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Description and evaluation of the United States coastal pelagic longline fishery interactions with target and non-target species in the western North Atlantic

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DESCRIPTION AND EVALUATION OF THE U.S. COASTAL PELAGIC LONGLINE FISHERY INTERACTIONS WITH TARGET AND NON-TARGET SPECIES IN THE WESTERN NORTH ATLANTIC

A Dissertation
Presented to
The Faculty of the School of Marine Science
The College of William & Mary in Virginia

In Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

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by
David William Kerstetter
2005

This dissertation is submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy

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Approved May 2005

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DEDICATION

This dissertation is dedicated to the memory of my great-grandmother,
Mary Porter Bales Quillian (1901-2004).

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ACKNOWLEDGEMENTS

There are many people and organizations to thank for their invaluable help during the long road to this dissertation. With all due apologies, it truly does take a village.

The importance of a knowledgeable and understanding advisor is essential for any undertaking of a doctoral program, and the support that Dr. John Graves has provided has been invaluable. My emphasis on highly migratory species fisheries management certainly would not have been possible without his encouragement to stay active with the International Commission for the Conservation of Atlantic Tunas (ICCAT). It takes a certain measure of confidence to support a student taking such an intellectual leap as I did from policy to marine science, to say nothing of exploring a research program in the relatively uncharted waters of the U.S. pelagic longline fishery. I believe that his trust has not gone completely unfulfilled and look forward to our future research and management collaborations.

I also gratefully acknowledge the participation and constructive reviews of my advisory committee: Dr. Richard Brill, Dr. Robert Diaz, Dr. John Musick, and Dr. Mark Patterson, all of VIMS, and Dr. Brian Luckhurst of the Bermuda Division of Fisheries.

I would like to thank Captain Greg O'Neill and crewmembers Victor Thompson, Richard Dixon, and Jeff Morris of the F/V *Carol Ann* for their patience during the time it took me to evolve into a semi-competent commercial longliner. Captain O'Neill especially was always interested in this work and provided numerous insights beyond the scope of these results. In this same light, I would also acknowledge the support of Vincent Pyle, owner of the F/V *Carol Ann*, and Greg Helsing of *A Fisherman's Best* seafood wholesaler, both of whom provided invaluable logistic support down in southern Florida while I was away from home and lab. I would also like to note my thanks for the insights and suggestions offered by Nelson "Hammer" Beideman, Executive Director of the Bluewater Fisherman's Association, the industry group for the U.S. pelagic longline fleet, and a long-time member of the U.S. ICCAT Advisory Committee.

The U.S. National Marine Fisheries Service (NMFS) has provided financial, logistic, and intellectual support throughout the course of the degree. Specifically, Kimberly Blankenbeker and Erika Carlsen of the International Fisheries Office supported my continued involvement with ICCAT and the U.S. ICCAT Advisory Committee even after my time as a Sea Grant Fellow ended. Dr. Eric Prince of the Southeast Fisheries Science Center encouraged my interest into pelagic longline fishery interactions and billfishes in general. Many other dedicated agency personnel also helped through their willingness to discuss obscure topics and dusty databases. Much of this doctoral work was supported through the NMFS Southeast Fisheries Science Center and NMFS Cooperative Research Program Grant # NA03NMF4540420.

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My family deserves special mention for their patient support and encouragement for a degree program that, at times, I'm sure appeared to be open-ended. As for my father, a former dean of graduate studies, well, my hope remains that those occasional trying moments have been made worthwhile with the granting of my doctorate.

Finally, I have to give special appreciation to my fiancée Kathleen Light, whom I met while down in southern Florida for my spring longlining season. Her patient support and unending belief in my abilities made the conclusion of this degree possible.

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ABSTRACT

Eighty-five monitored sets were used to investigate the interactions of pelagic fishes with commercial pelagic longline gear in the western North Atlantic during the fall mixed species fishery north of Cape Hatteras, North Carolina, and the spring swordfish fishery in the southern Gulf of Mexico and northern Caribbean Sea. This dissertation incorporates four components: 1) direct analyses of longline gear behavior using small time-depth recorders, 2) comparisons of catch rates and mortality of all species caught on size 16/0 non-offset circle and size 9/0 straight-shank J-style hooks, including analyses of time-of-capture utilizing electronic hook time recorders, 3) an evaluation of post-release survival of white marlin captured by longline gear using pop-off satellite archival tags (PSATs), and 4) a description of two PSATs attached to white marlin and subsequently ingested by sharks.

Data indicated that pelagic longline gear in the shallow coastal U.S. fishery is frequently in motion, even after hooks were presumed to have settled at depth. Effective fishing depths of the gear under several configurations were also shallower than predicted by commonly used catenary curve-based depth calculations. Catch rates between circle and J-style hook types were similar for most species, with only pelagic rays in the fall fishery showing an increased catch rate with J-style hooks. Yellowfin tuna and dolphinfish caught on circle hooks in the fall fishery were larger than those caught on J-style hooks. Most species were more commonly caught in the mouth with circle hooks rather than internally. A total of 28 white marlin were tagged with PSATs. Transmitted data from 17 of 19 reporting PSATs demonstrated survival following release. Estimates of post-release survival range from 60.7% (assuming that non-reporting tags were mortalities) to 89.5% (excluding non-reporting tags from the analysis). Two white marlin PSATs reported data consistent with predation or scavenging by sharks, including ingestion of the tags for seven and ten days respectively. This suggests that non-reporting PSATs may also be the result of unreported biological interactions.

U.S. COASTAL PELAGIC LONGLINE FISHERY INTERACTIONS

INTRODUCTION

Pelagic longline fishing gear is currently used throughout the world's oceans to commercially harvest swordfish *Xiphias gladius* and various tuna species *Thunnus* sp. The current form of this gear consists of a single strand of monofilament (the mainline) ranging from 5 to 40 miles in length; leaders (also called gangions), each with a baited hook, that are snapped onto the mainline; and buoy floats are attached at regular intervals to suspend the mainline at a pre-determined depth in the water column. Longline gear has evolved dramatically since the 1950s, when vessel crews were still hand-tying sections of natural fiber mainline together on each set (Yamaguchi, 1989). Hook depths and lengths of float lines (the monofilament lines that connect the buoys to the mainline) vary depending on the vessel's target species; for example, the gear is set deep for bigeye tuna *Thunnus obesus* in part by increasing the lengths of the leaders and float lines. Longline gear is adaptable to targeting a variety of species by varying factors such as the depth of the hooks, the number of leaders between buoy lines, the type and size of hook, and the bait type. Nonetheless, several strategies have developed over time for specific target species, such as fishing with chemical lightsticks at night when targeting swordfish (NMFS, 1999). Many vessels currently change strategies seasonally, so that the same vessel over the course of the year can be targeting yellowfin tuna *T. albacares* in the Gulf of Mexico during the springtime, dolphin *Coryphaena hippurus* off the Carolinas in the summer, and bigeye tuna off Georges Bank in the fall.

In the Atlantic Ocean, fleets of various nationalities have tended to target species based on economic factors. For example, the pelagic longline vessels of Japan targeted Atlantic bluefin tuna *Thunnus thynnus thynnus* during the development of the Atlantic longline fishery, but have since switched and now, along with the Peoples Republic of China, preferentially target bigeye tuna. The Taiwanese fleet, in contrast, still has many vessels which preferentially target albacore *T. alalunga*. Although there were some domestic vessels targeting bluefin tuna off New England's Stellwagen Bank as early as the 1950s (Wilson, 1960), the U.S. fishery had its greatest expansion in the 1970s with the development of the southern swordfish fishery. U.S. vessels have traditionally targeted yellowfin tuna and swordfish, with increasing prices for bigeye tuna resulting in seasonal targeting of that species north of the mid-Atlantic in the fall. In recent years, some U.S. vessels have also participated both in chartering arrangements with countries such as Brazil and in the South Atlantic swordfish fishery. Despite facing increasing domestic management restrictions, much of the U.S. longline fleet remains highly adaptable to changing economic and regulatory conditions.

Longline gear has been considered highly selective for large target species when compared with trawling or pelagic gillnetting (Yamaguchi, 1989). However, the well-publicized levels of incidental take of sea turtles and istiophorid billfish by longline vessels in the Atlantic Ocean, and albatross and sea turtles in the Pacific, have resulted in an increasing level of public concern. The National Marine Fisheries Service (NMFS) responded to this bycatch concern by including the Atlantic pelagic longline gear type as a distinct regional fishery in its broad policy statement entitled "Managing the Nation's Bycatch" (NMFS, 1998). In the past several years, the U.S. longline fishery has also been subject to closed areas as a management tool to reduce interaction rates with bycatch such as juvenile swordfish and bluefin tuna.

There is currently little comparative information regarding the nature of bycatch and bycatch mortality in the pelagic longline fishery. Important questions include the depth at which particular species are hooked by the gear and the change in efficiency resulting from different terminal gear (hook) types, such as the recently mandated change in the U.S. fishery to circle hooks from J-style hooks. Other factors, such as time on the hook, may also result in different survival rates at gear retrieval for the caught species. Perhaps the largest factor, however, is the question of vulnerability to the gear for the different species, i.e., when and where on the gear deployments are the fish hooked? This study addresses these issues with an emphasis on billfish bycatch.

The current stock status of many species under the purview of the International Commission for the Conservation of Atlantic Tunas (ICCAT) is either fully exploited or over-exploited, including the billfishes. The assessments used for these species are based on long time-series of commercial and recreational catch data, which are adjusted to presumably account for changes in the gear over the course of the various fisheries. The Standing Committee for Research and Statistics (SCRS) of ICCAT last assessed the Atlantic white marlin *Tetrapturus albidus* stock in 2002 and estimated a total biomass of approximately 12% of that necessary to produce maximum sustainable yield (B_{MSY}). Current harvests of white marlin in the ICCAT convention area are also estimated to be more than eight times the replacement yield, further contributing to the decline of the stock (ICCAT, 2002). The condition of the Atlantic blue marlin *Makaira nigricans* stock is only slightly better, at about 40% of B_{MSY} (ICCAT, 2001).

Both domestic and international management measures to reduce white and blue marlin fishing mortality are currently in effect. U.S. commercial fishermen have been prohibited from landing or possessing both Atlantic marlin species, in addition to sailfish *Istiophorus platypterus* and longbill spearfish *Tetrapturus pfleugeri*, since the approval of the Fishery Management Plan for Atlantic Billfish in 1988 (NMFS, 1988). In recent years, ICCAT has twice responded to the decreasing biomass of white and blue marlin by mandating the reduction in commercial pelagic longline and purse seine landings of both species (ICCAT 2000, 2001). However, even these measures may ultimately be ineffective in rebuilding these stocks. Goodyear (2002) found that a reduction in mortality of 60% from the 1999 level would be necessary to halt the decline of blue marlin; given the more over-fished status of the white marlin stock, even more drastic measures are likely necessary to achieve the same goal. Although pelagic longline gear is responsible for the majority of the blue marlin and white marlin mortality in the Atlantic (ICCAT, 2004), the U.S. Atlantic longline fleet contributes less than 5% of the total longline effort. Because the relative impact of foreign longline fleets is so much larger, any bycatch reduction strategies developed must also be exportable outside the United States fishery.

The characterization of coastal pelagic longline gear may also affect stock assessment methodologies. For example, the blue marlin habitat-based standardization model (HBS model) developed by Hinton and Nakano (1996) uses available information on the habitat preferences of pelagic fishes and the fishing depths of varying longline gear configurations to assess possible interaction rates. Presumably, high interaction rates of a gear type with a species outside that species' known habitat preference range would indicate a high population abundance. The HBS model was developed with data from the Pacific fleets, which historically switched from shallow (yellowfin tuna) to deep (bigeye tuna) longline sets. However, this model also makes several assumptions about feeding rates at depth and time that may not be valid without further analyses (Goodyear et al., 2002), yet the model is beginning to be widely used for explaining otherwise anomalous catch rates. Data from the gear behavior and catch rate work will further efforts to standardize the parameters of the model, specifically regarding the istiophorid billfishes.

This dissertation examines several aspects of the coastal U.S. pelagic longline fishery. The first chapter describes the physical behavior of the gear, including depths and movement patterns demonstrated during the effective fishing time, tested over varying gear configurations common in the current fishery. The second chapter compares the effect on catch rates and mortality rates at haulback between size 9/0 J-style hooks and size 16/0 circle hooks, including the description of time of feeding preferences and time to mortality through the use of electronic hook-time recorders. The third chapter addresses the issue of post-release survival of white marlin in this longline fishery through the use of pop-off satellite archival tags (PSATs). The final chapter examines biological interactions with sharks as a possible reason for non-reporting PSATs in this and previous post-release and habitat studies.

