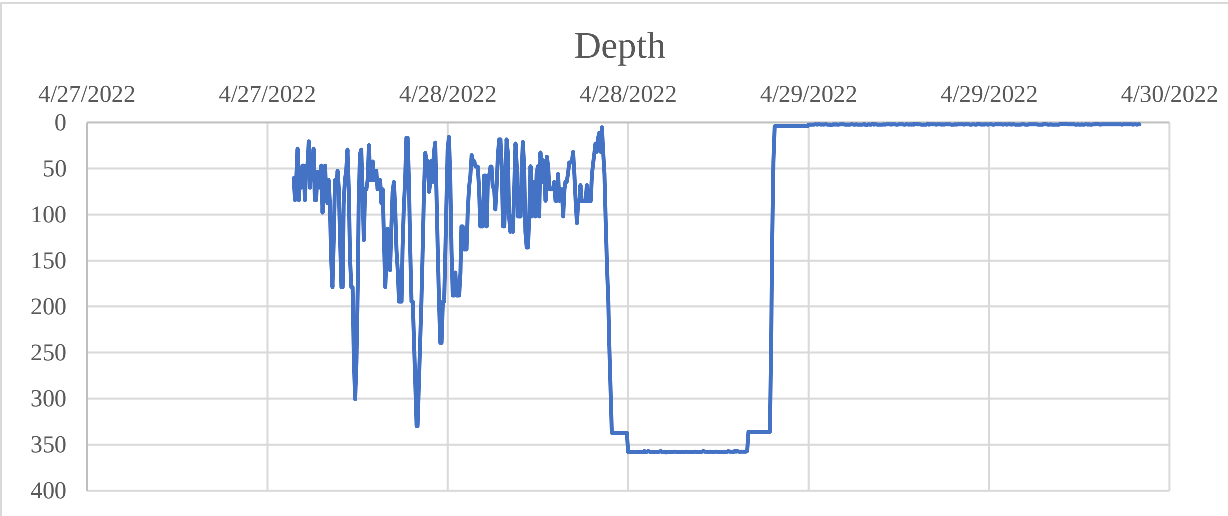


Figure 16. miniPAT tag 20P2067 depth time series data suggest erratic behavior prior to mortality event caused by post-release on commercial buoy gear. Data shows multiple attempts at deep dives immediately after post-release followed by one longer occupancy deep dive where mortality occurs and fish rises to the surface.

The deepest dive recorded in this experiment was approximately 890m. This particular individual was a swordfish within the GOM and completed the full 120-day tag duration (Figure 17). Although 700-800m dives are fairly common with our results of time series depth data, and also seen in other studies (Braun et al., 2019; Wolfe & Tracey, 2023), it is confirmation that juveniles can be exposed to higher pressure and lower temperatures like full sized adults. This particular individual was estimated at 115cm, which is evident of a sexually immature swordfish (Arocha, 2006), but can be seen at depths that 150cm or higher measured individuals occupy. The second recorded deepest dive was on an individual that underwent a mortality event. A dive of approximately 820m is seen following two full days of shallow water occupancy, ending in an abrupt rise to the surface, entailing a mortality event (Figure 18). It can be suggested that even under physiological stress due to interaction with commercial fishing gear, juvenile swordfish still have the capability to dive to great depths. Although in this case, a dive to high pressures exhibited under 800m of water, could have influenced mortality.

