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Post-Release Mortality of School-Size Atlantic Bluefin Tuna (Thunnus thynnus) in the U.S Recreational Troll Fishery

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POST-RELEASE MORTALITY OF SCHOOL-SIZE ATLANTIC BLUEFIN TUNA (*Thunnus thynnus*) IN THE U.S. RECREATIONAL TROLL FISHERY

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of
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DEDICATION

This thesis is dedicated to my parents John and Patricia Marcek, for their constant and unfailing support of all my endeavors.

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ABSTRACT

Atlantic bluefin tuna *Thunnus thynnus* (ABFT) support commercial and recreational fisheries throughout the North Atlantic Ocean. Due to heavy fishing pressure over the course of several decades, the eastern and western stocks of ABFT were overfished and the current biomass of the western stock is estimated to be approximately 19% of the biomass necessary for maximum sustainable yield. Despite a variety of management measures, including the implementation of minimum sizes and reductions of the total allowable catch (TAC) and country-specific quotas, little change was observed in the status of the western stock. The U.S. commercial and recreational ABFT fisheries are managed by the National Marine Fisheries Service (NMFS), which distributes the U.S. quota among domestic fisheries by gear type. The U.S. recreational fishery, which has historically targeted small or "school-size" (69-119cm) ABFT, is managed by open seasons, a minimum size, and bag limits (the number of ABFT allowed to be landed per vessel per day). Over the past 20 years, bag limits have been severely reduced due to decreased annual quotas, increasing the number of ABFT released each year, mostly within the school-size category. It is important, for the management of ABFT, to account for all sources of fishing mortality and the large number of releases in the recreational fishery each year could be a significant source of mortality. However, there is very little information available to assess post-release mortality of school-size ABFT in the U.S. recreational fishery. In this study, twenty pop-up satellite archival tags (PSATs) were deployed to estimate the post-release mortality of school-size ABFT captured under normal fishing conditions in the recreational fishery. PSATs recorded pressure (depth), temperature, and light data and were deployed on school-size ABFT caught using trolling methods. These tags were programmed to record data approximately every five minutes for a 31-day deployment. Nineteen tags (95%) reported to the satellites of the ARGOS system and approximately 85% (range: 34-100%) of all archived data were transmitted from each tag. Depth and temperature profiles were used to infer the survival of all 19 individuals whose tags reported (mortality=0% 95% CI=0%, 10%). Data from these tags were also used to investigate the short-term habitat utilization of school-size ABFT. During June to October, these fish spent the majority of their time in the upper 40m of the water column and at temperatures between 18 and 24°C. Individuals were more likely to make vertical excursions to depths exceeding 30m during the day than at night.

POST-RELEASE MORTALITY OF SCHOOL-SIZE ATLANTIC BLUEFIN TUNA (*Thunnus thynnus*) IN THE U.S. RECREATIONAL TROLL FISHERY

INTRODUCTION

Atlantic bluefin tuna *Thunnus thynnus* (ABFT) support commercial and recreational fisheries throughout the North Atlantic Ocean and its adjacent seas, including the Gulf of Mexico and the Mediterranean Sea. Currently the International Committee for the Conservation of Atlantic Tunas (ICCAT) recognizes separate eastern and western stocks of ABFT based on distinct spawning areas and putative differences in life history characteristics such as size and age at maturity. In the western Atlantic, the United States, Canada, and Japan are the major commercial harvesters of ABFT. Due to heavy fishing pressure in the 1960s and 1970s the western Atlantic stock of ABFT was overfished, and ICCAT instituted total allowable catches (TACs) and country-specific quotas to decrease fishing pressure on this stock. In addition, a minimum size of 30kg was implemented, but in recognition of the importance of the historical recreational fishery for small ABFT, the United States is permitted to land up to 10% of its ABFT quota in fish less than 30kg.

The U.S. ABFT quota is allocated among several gear types and the recreational sector is allotted 19% of the quota. Due to reduced TACs and country-specific quotas and the need to limit landings of undersized ABFT to no more than 10% of the U.S. quota, the U.S. National Marine Fisheries Service (NMFS) implemented increasingly restrictive bag limits for the recreational fishery between 1999 and 2013. As a result, the recreational fishery for juvenile ABFT is now largely a catch-and-release fishery. However, the fate of ABFT released from this fishery has not been investigated and may represent a significant source of fishing mortality. This thesis was designed to investigate the post-release mortality of recreationally caught ABFT between 27 and 47in (69-119cm) curved lower jaw fork length (CLJFL), commonly referred to as school-size ABFT. In addition, high-resolution pressure and temperature data recorded by the PSATs were used to investigate short-term habitat utilization and movement.

Bluefin Tuna Biology

Atlantic bluefin tuna have the largest geographical range of any pelagic species in the North Atlantic and are the only tuna species that permanently lives in temperate waters (Bard et al. 1998; Fromentin and Fonteneau 2001). Their range extends from the equator to areas north of Norway, and from the Mediterranean and its adjacent seas to the Gulf of Mexico (Mather et al. 1995). Peak spawning for ABFT occurs in May in the western Atlantic and June in the eastern Atlantic (Nishikawa et al. 1985; Mather et al. 1995; Schaefer 2001a; Rooker et al. 2007). ABFT are asynchronous broadcast spawners (Medina et al. 2002) with fertilization occurring directly in the water column and the eggs typically hatch after a two-day incubation period (Fromentin and Powers 2005). Few studies have investigated the growth rates of ABFT larvae, but Brothers et al. (1983) indicated that it is relatively fast when compared with other teleost fishes. Juvenile ABFT also grow rapidly, up to 30cm yr^{-1} (Fromentin and Powers 2005). ABFT display allometric growth as they age, their growth in length slows while their mass increases disproportionately (Mather et al. 1995; Fromentin and Powers 2005; Restrepo et al. 2010). ABFT are thought to live for up to over 30 years and obtain weights of up to 700kg (Restrepo et al. 2010).

Studies using a variety of techniques indicate that ABFT undergo trans-Atlantic migrations (Mather 1995; Block et al. 2001), movements that are believed to occur for both spawning and foraging (Mather et al. 1995; Block et al. 2001; Rooker et al. 2003, 2007, 2008; Dickhut et al. 2009). ABFT may migrate from the eastern Atlantic to western Atlantic foraging areas as early as age 1 (Rooker et al. 2003; Dickhut et al. 2009), and may remain in the western Atlantic for several years before returning to the Mediterranean Sea to spawn (Block et al. 2005; Dickhut et al. 2009). Conventional tagging studies suggest that juvenile ABFT spawned in the western Atlantic may also migrate from the New Jersey-Massachusetts area to the Bay of Biscay to forage (Mather et al. 1995). Electronic tagging studies performed by Block et al. (2005) also indicate that large ABFT (≥180cm CLJFL) may migrate from western spawning grounds to eastern Atlantic foraging areas.

Tagging studies have demonstrated that some ABFT participate in trans-Atlantic migrations, but the majority of fish tagged in the western Atlantic have been recovered in the western Atlantic (Mather et al. 1995; Stokesbury et al. 2004; Block et al. 2005; Wilson et al. 2005; Teo et al. 2007; Galuardi and Lutcavage 2012). This may suggest site fidelity for the majority of fish in the western Atlantic, however the majority of fish had short times at liberty.

From electronic tagging studies we know that ABFT spend the majority of their time in the warm surface waters, typically from 0-30m and 15 to 23°C (Brill et al. 2002; Stokesbury et al. 2004; Wilson et al. 2005; Galuardi and Lutcavage 2012). However, they are capable of utilizing the water column down to 1,000m and 3°C (Block et al. 2005, Teo et al. 2007). Larger ABFT exploit a greater range of temperatures and depths for foraging, and inhabit cooler waters than smaller ABFT during most times of the year (Brill et al. 2002; Stokesbury et al. 2004; Block et al. 2005; Wilson et al. 2005; Teo et al. 2007; Galuardi and Lutcavage 2012). During the breeding season mature ABFT that enter the Gulf of Mexico experience mean surface temperatures between 25 and 30°C and may use vertical excursions to cooler waters to prevent overheating (Teo et al. 2007).

Juvenile and adult ABFT are opportunistic feeders. Stomach contents and stable isotope analyses indicate that ABFT consume a large variety of prey including teleosts, elasmobranchs, and invertebrates (Ortiz de Zarate and Cort 1986; Eggleston and Bochenek 1990; Chase 2002; Estrada et al. 2005; Sara and Sara 2007). ABFT are known to have a high rate of digestion which allows them to maintain an elevated metabolic rate in an energy-poor environment (Brill 1996).

Bluefin Tuna Commercial Fisheries

Atlantic bluefin tuna have been exploited as a food source in the Mediterranean Sea dating back to Phoenician and Roman times (Desse and Desse-Berset 1994). Many different gear types have been used to capture these fish including seines, handlines, harpoons, drift nets, and traps (de Gaetani 1948; Doumenge and Lahaye 1958; Mather et al. 1995; Fromentin and Powers 2005). During the 16th century, traps became the dominant fishing method used to catch ABFT in the Mediterranean (Doumenge 1998; Ravier and Fromentin 2001) and records from this fishery provide the first known information regarding ABFT landings, 7,000-30,00mt yr^{-1} (Ravier and Fromentin 2002). There has been fishing pressure on ABFT in the Mediterranean for hundreds of years (Fromentin and Powers 2005).

During the 19th and early 20th centuries new methods of fishing for highly migratory species (HMS) were developed, including trolling and large, boat-operated seines, increasing capture efficiency of ABFT in the pelagic environment (Ravier and Fromentin 2001). In the mid-19th century a handline fishery specifically targeting juvenile ABFT and Atlantic albacore tuna in the Bay of Biscay (Bard 1981; Fromentin and Powers 2005) and a handline fishery in the North Sea (Tiews 1975; Mather et al. 1995) were developed, increasing the range of the ABFT fishery beyond the Mediterranean Sea. During the latter part of the 19th century a subsistence fishery for ABFT developed in the western Atlantic. This fishery used a variety of gears and eventually expanded into a commercial fishery during the 20th century (Mather et al. 1995).

The pelagic longline fishery for ABFT, led by the Japanese, developed during the 1950s and 1960s and quickly expanded throughout the Atlantic and its adjacent seas (Mather et al. 1995; Miyake et al. 2004; Fromentin and Powers 2005). Catches in the Japanese fleet quickly rose largely due to the exploitation of spawning ABFT in the Gulf of Mexico and large fish off the coast of Brazil. The Brazilian fishery lasted from 1962-1967, collapsing within five years of its onset (Fromentin and Powers 2005). Since catches peaked in 1965, the Japanese longline fleet has decreased its overall effort and moved out of the Gulf of Mexico and into the Central North Atlantic. By 2011, overall Atlantic landings of ABFT within the pelagic longline fleet had decreased to 2,769mt (SCRS 2012).

Purse seines were first developed during the 1930s (Meyer-Waarden 1959) and were used to target a number of species ranging from menhaden and sardines to tunas

(Schmidt 1959). The advent of the power block in 1955 resulted in a more efficient means of setting and hauling purse seines (Schmidt 1959), allowing fishermen to capture and harvest entire schools of ABFT which led to the expansion of Nordic and U.S. tuna fleets. The Nordic fleet operated in the North and Norwegian seas while the U.S. fleet operated off the east coast of the United States. In 1963 the Nordic purse seine fishery collapsed due to a change in the migration pattern of ABFT, overfishing, or a combination of these factors (Fromentin and Powers 2005).From the late 1950s to the mid-1960s the ability of purse seines to land large numbers of ABFT led to the expansion of the U.S. fleet from two vessels targeting juvenile ABFT to 21 vessels (Squire 1959; Wilson 1965; Mather et al 1995).

The development of caging operations, primarily in the Mediterranean Sea, drastically changed the ABFT fishery in the 1990s. Caging operations allow large numbers of live fish to be brought back to port and fattened in pens, increasing their value and allowing gradual harvest to maximize market prices. Due to more efficient on-board refrigeration and flash freezing techniques, pelagic longline vessels were able to exploit distant areas while maintaining their product in excellent condition (Fromentin and Powers 2005; Fromentin and Ravier 2005; Porch 2005). In the 1990s catches of ABFT in the eastern Atlantic dramatically increased, peaking at or above 50,000mt yr^{-1} (Fromentin and Powers 2005) and probably remained near that level for several years despite ICCAT measures to limit landings (Fromentin 2003; ICCAT 2005).

Bluefin Tuna Recreational Fisheries

Sport fishing for large pelagic species such as tunas, billfishes, and sharks began in the late 1800s and early 1900s in the western Atlantic. Popularized by Ernest Hemingway and others, big game sport fishing became widespread among wealthy anglers but was cost prohibitive to many others at the time (Farrington 1937). It was only after World War II that the charter and headboat fleets expanded and the cost of offshore fishing decreased to a point where the general public could take part in the recreational bluefin tuna fishery (Farrington 1949). Currently, recreational fishing for ABFT in the western Atlantic occurs on both charter and private boats from North Carolina to Maine in the U.S. (Bochenek 1989) and on charter vessels in southern Canada.