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Author's Note: This dissertation is comprised of four chapters. The second and third chapters are in review with fisheries journals as of May 2005, while the last chapter was published in the October 2004 issue of the journal *Fishery Bulletin*. With the agreement of my doctoral committee, the second and third chapters are presented in this dissertation not in the traditional format but as submitted for journal publication. Resized to fit the margin requirements, the fourth chapter is a copy of the pages in the journal publication.

DESCRIPTION OF COASTAL PELAGIC LONGLINE GEAR BEHAVIOR IN THE WESTERN NORTH ATLANTIC OCEAN

ABSTRACT

The performance of pelagic longline gear is believed to vary by changes in effective fishing depths and movements of individual leaders. To understand this behavior, depths of longline gear were measured by multiple deployments of small temperature-depth recorders (TDRs) in the U.S. commercial coastal fishery for a total of 85 sets. TDRs were attached to five-hook baskets of gear in both float lines at the junction with the mainline and on the leader lines in the first three hook positions. Float lines showed very little variation in movements over the duration of the sets; however, leader lines showed wide fluctuation during the set. Mean depths of hooks were often shallower than that predicted by the traditional catenary curve equation, even when corrected for the reduction rate calculated from the study sets. Mean depths and behavior of hooks were not related to either the float line length or the depths of leaders in the same position within the same set. Sinking speed for the gear showed that the majority of the gear reached settled depth within 20 minutes of deployment. Many large fishes caught on leader lines with attached TDRs exhibited large upward and downward movements, occasionally affecting adjacent baskets. Analysis of mean temperatures from TDR deployments revealed that most hooks were within 4° C of the sea surface temperature during set durations. The demonstrated unpredictable nature of shallow-set pelagic longline gear movements at depth, independent of temperature, may preclude the ability of most captains to selectively target this gear to specific depths.

INTRODUCTION

Pelagic longline fishing gear is used worldwide to commercially capture tunas *Thunnus* sp. and swordfish *Xiphias gladius*. Historically, longline gear consisted of small segments of natural fiber mainline with 2-30 attached branch lines, depending on target species (Shapiro 1950). Each segment was stored in a split-bamboo basket when not being fished and numerous baskets were tied together by hand during each set (Nakamura 1952). This storage system soon changed after the development of monofilament mainline and large storage reel technologies, but the name for a section of longline gear is often still called a "basket" of gear. Then, as with modern gear, the longline effectively fished at varying depths with identical leader lengths by being set with slack that allows the mainline to form a sagging curve (the "catenary curve') between the floats at the end of each basket (Fig. 1). The fragmented nature of the older-style gear enabled vessel captains to calculate the sag of the gear during deployment by factoring in the speed of the vessel over the known length of each basket. With the development of single-strand mainline, and then monofilament mainline, new techniques were required to calculate the sag rate. Many modern large-scale commercial longline vessels now use mechanical "line setters" while deploying gear, which draw mainline from the reel at rates faster than the forward movement of the vessel, thereby generating more predictable sag rates in the gear. However, many smaller longline vessels do not have line setters, in part because of the additional expense and crowded deck configurations, and instead rely on deploying the mainline to specific depths by varying speeds and float line lengths.

Gear in the U.S. Atlantic pelagic longline fishery falls into two general categories based roughly on the size and resulting operational area of the vessel. There remain approximately 13 large boats, generally steel-hulled, that can deploy over 35 miles of gear per set and who primarily target swordfish (N. Beideman, Bluewater Fisherman's Association, pers. comm.). Several of these U.S. vessels move between the Grand Banks where they target swordfish and bigeye tuna and the northeast coast of South America, where they have historically fished for bigeye and yellowfin tunas under foreign chartering arrangements. The majority of the U.S. domestic fleet consists of small vessels, often fiberglass-hulled, that deploy around 20 miles or less of mainline per set, targeting swordfish and tunas. These vessels engage in a seasonal migration pattern that ranges along the edges of the continental shelf from the Gulf of Mexico to the Windward Passage and up through the Atlantic Coast to Georges Bank. Vessels in the large boat category generally employ deep-fishing pelagic longline gear similar to that used by the foreign distant-water fleets, with line-setters used to ensure fairly predictable, regular depths of the hooks in the sets. The smaller vessels generally fish shallower gear and depend on the tension of the mainline to contract the baskets of gear into the catenary curve configuration between floats. Leader lines in this coastal fishery are generally less than 15 fathoms (~27 m) in length and are stored in boxes on deck. Float lines range from 2.5-15 fathoms (~9-27 m) and are stored on hydraulic reels also on deck.

Several authors have examined the relationship between vessel speed, mainline sag, and the effective fishing depths of longline gear. Wathne (1959) determined the depths of individual baskets of gear by marking the depth of the mainline on a depth sounder while the boat passed over the deployed gear. Murphy and Shomura (1953) described the relationship between setting speed and the related amount of sag allowed in the mainline. In the Gulf of Mexico, Wathne (1959) demonstrated that sag rates might be as important as leader length in determining the final depth positioning. It should be noted that the longline gear used for the Murphy and Shomura work (described by Niska 1953), was constructed of very different materials than those used today, and may have exhibited different soak characteristics and behavior. However, Yano and Abe (1998) observed that both older-style polyester multifilament gear and that made of nylon monofilament often fished shallower than predicted by Yoshihara (1959).

More recently, albatross bycatch concerns (Anderson and McArdle 2002) initiated research into the behavior of longline fishing gear using small temperature-depth recorders (TDRs) on leader lines to estimate sink rates, or the speed at which the deployed baits sink to normal fishing depths. Other research using TDR data has focused on the comparison of catch rates for various species caught by different setting styles of longline gear (e.g., Suzuki and Kume 1981, Yang and Gong 1986). These studies provided selected estimates of depths of the gear, but they did not include estimates of movement during the effective fishing period. Most longline vessel captains are well aware of the effects that water currents, abrupt temperature changes, and winds may create on the gear and frequently exploit these factors to alter the shape of the gear to target different species (D. Kerstetter, pers. obs.). Berkeley and Edwards (1996) observed, however, that surface temperature breaks rarely translate into similar temperature distinctions at depth.

Previous work with small TDRs to quantify longline gear behavior has revealed several different patterns based on recorder attachment location and ocean of study. Mizuno et al. (1997) attached TDRs at the joint between the individual leaders and the mainline. This study showed a generally consistent catenary curve distribution of the mainline in the basket with depth over time, although there was some deformity in the sag of the baskets over the deployment period, presumed to be the result of the sub-surface currents of the eastern central Pacific Ocean. However, the central Pacific is relatively stratified at depth compared with the western North Atlantic; with less influence from upwelling currents or interactions with large islands, one would expect the gear to maintain relatively constant depths. Evidence for a relatively more active water column in the Atlantic has been demonstrated with previous longline research. For example, Berkeley and Edwards (1996), working in the Gulf of Mexico, set their TDRs on the mainline at the center, the predicted lowest, point within the basket. Their data revealed extremely variable depths during the set. However, that study only deployed one large (27 g; 86 mm x 20 mm cylinder) TDR per basket, resulting in minimal information on the overall shape of the basket, as well as the behavior of the individual hooks within it.

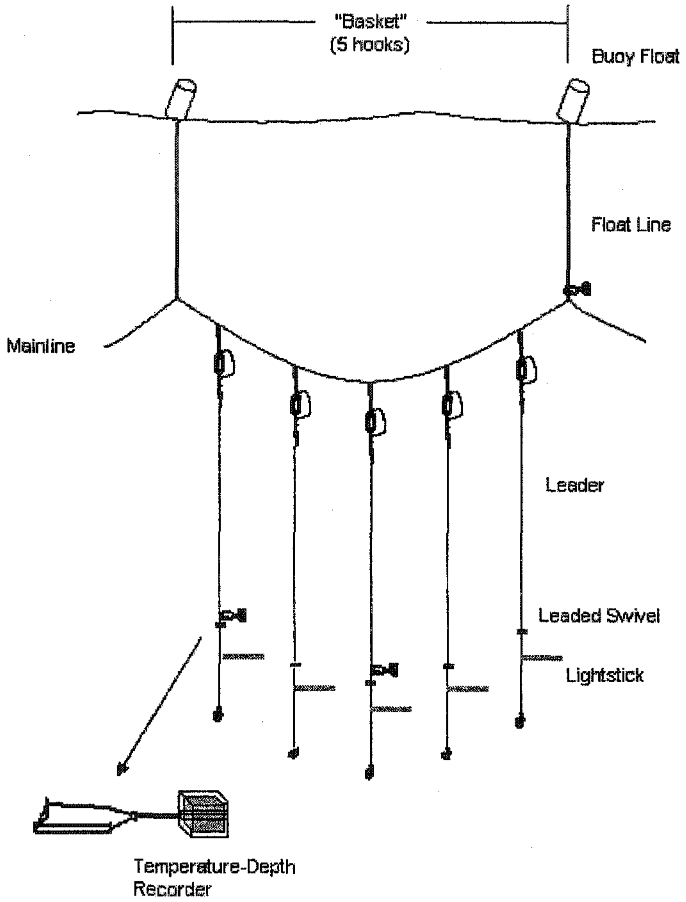
Although of smaller scale than the vessels in the distant-water fleet, the coastal pelagic longline fishery in many countries contribute a significant component of total longline effort in the western Atlantic Ocean. Description of this gear type is important to understanding the interactions at depth and temperature of the gear with the target and non-target species caught in this fishery. Most previous research occurred in the Pacific Ocean and from large vessels. To more accurately describe the coastal Atlantic fishery, this study presents TDR-obtained depth and movement patterns of coastal pelagic longline gear in the western North Atlantic.

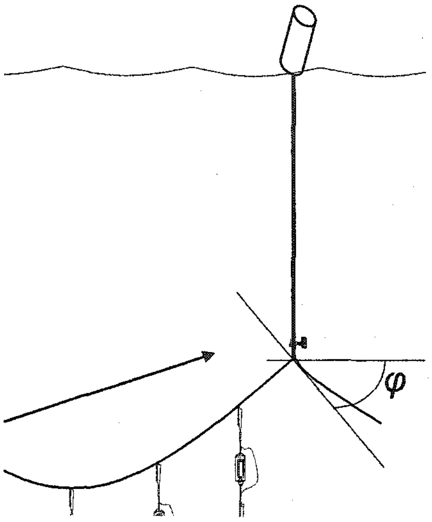
MATERIALS AND METHODS

The F/V *Carol Ann*, a 16 m LOA commercial coastal pelagic longline vessel, was used to make 85 sets in the western North Atlantic Ocean. These sets were roughly divided between two areas: 39 sets in the fall mixed-species fishery along the edge of the continental shelf in the Mid-Atlantic Bight and 46 sets in swordfish fishery in the southern Gulf of Mexico and Windward Passage (between Haiti and Cuba). Adjusting seasonally for different target species, individual leader lengths were 7.5 fathoms (fa; ca. 13.7 m) in the fall fishery and 15 fathoms (ca. 27.4 m) in the spring. Both lengths used a 46 g leaded swivel approximately two meters above (towards the mainline) from the hook. Two float lines (the line between the mainline and the surface float) lengths were used in each set. The fall fishery used primarily 5 and 2.5 fathom (ca. 9.1 and 4.5 m, respectively) float line lengths and the spring used 10 and 12 fathom (ca. 18.3 and 21.9 m, respectively) float line lengths. The gear configuration used 17 floats between each radar-reflecting high-flyer float or radio beeper buoy (18 baskets total), with five hooks per basket.

Two models of microTDRs were deployed in these sets: the "DSTmilli" TDRs (12.5 mm x 38.4 mm) manufactured by Star-Oddi (Reykjavik, Iceland) and the "LTD_1100" TDRs (21 mm x 15 mm) from Lotek Wireless (St. Johns, Newfoundland). TDRs on leaders were attached at haulback less than 5 cm above the leaded swivel on the leader (Fig. 1). TDRs were also occasionally attached near the clip to the mainline for the buoy drops and the individual leaders. Data were recorded by the TDRs at 14-, 28-, or 30-second intervals depending on deployment and model, and records were manually downloaded at sea into a laptop computer. An automatic bathythermograph (ABT-1, Alec Electronics, Japan) was occasionally deployed to assess the depth of the local thermocline in relation to the gear.

Fig. 1. Schematic diagram of gear basket used in the study, showing TDR placement and φ angle determination.


"Basket"
(5 hooks)
Buoy Float
Float Line
Mainline
Leader
Leaded Swivel
Lightstick
Temperature-Depth
Recorder


φ

TDR records were converted from pressure (psi) to depth[1] with corrections for the effects of latitude. Recorded depth changes were assessed following the entry into the water and data were analyzed every minute according to Yano and Abe (1996) to determine rate of sinking. The "turning point" of the leader was reached when the rate of descent first reached < 1 m per minute (approximately 25% of initial sinking rate). "Time to turning point" was from entry into the water until the turning point.