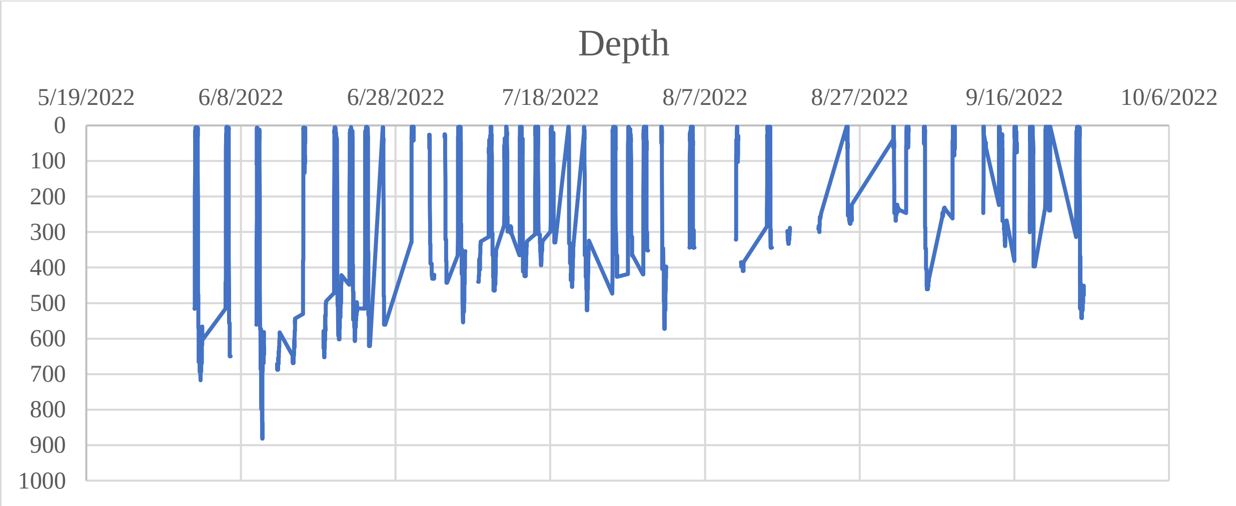


Figure 17. miniPAT tag 21P1678 depth time series data shows deepest recorded dive for this analysis, occupying a depth at ~890m.

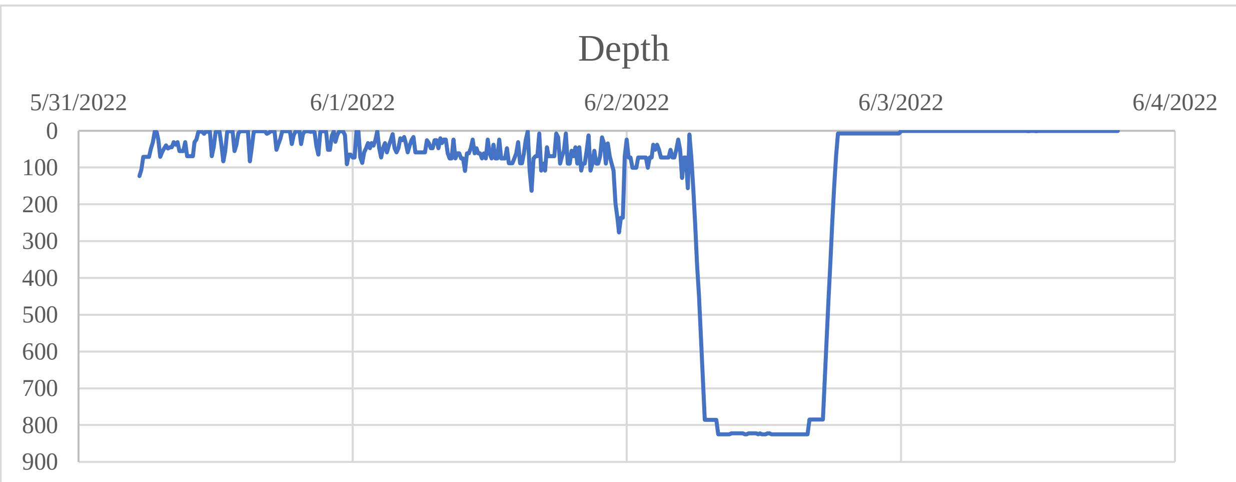


Figure 18. sPat tag 21P2015 depth time series data that shows a deep dive after post-release from commercial buoy gear that could be representative of juvenile swordfish having the capability of diving great depths after an experience of stress, but also insinuates that these great depths could influence mortality.