A wide range of size classes of ABFT are encountered in the U.S. recreational fishery, but typically, the fishery is dominated by the school size class. The U.S. recreational fishing season for ABFT varies depending on geography and size class. Trophy-size fish, those greater than 185cm CLJFL, are targeted from December to February in North Carolina, and from August to October in Massachusetts. Beginning in late May or June, school-size ABFT are targeted off Virginia and Maryland before the fish migrate up the coast, following concentrations of bait, to New England where they are targeted by recreational anglers until October or November.

Landings and releases by U.S. recreational anglers are estimated through two survey programs instituted by the National Oceanographic and Atmospheric Administration (NOAA), the Marine Recreational Information Program (MRIP) and the Large Pelagics Survey (LPS). Both of these surveys include a telephone component and an angler intercept component which are combined to estimate fishing effort and landings for various species; however, the LPS is specifically designed for large pelagics fisheries while the MRIP includes many other species. The LPS was developed by NMFS in 1992 and operates from Maine to Virginia between June and October. More recently, the LPS was modified to also estimate landings and releases of all size classes of ABFT and other large pelagic species encountered by the U.S. recreational fleet. From 1981 to 2011, estimates of U.S. recreational landings of ABFT ranged from 2,745 to 169,176 fish yr^{-1}. In recent years LPS interceptors have recorded the method used to capture ABFT and the survey has begun to estimate the number of ABFT releases based on angler intercepts. From 2006 to 2010 estimates of ABFT releases ranged from 7,548 to 13,401 fish yr^{-1} (LPS data), with 44 to 91% of these fish captured by trolling.

The 2003 year class was the strongest cohort in the western Atlantic since the 1970s and has had a large impact on the U.S. recreational fishery (Figure 1). As this year class entered the recreational fishery at age 2, large numbers of school-size ABFT were captured by anglers. At that time (2005) the United States was allowed 8% of its quota in ABFT under 30kg and as a result of this influx of small fish, the United States was in danger of exceeding the 8% allowance in the third year of a four year management period. In response, NMFS severely reduced the ABFT fishing season in 2006, resulting in low landings in the recreational fishery (Figure 1). As the 2003 year class grew it increased the average size and weight of the overall recreational landings of ABFT in the United States and caused U.S. anglers to greatly exceed their allotted quota.

Stock Status and Management

The member nations of ICCAT have been responsible for the management of tunas and tuna-like species in the Atlantic Ocean since 1969 (ICCAT 2013a). Currently, Atlantic bluefin tuna are managed as two separate stocks delineated by the 45 degree western meridian. However, this strict separation of stocks has come under scrutiny as recent studies indicate high mixing rates between juveniles of the eastern and western stocks on foraging grounds in the western Atlantic (Rooker et al. 2003; Dickhut et al. 2009).

The ICCAT Standing Committee for Research and Statistics (SCRS) assesses the status of fish stocks and may recommend a TAC for a stock if management action is warranted. TACs, when implemented, are often allocated among the member nations harvesting the stock as country-specific quotas. The member nations are responsible for distributing their quota among domestic fisheries and ensuring that overharvesting does not occur.

The TAC for western Atlantic ABFT was 2,660mt in 1983. Since then, it has fluctuated, decreasing to 2,261mt in 1994, then slowly increasing to a maximum of 2,700mt in 2003. The TAC was decreased in 2007 to 2,100mt and decreased further to 1,800mt between 2008 and 2010. The current TAC for western ABFT is 1,750mt inclusive of dead discards. The United States is allotted 923.7mt of the current TAC which is then divided among the domestic sectors of the ABFT fishery by NMFS based on the Fishery Management Plan for Atlantic HMS (NMFS 2006). Currently NMFS allocates the U.S. quota among seven sectors within the ABFT fishery: general (47.1%), angling (19.7%), purse seine (18.6%), longline (8.1%), harpoon (3.9%), trap (0.1%), and a reserve (2.5%). The reserve sector can be put to use if one or more sectors exceed the allotted catch to ensure that the U.S. does not surpass its overall quota (NMFS 2006).

In addition to decreasing the western ABFT TAC over time as mentioned above, ICCAT instituted a minimum size of 30kg throughout the Atlantic in 1992 to reduce landings of small ABFT. In recognition of the historical importance of undersized (<30kg) ABFT to the U.S. recreational fishery, ICCAT management recommendations have provided an allowance for the harvest of small (<30kg) ABFT. Through 2008 the United States was allowed to harvest 8% of its quota, by weight, as undersized ABFT. This percentage was increased to 10% at the 2008 ICCAT meeting when the TAC in the western Atlantic was reduced.

The U.S. recreational fishery for ABFT has been managed by NMFS since the late 1990s with size classes, open seasons and bag limits. The National Marine Fisheries Service recognizes six size classes of ABFT based on their length; young school, school, large school, small medium, large medium, and giant (Table 1). All size classes are encountered in the U.S. recreational fishery, but it is illegal to retain young school ABFT as they are under the U.S. minimum size (69cm CLJFL). Large medium and giant ABFT are caught in the recreational fishery and can be retained by recreational vessels but only one fish in this "trophy" category can be kept per vessel per year. In general, the season for ABFT in the United States begins January 1st and ends December 31st but can be closed within a given year for certain areas and size classes based on in-season estimates of landings. For instance, in 2006 the ABFT season was significantly shortened due to the United States nearly exceeding its four-year quota of small ABFT in the first three years of the management period. Bag limits have varied from 1999 to the present day both within and between years and for various size classes. For private vessels the bag limit in 1999 was either two school and one large-school or small-medium ABFT per vessel per day, or one large-school or small-medium ABFT per vessel per day depending on the time of year. Bag limits ranged between one and six ABFT for private vessels over a number of years before the current bag limit of one school, large-school, or small-medium ABFT was set in 2009. The bag limits for charter vessels and headboats have also decreased over the past several years.

Despite the increased management measures and a decreasing TAC there has been little change in the status of the western stock of ABFT. The stock is still overfished and overfishing is still occurring based on the current assessment under the high recruitment scenario (ICCAT 2013b). While a 20 year rebuilding program was instituted in 1995 there has been little change in the state of the ABFT stocks. The lack of success in the rebuilding program is likely due to a combination of factors including low recruitment and a lack of information regarding mixing rates between the eastern and western stocks, making it difficult to incorporate these mixing rates into assessment models. Another factor that may have an impact on the success of the rebuilding program is cryptic fishing mortality, such as post-release mortality of ABFT released from recreational fishing gear. Considering the large numbers of ABFT released from the U.S. recreational fishery each year, it is critical for effective management to obtain accurate estimates of post-release mortality.

Post-Release Mortality

Estimating post-release mortality of HMS such as ABFT is challenging. Small, coastal fishes can be maintained in captivity following capture facilitating observations of fate (Dunning et al. 1987), but it is not possible to study HMS under similar circumstances. Therefore, other methods must be used to estimate post-release mortality rates of HMS.

There are several methods that have been used to estimate the post-release mortality rates of HMS including inferences of mortality based on hooking location, acoustic tagging, and the use of pop-up satellite archival tags (PSATs). Skomal et al. (2002) and Prince et al. (2002) used hook location and tissue damage to infer the post-release mortality rate of juvenile ABFT and sailfish respectively. To properly assess the amount of damage caused by a hook, especially if the hook lodges deep in the viscera, it is necessary to sacrifice a large number of animals for dissection and make the assumption that any animal that is hooked deeply is moribund.

Acoustic tags have primarily been used to study short-term movements of several pelagic species including sailfish (Jolley and Irby 1979), blue marlin (Holland et al. 1990a; Block et al. 1992), black marlin (Pepperell and Davis 1999), and bluefin tuna (Brill et al. 2002). In these studies, fish were tagged with an acoustic transmitter and followed by boat using a hydrophone. The time that a fish was followed often depended on the availability of personnel and sea conditions, and typically ranged from hours to days. These studies typically selected only healthy individuals for tagging, but even with that bias, mortalities were observed.

PSATs were first attached to pelagic fishes in the late 1990s and were primarily used for investigations of movement and habitat utilization. In these studies the high cost of the PSATs motivated investigators to deploy them on healthy animals. However, PSATs can be useful in determining the post-release mortality of HMS, such as blue marlin (Graves et al. 2002), white marlin (Horodysky and Graves 2005), striped marlin (Domeier et al. 2003), and Atlantic bluefin tuna (Stokesbury et al. 2011). Mortality rates for these species have been estimated using tag deployments ranging from 5 (Graves et al. 2002) to 30 days (Stokesbury et al. 2011). Post-release mortality rates reported for HMS have ranged from 5% (Stokesbury et al. 2011) to 35% (Horodysky and Graves 2005) and vary greatly depending on species, fishing methods, and terminal gear. Based on these results, it is inappropriate to assume mortality rates are similar across species, or even within species if different methods or terminal gear are used (Horodysky and Graves 2005).

There has been only one study of the post-release mortality of ABFT using PSATs. Stokesbury et al. (2011) investigated the post-release mortality rate of large ABFT (114-432kg, small-medium to giant) caught in an experimental recreational fishery near Prince Edward Island, Canada. This study used experienced captains and anglers which decreased the likelihood of fish being fought for extended periods of time, and thereby reduced stress on the animal and increased the likelihood of survival. The fish were caught on drifted baits rigged with barbless circle hooks to reduce hook-induced trauma, further decreasing the likelihood of mortality.

In the U.S. recreational fishery, school-size (69-119cm CLJFL) ABFT typically constitute more than 50% of landed fish and normally comprise an even greater proportion of the released fish. LPS estimates indicate that between 3,427 and 45,722 school-size ABFT were released per year between 2002 and 2010. Of those released fish, between 44 and 91% were caught using trolling methods. To date, the post-release mortality rate of these fish has not been investigated with PSATs and considering the large number of releases of school-size ABFT from the U.S. recreational fishery, it is important to understand the impact of post-release mortality on this fishery.

Habitat Utilization

Conventional tagging has been used for many years to investigate the movements of fishes, including large pelagic species such as ABFT. Conventional tags can remain attached to the study organisms for several years providing researchers with information regarding the net displacement of each animal; however they do not provide any information on movements occurring during the time at liberty.

Internal archival tags have been used in several studies of ABFT movement and habitat utilization and provide detailed information on the horizontal and vertical movements of these animals (Block 2001; 2005; Teo et al. 2007). However, to obtain information from internal archival tags, the tags must be physically recovered and returned, resulting in high dependence on the fishery to recover the archival tags.

PSATs have given scientists the ability to investigate the habitat utilization of fishes using fishery-independent methods, without the need for designating a chase boat (acoustic tagging), or the need for tags to be recovered and returned by the fishery. Since their first use on pelagic fishes in the late 1990s by Block et al. (2001), PSATs have been used to investigate the movements and habitat preferences of highly migratory fishes.

Over the last decade the technology available for use in PSATs has advanced, resulting in increased data storage and processing capabilities and a smaller tag body. These features have allowed scientists to investigate horizontal and vertical movements of fishes on a finer time scale, as well as to deploy tags on smaller individuals (Graves et al. 2009; Galuardi and Lutcavage 2012).

Several studies have investigated the habitat utilization of large ABFT in the North Atlantic (Lutcavage 1999; Block et al. 2001; 2005; Stokesbury et al. 2004; Wilson et al. 2005; Teo et al. 2007), but only three studies have investigated the movements and habitat utilization of juvenile ABFT (Yamashita and Miyabe 2001; Brill et al. 2002; Galuardi and Lutcavage 2012). Yamashita and Miyabe used internal archival tags to investigate the movement and habitat utilization of seven school-size ABFT (70-90cm FL) in the Mediterranean for up to 7.5 months. Using ultrasonic telemetry Brill et al. (2002) tracked five school-size ABFT ranging from 74-106cm fork length (FL) for up to 48hrs offshore of Virginia Beach, VA during June and July. Galuardi and Lutcavage (2012) used PSATs to investigate the habitat utilization of 26 juvenile ABFT (six of which were school-size, 115-119 CLJFL), caught between June and October, ranging from 105 to 168cm FL near Cape Cod, MA. Time at large for these fish ranged from four to 366 days. These two studies of juvenile ABFT habitat utilization show similar trends in habitat utilization over the summer indicating juvenile ABFT spent the majority of their time in the upper portion of the water column and in relatively warm surface waters (Brill et al. 2002; Galuardi and Lutcavage 2012). Neither study incorporated a robust sample size of school-size ABFT (n=5 and n=6, respectively). Therefore, greater insight into the movement and habitat utilization of school-size ABFT could be obtained through increasing the number of fish tagged within this size class.

Project Objectives

As noted above there is little information regarding the post-release mortality of school-size ABFT released from the U.S. recreational fishery and limited information regarding the habitat utilization of these fish. In this thesis we used PSATs to investigate 1) the post-release mortality of school-size ABFT caught in the recreational troll fishery and 2) the short-term habitat utilization of school-size ABFT released between June and September near Point Pleasant, NJ and Chatham, MA.