Movements of the leaders were classified into six categories of depth variation using the methodology of Yano and Abe (1996). For each leader, TDR data from the first hour following deployment and last hour prior to haulback of the gear was removed, and the remaining time divided into three equal time intervals. A coefficient of variance (CV; = standard deviation/mean*100) and mean depth was calculated for each of the three intervals. Movement patterns were classified according to Table 1. TDR records from any basket with a fish at haulback were excluded from subsequent movement analyses.

A GPS unit was used on deck to record the deployment and recovery positions of each of the large high-flyer or beeper buoy floats at set and haulback. Distances were calculated using PROGRAM INVERSE (NGS 1975; modified by M. Ortiz, NMFS-SEFSC, Miami, FL). The mainline was pulled off the spool at the same rate as the vessel moved forward during set, and this distance was used for the estimate of the length of mainline in each basket. The differences between the distances between floats from set to haul were used to estimate the reduction rate (Gong et al. 1989). The reduction rates for the fall and spring sets were averaged by season, and the reduction rate percentage was converted into an estimate of φ, the angle between a line tangential to the mainline in a basket at the first leader and a horizontal line between floats (Yoshihara 1954; Fig. 2). The following equation (Yoshihara 1954) was then used to calculate the theoretical depth of the hooks:

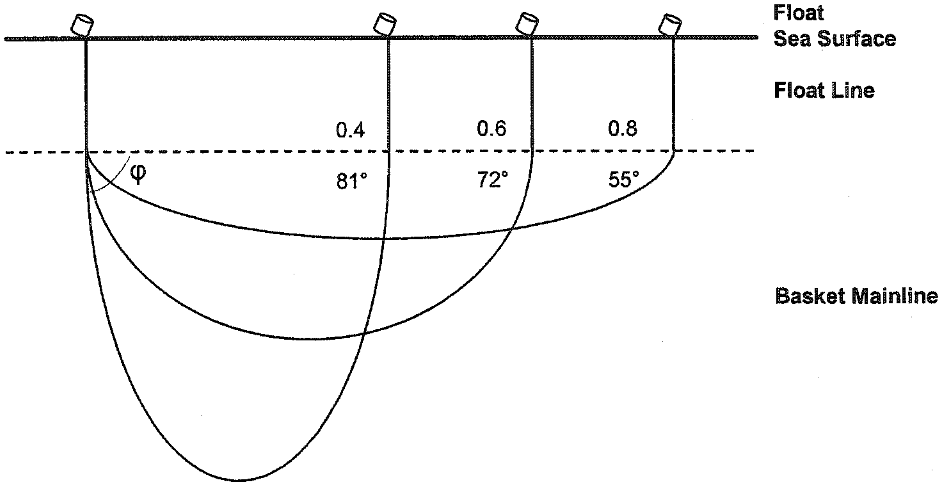
---

[1] Harris, R.D. 2000. Water level accuracy and correcting for error due to gravitational acceleration and liquid density. In-Situ, Inc. Tech. Note 001, 2 p.

Table 1. Characteristics of six types of pelagic longline leader movement at depth. The duration of each TDR record was split into three equal time intervals, and "CV" refers to the coefficient of variance for each interval.

Movement Type	**Description**
A	CV <10 for all three intervals
B	CV >10 for all three intervals
C	CV <10 for at least one interval; mean depths per interval always increasing
D	CV <10 for at least one interval; mean depths per interval always decreasing
E	CV <10 for at least one interval; mean depths per interval increasing, then decreasing
F	CV <10 for at least one interval; mean depths per interval decreasing, then increasing

Fig. 2. Diagram depicting changes in φ (bottom degree value) with changes in the reduction rate (redrawn from Gong et al., 1989).


Float
Sea Surface
Float Line
0.4
0.6
0.8
φ
81°
72°
55°
Basket Mainline

$$D_j = H_a + H_b + L \{(1 + \mathrm{Cot2}\ \varphi)^{1/2} - [(1\text{-}2j/n)^2 + \mathrm{Cot}\ \varphi]^{1/2}\} \qquad (1)$$

Where, D_j = Depth of the *j*-th hook on the *j*-th leader of a basket
H_a = Length of the buoy drop
H_b = Length of the leader
L = Half the length of mainline in a basket
n = Number of mainline sections in a basket

Initial raw TDR data processing used a custom S-PLUS routine. Subsequent statistical analyses were conducting using SAS SYSTEM V. 9.0 (SAS Institute, Cary, NC, USA). Generalized linear models (GLMs) were used to assess depth differences due to the frequent failure rate of the TDRs causing unbalanced sample sizes for varying leader lengths.

RESULTS

A total of 85 research sets was conducted on a commercial pelagic longline vessel operating in the western North Atlantic. In most sets (97.6%), gear was retrieved in the reverse order of set, so that the first hook deployed was the last to be retrieved. Gear was typically set during dusk and hauled back around dawn. Removing from consideration the reversed sets, and sets in which the mainline parted and required a search for the gear, the shortest (the last hook in the fourth section of gear) and longest (first hook in the first section) soak times in the fall fishery were 13:01h and 18:29h, respectively. In the spring fishery, the shortest and longest soak times were 11:12h and 17:23h, respectively. Over 600 individual TDRs were deployed during the 85 sets, of which 425 produced usable TDR datasets, or an average of five TDRs per set. A higher rate of TDR failure (defined as the lack of a usable dataset) was observed in the spring fishery.

Distances between floats generally decreased between the initial deployment of the gear and the time of gear haulback. In the fall fishery, mean length of the sets was

25.36 km ±3.10 and 20.76 km ±1.64 at haulback, while in the spring, mean length of the sets was 28.89 km ±4.70 and 23.95 km ±5.52 at haulback. Lengths between floats (four lengths per study set) were averaged by set to provide an estimated set-specific mean reduction rate using the following equation (Yang and Gong 1989):

$$\text{Mean reduction rate}_i = X_i / S_i \qquad (2)$$

Where, X = Distance between floats at haulback in section i

S = Distance between floats at gear deployment in section i

The overall calculated mean reduction rate per set was 0.88 ±0.62 in the fall fishery and 0.82 ±0.12 in the spring fishery.

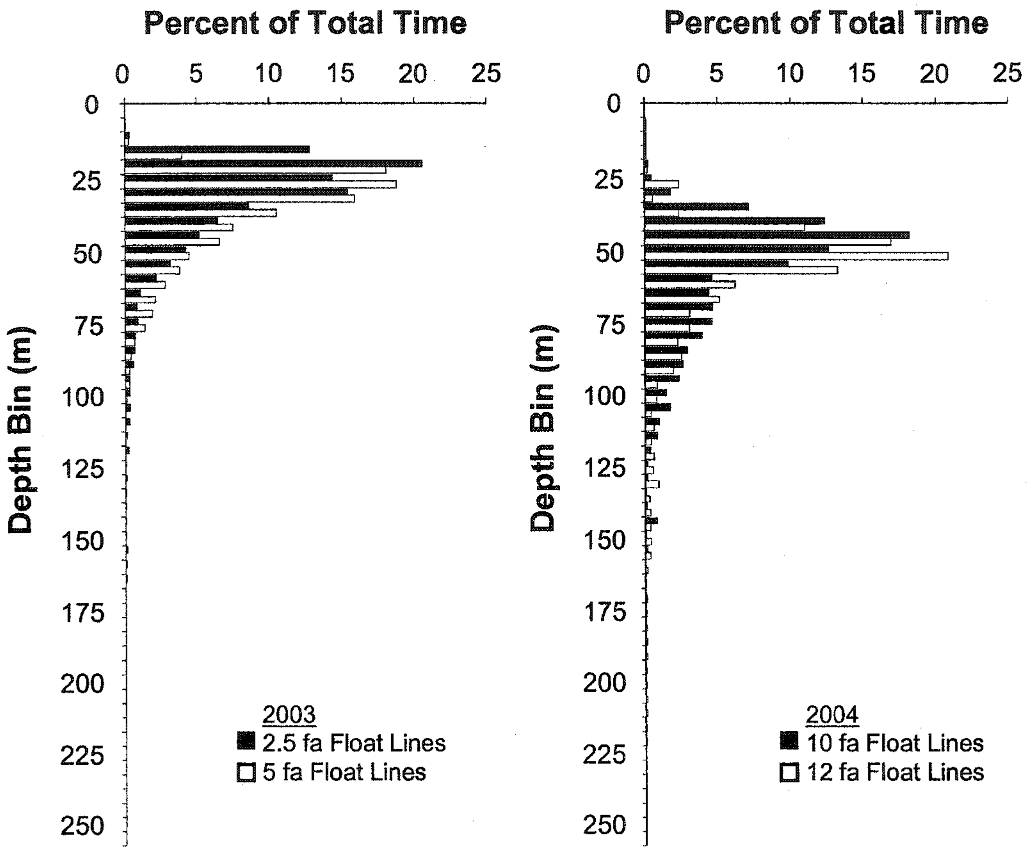
Depths of the hooks varied by leader and float line lengths, but all hooks exhibited consistent sinking rates of approximately 4 m per minute to the turning point (Table 2). The sinking rate to the turning point during the spring was significantly faster in the spring fishery ($P < 0.05$). Maximum depths of the gear were assumed to follow the catenary curve distribution and occur at the middle hook (hook three). The observed mean maximum depths were 25.0 m ±16.8 and 27.4 m ±15.5 for the 2.5 fa and 5 fa float lines in the fall and 49.69 m ±21.5 and 52.68 m ±21.9 for the 10 fa and 12 fa float lines in the spring, respectively. In contrast, using the calculated reduction rates from the GPS coordinates of the sets to the values of φ from Yoshihara (1959), maximum predicted depths for the 2.5 fa and 5 fa float lines were 98.0 m and 102.6 m in the fall and 157.1 m and 160.8 m for the 10 fa and 12 fa float lines in the spring.

Tests of mean hook depth differences based on gear configuration showed no significant difference in the mean hook depths of the two float line lengths in the fall season (2.5 fa and 5 fa), although the difference in mean hook depths in the spring season (10 fa and 12 fa) was significant ($P = 0.011$). The leader lengths were longer in the spring fishery (15 fa or ca. 27.4 m, versus 7.5 fa or ca. 13.7 m in the fall) and the difference in mean hook depths between the spring and fall seasons was highly significant ($P < 0.0001$; Fig. 3). Within the fall season, no relationship in mean hook

Table 2. Turning point and stable depths, times, and sinking rates by float line length.

Float Line Length (n)	**Turning Point Depth**	**Time to Turning Point (mm:ss)**	**Sinking Rate to Turning Point (m/min)**
2003-2.5fa (28)	23.25 m ±7.77	7:32 ±2:29	3.10 ±0.58
2003-5fa (28)	24.47 m ±9.51	7:34 ±2:28	3.24 ±0.56
2004-10fa (60)	42.17 m ±8.02	10:47 ±3:02	4.10 ±1.04
2004-12fa (51)	43.86 m ±9.17	10:47 ±4:05	4.31 ±0.91

Fig. 3. Histograms of total hook time at depth for leaders with 2.5 fa and 5 fa float lines (left) and 10 fa and 12 fa float lines (right).


Percent of Total Time
0
5
10
15
20
25
Depth Bin (m)
0
25
50
75
100
125
150
175
200
225
250
2003
■ 2.5 fa Float Lines
□ 5 fa Float Lines
Percent of Total Time
0
5
10
15
20
25
Depth Bin (m)
0
25
50
75
100
125
150
175
200
225
250
2004
■ 10 fa Float Lines
□ 12 fa Float Lines

depths was seen among either individual sets or 2.5 fa and 5 fa float line lengths. The spring season, however, saw significant effects between 10 fa and 12 fa float line lengths and among individual sets ($P = 0.006$ and $P = 0.022$, respectively).

Wide fluctuations in depth over time occurred in almost all of the study baskets (Fig. 4). The mean depths and standard deviations by movement type are found in Table 3. Categorizing each TDR record into the six general categories of Yano and Abe (1998), the movement pattern A with the least vertical variation only occurred one time, while movement type B, with the most vertical movement, was predominant with 63.4% of all recovered TDR records. Very few records indicated movement with hooks becoming progressively deeper during the set duration (type D). The junction of the float line and the mainline showed very little fluctuation in all baskets observed (Fig. 5).

Mean sea surface temperatures were 24.2° C in the fall and 25.8° C in the spring. Mean temperature records from the fall TDR deployments (after removing the one hour after deployment and one hour prior to haulback) were 21.4° C for 2.5 fa float lines and 20.5° C for 5 fa float lines. In the spring, mean temperatures at depth were 22.7° C for 10 fa and 22.1° C for 12 fa float lines. ABT records revealed weak (< 5° C difference) thermoclines in all areas fished in this study. Mean thermocline depths were between 50-70 m in the fall fishery and 90-150 m in the spring fishery.