Discussion

Post-Release Mortality

Post-Release mortality of juvenile swordfish caught on commercial buoy gear was predicted with a total of 38 reporting tags. Seven tags deployed did not properly report, and is a common occurrence in satellite tag research studies (Dewar & Polovina, 2005; Fenton, 2012; Holdsworth et al., 2007; Loefer et al., 2007; Sedberry & Loefer, 2001). Improper reporting can be caused by numerous reasons including: coverage of antennas due to floating structure (i.e.

coverage from matts of Sargassum), predation events destroying the tag, internal tag malfunction, and transmission quality. The seven tags that did not report adequate data for post-release mortality predictions were excluded from this analysis.

Vertical depth profiles of swordfish that represent true post-release mortality events (8 days or less after post-release), can be seen in Figure 6. Out of the 16 tags that show evidence of post-release mortality events, eleven took place five days or less post-release, and nine of these were within the first two days. Length estimates of individual tagged fish range from 90-120cm (LJFL) on all recorded mortalities and were considered viable for tagging according to the ACESS scale. It is worthy to note that the smallest fish tagged was estimated at 60cm (LJFL) survived for the full 30-day tag duration. The largest tagged individuals were estimated at 120cm (LJFL) and four of five also survived for the full 30-day tag duration. Only two out of the 16 individuals that exhibited a post-release mortality contained internal hooking locations such as the throat or esophagus, the remaining 14 individuals were hooked in either the bill or jaw area. There was one instance of predicted mortality, where the tag was placed too far internally into the fish. The observer reported that a tag stopper was not used and the entirety of the three-inch tagging needed pierced the dorsal region of the fish, often referred to as “buttonholed”. Surprisingly this fish survived throughout the full 30-day tag duration, exhibited normal vertical movements of swordfish, and was the longest straight-line distance traveling individual (Figure 13 and Figure 7c).

15 out of 38 individual released fish successfully reached the full programmed deployment (30-120 days). There is no clear category in Table 2 or Table 3 that could be the undoubtable cause of mortality or survival for any of these individuals. Release conditions, fight time, hook location, hook removal, resuscitation occurrence are all things hypothesized to influence mortality, but in this study varied across each individual and their mortality outcomes. The fish with the longest fight time (~9 mins) survived the full 30 tag duration, while other tags subject to a fight time of two mins or less died within the first couple of days of tag deployment. Hooking location varied across all individuals, but also prove not explicitly influential of post-release mortality. The significance of this was not explicitly analyzed due to the sample size being too small. Out of 6 fish that needed resuscitation, 3 of them survived and 3 were subject to mortality events. Hook removal status also proves to be not explicitly influential as multiple hooks were removed on fish that died within the post release mortality value, while fish survived the full 30 days of tag deployment with hooks still intact at release. When considering all

parameters of the full catch, tag, and release experience, there are no clear categories that fully explain mortality or survival, making it difficult to accurately predict the probability of post release mortality strictly based on boat side observation.

Results of the "Release Mortality" program show that with a mortality rate of 42.1% (60.5% for mortality associated with fully expressed individuals), approximately 1280 tags would needed to be deployed to increase the precision of the mortality estimates to +/- 5% of the true value reported by this study (Figure 9). It has been noted in previous studies that individual experiments deploying less than 100 tags have a higher probability of producing deviated results +/- 5% from the estimated post-release mortality and +/- 25% from the true value (Goodyear, 2002). It is highly unlikely to conduct an experiment with 1000+ satellite tags, due to application and funding limitations, however providing these simulations when conducting post-release mortality analyses can help improve the estimates of overall total removals from the population. Performing this analysis on a newly emerging South East commercial fishing industry that is considered <1% of total removals by gear type (ex. Handline gear) can be useful when assessing stock populations by reflecting the most accurate predictions of total removal by the commercial fishing industry as a whole. This is analysis also proves useful in the fact that buoy gear has already shown potential to be a good alternative gear over PLL and a future increase of participation could eventually be seen (Kerstetter & Garvey, 2020).