METHODS

Fishing Operations

Based on their availability school-size ABFT were captured by trolling lures or lure/bait combinations in waters offshore of Point Pleasant, NJ and Chatham, MA during the summer of 2012. The gear used ranged from 30 to 130 class reels with 50-200lb test monofilament or braided line rigged with a variety of terminal tackle, including spreader bars, daisy chains, cedar plugs, Slug-gos, and Islander/ballyhoo combinations. All terminal tackle was rigged with large "J" style hooks. ABFT were tagged from both charter and private recreational vessels. To avoid biasing the results of this study all decisions regarding the use of tackle and fishing methods were left to the captain and crew. It was common practice for charter vessels to keep the first school-size ABFT captured for the client. On private recreational boats the decision to tag or keep a fish was made by the captain and crew once the fish was close enough to the boat to determine its size. Typically, with small bag limits (1 or 2 fish) recreational fishermen do not want to keep school-size fish and were more likely to retain a large-school ABFT to fill their bag limit. This allowed me a greater ability to tag school-size ABFT on recreational boats than on charter vessels. A minimum of 30 minutes was maintained between consecutive tagging events to avoid oversampling a single school and potentially biasing the results based on the condition of that school.

Tagging Methods

The use of animals in this study was approved under the Institutional Animal Care and Use Committee guidelines (IACUC-2011-07-11-7390-jegrav). All fish in this study were handled in a manner typical of the recreational fishery and care was taken not to instruct anglers in catching or handling methods. The first 20 school-size ABFT available for tagging (not retained by the vessels) were tagged with a minimum time interval of 30min between consecutive tagging events. This time interval was used to reduce the likelihood of sampling more than one fish from a single school. All fish were brought into the vessel by lifting them over the gunwale by the terminal tackle or a lip-gaff, or by pulling them through a door in the transom of the vessel (tuna door). Fish were then placed directly on the deck or on a salt-water soaked towel and their eyes were covered with a damp cloth. This had the effect of calming the fish and minimized the chances of further injury. The hook was removed, the fish measured (CLJFL), and a PSAT tag was inserted into the dorsal musculature using a 10cm stainless steel applicator attached to a 0.3m tagging pole. The tag anchor was inserted approximately 8cm deep into an area approximately 6cm posterior and 4cm ventral to the origin of the first dorsal fin (Figure 2). In this area the nylon tag anchor passed the pterygiophores that supported the dorsal fin and was firmly attached (Graves et al. 2002). After tagging, the fish was released. Gear type, fight time, total time (hooking to release), hooking location, location and severity of bleeding, overall condition, GPS coordinates of release, date, and length were recorded for each fish.

Tag Features

The HR X-Tag model PSAT from Microwave Telemetry, Inc. (Columbia, MD, U.S.A.) was used in this study. This tag is slightly buoyant, measures 12cm by 3.2cm, and weighs 40g in air. The body of the tag contains a lithium composite battery, a microprocessor, a pressure sensor, a temperature gauge, a light sensor, and a transmitter, all housed in a black, resin-filled, hermetically sealed, carbon-fiber tube rated to withstand pressures equivalent to 2,500m (>3,500psi). Flotation is provided by a resin bulb embedded with buoyant glass beads. This tag model is also equipped with an emergency release mechanism, which is triggered if the tag exceeds a depth of 1,250m, and a constant depth release function causing the tag to release from the animal if it remains at the same depth (+/-3m) for 4 days. The tags were programmed to record and archive a continuous series of temperature, light, and pressure (depth) data every five minutes for 31 days. Once released from the study animal, the tags transmit archived and real-time temperature, light, and pressure (depth) data to orbiting satellites of the Advanced Research and Global Observation Satellite (ARGOS) system.

PSATs were rigged for deployment with an assembly composed of 16 cm of 200-pound test monofilament fishing line attached to a large hydroscopic, surgical grade nylon intramuscular tag anchor (3.2cm long x 2.4cm wide). The monofilament was double crimped and covered with heat-shrink tubing according to the methods of Graves et al. (2002).

Data Analysis

Survival of released ABFT was inferred by analyzing the time series of water temperature, pressure (depth), and light level measurements recorded by the PSATs. Healthy ABFT move up and down in the water column, changing depth and temperature over time, whereas, moribund fish typically sink to the bottom. Although rare, predation of the tag (and fish) may occur. In these situations an ingested tag will likely continue to record changes in pressure and temperature, but the day/night light cycle will not be apparent. Most angling-related mortalities of HMS appear to occur within 48 hours of release (Graves et al. 2002; Stokesbury et al. 2004; Wilson et al. 2005). Therefore, for the purposes of this study, five days of data were used as the threshold for including tags in the analysis of post-release survival.

Confidence intervals (95%) for estimates of post-release mortality were calculated using bootstrapping methods implemented in software developed by Goodyear (2002). Confidence intervals were calculated based on 10,000 bootstrap samples with an underlying release mortality of 0% for experiments containing 10-200 tags, assuming no tagging induced mortality, no tag shedding, and a natural mortality rate of 0.2.

Net movement was estimated as a minimum straight line distance between the point of tag deployment (fish release) and the first reliable position of the detached tag (ARGOS location codes 1, 2, or 3). Directions and magnitudes of displacements were generated using ArcGIS 10 (Esri, Redlands, CA).

Time-at-depth and time-at-temperature data were summarized into 10m and 1°C bins, for each individual, as described in Holland et al. (1990b). These data were then expressed as a fraction of the total deployment time and averaged across all individuals.

Proportion of time at depth and time at cool temperatures were calculated for each individual during day and night time periods for each day of tag deployment. Data from all individuals were pooled to create a time series of data extending from the first tag deployment to the last tag release. Diel differences in the proportion of time at depth and the proportion of time at cool temperatures were investigated where day was defined as the midpoint between sunrise and sunset +/-3hrs and night was defined as the midpoint between sunset and sunrise +/-3hrs. Six hour intervals were chosen to define day and night to allow sufficient data to detect potential diel differences while leaving enough time between day and night intervals to reduce the correlation. Sunrise and sunset times were taken from the U.S. Naval Observatory website (http://aa.usno.navy.mil/faq/docs/RST_defs.php).

The proportion of time at depth was defined as the time spent below 30m divided by the total time in any day or night period, given the drastic decrease in the proportion of time spent at depths exceeding 30m (Figure 3). The proportion of time at cool temperatures was defined as the time spent at temperatures five or more degrees cooler than SST based on school-size ABFT spending 90% of their time within 5°C of SST (Figure 4). A generalized linear model with repeated measures (GENMOD procedure in SAS, vers. 9.2, SAS Inst., Inc., Cary, NC) was used to analyze the proportion of time at depth and the proportion of time at cool temperatures. Repeated measures were used because multiple measurements were taken for each fish. The proportion of time at depth was analyzed using the following model:

$$Y_{jk}=\mu+\gamma+\alpha_j+\delta_{(k)}+\rho_k+\omega+\gamma^*\alpha_k+\varepsilon_{ijk}$$

where Y_{jk} is the mean proportion of time spent across all fish, at depths exceeding 30m in area j, in time period (day or night) k The overall mean proportion of time at depth (the intercept) is μ, γ is the effect of fish length (cm), α is the area effect (MA or NJ), δ is the effect of the calendar date which is nested in time period ρ (day or night), ω is the effect of sea surface temperature (degrees C), and ε is the random unexplained error. All effects were considered fixed. Potential interactions were examined based on their potential biological relevance and were investigated using the Quasilikelihood Information Criterion (QIC), which is analogous to AIC analysis for non-likelihood based estimators. Interactions that were investigated included time period and sea surface temperature (SST), fish length and SST, fish length and area, and fish length and time period. GENMOD uses a non-likelihood based estimator and therefore the "best" model was selected based on the lowest QIC value.

The proportion of time at cool temperatures was also analyzed using a generalized repeated measures model (GENMOD procedure in SAS, vers. 9.2, SAS Inst., Inc., Cary, NC). The statistical model fit to these data was:

$$Y_{jk}=\mu+ \gamma+\alpha_j+\delta_{(k)}+\rho_k+\omega+\varepsilon_{ijk}$$

where Y_{jk} is the mean proportion of time spent across all fish at temperatures five or more degrees cooler than SST in area j at time period k. The overall mean proportion of time at cool temperatures is μ. All other effects were the same as in the previous model.

The potential interactions investigated with QIC analysis were the same as in the previous model.

Potential diel and crepuscular differences in the mean depth and temperature of waters occupied by school-size ABFT were also investigated. For the purposes of these analyses, crepuscular periods were defined as sunrise and sunset +/- 30min, mid-day was defined as the midpoint between sunrise and sunset +/- 30min, and mid-night was defined as the midpoint between sunset and sunrise +/- 30min. One hour intervals were used for each of the four time periods to reduce the likelihood of any crepuscular signals being dampened by including extraneous data. Differences in mean depth were analyzed using a general linear mixed model with repeated measures (MIXED procedure in SAS, vers. 9.2, SAS Inst. Inc., Cary, NC). The data were $\log_e$-transformed to meet the assumption of homogeneity of variance (Logan 2010). To allow for the $\log_e$ transformation 0.01 was added where the mean depth was equal to 0. Potential interactions, including time period and area, time period and length, length and area, and time period and tagging day, were addressed using Akaike Information Criterion (AIC) and the "best" model was selected using the lowest AIC value (Logan 2010). The mean depth occupied by individual fish during different time periods was modeled using a general linear mixed model with repeated measures of the form:

$$Y_{ijk}=\mu+\lambda+\gamma+\alpha_j+\delta+\rho_k+\gamma^*\alpha_j+\delta^*\rho_k+\varepsilon_{ijk}$$

where Y_{ijk} is the $\log_e$-transformed mean depth occupied by fish i, in area j, during time period k. The overall mean depth (intercept) is μ, γ is effect due to the length of the fish (cm), α is the area (MA or NJ) effect, δ is the effect of calendar date, ρ is the effect of time period (dawn, day, dusk, night), and λ is the random effect of individual fish. All factors were considered fixed except λ.

The mean temperature occupied by school-size ABFT was also modeled using a general linear mixed model with repeated measures (MIXED procedure in SAS, vers. 9.2, SAS Inst. Inc., Cary, NC) of the form:

$$Y_{ijk}=\mu+\lambda+\gamma+\alpha_j+\delta+\rho_k+\delta^*\rho_k+\varepsilon_{ijk}$$

where Y_{ijk} is the mean temperature occupied by fish i, in area j, during time period k. The overall mean temperature occupied by school-size ABFT is μ. All other effects are the same as in the previous model. The data were $\log_e$-transformed to meet the assumption of homogeneity of variance (Logan 2010). Potential interactions were investigated as in the previous model.

Diel differences in vertical excursions, defined as any movement resulting in the fish exceeding a depth of 30m, were characterized for each fish where day was defined as the midpoint between sunrise and sunset +/-3hrs, and night was defined as the midpoint between sunset and sunrise +/-3hrs. Vertical excursions for school-size ABFT were generally of short duration, therefore, a higher proportion of these excursions could be missed in the brief time periods of dawn and dusk. Due to this potential sampling error crepuscular periods were excluded from these analyses following Kerstetter et al. (2003). Diel differences in the vertical movements of school-size ABFT were examined using a generalized linear mixed model (GLIMMIX procedure in SAS, vers. 9.2, SAS Inst. Inc., Cary, NC) of the form:

$$Y_{ik}=\mu+\rho_k+\lambda+\delta+\varepsilon_{ik}$$

Where Y_{ik} is the mean number of vertical excursions that fish i undertook in time period k (day or night). The overall mean number of vertical excursions is μ (the intercept), λ is the random effect due to individual fish, ρ is the time period (day or night), and δ is the random effect due to tagging day. These data were assumed to have a negative binomial distribution.

RESULTS

Tagging

Twenty PSATs were deployed on ABFT between June 19 and September 22, 2012 off Point Pleasant, NJ (n=3) and Chatham, MA (n=17, Table 2). All 20 fish tagged with PSATs were caught on spreader bars with artificial squid rigged with large "J" hooks. Fight times ranged from 4 to 11 minutes (7.5 +/-1.9min). Once fish were brought into the vessel the entire tagging process took between 0.5 and 4 minutes (1.7 +/-0.8min). Total time, from hooking to release, ranged from 5.5 to 12 minutes (9.1 +/-0.5min). Fish length was 91 to 119cm CLJFL (108.4 +/-1.9cm) and all fish were hooked externally, meaning the hook was visible and generally lodged in or around the buccal cavity. Ten percent (n=2) of the fish tagged in this study were hooked in the corner of the jaw, 20% (n=4) were hooked in the lower jaw, 55% in the upper jaw (n=11), and 15% in the orbit not puncturing the eye (n=3). The severity of bleeding was categorized as no bleeding, light bleeding, and heavy bleeding. Twenty percent (n=4) of tagged fish did not bleed, 70% (n=14) had light bleeding around the hook wound, and 10% (n=2) were experiencing heavy bleeding, one from the orbit and one from the upper jaw, where it was hooked, and from the lower jaw, where it was lip-gaffed.

Nineteen of the 20 PSATs (95%) deployed in this study reported. Of these, four tags released prematurely after 6, 7, 16, and 26 days at large (Table 3). All 19 reporting tags remained attached for at least six days, exceeding our minimum time threshold of five days to be included in the analysis of post-release mortality. Fifteen tags remained attached for 31 days and the mean time of tag attachment for the 19 reporting tags was 27.3 +/-1.9days. Tags transmitted between 34 and 100% of their archived data (84.8 +/- 3.1%, Table 3). Excluding the four premature releases, the minimum straight-line distance traveled for tagged ABFT ranged from 44.4 to 402.5km (163.8 +/- 23.8km) during the 31 day tagging period (Table 3, Figure 5).