TDR records with fish caught in the same basket of gear were excluded from analyses due to the broad depth changes resulting from the movements of the hooked animals. We recovered 33 TDR records from leaders that caught fish, including 12 swordfish, 4 yellowfin tuna *Thunnus albacares*, and 2 blue sharks *Prionace glauca* (Fig. 6). Swordfish showed only minor vertical movement while on the line, while yellowfin tuna showed clear activity once hooked. One sailfish *Istiophorus platypterus* was caught on a leader with a TDR and exhibited little vertical movement while on the line. Blue sharks exhibited only gradual depth changes almost indistinguishable from TDR records from hooks in the same set that had no fish. TDRs were also recovered with 8 pelagic stingrays *Pteroplatytrygon violacea*, which displayed very little vertical movement after hooking.

Fig. 4. Six patterns (types) of hook movement at depth during the duration of the set as recorded by TDRs. Type A: constant stable depth, type B: large upward and downward movements, type C: depth decreasing over time, type D: depth increasing over time, type E: depth increasing, then decreasing, and type F: depth decreasing, then increasing. Type B was most common in this work and type A least common.

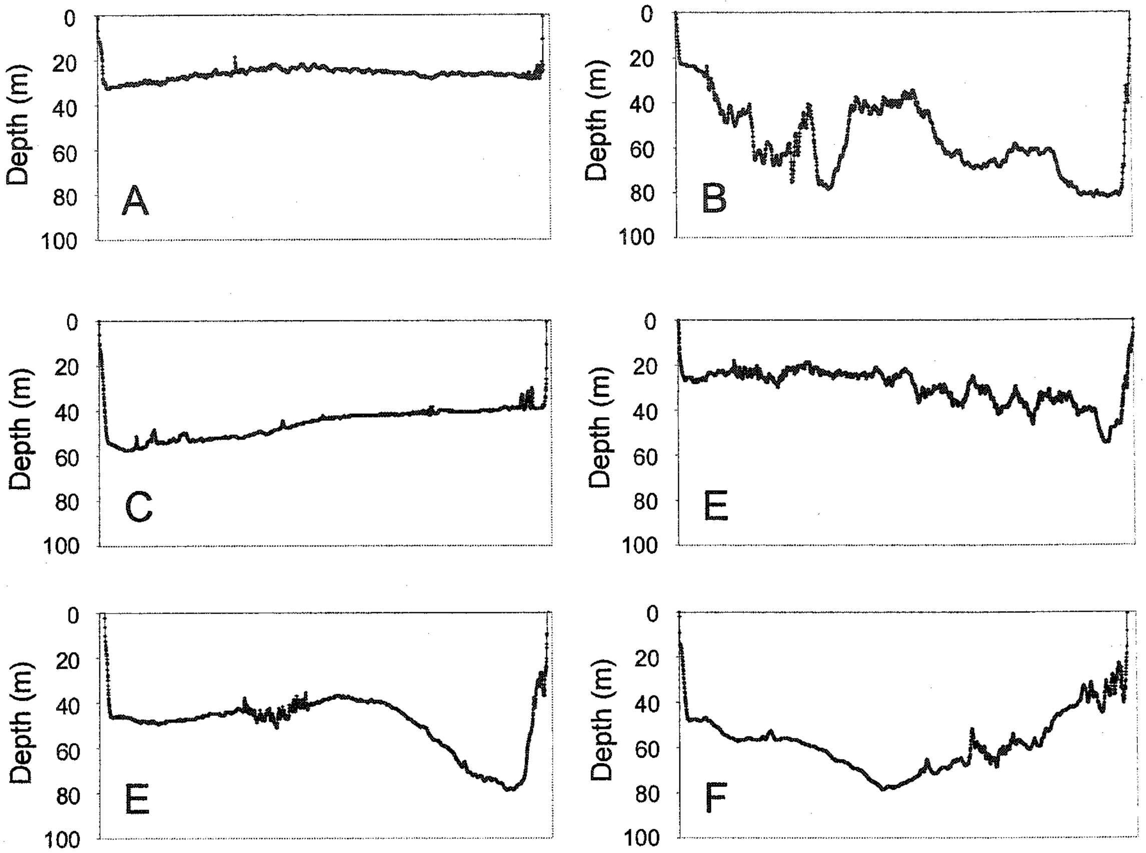
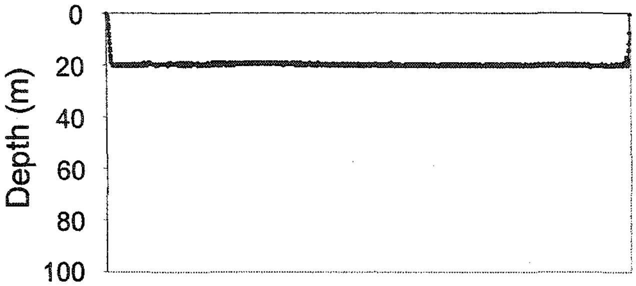

Depth (m)
0
20
40
60
80
100
A
B
C
E
E
F

Table 3. Six movement types and depth range of individual leader lines by float line length. Depth means are taken after removing first and last hour of set.

Float Line Length (n)	**A**	**B**	**C**	**D**	**E**	**E**
	Mean SD (n)	**Mean SD (n)**	**Mean SD (n)**	**Mean SD (n)**	**Mean SD (n)**	**Mean SD (n)**
2003-2.5fa (28)	--	24.32 ±16.04 (71)	--	--	--	--
2003-5fa (28)	--	24.50 ±11.76 (34)	38.55 ±7.82 (3)	17.82 ±7.39 (13)	39.39 ±24.26 (12)	30.98 ±0.78 (2)
2004-10fa (60)	26.73 ±0.0 (1)	44.04 ±17.32 (13)	37.34 ±5.30 (7)	31.84 ±6.69 (11)	--	45.06 ±18.15 (9)
2004-12fa (51)	--	33.28 ±16.35 (22)	38.95 ±1.12 (3)	51.36 ±17.63 (3)	42.78 ±13.21 (3)	51.79 ±11.80 (4)

Fig. 5. Movement pattern at depth for junction of float line and mainline.


0
20
40
60
80
100
Depth (m)

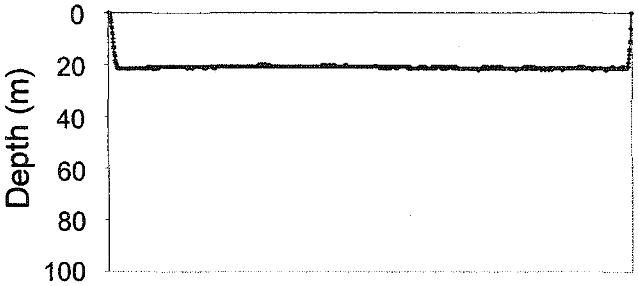
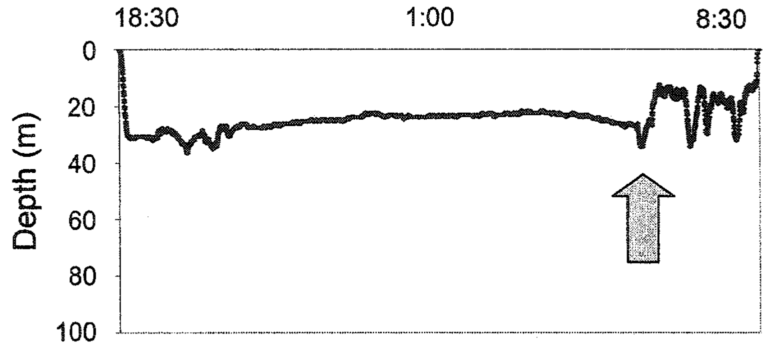
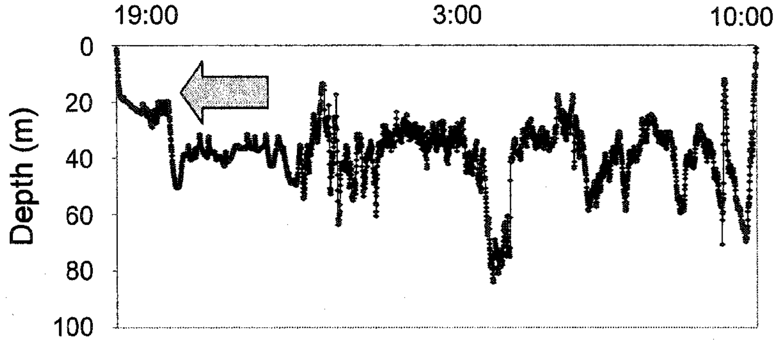

0
20
40
60
80
100
Depth (m)

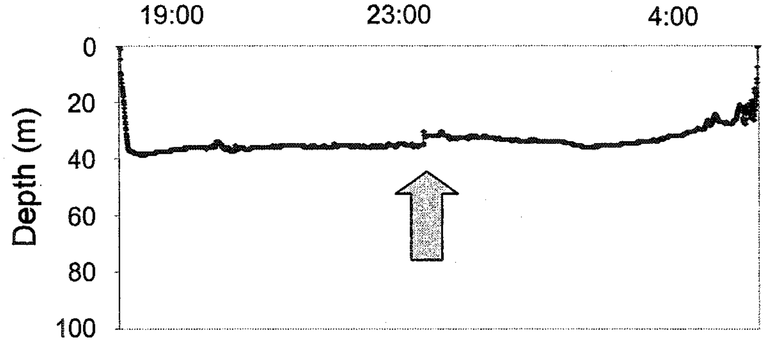
Fig. 6. Movements at depth for four species of fishes caught in the western North Atlantic on pelagic longline gear leaders with attached TDRs. Arrow denotes point of hooking for respective animal, and all animals were alive at retrieval (haulback) of the longline gear.



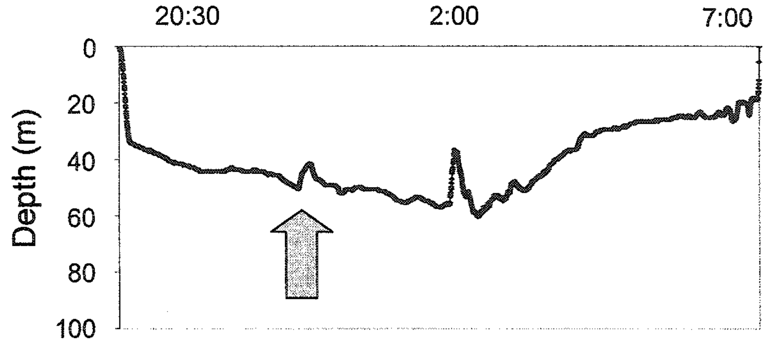
Blue Shark
Prionace glauca
Set 28-2003



Yellowfin Tuna
Thunnus albacares
Set 37-2003



Sailfish
Istiophorus platypterus
Set 55-2004



Swordfish
Xiphias gladius
Set 44-2004

DISCUSSION

Description of pelagic longline gear is essential to understanding the interactions between the gear and pelagic fishes. Small TDRs have been used in several previous studies of tuna fisheries (e.g., Mizuno et al. 1997) to examine the operational fishing depths of this gear. The relatively low cost of these devices allows more complete descriptions of the basic basket of gear than catenary curve estimations alone. However, the technology involved with these small TDRs is still evolving, as evidenced by the high failure rate of the TDRs in this study. Berkeley and Edwards (1996) reported similar difficulties with their TDRs, which resulted in no more than seven operational TDRs on each set.

Recorded hook depths in this study suggest that the choice of specific float line and leader length combinations has little effect on the actual depth fished by the coastal pelagic longline gear. While significant differences did appear between certain gear configurations, most combinations of leader lengths and float line lengths did not show large differences. However, line setters to construct more predictable shortening rates were not used here, nor are they found on most coastal longline vessels in this fishery. As previously suggested by Mizuno et al. (1997), oceanographic or atmospheric conditions such as thermocline depth may contribute a greater effect to depth than a specific gear configuration. Many of the hooks approached or crossed the weak local thermocline, but rarely were the hooks in any gear configuration completely below the thermocline for the duration of the set. TDR records indicated that the majority of hooks after reaching settled depth were within 4° C of the sea surface temperature. Assuming that temperatures within 8° C of the sea surface bound the preferred habitat of such epipelagic species as yellowfin tuna (Brill et al. 1999), almost all hooks were within the appropriate range. These same deployments may not have been as efficient for other species such as bigeye tuna. Matsumoto et al. (2001) observed with Pacific TDR deployments that most istiophorid billfishes were caught in depths shallower than 120 m and in the zone of the thermocline.