When executing an experiment that utilized satellite tagging technologies, there are multiple factors dealing with the tagging experience that are thought to influence mortality estimates, including: tag shedding, tagging mortalities, tag failure, and natural mortality rates. For the sake of this experiment, tag shedding, tag mortalities, and tag failure were all assumed to be zero due to the tag duration and the decision of excluding all instances from analyses. It should be noted that longer tag durations provide more time for these instances to occur, and should be considered when tag durations exceed a full month. Natural mortality was listed as 0.2 (Fenton, 2012; Goodyear, 2002; Orbesen et al., 2018) and was included in the simulation due to tag duration length. Little analysis has been done on swordfish post-release mortality rates after being caught from commercial buoy gear, so the 30-day tag period was chosen to fully distinguish survival and return of natural behavior weeks after capture. Although it was not known exactly how long it could take a mortality event to occur after post-release, it was assumed that natural predation could take place between a possible post-release mortality event, and the full 30-day tag expression. It is often suggested to program tag duration no longer than required for the majority of mortality instances to be fully expressed when estimating post-release mortality rates, so 30 days was used to encompass all potential mortalities caused by post-release, with an 8-day threshold to encompass all mortalities thought to be associated with the capture event (Goodyear, 2002).

Although post-release mortality estimates used in combination with these simulations can provide useful insight on overall removals, it is worthy to note that there is an overall assumption being made for this model. For "Release Mortality" it is assumed that all individual fish have the same probability of mortality explicitly due to the catch-and-release experience. However, this is not true given the variability of biological factors (species, length, weight), environmental influence (SST, weather), and execution of fishing practices (bait type, hook type, gear, skill level of fisher) that are associated with the probability of mortality. Some, but not all of these variables are controllable by the researcher. For the variables that are not controllable it is noteworthy to consider how they may affect the PRM rate that was derived from the experiment. The sensitivity analysis conducted on independent variables, tag shedding and tagging induced mortality, show and increase in the 95% confidence range for the estimated PRM when they are added into the simulation. This proves that these variables should be considered when conducting a satellite tagging experiment.

Horizontal and Vertical Movements

Straight line net displacement results insinuate variability of horizontal movement patterns in juvenile swordfish occupying the GOM and Florida Straits. Typically, swordfish are recorded travelling in a south to north trajectory in the summer months in search of warmer waters and prey abundance. Juvenile swordfish have been suggested to make similar horizontal movements as adults, but tend to be less resistance to colder waters, thus following smaller scale movements (Braun et al., 2019). Straight line calculations range from 18km to 945km, with the furthest trajectory still occupying those tropical water conditions (Turks and Caicos). In this experiment, there were five fully expressed tags that reported horizontal movements of juvenile swordfish beginning at the coast of southeast Florida and ending near the coast of South Carolina (550+ km). It is theorized that these movements follow the Gulf Stream but seasonal variability is evident as transmission dates fall in Summer, Spring, and Fall months. Swordfish lengths varied when a comparison of horizontal movements was conducted on these five individuals, with a range of 60cm-120cm (LJFL). The smallest fish of the study (60cm) exhibited a straight-line movement approximately the same distance as the largest tagged individual (120cm), this reiterates that length is not necessarily representative of distances traveled in horizontal migrations. Although the reasons predominantly north to south trajectories are seen in the Atlantic are unclear, it has been suggested that these movements can be associated with oceanographic features such as thermal boundaries between water masses where prey species may be more concentrated (Luckhurst, 2007). It is important to note that these tag deployments are a relatively short-term tag duration and could have been made on individual fish while occupying their foraging grounds where fish remain for a period of time. A 30-day tag duration may not be enough time to exhibit migratory movements.

Horizontal movements in the GOM varied directionally, excluding any northern trajectories. However, individuals are predicted to not exit the boundary of the West Florida shelf of the GOM. One tagged individual shows a straight-line distance that is expressed directly along the shelf line. This, and other movements seen directly anterior to the shelf can be a prediction of foraging preferences due to marine managed areas (MMAs). These movements can be directly correlated with the DeSoto Canyon Closed area in the GOM. Due to the nature of the OFRP, participants were able to fish in these areas, otherwise closed to PLL gear (HMS 2023). Movement within these areas, but not away from, can suggest high forage potential, and thus exhibit small and/or bounded movements associated with the West Florida continental shelf where prey abundance is thought to be more concentrated.