All ABFT tagged in June were caught near Point Pleasant, NJ. Two of these fish had net displacements of less than 65km (Figure 5) over deployment periods of seven and 26 days, while the third individual (BFT-1) had a net movement in a northeasterly direction approximately 266km over 31 days. The remaining 16 fish were caught near Chatham, MA; five in August and 11 in September. Of the fish tagged in August, three had net displacements of less than 100km of the tagging site and moved in a northerly direction while two fish (BFT-4 and BFT-8) had net displacements of approximately 207km and 118km, respectively, in a southwesterly direction. Fish tagged in September typically had longer displacements (172.4 +/- 30.8km). Nine fish had net displacements in a southerly direction while two (BFT-10 and BFT-11) had net displacements almost due east.

Based on visual inspection of the depth, temperature, and light profiles we inferred that all 19 individuals with reporting tags survived. The tag of BFT-16 (and possibly the individual) appears to have been consumed 12 days after release. This is evident from a visual inspection of the depth, temperature, and light profiles from the tag data (Figure 6). The depth profile reveals a fairly consistent vertical behavior for the duration of the tag deployment, while the temperature profile indicates an abrupt increase in temperature from ambient on October 2nd. From October 2nd to October 6th the temperature remained elevated and did not vary with depth. Concurrent with the increase in temperature was a decrease in light and a loss of day/night differences. These temperature and light data are consistent with the tag having been consumed by an endothermic organism. As this apparent predation event occurred 12 days after release of the fish it was not considered a fishing-related mortality for the purposes these analyses. Based on these data, survival of all 19 fish results in an estimated mortality rate of 0% for school-size ABFT released in the recreational troll fishery. The 95% confidence intervals for the post-release mortality of school-size ABFT in this study were calculated using the software developed by Goodyear (2002), using an underlying mortality rate of 0%, based on the estimate from the current study. Based on the results of 10,000 simulated experiments the confidence intervals for an experiment deploying 19 tags on school-size ABFT in the recreational troll fishery range from 0 to 10% (Figure 7)

Habitat Utilization

Using a generalized linear model with repeated measures we determined that the diel difference in the proportion of time spent at depth was marginally significant (χ^2=3.48, P=0.06), with fish spending a higher proportion of time at depth during the day than at night. The proportion of time at depth increased through time (June to October, χ^2=7.39, P=0.02) regardless of time period (day: 0.014, CI=0.002, 0.027; night: 0.019, CI=0.005, 0.033), where CI designates the upper and lower limits of the 95% confidence interval. The interaction between the length of the fish and the capture location was not significant in this model (χ^2=1.97, P=0.16) indicating that the behavior of ABFT of a given length was the same regardless of the capture location. Sea surface temperature was not a significant predictor of the proportion of time at depth (χ^2=0.00, P=0.96).

The proportion of time at cool temperatures decreased through time (June to October) at night (-0.02, CI=-0.03, -0.005) but did not change significantly during the day (-0.009, CI=-0.02, 0.002). Individual variation among fish was an important factor in determining the proportion of time spent at cool temperatures. The proportion of time individual ABFT spent at temperatures five or more degrees cooler than was not affected by SST (χ^2=1.35, P=0.25), fish length (χ^2=1.23, P=0.27), or location (χ^2=0.63, P=0.43), and did not differ between day and night periods (χ^2=0.41, P=0.52).

The interaction between fish length and area was significant in predicting mean depth (F=6.86, P=0.03). As fish length increased, the mean depth occupied by fish in NJ increased, whereas the mean depth occupied by fish in Massachusetts decreased with increasing length (Figure 8). However, it is likely that this is an artifact of the low sample size of fish captured in NJ because the slope is not significantly different from 0. The interaction of time period (dawn, day, dusk, night) and tagging day was significant (F=3.38, P=0.02). As time progresses, from the first tag deployment to the last day, the mean depth occupied by individual fish increased during all time periods, but the rate of increase was significantly slower at dawn (Figure 9) indicating school-size ABFT have a narrow depth preference during the shift from night to day. The individual variation among fish was an important factor in determining the mean depth fish occupied at different time periods.

The interaction of tagging day and time period was also a significant predictor of the mean temperature occupied by school-size ABFT (F=2.88, P=0.04). During day, dusk, and night the mean temperature occupied by school-size ABFT decreased through time (from July to October). The opposite behavior was observed at dawn; mean temperature increased with tagging day (Figure 10). Length was not significant in predicting the mean temperature occupied by school-size ABFT ($F=0.01$, $P=0.90$) and there was no significant difference in the mean temperature inhabited by fish in Massachusetts or New Jersey ($F=0.56$, $P=0.46$). Individual variation among fish was a significant factor in determining the mean temperature occupied by school-size ABFT. There was a significant difference in the number of vertical excursions that occurred during day and night ($F=33.2$, $P<0.0001$), such that vertical excursions are more likely to occur during the day.

DISCUSSION

Post-Release Mortality

We deployed 20 PSATs to estimate the post-release mortality rate of school-size ABFT caught in the recreational troll fishery. Nineteen tags reported and the data were consistent with the survival of those individuals. Early PSAT studies of post-release mortality typically considered non-reporting tags as no data, but in some cases included a more conservative estimate in which non-reporting tags were considered mortalities (Graves 2002; Kerstetter 2003). More recently, it has become the convention to count non-reporting tags as no data rather than as mortalities (Domeier et al.2003; Horodysky and Graves 2005). This is due to technological advances in current PSAT models with mechanisms to release tags from moribund fish, including a maximum pressure release mechanism and a constant pressure release. If a mortality were to occur one of these mechanisms would likely be triggered, causing the tag to release and the data would be consistent with a mortality. However, it is possible that a non-reporting tag could result from a predation event during which the tag was damaged (Kerstetter et al. 2004). Predation of tags and tagged fish is not uncommon and has been documented in several studies using both acoustic tags (Jolley and Irby 1979; Block et al. 1992; Pepperell and Davis 1999) and PSATs (Kerstetter et al. 2004; Polovina et al. 2008; this study). Including non-reporting tags as mortalities would bias the estimated mortality rate upwards if tags fail to report for reasons other than catch-and-release induced mortality (Goodyear 2002). Therefore, the single non-reporting tag in this study was considered as no data rather than as a mortality.

Data from one tag in this study (BFT-16) were consistent with a predation event occurring 12 days after the fish was released. In this instance, the depth profile (number and nature of vertical movements) was fairly consistent throughout the 16 day deployment of the tag and did not show a noticeable change over that time, but the temperature and light data revealed a significant change at day 12 leading to the inference of a predation event. The temperature recorded by the tag increased abruptly from approximately 19°C to 25°C on day 12 (Figure 6) and did not vary with depth, as was noted in this fish prior to that date, but remained elevated over a four day period before rapidly dropping back to 19°C (Figure 6). Over this same time period the light sensor was not subjected to changes in light (i.e., there was no day/night signal over the four days). These observations are consistent with the tag, and potentially the fish, being consumed on day 12 and regurgitated on day 16. The putative internal temperatures recorded by the tag are too low for most marine mammals, which have body temperatures closer to that of humans (Kasting et al. 1989), but are within the range reported for some endothermic sharks. The tag predator, in this case, was most likely a mako shark (*Isurus oxyrinchus*) or a porbeagle shark (*Lamna nasus*), both of which are known to consume scombrids (Stillwell and Kohler 1982; Joyce et al. 2002) and maintain internal temperatures 7-10°C above ambient (Carey and Teal 1969).

It has been shown in several studies that the majority of angling or tagging related mortalities of HMS occur within minutes to hours after release (Stokesbury et al. 2004; Horodysky and Graves 2005; Wilson et al. 2005). These mortalities are likely due to hook-induced tissue damage and bleeding, or the overall stress of the capture and tagging events. The inferred predation of BFT-16 occurred 12 days after release and we assume that this predation was not directly related to the capture and tagging of the fish.

The results of this study indicate that all 19 fish whose tags reported survived for a minimum of six days, yielding a post-release mortality rate of 0% (CI=0%,10%; Figure 7). The mortality rate for the current study is lower than that inferred based on hook location for juvenile ABFT (63-131cm curved fork length) caught on natural baits rigged with either circle hooks (4%) or "J" hooks (28%, Skomal et al. 2002). The fishing method used by Skomal et al. (2002) to catch juvenile ABFT is very different from high-speed trolling which was employed in this study. Fish are more likely to swallow the bait in a fishery involving chunking or when baits are dropped back during slow trolling, as in the white marlin and sailfish fisheries (Graves and Horodysky 2010). In these types of fisheries the fish has more time to consume the bait before the hook is set, increasing the chances of deep-hooking which can result in damage to vital tissues and organs. In high speed troll fisheries, the target species often attacks the bait more aggressively, often hooking itself, with the hook lodging in or around the mouth (Graves and Horodysky 2010, this study).

In the only study of post-release mortality of ABFT, Stokesbury et al. (2011) used PSATs to investigate the post-release mortality of giant ABFT (114-455kg) in the Gulf of St. Lawrence, off the coast of Prince Edward Island, Canada. Their study focused on an experimental recreational fishery in which experienced anglers used the chunking method of fishing and rigged the baits with custom-made, barbless circle hooks. Sixty fish were caught in this study, one of which was dead upon inspection at the boat. Of the 59 tags deployed, four did not report and two transmitted data consistent with mortality of the tagged ABFT. The estimated mortality rate for this experimental fishery when removing the non-reporting tags from analyses and including the fish that died before tagging as a mortality was 5.6% (three mortalities out of 55 individuals). It should be noted that this value may underestimate the true mortality rate of the fishery if inexperienced anglers and captains were to participate.

The current study provides the first estimate of post-release mortality for school-size ABFT caught under normal recreational fishing conditions (0%, CI=0%, 10%). This study was limited by a small sample size (19 reporting tags) and it is likely that the true post-release mortality rate is greater than 0%. The 95% confidence interval of 0-10% mortality calculated for our results is smaller than that of Stokesbury et al. (2011), 1.7-13.6%despite the lower sample size in our study. This is due to the absence of observed mortalities in the current study versus the three mortalities (two inferred, one observed) in Stokesbury et al. (2011). If a single mortality had been inferred in this study it would change the estimated post-release mortality rate to 5.3% and greatly expand the confidence interval to between 0 and 21%. To obtain a more precise estimate of post-release mortality of school-size ABFT caught in the recreational troll fishery, more PSATs would need to be deployed. Based on simulations using an underlying mortality rate of 0% as estimated by this study, a minimum of 60 tags would be required to reduce the confidence intervals to within 5% of the true mortality rate. If the mortality rate is closer to that seen with a single mortality (5.3%) it would require a minimum of 200 tags to reduce the confidence intervals to within 5% of the true mortality rate. With the current cost of PSATs near $4,000 it may not be feasible to explore the post-release mortality rate of school-size ABFT in the recreational troll fishery to the extent necessary to obtain a high-precision estimate.

Using the confidence interval of 0-10%, the post-release mortality calculated in this study, and the number of releases of school-size ABFT in the U.S. recreational fishery from 2002 to 2010 based on estimates from the LPS, it is possible to estimate the upper and lower limits of school-size ABFT that would have died after release. There would have been an additional mortality of 0 to 2,147 ABFT per year between 2002 and 2010 (Table 4). For comparison, the recreational landings of ABFT in those years ranged between 1,450 and 10,848 school-size ABFT (Table 4) indicating that when compared with the landings of school-size ABFT, post-release mortality does not represent a significant source of fishing mortality.

Habitat Utilization

To date, only three studies have focused on the movement and habitat utilization of juvenile ABFT. Yamashita and Miyabe (2001) found that juvenile ABFT in the Mediterranean spent the majority of their time in the top 50m of the water column but made excursions exceeding 700m. Brill et al. (2002) reported that juvenile ABFT in the western Atlantic spent ~90% of their time in the top 15m of the water column but exploited depths exceeding 160m. Similarly, Galuardi and Lutcavage (2012) found that juvenile ABFT spent the vast majority of their time in the upper 20m of the water column while making periodic excursions to depths up to 800m. Data from the current study indicated a similar trend in the proportion of time at depth with juvenile ABFT spending 67% of their time in the top 20m of the water column and 90% of their time in the upper

40m of the water column, while occasionally making excursions to depths exceeding 190m. These studies clearly demonstrate that while juvenile ABFT are capable of exploiting depths exceeding 150m they spend the majority of their time at relatively shallow depths. The four studies of habitat utilization of juvenile ABFT indicate similar behaviors for this size range of fish (70-168cm FL). However, there are a few differences in depth and temperature utilization which may be due to factors such as location, time of year, the recording frequency of the devices used to gather data, or a combination of factors.

Roffer (1987) found that the distribution of juvenile ABFT is related to water temperature and that these fish appear to have a preferred temperature range between 18 and 23°C. School-size ABFT in the current study spent 80% of their time between 17 and 24°C (Figure 11). This temperature range is comparable to juvenile ABFT tagged off of Virginia Beach, VA which spent ~90% of their time in waters exceeding 20°C (Brill et al. 2002). While ABFT in the current study frequently experienced temperature changes of greater than 10°C over short time intervals, consistent with the findings of Brill et al. (2002), the fish spent 90% of their time within 5°C of sea-surface temperature (Figure 4).