The TDR records, in general, demonstrated slow but consistent vertical movement of almost all of the hooks in all of the sets, regardless of hook position in the basket. Hooks also followed a similar sinking rate and pattern following deployment of the gear, although the spring hooks sank at a slightly faster rate to the turning point. Boggs (1992) reported that many pelagic fishes were captured in Hawaiian longline operations while the gear was moving through the water column. Although Kerstetter and Graves (in review) observed few animals with hook-timer records indicating capture during the rapid movement of the gear associated with set or haul of the gear, the results of the present study demonstrate that the leaders of this shallower gear even at the point of the leaded swivel are often constantly in motion. The TDR records over the duration of each set also demonstrated wide fluctuations in depth and behavior pattern for most sets. In addition to the regular movements of hooks at depth for gear, the activity of an animal hooked in one basket often caused perceptible movements in adjacent baskets.

The knowledge of the effective fishing depths of pelagic longline gear has implications for certain stock assessment methodologies. Hinton and Nakano (1996) developed a model to standardize catch rates of blue marlin in the Pacific Ocean based on several assumptions about habitat preferences and limited knowledge of the behavior of pelagic longline gear. Other studies have assessed the fishing efficiency of "deep" and "shallow" longline gear using catenary curve assumptions to estimate depth of deployed hooks. However, to be effective, any model of longline gear interactions necessarily requires accurate data on movements made by the gear while fishing. Previous work has described general longline gear behavior in limited deep sets using a large research vessel entirely in the Pacific Ocean (e.g., Mizuno et al. 1999; Yano and Abe 1998) and showed limited movement of the hook depths over time. The applicability of their findings may not be reflective of the different current patterns, neritic-pelagic shelf interactions, or differences in fishing vessels or techniques in the Atlantic. Ultimately, determination of the behavior of the longline gear may also allow more accurate predictors of habitat based on data catch composition at depth. While this study found wide variation and vertical movement in the fishing depths of the gear in the coastal Atlantic longline fishery, the results present evidence that this gear fishes shallower depths than would be predicted through estimated catenary curve depth distributions.

The description of the predominant gear type used by the U.S. pelagic longline fishery may allow the identification of factors contributing to the catch rates of the various pelagic species. Additional characterizations of longline gear behavior may allow both standardizations of gear effort by depth and further inferences on the vulnerability of different catch species to the gear at varying depths and times. Appropriate gear effort standardization, in conjunction with better characterization of biological parameters of target and non-target species, may allow more accurate stock assessments for important commercial and recreational pelagic fishes.

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EFFECTS OF SIZE 16/0 CIRCLE VERSUS SIZE 9/0 J-STYLE HOOKS ON TARGET AND NON-TARGET SPECIES IN A PELAGIC LONGLINE FISHERY

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ABSTRACT

The U.S. Atlantic coastal pelagic longline fishery that targets tunas and swordfish also interacts with a wide range of non-target species including billfishes and sea turtles. Preliminary studies indicate that a change in terminal gear from J-style hooks to circle hooks may reduce bycatch mortality, but the effects of this change on catch rates of target species are unclear. To evaluate this, we monitored catch composition, catch rates, hooking location, and number of fish alive at haulback during 85 sets in the fall and spring seasonal fisheries from a commercial vessel operating in the western North Atlantic. Circle (size 16/0 0° offset) and J-style (size 9/0 10° offset) hooks were deployed in an alternating fashion. Hook-time recorders were used to assess time at hooking and temperature-depth recorders to measure gear behavior.

Catch rates for most species categories were not significantly different between hook types, although circle hooks generally had higher tuna catch rates *in the fall and lower swordfish catch rates in the spring. In the fall, total catches and catches of pelagic rays were significantly higher on J-style hooks. Yellowfin tuna in the fall and dolphinfish in the spring caught on circle hooks were significantly larger than those caught on J-style hooks. In both seasonal fisheries, circle hooks caught fishes in the mouth more frequently than J-style hooks, which hooked more often in the throat or gut, although these overall differences between hook types were not statistically significant. Yellowfin tuna in the fall fishery were over four times more likely to be hooked in the mouth with circle hooks than with J-style hooks. Several target and bycatch species showed higher rates of survival at haulback with circle hooks, although only for dolphinfish in the fall fishery was this difference statistically significant. Our results suggest that the use of 0° offset circle hooks in the coastal pelagic longline fishery will increase the survival of bycatch species at haulback with minimal effects on the catches of target species.*

KEY WORDS

Pelagic longline, bycatch, circle hooks, survival, discard mortality

INTRODUCTION

Pelagic longline fishing gear is currently used throughout the world's oceans to commercially harvest swordfish *Xiphias gladius* and tunas *Thunnus* spp. Pelagic longline gear also interacts with non-target pelagic species, including istiophorid billfishes, sharks, sea turtles, and on occasion, marine mammals. Reducing the rate of interaction and mortality of non-target species has been identified as a management priority both domestically and internationally. Interactions with billfishes by the pelagic longline fleet have created concern because of the depressed condition of Atlantic billfish stocks and the importance of these species to recreational anglers.

The fishing mortality on bycatch species resulting from pelagic longline fishing may be reduced by decreasing interaction rates and/or the number of animals dead at haulback. Recent attention has been given to circle hooks (a hook with the point turned perpendicularly back to the shank) as a means to reduce bycatch mortality. In contrast to J-style hooks, circle hooks tend to slide over soft tissue and rotate as the eye of the hook exits the mouth, frequently resulting in the hook catching in the jaw (Trumble et al., 2002). Circle hooks have been used for years by commercial fisheries in the U.S. Pacific Northwest (IPHC, 1998) and are increasingly being used voluntarily in a number of U.S. recreational fisheries. Most research into the effects of hook type and survival has occurred in the recreational fishery where catch and release fishing practices are common. These studies have shown reduced rates of serious injury with circle hooks (Prince et al., 2002; Skomal et al., 2002; Malchoff et al., 2002) and increased rates of postrelease survival (Horodysky and Graves, 2005). In the pelagic longline fishery, a higher proportion of fishes caught in the mouth or jaw should result in less physical damage to the animal and presumably higher rates of survival at haulback and after release for bycatch species.

Little is known about the effects of terminal gear changes in the pelagic longline fisheries. Falterman and Graves (2002) found mortality at haulback of the longline was 31% for target and bycatch fishes caught on circle hooks and 42% for those caught on J-style hooks, although this difference was not statistically significant. Hoey (1986) observed a similar pattern in his review of the U.S. pelagic longline fleet records (survival rate at haulback: 38% J-style hook and 51% circle hook; no significance noted). Yamaguchi (1989) hypothesized that differences in survival at haulback were related to hook location, in that jaw-hooking allowed the fishes to continue to swim while on the line. Berkeley and Edwards (1996) noted that fish caught on circle hooks, even those on the line for many hours, were generally alive at haulback. In the U.S. Atlantic longline fleet (which generally used J-style hooks), 80% of the billfish caught in 1998 were reported alive at haulback[1]. In contrast, less than 40% of the billfishes caught by the Venezuelan longline fleet (which also primarily used J-style hooks) were alive at haulback (Jackson and Farber, 1996).

The use of circle hooks with pelagic longline gear has not been readily accepted, and a large percentage of the international pelagic longline fishery in the Atlantic Ocean continues to use straight-shank or J-style hooks. Some vessels targeting tuna switched voluntarily to circle hooks following preliminary studies that this hook style may increase tuna catch rates (e.g., Hoey, 1996; Falterman and Graves, 2002). The International Commission for the Conservation of Atlantic Tunas (ICCAT) has encouraged the use of circle hooks in the Atlantic pelagic longline fisheries for several years. However, only the U.S. longline fleet is currently required to use circle hooks (69 F.R. 40733), a regulatory action precipitated by concerns over gear interactions with sea turtles, not pelagic fishes.

Little work has been conducted on comparisons of hook types on bycatch rates and mortality in the U.S. Atlantic pelagic longline fishery. Berkeley and Edwards (1996) observed a lower rate of mortality at haulback for the billfishes caught on circle hooks in the northern Gulf of Mexico. However, that study did not compare hook types per se, and the authors only noted this observation and suggested it as an avenue for future research. More recently, a multi-year project with the U.S. Grand Banks pelagic longline fleet compared the efficiency of several hook types on catches of swordfish, bigeye tuna *Thunnus obesus*, and sea turtles. Circle hooks (size 18/0) baited with squid decreased swordfish catch rates, yet increased tuna catches compared with similarly baited size 9/0

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[1] Cramer, J. 2000. Species reported caught in the U.S. commercial pelagic longline and gillnet fisheries from 1996-1998. NMFS Sustainable Fisheries Division publication, SFD-99/00-78.

J-style hooks[2]. Circle hooks also significantly reduced the number of loggerhead *Caretta caretta* and leatherback *Dermochelys coracea* sea turtle interactions.

It appears that circle hooks have promise for reducing bycatch mortality, but this potential not been well quantified. We undertook this study to assess the nature of the differences in catch rates and condition of target and non-target species caught with circle and J-style hooks in the western North Atlantic coastal pelagic longline fishery.

MATERIALS AND METHODS

We conducted 85 sets on a commercial pelagic longline fishing vessel (F/V *Carol Ann*; ca. 16 m LOA) during two field seasons. The first (fall) season lasted from July through September 2003 and consisted of 39 sets in the mixed tuna and swordfish fishery along the mid-Atlantic continental shelf between Wilmington Canyon (offshore from Maryland) northward to Lydonia Canyon on the southwestern edge of Georges Bank, within the NOAA Fisheries Mid-Atlantic Bight (MAB) and Northeast Coastal (NEC) statistical areas. The second (spring) season lasted from January through April 2004 and consisted of 46 sets targeting swordfish in three southern locations: the Yucatan Channel (between Mexico and Cuba), the Windward Passage (between Haiti and Cuba), and the western Florida Straits around Key West, Florida. These second areas are encompassed by the Gulf of Mexico (GOM) and Caribbean (CAR) statistical areas.

Four sections of pelagic longline gear were fished as part of normal commercial operations (Figure 1). A section consisted of 90 hooks and was separated by either a radar-reflecting high-flyer float or radio location buoy. Size 16/0 0° offset circle (Mustad #39660ST or #39666DT) and 10° offset size 9/0 J-style (Mustad #7698 or Eagle Claw #9016) hooks were alternated in each of the four sections. Each basket (the section of line between small buoy floats) contained five hooks to ensure alternating positions of each hook within the baskets along the mainline (i.e., one basket would have C-J-C-J-C and the next would have J-C-J-C-J). Leaders were stored in separate leader boxes by hook type and color-coded with plastic chafing gear at the junction of the clip and leader.

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[2] Watson, J., D.G. Foster, S. Epperly, and A. Shah. 2004. "Experiments in the western Atlantic northeast distant waters to evaluate sea turtle mitigation measures in the pelagic longline fishery." 123p. http://www.mslabs.noaa.gov/mslabs/docs/watson4.pdf

Adjusting for different target species, individual leader lengths were 7.5 fathoms (ca. 13.7 m) in the fall fishery and 15 fathoms (ca. 27.4 m) in the spring, a standard practice within the fleet. Two buoy drop lengths were used in each set, alternating every 30 hooks, usually 5- and 2.5-fathom (ca. 9.1 and 4.5 m, respectively) lengths in the fall and 10- and 12-fathom (ca. 18.3 and 21.9 m, respectively) lengths in the spring. Squid *Illex* sp. were used in the fall fishery and Atlantic mackerel *Scomber scombrus* or a mixture of squid and mackerel in the spring fishery.

We recorded species, hook type, hooking location on the animal, mortality at the time of haulback, buoy line length, and gangion number during haulback. Lengths of fish not retained (e.g., longfin mako sharks *Isurus paucus* and live billfishes) were estimated, as were the lengths of any fish damaged by scavenging or the haulback process. Fish of sufficient length for legal retention were counted as "retained" even if damaged. Due to the difficulty of distinguishing among species without removal from the water, all carcharhinid sharks (other than the easily-distinguished oceanic whitetip *Carcharhinus longimanus* and blue shark *Prionace glauca*) were recorded at the family level. Categories of hooking location were modified from Yamaguchi (1989) and include such descriptors as "corner", "lower jaw", and "upper jaw." However, the low number of individuals of some species required a collapse of the categories into "external" and "internal" designations: locations were considered "external" if the bend of the hook was visible when the mouth was open, i.e., the bend of the hook was not posterior to the esophageal sphincter of the animal, including hooking locations on the body ("foul hooked"). All other locations were considered "internal."