One miniPAT deployed in the GOM produced an estimated track following a similar pattern of occupying the West Florida continental shelf. This track prediction shows a higher northern occupancy when compared to other predicted straight-line distances in the GOM, but potentially remains within the bounds of the Desoto Canyon, or close to it. This 120 day fully expressed tag results in a southward track prediction, following a return to ~2 km away from the original tagging location (Figure 11). Again, this can be suggested as foraging preference due to prey abundance within the MMAs. In this instance, and many other straight-line predictions in this experiment, it can be suggested that deployment locations and first transmission locations near each other can be evident of small movements due to high prey abundance and optimal water temperature levels. There is evidence of these smaller movements in both the GOM and the Florida Straits, which may suggest juvenile swordfish horizontal movements aren't as variable across the two water masses.

Vertical movements represented by time depth series and time at depth occupancy histograms, show that typical daily vertical migration is evident in the majority of tagged individuals (Figure 14). Occupancy of near surface waters during the night hours and deep waters during the day is the predominant pattern seen across individuals that survived past the post-release time period. There is also evidence in this experiment of non-typical swordfish behavior prior to mortality events, whether the cause be release from buoy gear or predation. Variability in vertical movements of fish that died prior to completing the full tag duration is present, and can be assumed to be caused by the catch and release experience. Figure 6d is representative of this as numerous shallow (<100m) dives can be seen throughout the first full day after release, following one longer deeper dive (~800m) where mortality occurred, and then the tag rose to the surface, most likely due to a scavenging event. Predation events can be difficult to detect, but can be predicted by the evidence of normal behavior followed by an unexpected consistent depth occupancy lasting 12 hours or longer. Figure 6e shows a potential predation event preceded by normal swordfish behavior. This individual tag was deployed for 7 days, but displayed typical swordfish movements up until the 7^{th} day, where shallow dives can be seen, ending in a consistent occupancy at the surface. This can be evident of a juvenile swordfish predation event occurring at near surface waters as the fish is foraging at night. Various nocturnal shark species are known to occupy these shallower depths at night and day times, so unexpected consistent occupancy of surface waters can be assumed to be a shark predation event.

Figures 15a reports a short-lived deep dive (400 meters +) for approximately 12 hours, followed by occupancy of near surface waters. Although juvenile swordfish have been seen making multiple DVM movements throughout the day (Braun et al., 2019), the produced vertical depth profile of this tag do not represent typical swordfish movements. Maximum light levels for this particular tag show very low light levels (<5%) during the time spent at the surface, as well as at depths greater than 300 meters. Although this individual was predicted to survive post-release mortality, it is possible that this swordfish was predated on shortly after the 8-day post-release value and the tag was consumed. Minimum and maximum daily temperature data, shows a range of 5 degrees or less, which could be hypothesized to be internal readings of a large endothermic shark species, such as a Great White (*Carcharodon carcharias*), Shortfin Mako (*Isurus oxyrinchus*) or even a Big-eyed Thresher shark (*Alopias superciliosus*) (Arostegui et al., 2020; Holts & Bedford, 1993; Skomal et al., 2017; Santos et al. 2021). Figure 15b and Figure 15c are additional examples of a tag ingestion scenario, where daily depth time-series and light levels do not insinuate typical swordfish behavior. In this particular case, light levels and daily temperature ranges varied a little more than the other hypothesized ingested tag. Light levels for

Figure 15b never reach zero, but stayed consistent at 20% over the course of six days. For this scenario it has been hypothesized that this mortality occurred and the archival tag was ingested. Usually, light levels consistent with zero produce hypotheses of ingested tags, but this individual swordfish was released with the hook and leader still attached. The fishers were using electric LED light devices seen when targeting swordfish, so it is thought they electronic light could have been ingested with the tag, which could explain some light being captured. Based on previously published studies of ectothermic shark species that inhabit the southern Florida waters, it is hypothesized that both tags (Figure 15b-c) movements are consistent with Silky shark (*Carcharhinus falciformis*) vertical movements, however it is not certain (Hueter et al., 2018).