The behavior of juvenile ABFT in the current study is similar to that reported for adult ABFT in several studies. Both juvenile and adult ABFT spend the majority of their time in the upper portion of the water column at relatively warm temperatures. However, tagged adult ABFT have been recorded at depths exceeding 1,000m and temperatures as cold as 3°C (Block et al. 2001; Teo et al. 2007) indicating a greater temperature range than that seen in juvenile ABFT. Adult ABFT tagged with either acoustic tags (Lutcavage et al. 2000) or PSATs (Stokesbury et al. 2004; Wilson et al. 2005) spent at least 50% of their time in the top 20m of the water column and the majority of their time at temperatures between 15 and 26°C. The difference in the range of temperatures exploited by adult and juvenile ABFT may be related to the development of endothermy in tunas. Endothermy is developed in the juvenile stages of tunas (Dickson 1994). It is accompanied by increases in the ability to produce and retain metabolic heat, and is correlated to changes in body shape (Graham and Dickson 2001). As tunas grow there is a decline in the ratio of surface area to volume and an increase in girth leading to a higher thermal inertia for larger fish (Graham and Dickson 2001). In addition, the red muscle of large tunas is more protected from the water than in small tunas, potentially decreasing the rate at which heat is lost (Graham and Dickson 2001). These observations were supported by data gathered from archival tags deployed on bigeye tuna in the Pacific Ocean. A bigeye tuna measuring of 131cm FL returned to the surface to thermoregulate approximately half as frequently as a fish measuring 79cm FL (Musyl et al. 2003) indicating a potential link between size and the ability to retain metabolic heat in tunas.

The results of the current study indicate that school-size ABFT spent a higher proportion of time at depth during the day than at night but there was no diel difference in the proportion of time spent at cool temperatures. The observation of mean depths corresponds to the results of Wilson et al. (2005) in adult ABFT, but contrasts with the studies done by Brill et al. (2002) and Galuardi and Lutcavage (2012), both of which indicated that there were no diel differences in the distribution of depths or temperatures experienced by juvenile ABFT. The difference between the studies of juvenile ABFT could be due to differing oceanographic conditions between locations or time of tagging, both time of year and different years. In addition, there may be differences in the availability of prey species that affected the distribution of juvenile ABFT over the time of tag deployment.

Mean depths and temperatures of school-size ABFT were not different through time for all time periods except dawn in the current study. The lack of diel differences in mean depth and temperature contrasts with the results reported for adult ABFT by Stokesbury et al. (2004), who reported deeper mean depths at night than during the day. It is likely that this behavior was not related to feeding as closely related species such as Pacific bluefin tuna (*Thunnus orientalis*) appear to have poorer low-light vision than other marine fishes (Ishibashi et al. 2009; Matsumoto et al. 2009; Matsumoto et al. 2011; Torisawa et al. 2011) and are presumed not to feed at night (Kitagawa et al. 2007). However, tunas may feed on nights near the full moon when it is likely that light penetrates further into the water column as several studies have documented an effect of lunar phase on nighttime depth distributions of various tuna species (Schaefer and Fuller 2002; Musyl et al. 2003; Wilson et al. 2005; Bestley et al. 2009).

Crepuscular differences in mean depth and temperature of school-size ABFT have not been investigated in previous studies but the data from the current study indicate that mean depth at all time periods increased as time progressed from June to October. The rate of increase was slower for the dawn time period relative to all other time periods (Figure 9). Mean temperature decreased slightly through time (June to October) in all time periods except dawn, which increased slightly. The increase in mean depth with only a slight decrease in mean temperature is indicative of an increased mixed surface layer. This increase in the depth of the mixed layer may be due to storms mixing the water column in the latter portion of this study.

The number of vertical excursions undertaken by school-size ABFT was greater during the day than at night. This may be linked to the highly visual nature of ABFT as predators. Tunas have the highest retinal cell density in the ventro-temperal region demonstrating that their best visual axis is up and forward (Tamura and Wisby 1963; Kawamura et al. 1981; Somiya et al. 2000) indicating that they are most likely to attack potential prey that are silhouetted by downwelling light from below. It follows that ABFT would be more likely to make excursions to depth during the day when downwelling light is at its greatest and they are more likely to see prey items as silhouettes against a bright background.

The four studies of western Atlantic juvenile ABFT habitat utilization reveal similar behavioral patterns although there are some minor differences among the studies which are likely due to variation in the spatial and temporal coverage of these studies, as well as variation in prey availability. The data from these studies indicate juvenile ABFT are surface oriented, spending the majority of their time in the upper 20-30m of the water column and in waters greater than 18°C during the summer (Yamashita and Miyabe 2001; Brill et al. 2002; Galuardi and Lutcavage 2012; this study).

Conclusions

Bluefin tuna are an important commercial and recreational resource throughout the North Atlantic Ocean. Recent stock assessments indicate that the biomass of the western stock of ABFT is approximately 19% of that necessary for maximum sustainable yield based on the high recruitment model (SCRS 2012). Despite management measures introduced over the past 20 years, including a minimum size and decreasing TACs, little recovery has been observed in the western Atlantic stock and overfishing is still occurring (SCRS 2012). Bag limits within the U.S. recreational fishery have been reduced over the last 20 years resulting in a recreational fishery that is largely catch-and-release. This has led to concerns regarding the fate of the high numbers of juvenile ABFT released from the recreational fishery. In light of these concerns this study investigated the post-release mortality of school-size ABFT caught using the most common method in the U.S. recreational fishery, trolling. Although somewhat limited by a small sample size of PSATs, the results of this study suggest the post-release mortality of school-size ABFT caught using trolling methods is relatively low and is likely not a major contributor to the overall fishing mortality of ABFT.

The recreational fishery uses methods other than trolling, including chunking, jigging, sight casting, and fly fishing (see Appendix 1). While trolling appears to result in a low post-release mortality rate other methods of recreational fishing will likely have different rates of post-release mortality. Therefore, it would be beneficial to investigate the effects of different fishing methods, gear types (circle versus "J" hooks), and fight times on the post-release mortality of ABFT. Different size classes of ABFT may also incur different mortality rates (Stokesbury et al. 2011) and this merits investigation. Other interactions with recreational fishing gear may also contribute to the overall fishing mortality of ABFT. Many ABFT interact with fishing gear but are not caught and these interactions probably results in another form of cryptic fishing mortality which should be investigated.

The results of this study, in conjunction with previous investigations (Yamashita and Miyabe 2001; Brill et al. 2002; Galuardi and Lutcavage 2012), provide insights into the habitat utilization of juvenile ABFT. Given the small sample size and limited spatial and temporal coverage the results of this study should only be applied to school-size ABFT offshore of New Jersey and Massachusetts during the summer. The higher frequency of dives and the increased proportion of time spent at depth during the day, in concert with studies of tuna vision (Ishibashi et al. 2009; Matsumoto et al. 2009; Matsumoto et al. 2011; Torisawa et al. 2011) suggest that juvenile ABFT are well-suited to foraging in areas where prey are likely to be backlit by the downwelling sunlight. Therefore, while ABFT are likely to forage in near-surface waters, the high proportion of time spent there is probably related to foraging, thermoregulation, or other reasons.

There have been several studies on the movements and habitat utilization of adult ABFT, however, juvenile ABFT habitat utilization has not been well studied. It is important to better understand the habitat utilization of juvenile ABFT in order to avoid potential interactions with commercial fisheries such as the longline fishery which has historically discarded large numbers of ABFT. To date, data have been recovered from 25 PSATs deployed on school-size ABFT, 19 large-school ABFT, and 1 small-medium ABFT with limited spatial and temporal coverage. While acoustic and internal archival tags have been deployed within these size classes, short tracks and a small sample size for acoustic tags, and low tag returns for internal archival tags have resulted in less information than anticipated. Therefore, the habitat utilization of juvenile ABFT requires additional investigation to elucidate differences in behavior between different size classes, areas, and times of year.

APPENDIX 1: History of the ABFT Fishery (Last 30 Years)

In order to gain insight into how the recreational ABFT fishery has changed over the last 30 years five captains with a minimum of 13 years of experience in the ABFT fishery were interviewed. These captains represented areas with historically high landings of ABFT: Cape Cod, MA (n=2), Point Judith, RI (n=2), and Ocean City, MD (n=1). While there is some regional variation in the methods used to target school-size ABFT, trolling lures seems to be the dominant method, followed by chunking, the process of drifting baited hooks while chumming, though several captains mentioned that jigging and sight casting are both increasing in popularity. The methods used by the captains often depend on the behavior of the fish. Typically, early in the season when ABFT are dispersed, captains troll lures almost exclusively to cover a large area during the day and increase the odds of encountering fish. When ABFT begin to congregate on schools of bait, chunking and jigging methods are used increasingly. Different methods are also used to target different size classes of fish. Trolling is most commonly used for smaller ABFT (school and large-school) while chunking is common for larger fish (large-medium and giant), especially in Massachusetts. However, captains noted that all size classes can be caught using any method.

Several captains noted that there have been small but significant changes in the types of gear used in the ABFT fishery including smaller sized terminal tackle and a larger variety of lures. These changes also include the use of fluorocarbon line and leaders, which typically have a smaller diameter while maintaining the strength of monofilament. Fluorocarbon line is also virtually clear making it difficult for fish to see. The materials typically used to manufacture rods have also shifted from fiberglass to graphite and reels have become smaller and lighter.

The most significant change in the ABFT fishery in the last 30 years is probably the increasingly strict regulations placed on charter and recreational captains. The captains interviewed for this study generally believe that the current bag limits for ABFT have decreased the interest of clients in targeting ABFT. This tends to have two effects, 1) a decrease in the number of trips targeting ABFT and 2) once the bag limit is reached the charter shifts their focus to other species. One captain indicated that in the last 20 years the number of ABFT trips that he charters has decreased from 30 to 40 trips per year to two or three trips per year.

Table 1. Size classes of Atlantic bluefin tuna. Lengths and weights were obtained from the Atlantic Bluefin Tuna Status Review Team (2011). Ages were obtained from Restrepo et al. (2010). Retention of young-school bluefin tuna is prohibited and the large-medium and giant size classes are considered "trophy" fish in the recreational fishery.

Size Class	Length (cm)	Weight (kg)	Age (Years)
Young School	<69	<6.4	<2
School	69-<119	6.4-<30	2-4
Large School	119-<150	30-<62	4-6
Small Medium	150-<185	62-<107	6-9
Large Medium	185-<206	107-<141	9-11
Giant	≥206	≥141	>11

Table 2. Catch information for 20 school-size ABFT caught by trolling in the U.S. recreational fishery and tagged with PSATs in the summer of 2012. Deployment location NJ is off of Point Pleasant, NJ and MA is off of Chatham, MA.

Fish	Deployed (2012)	Deployment Location	Length (cm)	Hooking Location	Bleeding	Location of Bleeding	Fight Time (min)	Tagging Time (min)	Total Time (min)
1	6/19	NJ	109	corner of jaw	None	NA	7.0	3.0	10.0
2	6/19	NJ	107	orbit	Heavy	orbit	7.0	4.0	11.0
3	6/19	NJ	102	upper jaw	Light	under orbit	10.0	2.0	12.0
4	8/2	MA	109	upper jaw	Light	upper jaw	6.0	2.0	8.0
5	8/2	MA	107	corner of jaw	None	NA	6.0	1.0	7.0
6	8/2	MA	107	lower jaw	Light	lower jaw	9.5	1.0	10.5
7	8/4	MA	107	upper jaw	Light	upper jaw	6.0	1.0	7.0
8	8/29	MA	117	orbit	Light	orbit	7.0	2.0	9.0
9	9/12	MA	114	lower jaw	Light	lower jaw	11.0	1.0	12.0
10	9/12	MA	114	upper jaw	Light	upper jaw	4.0	2.0	6.0
11	9/14	MA	109	upper jaw	Light	upper jaw	9.0	2.0	11.0
12	9/14	MA	117	upper jaw	Heavy	upper jaw and lip-gaff wound under jaw	7.0	2.0	9.0
13	9/15	MA	117	upper jaw	Light	upper jaw	5.0	1.0	6.0
14	9/15	MA	114	upper jaw	None	NA	5.0	0.5	5.5
15	9/15	MA	91	upper jaw	Light	upper jaw	6.0	1.0	7.0
16	9/21	MA	91	lower jaw	Light	lower jaw	7.5	2.0	9.5
17	9/21	MA	119	upper jaw	Light	upper jaw	10.0	1.0	11.0
18	9/22	MA	99	upper jaw	None	NA	8.0	1.0	9.0
19	9/22	MA	99	lower jaw	Light	lower jaw	9.5	1.5	11.0
20	9/22	MA	119	orbit	Light	orbit	9.0	2.0	11.0