Time-at-hooking was assessed with electronic hook-time recorders (HTRs: model HT600; Lindgren-Pitman, Inc., Pompano Beach, Florida, USA). This HTR model is activated by approximately seven pounds of pull and records time of hooking for up to 24 hours. The HTRs were manually attached during the setting operation between the individual leaders and the mainline on the first 180 hooks per set and examined at haulback for activation. HTR records of less than two minutes or greater than the duration of the set were omitted from subsequent analyses, as they were likely activated by the action of the gear. Data from activated HTRs were recorded along with the local time to determine the time that the animal was hooked. Activated HTRs without an attached animal or damage to the leaders were noted to provide an estimate of false activations, and it was also noted if an animal did not activate the HTR. To further evaluate the time of hooking for animals with HTR records, local sunrise and sunset times were obtained from the TIDES & CURRENTS computer program (v. 2.00; Nautical Software, Inc., Portland, OR, USA).

Small temperature-depth recorders (TDRs: DSTmilli model, Star-Oddi Corporation, Rekjavik, Iceland and LTD_1100 model, Lotek Wireless, St. Johns, Newfoundland, Canada) were also deployed on each set and placed on the leaders approximately 4 m above the bait. Data from the TDR deployments were used to calculate maximum depths, as well as the length of time the gear was sinking after deployment or rising during haulback.

Catch rates were expressed as catch-per-unit-effort (CPUE) values of the number of individuals caught per 1,000 hooks. Catches were broken down into individual species and the following species groups: "ALL SWO" for all swordfish, "RET SWO" for only retained (of legal size) swordfish, "ALL RET" for all retained fishes, "ALL TUNA" for all thunnid tunas, "ISTIO" for all istiophorid billfishes, and "UIC" for unidentified carcharhinid sharks.

Statistical tests were performed using SAS (v. 9.0; SAS Institute, Cary, NC, USA). Chi-square goodness-of-fit tests were used to compare catch rates within each seasonal fishery on each of the different buoy drop lengths. All remaining tests were performed only for species or species groups with > 10 individuals. Differences in CPUE between circle hooks and J-style hooks for the species with > 10 individuals were tested with paired *t*-tests after performing the $X'=\log(X+1)$ transformation to conform to the assumption of normality (Zar, 1996). Because most species were not present across both seasons (precluding the use of an ANOVA analysis), multiple GLMs were performed on length frequency data for the three species most frequently caught and/or retained to assess potential size-selectivity for each hook type. Only measured lengths were included in length-frequency tests. The α-significance level of all tests was subject to the Bonferroni correction to account for the multiple testing of the non-independent datasets.

Two-way analyses of variance tests (ANOVAs) were used to assess the relationship between lengths of time surviving and hook type, lengths of time surviving and individual length, and lengths of time surviving and hook location.

For the purposes of this study, fish that did not actively move in the water or on deck were considered "dead," as per Falterman and Graves (2002). The Cochran-Mantel-Haenszel chi-square test (CMH χ^2) was used to compare differences in survival at haulback for infrequently caught species due to the robust nature of the test to relatively low sample sizes, and also used to compare differences in hooking location between the two hook types. Odds ratios were used to calculate the relative increase of certain conditions (e.g., being dead at haulback on a J-style hook vs. circle hook).

RESULTS

Catch Rates

We conducted 85 sets between July 2003 and April 2004, deploying 30,600 test hooks and 15,300 hook-timers (Appendix 1). Sets were split between the fall fishery (n = 39) in the Mid-Atlantic Bight and Northeast Coastal statistical areas (MAB/NEC) and the spring fishery in the southern Gulf of Mexico and Caribbean areas (GOM/CAR). All gear was hauled in reverse order of set – i.e., the last section set out at night was the first to be retrieved in the morning – with the exception of two sets in 2003 which were hauled in the order they were set due to adverse weather conditions. Removing from consideration the two reversed sets, and eight sets in which the mainline parted and required a search for the gear, the shortest (the last hook in the fourth section of gear) and longest (first hook in the first section) soak times in the fall fishery were 13:01h and 18:29h, respectively. In the spring fishery, the shortest and longest soak times were 11:12h and 17:23h, respectively.

The fall fishery used squid bait, but the spring fishery used either all mackerel baits or a combination of squid and mackerel on various sets. Comparisons of both swordfish and overall catch rates between the two bait combinations in the spring GOM/CAR fishery showed that overall catch rates decreased significantly during all mackerel sets ($P = 0.034$). However, the GOM spring fishery targeted swordfish, and there was not a significant difference in swordfish catch rates between bait types.

Catches are summarized for both seasons in Figure 2 and Table 1. The targeted species in each fishery (nominally yellowfin tuna *Thunnus albacares* in the fall fishery and swordfish in the spring) was the most commonly caught, retained species. The mixed-species MAB/NED fall fishery caught 615 fishes representing 22 species, with yellowfin tuna, pelagic stingray *Dasyatis violacea*, and swordfish comprising 56.6% of the catch. In contrast, sets targeting swordfish in the GOM/CAR spring fishery caught 853 fishes representing 29 species, with swordfish comprising 65.5% of the catch. Many fishes were damaged by scavenging while on the line, including 23 yellowfin tuna, eight swordfish, three bigeye tuna, and three albacore *Thunnus alalunga* in 2003, and 25 swordfish, one blue marlin *Makaira nigricans*, one escolar *Lepidocybium flavobrunneum*, and one wahoo *Acanthocybium solanderi* in 2004. This represents a loss of 19% of the total yellowfin tuna caught in 2003 and 4.5% of total swordfish caught in 2004.

Catch rates varied between the two field seasons and among species and species groups. The fall season had an overall CPUE of 43.8 (per 1000 hooks) for all species, with a significantly lower catch rate on circle hooks than on J-style hooks (38.0 versus 49.5; $P = 0.027$), although 19.3% of the total catch was pelagic stingrays, a bycatch species (Figure 3). Comparing only retained species, the catch rate differences between hook types were not statistically significant. Yellowfin tuna in the fall fishery had the highest overall CPUE for an individual species (8.6), and circle hooks had a significantly higher CPUE (10.7) than J-style hooks (6.4) for this species (t-value = 2.47, $P = 0.018$). Of all the species and species groups, only the pelagic stingray showed a significantly higher catch rate on J-style hooks (12.5 versus 4.4 on circle hooks; $P < 0.0001$). The spring season CPUE for all species (51.5 fish per thousand hooks) was higher than that of the fall (43.8), but this difference was not significant. Swordfish had the highest overall CPUE during this season of any species (33.7 per 1000 hooks; including both retained and released undersized animals). No species or species group in the spring season had a statistically significant catch rate difference between the hook types.

Chi-square goodness-of-fit tests were used to evaluate the hypothesis that catch was constant across leader number (i.e., expected values = 20% of the catch at each of the five leaders). In the fall fishery, only dolphinfish *Coryphaena hippurus* showed a significant preference for the shallower hooks next to the buoy floats ($n = 93$; $\chi^2 = 10.82$, $P = 0.029$). In the spring fishery, both retained swordfish ($\chi^2 = 52.5422$, $P < 0.0001$) and "UIC" (sharks; $\chi^2 = 10.2143$, $P = 0.037$) showed significant preferences for the deeper hooks (i.e., hook numbers 2, 3, and 4). No other species or species group in the fall or spring fisheries showed significant differences, indicating fairly equal catch rates across all hook positions within baskets.

Chi-square goodness-of-fit tests were also used to evaluate whether catch rates were equal among buoy drop lengths per season. In the fall fishery, only yellowfin tuna showed a significant preference for a particular buoy line length, in this case for the shorter 2.5-fathom lines ($n = 121$; $\chi^2 = 12.0839$, $P = 0.002$).

To assess possible relationships between individual size and hook type, length-frequencies were separately tested within and between seasons for hook type (Table 2). Only yellowfin tuna in the fall (Figure 4A) were significantly longer on circle hooks ($n = 90$; $P = 0.009$; mean sizes: 116 cm (±9) FL circle and 111 cm (±7) FL J-style). In the spring, only dolphinfish (Figure 4B) showed a significant length-frequency difference between hook types ($n = 23$; $P = 0.0081$; mean sizes: 98 cm (±14) FL circle and 86 cm (±6) FL J-style). No similar effect of hook types was seen with lengths of either swordfish or escolar, the two other retained species caught in sufficiently large numbers for robust statistical analyses.

Mortality at Haulback and Hooking Location

Mortality rates at haulback varied considerably among species and between seasons (Table 1). Within seasons, significantly fewer escolar in the spring fishery were dead at haulback on circle hooks versus J-style hooks (26% and 58%, respectively; $\chi^2 = 6.285$, $P = 0.01$). Similarly, dolphinfish were significantly more likely to be alive on circle hooks ($\chi^2 = 8.333$, $P < 0.004$), and 5.8 times more likely to be dead at haulback in the fall fishery when caught with J-style hooks. Mortality at haulback was not significantly different for any other species or species group during either seasonal fishery, including the putative target species. Smaller species, such as the mesopelagic lancetfishes *Alepisaurus* spp. and snake mackerel *Gempylus serpens* were frequently dead or dismembered at haulback, preventing accurate evaluations of mortality related to hook type.

Hooking locations varied widely between hook types and fishing seasons, and among species (Figure 5). For example, circle hooks were lodged in the jaw in 82% of the yellowfin tuna, with most of those hooked in the corner of the jaw (68%). The istiophorid billfishes were predominantly (92.8%) hooked in the jaw with both hook types. In contrast, circle hooks lodged in the jaw of swordfish 74% of the time in the fall fishery, while only 54% were hooked in this location in the spring fishery. In the spring fishery, more swordfish swallowed the circle hook (3% in fall versus 11% in spring) and were foul-hooked (3% in fall versus 11% in spring). For swordfish caught on J-style hooks, the hooks lodged in the palate 44% of the time in fall and 46% in spring, and were swallowed 23% of the time in fall and 24% of the time in spring.

Most species were caught in insufficient quantities in both seasons to allow meaningful comparisons of precise hook location by hook type, requiring the collapse of the hooking location categories into "external" and "internal". During the fall season, yellowfin tuna, swordfish, and dolphinfish were all significantly more likely to be hooked externally with circle hooks ($P = 0.005$, $P < 0.0001$, and $P < 0.0001$, respectively). Yellowfin tuna in the fall season were over four times as likely to be externally hooked when caught by circle hooks (odds ratio: 4.02). Circle hooks were more likely to hook both swordfish and escolar externally than J-style hooks ($P < 0.0001$) during the spring season. Several species did not show a clear trend for specific hooking locations between hook types. Pelagic rays, for example, were caught in the mouth 93% of the time with circle hooks and 84% with J hooks, although all eight foul-hooked animals were caught on J-style hooks. Lancetfishes were caught during the spring GOM/CAR season in the jaw 88% of the time with circle hooks and 94% with J-style hooks. In the fall MAB/NEC fishery, blue sharks were caught 26% of the time internally on both hook types, but all three foul-hooked or entangled sharks were caught on J-style hooks.

Total bycatch of protected species (nine combined marine mammals and sea turtles) was minimal in this study, comprising only 0.6% of the total catch, and all protected species were released alive following removal of the attached fishing gear (Table 3). Five of the turtles were loggerheads, all caught with J-style hooks hooked in either the roof/throat ($n = 4$) or in the lower jaw ($n = 1$). The remaining four turtles were leatherbacks and were foul-hooked in the front flipper, three by J-style hooks and one with a circle hook. Both marine mammals were pilot whales *Globicephala* spp. that were entangled by their tails with the mainline.

Time of Capture

A total of 599 activated HTRs was recovered with fish (or identifiable fish parts) on the leader, representing 23 different species or species groups (Table 4). Yellowfin tuna in the fall fishery and swordfish in the spring fishery showed a significantly higher mortality rates with increased time on the hook ($P < 0.0001$). Only yellowfin tuna exhibited a significantly higher survival rate over time with circle hooks ($P = 0.0004$). However, few species were caught frequently enough on both hook types and HTRs to permit this analysis. No species or species group exhibited significantly longer survival time as a function of individual size. Only yellowfin tuna in the fall fishery and swordfish in the spring fishery were caught in sufficient numbers in both hooking locations (internal or external) and with HTR records to assess a relationship between survival time and hooking location – neither species exhibited a significant relationship.

Time at hooking varied among species. Almost all swordfish were hooked at night (99%) with only four hooked during daylight periods in the fall season (Figure 6). All of the bigeye tuna caught on leaders with HTRs ($n = 17$) were caught during the night, as were all but one blackfin tuna *Thunnus atlanticus* ($n = 7$). Yellowfin tuna showed no clear preference between daylight (57%) and nighttime (43%) feeding. Only one of 28 escolar was caught during daylight, and this animal was hooked just prior to local sunrise. Blue sharks were more often hooked at night (85%). Dolphinfish with HTR records were almost all caught during daylight (95%). The two individuals hooked at night were caught within 45 minutes of local sunrise. All but two of the 21 billfish with known capture times were caught during daylight hours. The two exceptions were a sailfish *Istiophorus platypterus* caught less than an hour prior to local sunrise during nautical twilight, and a large blue marlin caught at 12:01 a.m. local time on a clear night.