Conclusion

This experiment is unique in the sense that within restoration effort conducted by NOAA and NFWF (OFRP), a representation and inference of PRM can be made on a relatively new and expanding commercial fishery that is executed in the North Atlantic, specifically Southeast Florida encompassing the Florida Straits. Although this experiment provides a sample size (n=38) that is generally larger than other billfish and swordfish mortality analyses that have been seen in the past (Fenton, 2012; Kerstetter & Graves, 2007; Wolfe & Tracey, 2023), there is potential variance of these results when compared to the PRM rate after interaction with swordfish buoy gear. The “Release Mortality” program indicated a necessary sample size of approximately 1280 fish to reach 95% confidence in the experimental mortality rate. A sample size this large is generally not possible due to funding, time, and experimental execution limitations. Although there are assumptions used within this modeling, it can be useful when attempting to improve estimates of total removal in stock assessments.

Horizontal movement expressed as straight-line distance traveled varied throughout individual swordfish in this experiment and can be attributed to previously noted seasonal migrations of swordfish and foraging preference movements. South to north movements dominate the straight-line distance estimations, but evidence of westward, eastward, and southward movements was also predicted. Both small and long distances were predicted for both individual who underwent a mortality event, and individuals who survived throughout the entire tag duration. Several swordfish who died were seen making 200+ nm south to north distances following the Gulf Stream, while multiple individuals expressed small travel distances, 50nm or less. This can be predicted that juvenile swordfish are capable of migrating long distances within a short period of time, but also occupy the same area for a length of time due to high foraging preference, high prey abundance, and optimal tropical to subtropical water conditions. Generally, adult swordfish are seen following seasonal migrations of north to south in summer months following warmer waters. This is seen in this experiment as well, but is seen year-round, and only from half of the individuals tagged. For horizontal movements it can be concluded that juveniles may express shorter migrations when compared to adults due to high prey abundance and the ability to consume smaller prey. Horizontal movements of individuals tagged in the GOM and the Florida Straights exhibited these patterns.

Vertical movements also varied throughout the experiment, but mainly can be attributed to irregular swordfish behavior due to the inability to handle stress from the catch-and-release experience. The majority of irregular vertical movements were captured post-release from buoy gear, followed by a mortality event of depth occupancy for longer than 12 hours. The other two irregular swordfish vertical movements noted were attributed to predation and an ingested satellite tag. All tags that reached full expression were seen following normal swordfish depth occupancy of shallow surface water depths during the night time followed by deep dives below the thermocline during the day. Although adult swordfish are reported to make a singular daily vertical migration following light levels and similar prey DVM patterns, but juveniles and adults have been seen making multiple deep dives in one day versus just a singular pattern. Juveniles in this experiment were seen doing this as well, which can translate to juveniles having resilience to depths that full grown swordfish can also occupy.

Overall, 16 individual fish exhibited a post-release mortality, producing a 42.1% mortality rate. In turn, a 57.9% survival rate can be signified, suggesting majority of swordfish do survive, and thus a release after catch on buoy gear is still warranted. To fully encompass the interaction the commercial fishing industry has for this particular technique of gear, all juvenile swordfish encountered were tagged, unless no movement was detected. This was done to represent the unobserved practices of commercial buoy gear fishermen while simultaneously limiting potential bias on the fish that were chosen. Current stock predictions of Atlantic swordfish include a non-overfished population, but providing PRM of a gear represented as less than 1% of removals can bridge the gap between unknown mortality probability of the species as a whole. Management implications that could limit mortality events on catch of buoy gear consists of either raising the retention size to allow for sexually immature swordfish the opportunity to replace themselves in the population, or implicating stricter gear requirements. To determine the possible gear requirements that could limit mortality, further research would be needed.