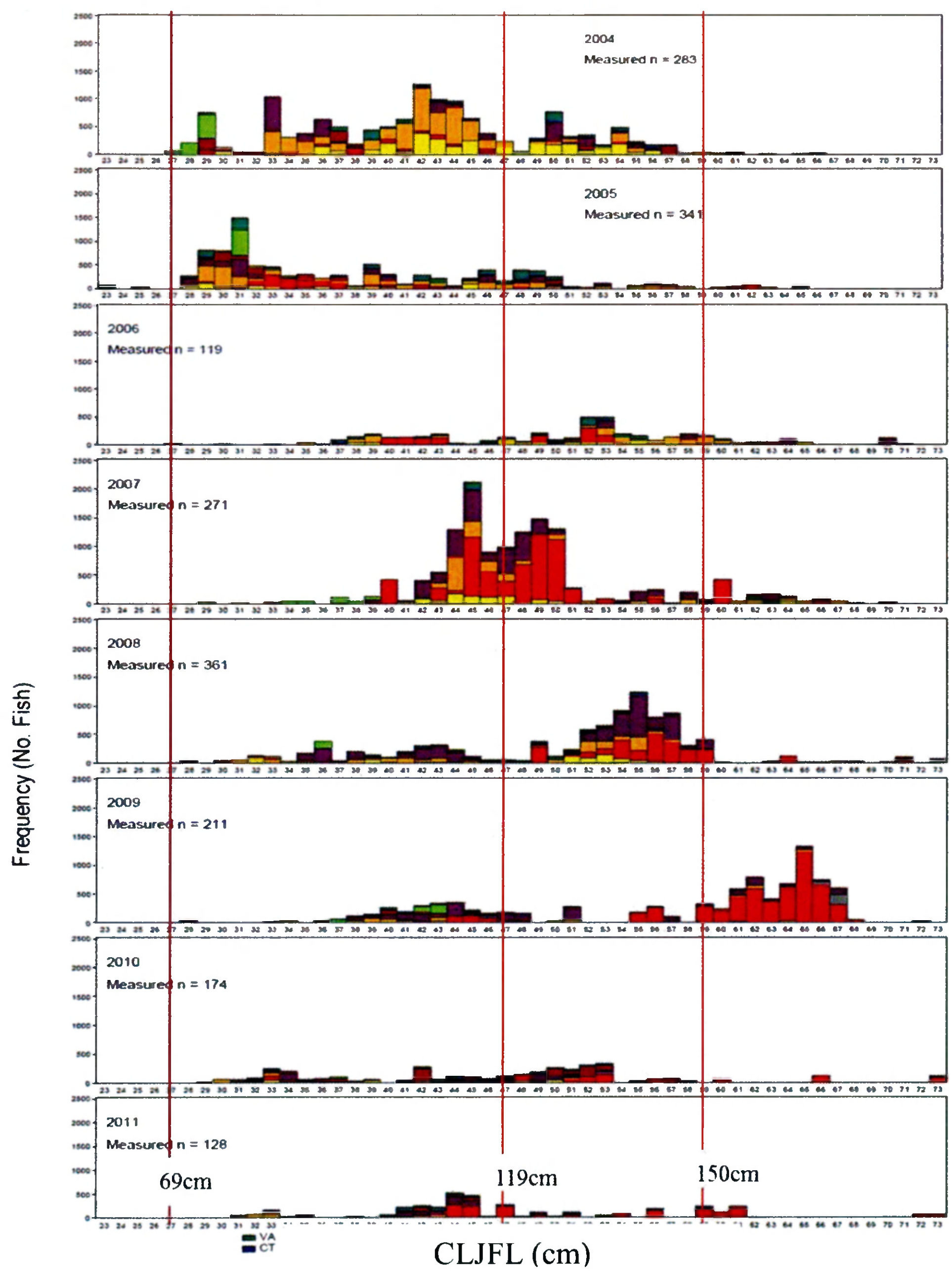
Table 3. Deployment and reporting dates of 20 PSATs deployed on school-size ABFT caught by trolling in the U.S. recreational fishery during the summer of 2012. Asterisks indicate tags that released prematurely.

Fish	Deployed	Reported	Days Deployed	% Data	Straight Line Distance (km)
1	6/19/2012	7/19/2012	31	79	266.1
2*	6/19/2012	6/29/2012	7	34	36.4
3*	6/19/2012	7/15/2012	26	86	62.1
4	8/2/2012	9/2/2012	31	89	207.3
5	8/2/2012	9/2/2012	31	85	44.4
6*	8/2/2012	8/8/2012	6	100	59.4
7	8/4/2012	9/4/2012	31	80	97.9
8	8/29/2012	9/28/2012	31	89	118.0
9	9/12/2012	10/12/2012	31	86	134.6
10	9/12/2012	10/12/2012	31	86	109.6
11	9/14/2012	10/14/2012	31	88	48.6
12	9/14/2012	10/14/2012	31	87	245.1
13	9/15/2012	10/15/2012	31	87	402.5
14	9/15/2012	10/15/2012	31	88	189.9
15	9/15/2012	10/15/2012	31	91	121.3
16*	9/21/2012	10/6/2012	16	98	18.0
17	9/21/2012	10/21/2012	31	89	169.8
18	9/22/2012	10/22/2012	31	90	116.4
19	9/22/2012	10/22/2012	31	80	185.8
20	9/22/2012				Did Not Report

Table 4. Large Pelagics Survey estimates of the number of school-size ABFT landed and released from the U.S. recreational fishery each year (2002-2010) and the number of mortalities associated with either a 5% or 10% post-release mortality rate.

Year	Landings	Releases	Morality Rate	
			5%	10%
2002	10363	3252	163	325
2003	7589	2007	100	201
2004	10848	16962	848	1696
2005	7663	21469	1073	2147
2006	1450	8222	411	822
2007	6086	6902	345	690
2008	3014	4923	246	492
2009	2573	2100	105	210
2010	1836	4378	219	438

Figure 1. Landings of Atlantic bluefin tuna in the U.S. recreational fishery by year estimated by the Large Pelagics Survey. Years 2004 and 2005 represent typical landings with most individuals within the school size-class. The reduced landings over all size classes in 2006 were due to a shortened open season because the United States was in danger of exceeding its quota of undersized ABFT in the fourth year of the four-year management period. Years 2004 to 2009 show the 2003 year class progressing through the recreational fishery size classes and into the commercial size range ($\geq$185cm curved lower jaw fork length).



2004
Measured n = 283
2005
Measured n = 341
2006
Measured n = 119
2007
Measured n = 271
2008
Measured n = 361
2009
Measured n = 211
2010
Measured n = 174
2011
Measured n = 128
69cm
119cm
150cm
VA
CT
Frequency (No. Fish)
CLJFL (cm)

Figure 2. Tagging of school-size Atlantic bluefin tuna. The tag anchor was implanted into the dorsal musculature posterior and ventral to the anterior insertion of the first dorsal fin as indicated by the arrows.

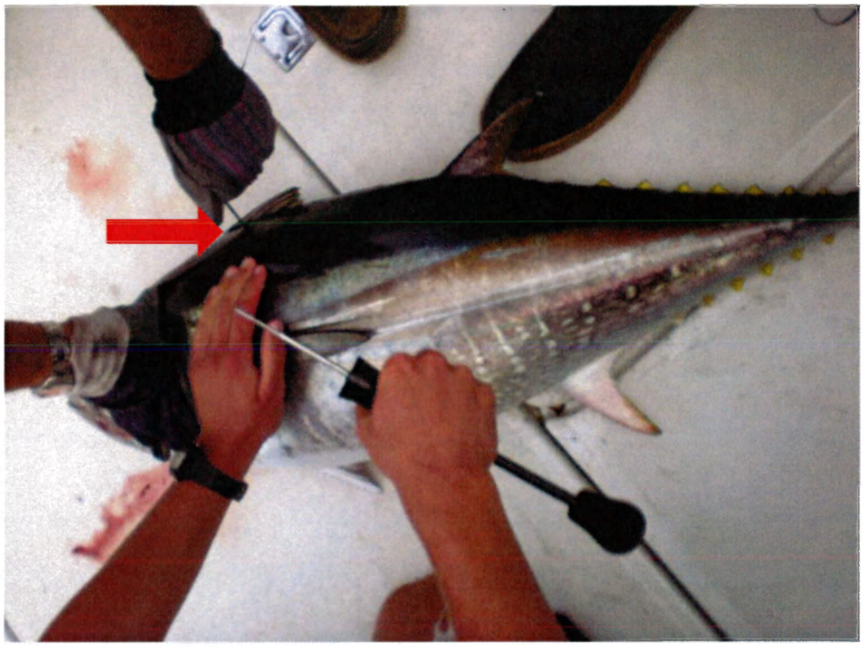


Figure 3. The proportion of time spent at depth in 10-meter bins pooled across all school-size Atlantic bluefin tuna. The vast majority of time, between June and October, was spent in the top 30 meters of the water column.

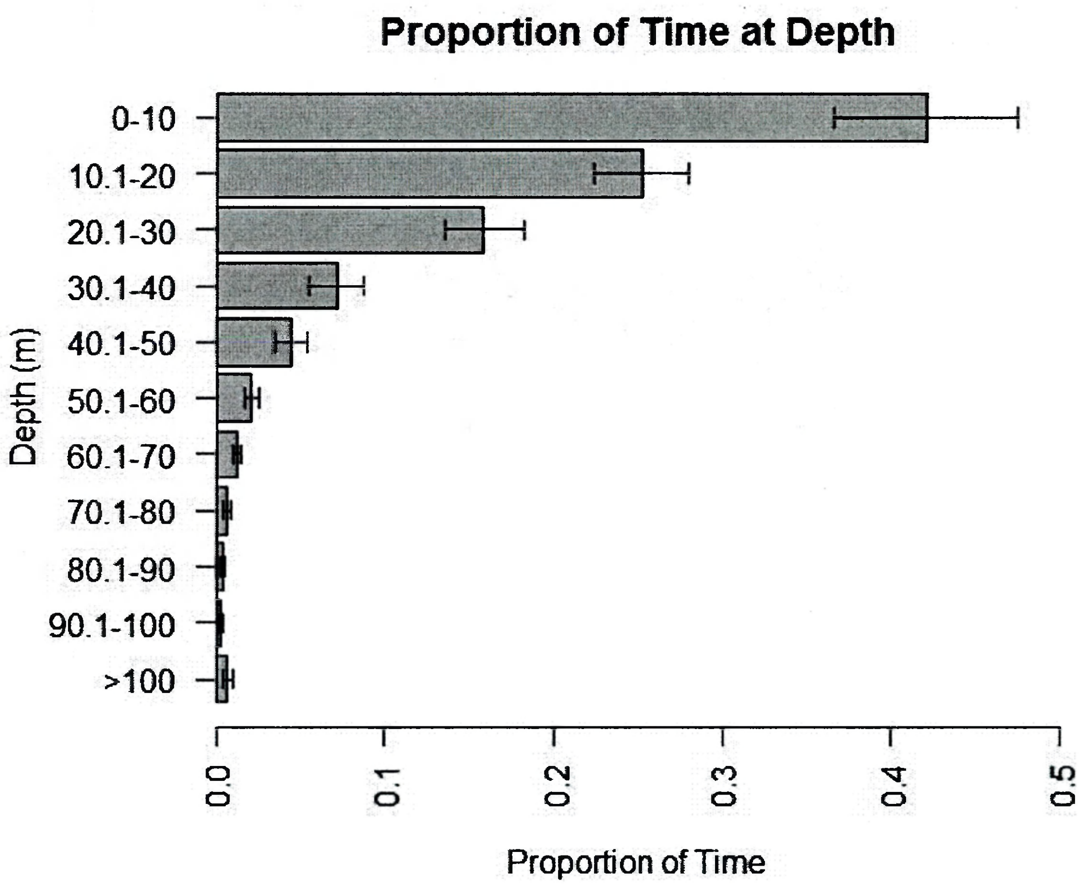
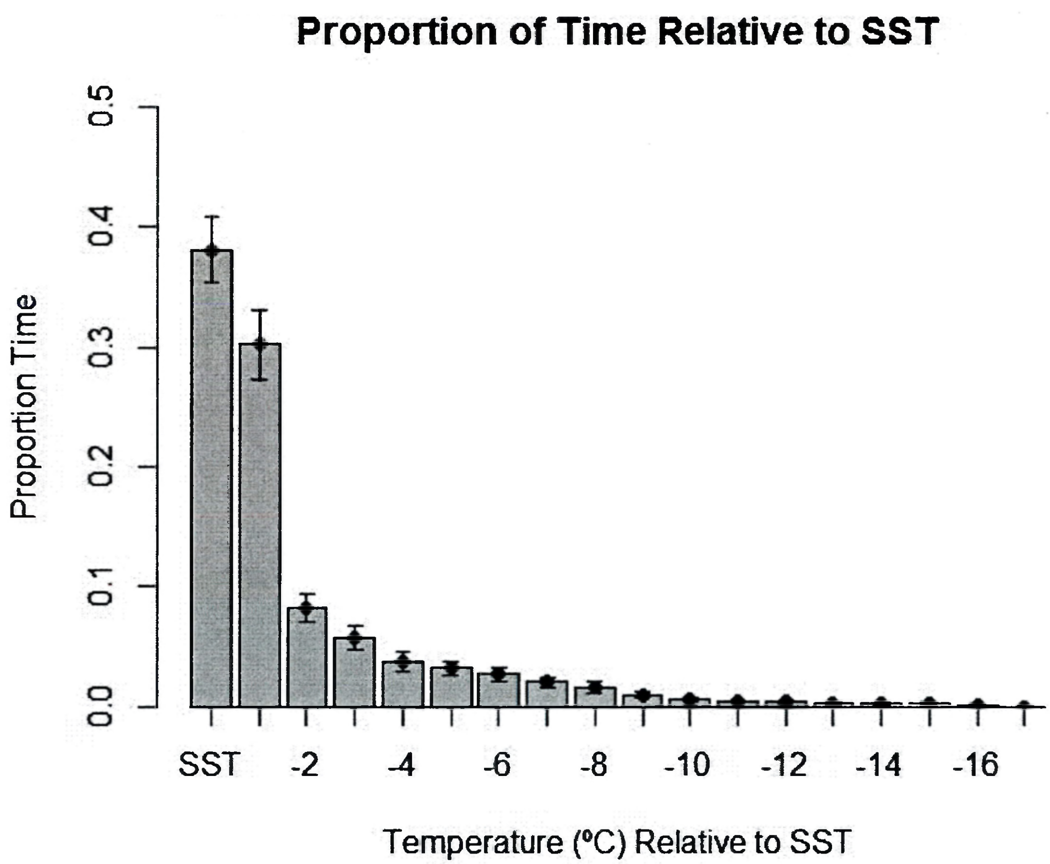

Proportion of Time at Depth
Depth (m)
0-10
10.1-20
20.1-30
30.1-40
40.1-50
50.1-60
60.1-70
70.1-80
80.1-90
90.1-100
>100
0.0
0.1
0.2
0.3
0.4
0.5
Proportion of Time

Figure 4. The proportion of time spent at temperatures relative to sea surface temperature pooled across all school-size Atlantic bluefin tuna. School-size ABFT spent ninety percent of their time within 5°C of sea surface temperature.