Body size of the caught animals clearly affected the activation rates for HTRs. We caught 338 swordfish on HTRs over both seasons, and only 15 HTRs (4%) failed to activate (8 of these 15 inactivation events were juvenile swordfish under 100 cm lower jaw-fork length). HTRs were also attached to leaders catching 25 istiophorid billfishes combined during both seasons, only one of which failed to activate. Thunnid tunas also had a high rate of HTR activation (98% overall). However, several smaller species, presumably because their small body size did not enable them to generate sufficient force to activate the HTR mechanism, had extremely low rates of HTR activation. These included alepisaurid lancetfish (17%) and snake mackerel, which had HTR activation rates at haulback of almost 0%. Pelagic stingrays also had very low rates of HTR activation (12%) regardless of individual size. Discounting small animals (< 5 kg approximate weight) and pelagic stingrays, only 25 HTRs failed to activate in 2003 and 30 in 2004. Over both field seasons, 173 HTRs (1.1% of those activated) were recovered without a hooked animal or damage to the bait or leader.

TDR data indicate that most gangions reached fishing depth approximately 15 minutes after deployment, and baits were generally retrieved from this depth during haulback in approximately 15 minutes. Analysis of these TDR data in conjunction with the time-at-hooking data revealed that very few animals were caught during set out or haulback of the gear. Dolphinfish were a notable exception to this pattern, with six of 34 fish in the fall, and three of five fish in the spring, caught during set out or haulback. Mean maximum depths (depth of middle hook in basket) of the gear were 20.3m (SD ± 13.1m) for a 2.5fa buoy drop and 23.8m (SD ± 10.2m) for a 5fa buoy drop in the fall, and 52m (SD ± 21.7m) for a 10fa drop and 54m (SD ± 22.9m) for a 12fa drop in the spring. Leaders with TDRs attached caught a total of 31 fish (8% of TDR deployments) during the fall and spring fisheries.

DISCUSSION

Catch Rate Comparison

The gear deployment configurations we used were standard for the U.S. Atlantic coastal pelagic longline fishery, with the only differences being the alternating hook types and the use of approximately 15 TDRs and 180 HTRs per set. The choices of leader lengths, buoy drop lengths, leaded swivel weights, locations, lightstick color, and bait types were typical of the vessels in this fishery. The locations and seasons were chosen specifically because they are traditional fishing areas for the U.S. coastal pelagic longline fleet.

We found few significant differences in catch rates of target or bycatch species between size 16/0 0°-offset circle hooks and size 9/0 10°-offset J-style hooks. Yellowfin tuna exhibited significantly higher catch rates with circle hooks in the fall fishery, mirroring previous studies comparing catch rates among hook types. Although not significant, escolar and dolphinfish also had higher catch rates on circle hooks in the spring GOM/CAR swordfish fishery. In his review of the Gulf of Mexico pelagic longline fishery, which primarily targeted yellowfin tuna, Hoey (1996) reported that vessels caught 32.9 fish per set using circle hooks and only 27.2 fish per set using J-style hooks (122 and 75 sets, respectively). Falterman and Graves (2002) found a significant increase in CPUE for circle hooks relative to J-style hooks for both yellowfin tuna (mean CPUEs 33 and 1.3 per 1000 fish, respectively) and a composite "all fishes" category (mean CPUEs 50.5 and 23 per 1000 fish, respectively), although the low number of fish caught overall in their study prevented comparisons across other species. It is worth noting that both Hoey (1996) and Falterman and Graves (2002) observed fisheries using predominantly live fishes as bait, rather than the frozen squid and/or mackerel used in our study. Falterman and Graves (2002) also used a smaller J-style hook (size 7/0 versus the size 9/0 in this study), as well as offset size 14/0 and 16/0 circle hooks. Varying hook sizes and shapes may affect catch rates through unquantified gape size or other morphological feeding limitations among various species groups. For example, smaller hooks caught more sea bream *Pagellus* spp. than larger hooks in a study by Erzini et al.

(1998), while catch rates for serranid groupers were unaffected by hook size (Bacheler and Buckel, 2004). By using two standard hook sizes and shapes, this study attempted to minimize possible confounding factors.

Mortality at Haulback and Hooking Location

There were clear differences in survival of fishes caught on the two hook types used in this study. The overall lower rate of internal gut hooking we observed with circle hooks is consistent with the findings of prior studies on serranid groupers (Bacheler and Buckel, 2004), striped marlin *Tetrapturus audax* (Domeier et al., 2003), and white marlin *T. albidus* (Horodysky and Graves, 2005) Our results demonstrated that 88% of all yellowfin tuna caught in the MAB/NEC fall fishery were caught in the jaw by circle hooks, comparable to the results seen by Skomal et al. (2002) in which 95% of all juvenile bluefin tuna *Thunnus thynnus* caught on circle hooks in a recreational fishery were caught in the jaw. In conjunction with the HTR data showing that at least one species has longer survival times after being caught on circle hooks, the results of this study suggest that the use of circle hooks will result in lower mortality rates at haulback of target and non-target species.

As evidenced in this and previous pelagic longline studies, hooks often lodge in locations other than the jaw or gut. Falterman and Graves (2000) reported that gut-, foul-, and roof-hooking events were seen with J-style hooks, but not circle hooks, in the Venezuelan pelagic longline fishery. A total of 19 swordfish in this study were hooked in the bill, primarily with circle hooks, and more than 5% of all swordfish caught during the fall fishery were hooked in the bill or entangled with the gangion. Stillwell and Kohler (1985) noted that many of the squid and mesopelagic fishes in swordfish gut contents showed evidence of decapitation or slashing. This feeding behavior may explain the relatively high incidence of bill hookings. We also observed several fishes in which the point of the hook exited the eye or eye socket. Of the animals hooked through the eye in this study, eight were hooked with circle hooks and nine with J-style hooks. The large circle hook (size 16/0) used in this commercial gear study may increase the probability of hooks exiting through the eye socket. Skomal et al. (2002) reported that three of the 101 juvenile bluefin tuna landed in their study had eye damage resulting from hooks exiting in this location, and Horodysky and Graves (2005) only had one of 40 white marlin caught through the eye socket with recreational fishing gear and smaller, size 8/0 circle hooks.

Time of Feeding

This study observed several patterns of feeding times among species, and some clearly demonstrated a preference for day or night feeding. Swordfish caught on hook timers were either hooked during dark or nautical twilight. No difference in the times of feeding at night was observed between under-sized (<120 cm LJFL) and legally retainable swordfish. All of the escolar were also caught at night or nautical twilight. Extremely active and presumably feeding bigeye tuna have been caught during daylight hours on other pelagic longline sets (D. Kerstetter, pers. obs.), although 92.8% of the bigeye tuna caught on HTRs in this study were caught during nighttime periods. In contrast, 97.8% of dolphinfish caught during both seasons were caught during daylight or nautical twilight.

Other species' feeding patterns were more varied, including the other tunas and billfishes. Yellowfin tuna and albacore demonstrated no preferential time of feeding. The billfishes fed primarily during the daylight and crepuscular hours; only one billfish was caught at night. This blue marlin was caught at approximately midnight on a clear night with moonlight, where visual feeding strategies may have been possible. The apparent preference for billfish to feed during daylight hours might suggest for more selective setting strategy to reduce billfish bycatch for the gear, especially with swordfish-targeting vessels. However, the demonstrated feeding of billfish to feed during the sunrise period, when swordfish vessels usually haul back the gear, may preclude this preference as a bycatch reduction technique.

We found that very few animals were hooked during either setting or hauling of the gear. Only 19 fish total were caught within 30 minutes of the leader reaching the surface at haulback, nine of which were dolphinfish and three billfish (two blue marlin and one sailfish). Actively moving baits presumably are more attractive to fish, causing some to hypothesize that many fish are caught during haulback of the gear. TDRs deployed in this study found that many leaders experienced vertical movement during the time that the baits were presumed to have settled at depth, a finding consistent with Berkeley and Edwards (1996). However, these same TDR records clearly showed the movements of the hooks associated with set and haulback. Boggs (1992) indicated that 88% of bigeye and yellowfin tuna were caught when the gear was assumed to have settled to the target depths; however, a substantial proportion of.striped marlin, shortbill spearfish *Tetrapturus angiorostris*, and dolphinfish were caught during setting or hauling. In contrast, Berkeley and Edwards (1996) found that a high proportion of yellowfin tuna were hooked during haulback. Although Boggs (1992) indicated that large percentages of some species caught in the Hawaii fishery were hooked during the set or haul of the gear, the much deeper depths fished in the Hawaii study also meant that the hooks were moving for longer periods of time and through additional water layers. The shallower depths and shorter gear used in the U.S. coastal longline fishery on the Atlantic coast may therefore have lower catch rates of billfishes and dolphinfish than vessels fishing at deeper depths with longer gear for bigeye tuna in waters with a deeper mixed layer.

We found that mortality at haulback for yellowfin tuna was significantly related to the time on the hook, and several different species caught on leaders with TDRs exhibited vertical movement for several hours after hooking. For obligate ram-ventilating fishes such as the scombrids, the effective constrained swimming area resulting from capture on the line may prevent adequate respiration, translating into higher observed mortality rates at haulback. Several bigeye and yellowfin tuna survived after hooking for over 12 hours, and although not a significant relationship, those hooked in the jaw tended to survive for longer periods of time. One large blue marlin in 2004 was caught with a circle hook in the corner of the jaw and was still alive at haulback over 14 hours later. Many escolar, even those under 100 cm FL, were alive at haulback despite being on the line for over seven hours. Clearly, pelagic fishes can survive being hooked on the longline gear for extended periods, especially if hooked in the jaw. The survivability of fish caught on pelagic longline gear is clearly a combination of several factors, including hooking location (a function of hook type) and time on the line. Boggs (1992) noted a high survival rate for striped marlin and bigeye tuna, some even after six hours on the line. Berkeley and Edwards (1996) also noted that approximately half of the blue and white marlin hooked on the line for five hours or more were alive at haulback

Management Implications

The release of live, longline-caught bycatch species could promote the recovery of depleted stocks by reducing fishing mortality. Many pelagic fishes demonstrated survival in this study for long periods of time after capture, especially when hooked in certain locations, such as the jaw. We found that several pelagic fishes, including the billfishes, are hooked more frequently externally with circle hooks than the traditional J-style hooks, which is consistent with trends observed in several other studies.

The results of our study showed that catch rates for targeted species may not change with the mandatory change to circle hooks for the U.S. pelagic longline fishery, but that both target and non-target species caught by circle hooks may remain alive longer after capture. However, we only examined two fishing areas, the fall mixed fishery and the spring swordfish directed fishery. Results from other areas, such as the northern Gulf of Mexico yellowfin tuna fishery, may differ. Our results suggest that the use of circle hooks will not prevent the catch of sea turtles; several were caught in this study with both hook types. Circle hooks will also not prevent the capture of billfishes, although they may increase the rate of survival at haulback for these fishes and thereby reduce overall fishing mortality. There may be additional benefits to the coastal pelagic longline fishery from the switch to circle hooks. For example, the circle hooks in this study caught far fewer pelagic rays, a common bycatch species in the MAB/NEC areas. By decreasing the catch of some nuisance or non-market bycatch species, the use of circle hooks may save both crew time and overall vessel trip expenses such as those involved in the replacement of lost hooks.

Conclusion

Our results demonstrate that the use of 0° offset size 16/0 circle hooks in the U.S. coastal pelagic longline fishery can reduce mortality at haulback for a suite of bycatch fishes without significantly affecting catch rates of commercially important species. In some situations, the use of circle hooks may even increase the catch of target species, such as yellowfin tuna. Circle hooks are more likely to hook animals externally rather the internally, and fishes caught on circle hooks exhibited longer survival time on the line. This longer survival time with circle hooks may also allow a higher percentage of undersized swordfish and istiophorid billfishes to be released alive than those animals caught with J-style hooks and increase ex-vessel revenue by resulting in a higher quality product.

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Table 1. Catch composition and percent mortality at haulback by hook type for ten most commonly caught fishes, separated by field season. Numbers include both retained and discarded animals. Asterisk (*) indicates significant difference.