This experiment can be considered a continuation of Fenton (2012), with an emphasis of commercial buoy gear. With an increase in sample size and not incorporating other fishing techniques, this analysis can provide insight on semi-accurate PRM rates for the buoy gear fishery, which serves importance due to the emergence of commercially executed buoy gear in Southeast Florida. Using the results of mortality rates from individuals released from buoy gear only in Fenton 2012 and combining them with this analysis, a survival rate of 60.8% and thus a mortality rate of 39.1%, which provides further evidence that release of minimum sized swordfish is warranted. In comparison to studies of similar gear type that are included in the handline category like buoy gear (i.e. recreational Deep Drop Gear), buoy gear shows a higher mortality rate (Tracey et al., 2023). This can be an example of how free-floating gear that is not tended immediately after hooking an individual fish can prove to be less effective when limiting mortality events. Management implications that could potentially improve the mortality rates would be lessening the maximum number of buoys allowed. This could provide an increase in tending interaction with the gear, and thus limit stress on individual fish due to fighting buoy gear after being hooked.

The results of this study have provided a continuation of post-release survival on juvenile swordfish after catch on buoy gear, information that was lacking in scientific literature. A continued confirmation of PRM rates of juveniles can provide insight for management implications as juvenile mortalities are underrepresented within current stock assessment methods. The results from this study, and previous studies (Fenton, 2012) can be included in ICCAT stock assessment analysis to determine how many juveniles are removed, and therefore not replaced, due to current enforced regulations. Including these in stock assessments can provide further evidence on why international collaboration is needed on enforcing the size limit suggested by ICCAT while operating under the preferred release methods of undersized swordfish.

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Appendix A:

SWO_OBS ID_YEAR_##

OFRP S-PAT DATA SHEET

Trip Information

Date: ______________ Time: ______________

Trip Number: ______________ Gear Deployment/ Event#: ___________

Vessel Name: ____________ Vessel ID#: ___________

LAT:______ deg ______ min N / S LON: ______ deg ______ min E / W

Power Hauler? Yes / N Surface Temp: ______________

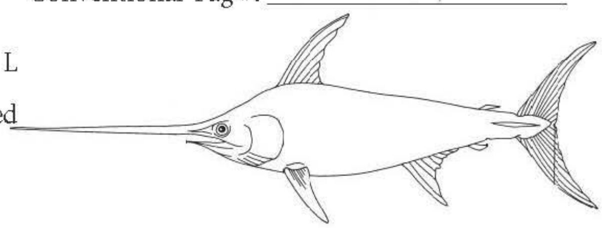
Tagging information

Satellite Tag #:______________________ Conventional Tag #: ______________________

Position: Above lateral Line? Y / N Side? R / L

Fork Length: _____________ estimated / measured

Weight: _______________ estimated / measured



Sketch tag placement and other details

Hooking Information

Leader cut? Y / N Lightstick Used? Y / N Color: ____________

Hook Type: C / J Chemical / Electric Fight Time: ____________ estimated/timed

Remaining Leader: ________ Size: _________ Brand: _________ Model: _________

Location: Upper Jaw Lower Jaw In mouth Bill Gills Throat/Deep Opercle Ventral Head Tail UK

Hook Removed? Y / N Dehooker Used? Y / N Bait type: ______________ dead / alive

Notes:

Release Condition: ☐DEAD ☐WEAK ☐STRONG

	1	2	3
Activity	Inactive(belly up)	slight movement	Active
Color	Grey/Dark Bronze	Patchy Blue-Grey	Bright Silver/Blue
Eyes	Both Lacerated	One Lacerated	Both Intact
Bleeding	Heavy	Minor	None Obvious
Body	Obvious Deep Cuts	Shallow Cuts	Intact
Gills	Torn/Broken	Abrasions	Intact
Injuries	Yes	No	UK

Resuscitation occur? Y / N