Proportion of Time Relative to SST
Proportion Time
0.0
0.1
0.2
0.3
0.4
0.5
SST
-2
-4
-6
-8
-10
-12
-14
-16
Temperature (°C) Relative to SST

Figure 5. Tagging and pop-up locations of PSATs deployed on school-size Atlantic bluefin tuna during the summer of 2012. Tagging and pop-up locations are denoted by the yellow circles and red squares, respectively. The distance traveled by each fish is indicated by the purple lines for fish released in June, green lines for August, and red lines for September).

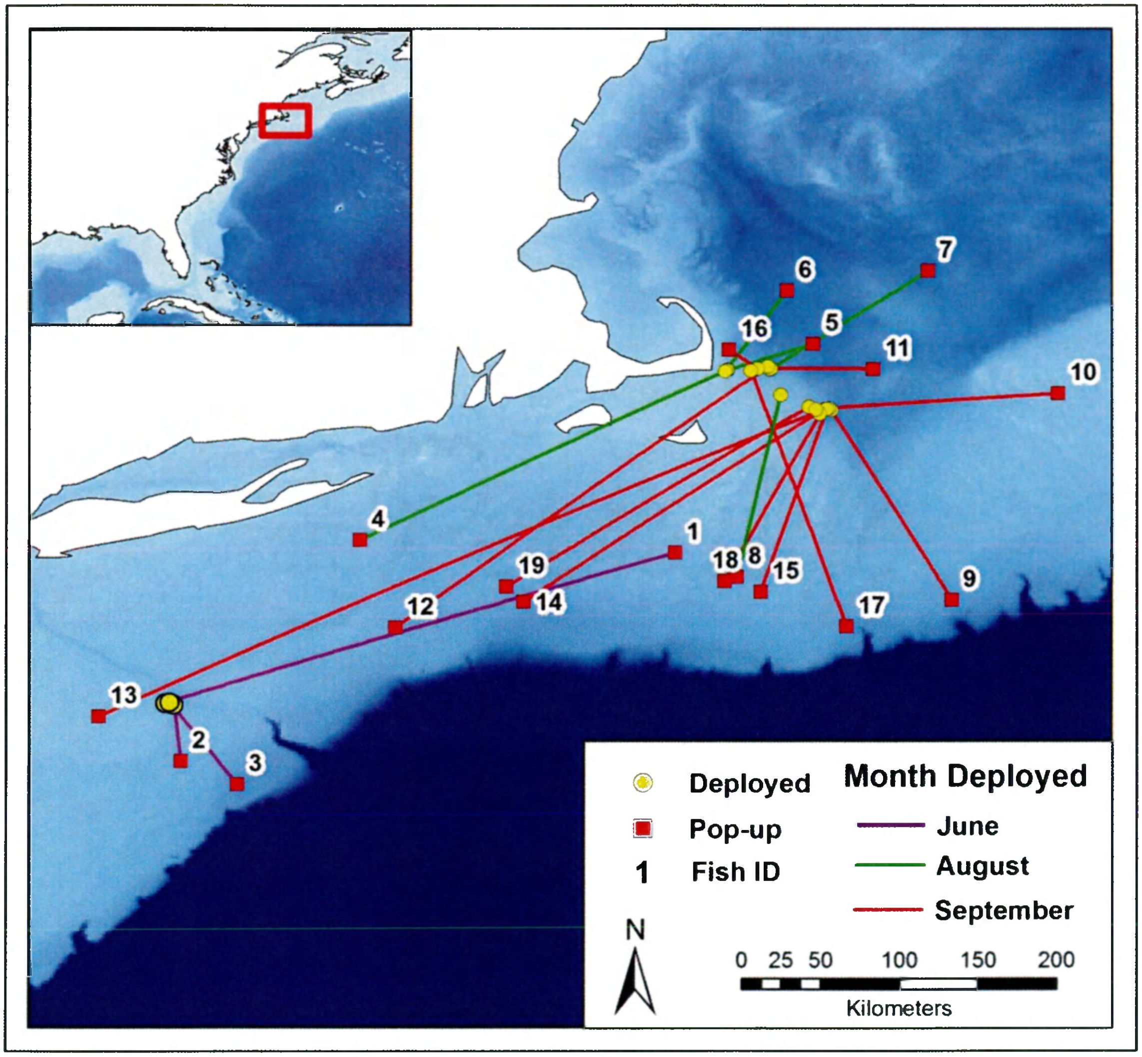

7
6
16
5
11
10
4
1
19
18
8
15
9
12
14
17
13
2
3
Deployed
Pop-up
1 Fish ID
Month Deployed
June
August
September
N
0 25 50 100 150 200
Kilometers

Figure 6. Depth, temperature, and light profiles for BFT-16, a school-size Atlantic bluefin tuna, over the 16 day pop-up satellite archival tag deployment period. The data are consistent with the tag (and possibly the fish) being consumed. Note an abrupt increase in temperature on October 2^{nd} (day 12), and a lack of variation in temperature with depth after that date. On October 2^{nd} there was a loss of the day/night cycle. These data are consistent with predation by an endothermic predator, most likely a shark.

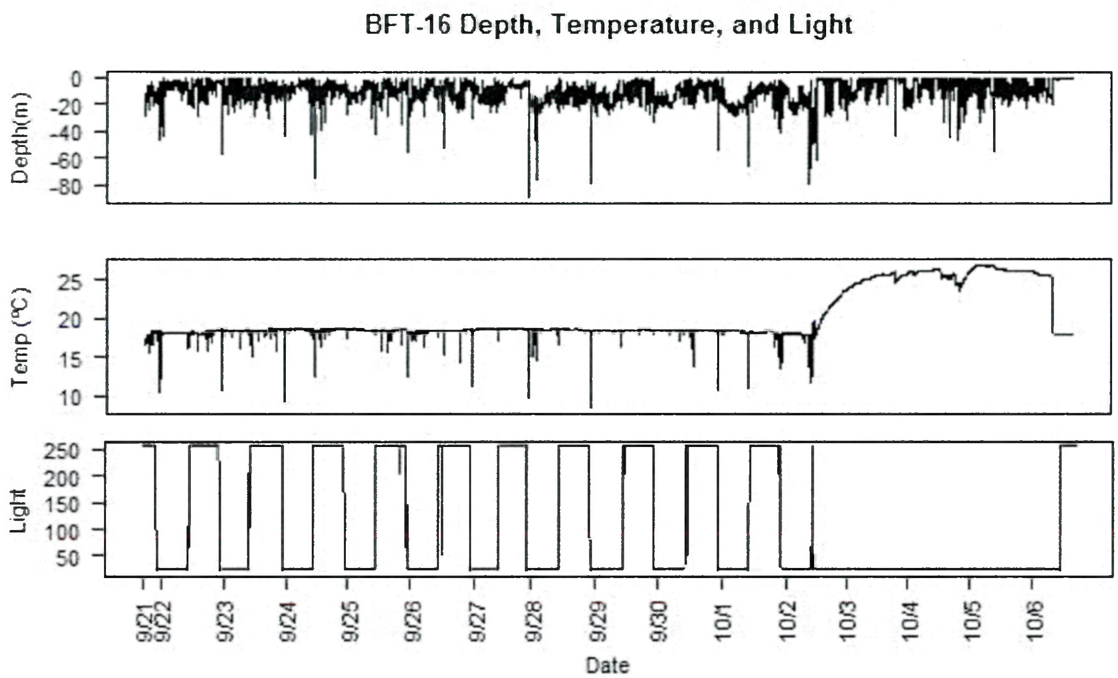

BFT-16 Depth, Temperature, and Light
Depth(m)
0
-20
-40
-60
-80
Temp (ºC)
25
20
15
10
Light
250
200
150
100
50
9/21
9/22
9/23
9/24
9/25
9/26
9/27
9/28
9/29
9/30
10/1
10/2
10/3
10/4
10/5
10/6
Date

Figure 7. Confidence limits around the estimated post-release mortality rate of 0% with varying numbers of tags deployed; confidence intervals were estimated following Goodyear (2002).

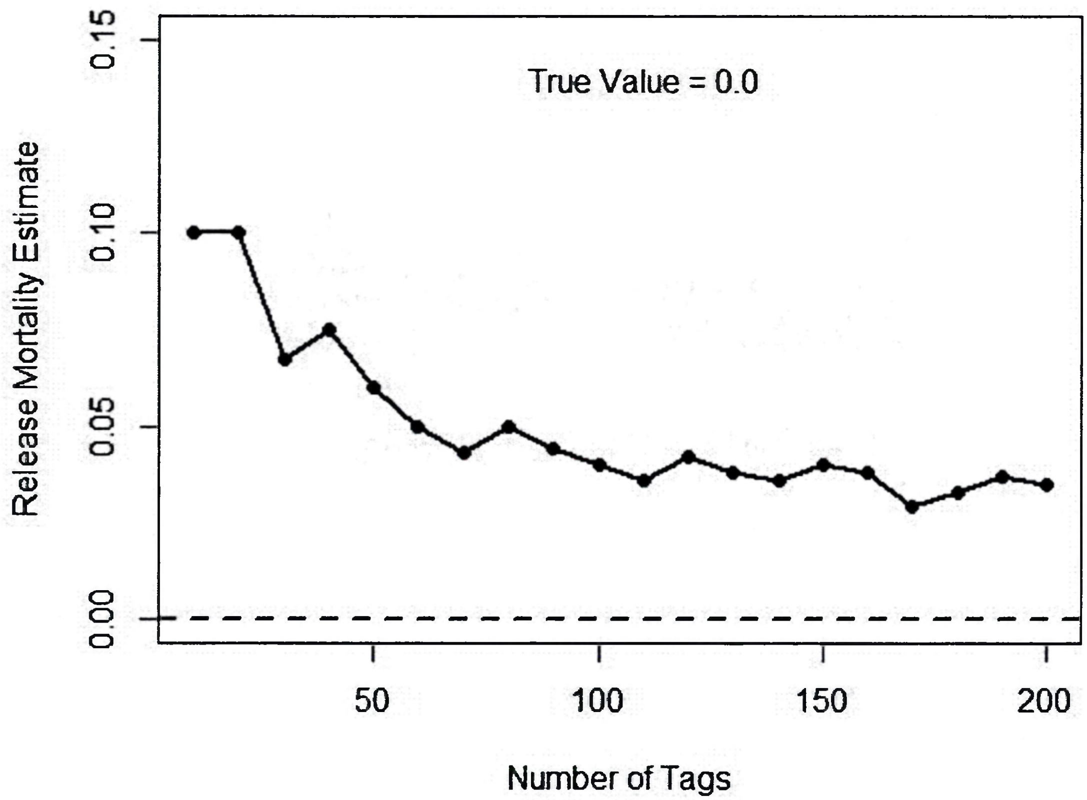
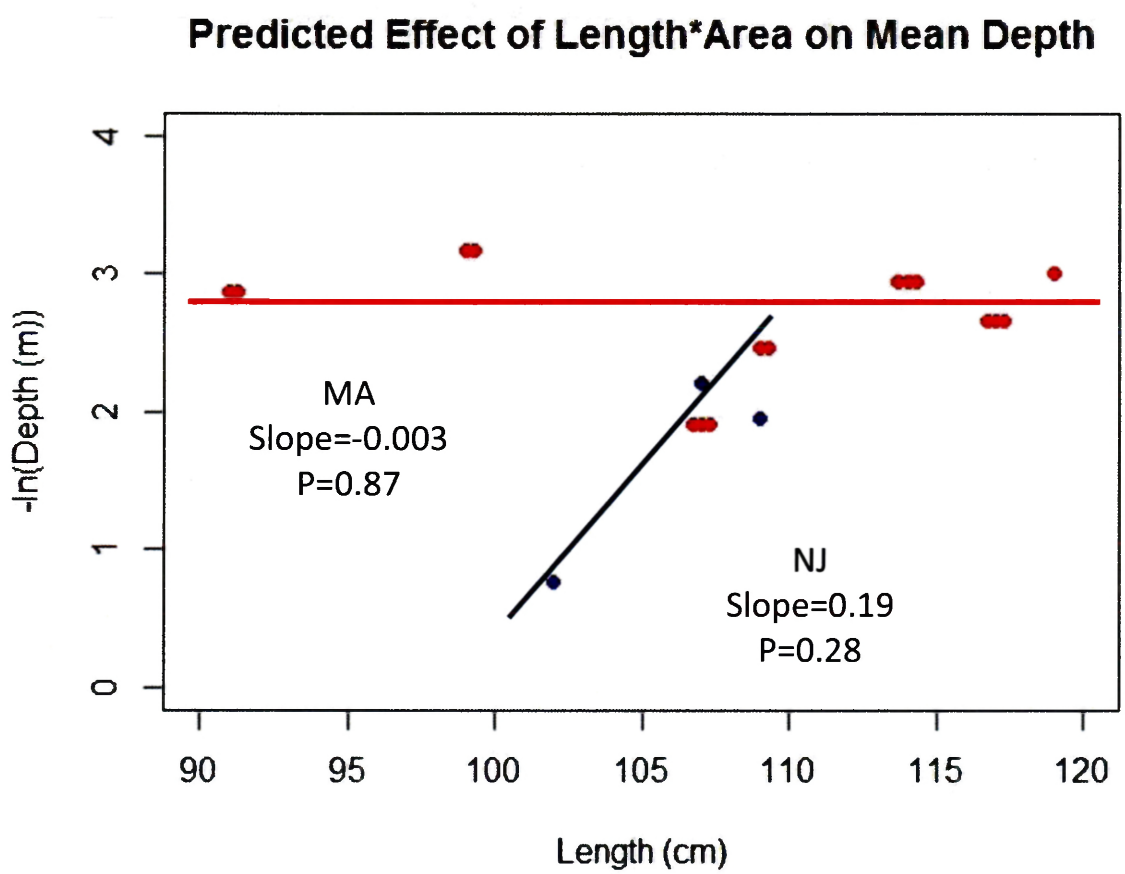

True Value = 0.0
Release Mortality Estimate
0.00
0.05
0.10
0.15
50
100
150
200
Number of Tags

Figure 8. The interaction of fish length and area for the mean depth occupied by school-size Atlantic bluefin tuna. Mean depth increased with fish length in NJ but decreased slightly with increasing length in MA. Log units of 0 to 4 correspond to depths of 0 to 25 meters. This interaction, while statistically significant is likely not of biological significance as cardiac function of tunas is dependent on ambient temperature which decreases with depth and is not dependent on the size of the fish.



Predicted Effect of Length*Area on Mean Depth
-ln(Depth (m))
0
1
2
3
4
MA
Slope=-0.003
P=0.87
NJ
Slope=0.19
P=0.28
90
95
100
105
110
115
120
Length (cm)

Figure 9. The interaction between time period (dawn, day, dusk, night) and tagging days for the mean depth occupied by school-size Atlantic bluefin tuna. As tagging days increased mean depth also increased. The rate of increase was slower for dawn than all other time periods. Log_e units of -1 to 4 correspond to depths of 0.3 to 40 meters.

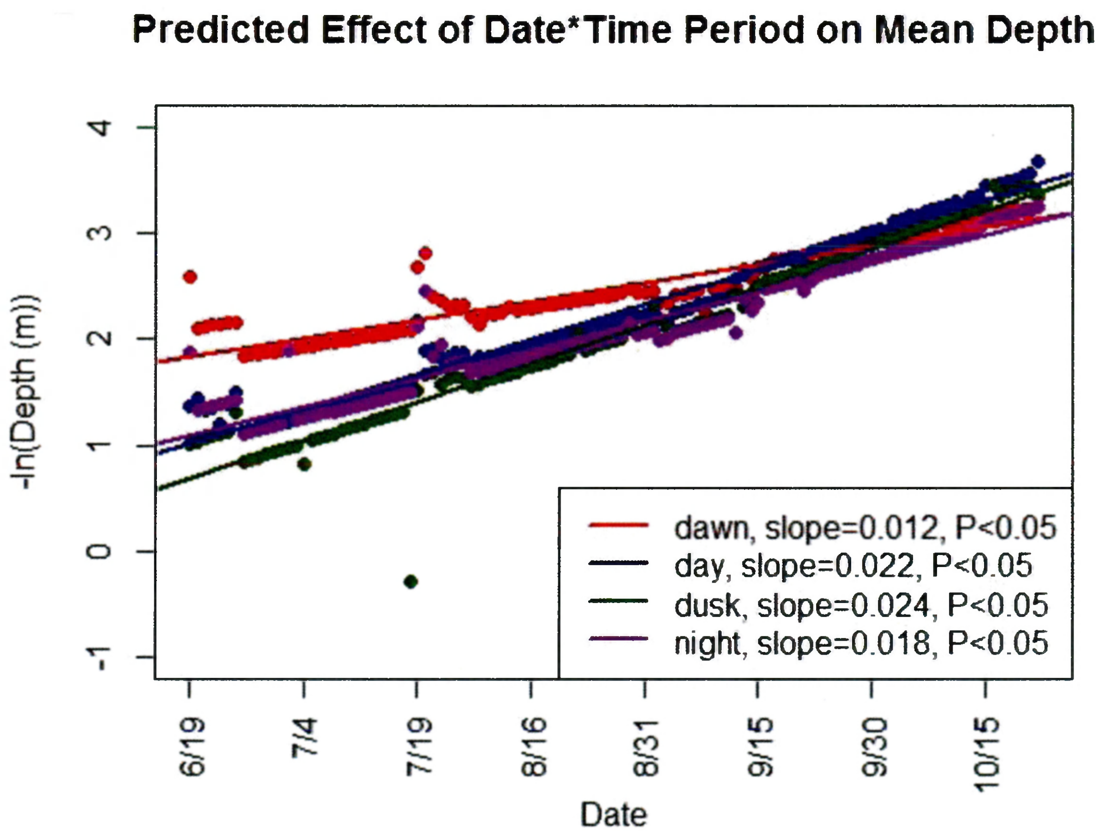

Predicted Effect of Date*Time Period on Mean Depth
-ln(Depth (m))
4
3
2
1
0
-1
dawn, slope=0.012, P<0.05
day, slope=0.022, P<0.05
dusk, slope=0.024, P<0.05
night, slope=0.018, P<0.05
6/19
7/4
7/19
8/16
8/31
9/15
9/30
10/15
Date

Figure 10. The interaction of time period (dawn, day, dusk, night) and tagging day for mean temperature occupied by school-size Atlantic bluefin tuna. As tagging days increased the mean temperature decreased for all time periods except dawn, which increased. Log_e units of 2.7 to 3.1 correspond to temperatures of 15 to 22°C.

Predicted Effect of Date*Time Period on Mean Temp

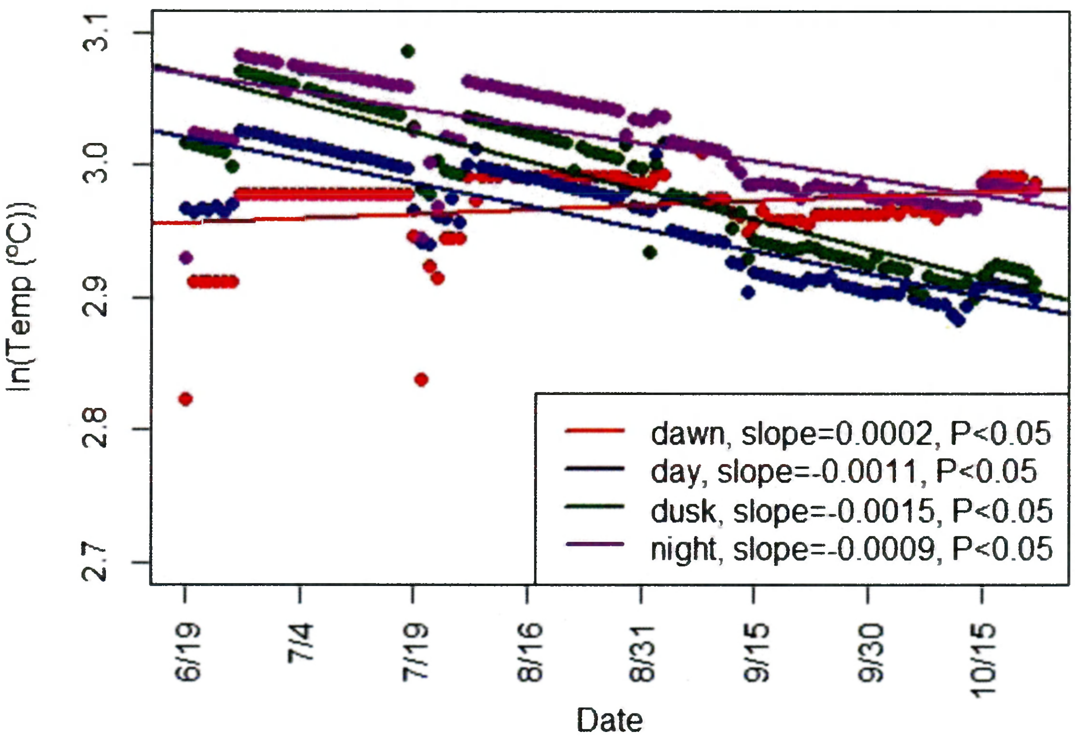
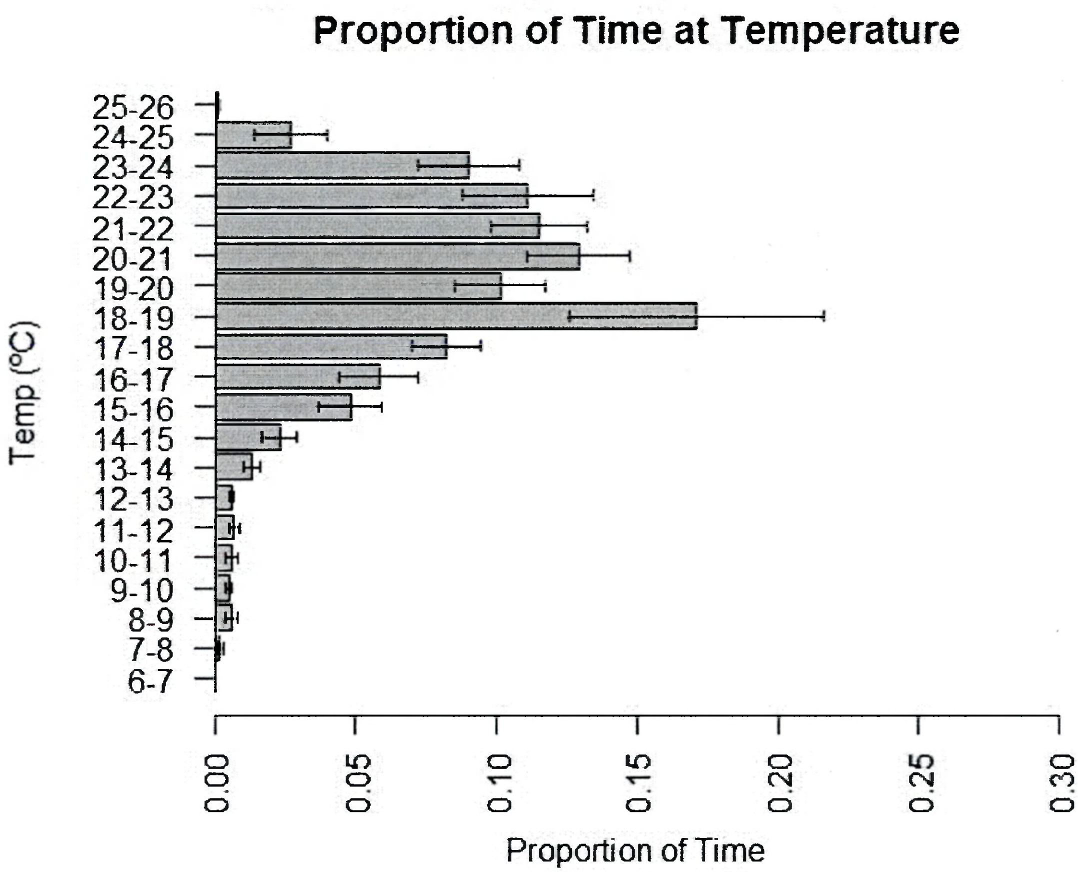


Figure 11. The proportion of time spent at temperature in 1°C-bins pooled across all school-size Atlantic bluefin tuna. The majority of time, between June and October, was spent between 18 and 24°C.



Proportion of Time at Temperature
Temp (ºC)
25-26
24-25
23-24
22-23
21-22
20-21
19-20
18-19
17-18
16-17
15-16
14-15
13-14
12-13
11-12
10-11
9-10
8-9
7-8
6-7
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Proportion of Time

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