Season 1: Fall 2003 (MAB/NEC)

		Percent Mortality	
Species	*Percent Composition (n)*	*Circle Hook*	*J-style Hook*
Yellowfin tuna *Thunnus albacares*	19.7 (121)	58.7	69.6
Pelagic stingray *Dasyatis violacea*	19.3 (119)	3.2	4.5
Swordfish *Xiphias gladius*	17.6 (108)	77.5	79.4
Dolphin *Coryphaena hippurus* *	15.1 (93)	6.5	29.8
Blue shark *Prionace glauca*	10.1 (62)	7.4	22.8
Alepisaurus spp.	2.9 (18)	50.0	62.5
White marlin *Tetrapturus albidus*	2.8 (17)	40.0	33.3
Albacore *Thunnus alalunga*	2.4 (15)	83.3	100.0
Bigeye tuna *Thunnus obesus*	2.3 (14)	62.5	83.3
Unidentified Carcharhinid shark	1.8 (11)	0.0	0.0

Other species: Shortfin mako shark *Isurus oxyrinchus* (7), tiger shark *Galeocerdo cuvier* (7), manta ray *Manta birostris* (6), ocean sunfish *Mola mola* (5), scalloped hammerhead shark *Sphyrna lewini* (3), snake mackerel *Gempylus serpens* (2), longfin mako shark *Isurus paucus* (2), blue marlin *Makaira nigricans* (1), *Cubiceps capensis* (1), sailfish *Istiophorus platypterus* (1), skipjack tuna *Katsuwomus pelamis* (1), and wahoo *Acanthocybium solanderi* (1).

* Significant difference (CMH $\chi^2 = 8.3331$, $P = 0.0061$)

Season 2: Spring 2004 (GOM/CAR)

		Percent Mortality	
Species	*Percent Composition (n)*	*Circle Hook*	*J-style Hook*
Swordfish *Xiphias gladius*	65.5 (559)	74.4	75.7
Unidentified Carcharhinid shark	8.0 (69)	33.4	46.7
Escolar *Lepidocybium flavobrennum*	7.5 (64)	26.3	57.7
Alepisaurus spp.	2.7 (23)	50.0	86.7
Dolphin *Coryphaena hippurus*	2.7 (23)	7.7	10.0
Oilfish *Ruvettus pretiosus*	1.9 (16)	20.0	66.7
Great barracuda *Sphyraena barracuda*	1.8 (15)	16.7	100.0
Sailfish *Istiophorus platypterus*	1.6 (14)	14.3	42.8
Bigeye tuna *Thunnus obesus*	1.1 (9)	57.1	100.0
Snake mackerel *Gempylus serpens*	1.1 (9)	75.0	80.0

Other species: Blackfin tuna *Thunnus atlanticus* (8), blue marlin *Makaira nigricans* (8), tiger shark *Galeocerdo cuvier* (6), ocean sunfish *Mola mola* (6), white marlin *Tetrapturus albidus* (4), yellowfin tuna *Thunnus albacares* (3), *Cubiceps capensis* (3), wahoo *Acanthocybium solanderi* (2), bigeye thresher shark *Alopias superciliosus* (2), oceanic whitetip shark *Carcharhinus longimanus* (2), albacore *Thunnus alalunga* (1), king mackerel *Scomberomorus cavalla* (1), longbill spearfish *Tetrapturus pfleugeri* (1), shortfin mako shark *Isurus oxyrinchus* (1), oceanic puffer *Lagocephalus lagocephalus* (1), pelagic stingray *Dasyatis violacea* (1), scalloped hammerhead shark *Sphyrna lewini* (1), and Atlantic cutlassfish *Trichiurus lepturus* (1).

Table 2. Results of Bonferroni-corrected t-tests (significance at $P = 0.05/5$, so that $P_{\text{adj}} = 0.01$) on length frequencies by hook type, separated by field season. Note that numbers include both retained and discarded animals. Mean lengths given in centimeters.

Season 1: Summer/Fall 2003

	Mean Length (SD)		
Species	*Circle Hook*	*J-style Hook*	*t Value (Pr>|t|)*
Yellowfin tuna *Thunnus albacares* (*n* = 90)	116.1 (±9.24)	111.3 (±6.88)	2.69 (P=0.0086)*
Swordfish *Xiphias gladius* (*n* = 62)	128.0 (±23.84)	140.8 (±30.97)	-1.73 (P=0.0885)
Dolphinfish *Coryphaena hippurus* (*n* = 88)	85.7 (±18.81)	82.7 (±19.60)	0.73 (P=0.4659)

Season 2: Winter/Spring 2004

	Mean Length (SD)		
Species	*Circle Hook*	*J-style Hook*	*t Value (Pr>|t|)*
Swordfish *Xiphias gladius* (*n* = 471)	145.9 (±29.95)	141.63 (±29.88)	1.53 (P=0.1264)
Escolar *Lepidocybium flavobrennum* (*n* = 55)	89.8 (±28.16)	92.39 (±16.18)	-0.42 (P=0.6737)†
Dolphinfish *Coryphaena hippurus* (*n* = 23)	98.5 (±13.68)	85.6 (±6.52)	2.98 (P=0.0081) *†

* Significant at $P<0.01$ level

† Satterthwaite t-test for unequal variances

Table 3. Catch composition and details for protected species interactions. All animals were released alive. Area abbreviations for NOAA Fisheries statistical areas: "NEC" Northeast Coastal, "MAB" Mid-Atlantic Bight, "GOM" Gulf of Mexico, and "CAR" Caribbean.

Date	Set	Area	Species	Hook Type	Hooking Location
4 Aug 03	7	NEC	Loggerhead Turtle	J-style	Roof/Throat
9 Aug 03	11	NEC	Loggerhead Turtle	J-style	Roof/Throat
7 Sep 03	23	MAB	Shortfin Pilot Whale	N/A	Entangled in mainline
14 Sep 03	30	MAB	Shortfin Pilot Whale	N/A	Entangled in mainline
8 Oct 03	37	MAB	Leatherback Turtle	J-style	Foul-hooked
9 Oct 03	38	MAB	Leatherback Turtle	J-style	Foul-hooked
9 Oct 03	38	MAB	Loggerhead Turtle	J-style	Roof/Throat
10 Oct 03	39	MAB	Loggerhead Turtle	J-style	Roof/Throat
10 Feb 04	52	GOM	Loggerhead Turtle	J-style	Lower Jaw
27 Feb 04	59	CAR	Leatherback Turtle	Circle	Foul-hooked
9 Apr 04	77	GOM	Leatherback Turtle	J-style	Foul-hooked

Table 4. Summary of time on line (hours:minutes) for major species, with sample size (n) and standard deviation in parentheses beneath. Numbers include both retained and discarded animals. Only swordfish and yellowfin tuna in 2003 were significantly more likely to be dead at haulback with an increased lengths of time on the line: an asterisk (*) indicates significance at the $P < 0.0001$ level.

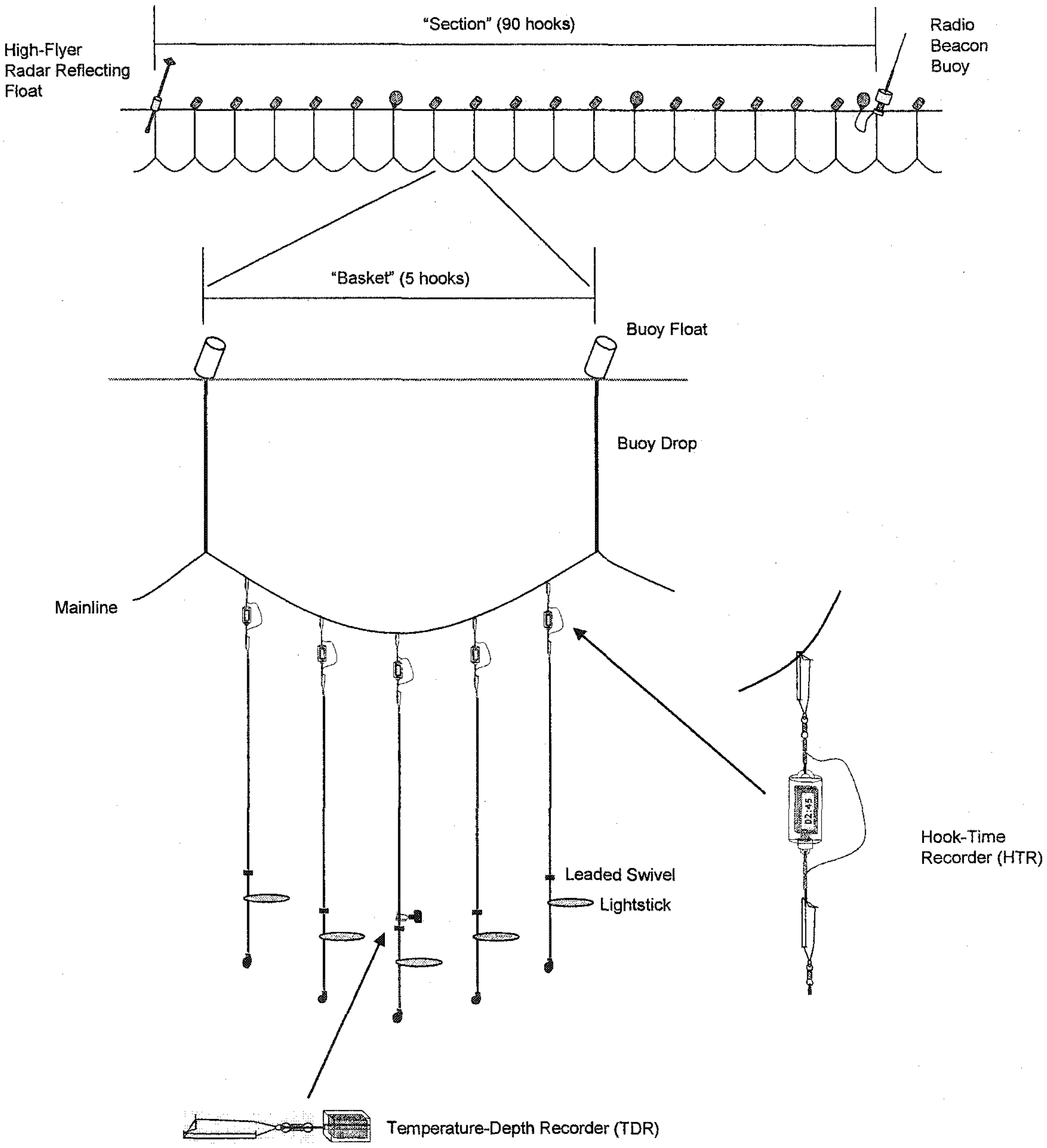
Species	Year	Circle Live	Circle Dead	J–style Live	J–style Dead
Blue shark *Prionace glauca*	2003	12:44	11:47	11:13	14:33
		(17; ±4:21)	(2; ±6:04)	(15; ±4:29)	(5; ±0:23)
Dolphinfish *Coryphaena hippurus*	2003	2:24	16:06	3:34	9:24
		(16; ±2:08)	(1; n/a)	(11; ±2:05)	(3; ±5:31)
	2004	0:32	10:41	0:18	[none]
		(2; ±0:09)	(1; n/a)	(2; ±0:06)	
Escolar *Lepidocybium flavobrunneum*	2004	8:30	8:40	9:22	13:43
		(12; ±2:57)	(6; ±4:09)	(4; ±0:24)	(6; ±4:02)
Swordfish *Xiphias gladius*	2003*	9:07	13:28	7:29	12:36
		(5; ±4:17)	(18; ±2:56)	(2; ±2:12)	(28; ±3:40)
	2004	8:28	10:12	6:59	9:48
		(31; ±3:52)	(92; ±3:30)	(30; ±3:23)	(110; ±3:40)
Unidentified Carcharhinid shark	2003	4:11	[none]	8:39	[none]
		(2; ±3:33)		(3; ±2:43)	
	2004	4:33	[none]	7:08	9:33
		(3; ±1:10)		(5; ±5:01)	(4; ±5:16)
Yellowfin tuna *Thunnus albacares*	2003*	6:21	14:05	5:18	14:01
		(15; ±5:46)	(19; ±5:56)	(7; ±3:02)	(14; ±5:02)
	2004	[none]	2:36	[none]	10:05
			(1; n/a)		(1; n/a)

Other species caught on HTRs: blackfin tuna *Thunnus atlanticus* (8), blue marlin *Makaira nigricans* (8), sailfish *Istiophorus platypterus* (8), tiger shark *Galeocerdo cuvier* (6), ocean sunfish *Mola mola* (6), white marlin *Tetrapturus albidus* (4), *Cubiceps capensis* (3), wahoo *Acanthocybium solanderi* (2), bigeye thresher shark *Alopias superciliosus* (2), oceanic whitetip shark *Carcharhinus longimanus* (2), albacore *Thunnus alalunga* (1), king mackerel *Scomberomorus cavalla* (1), longbill spearfish *Tetrapturus pfleugeri* (1), shortfin mako shark *Isurus oxyrinchus* (1), oceanic puffer *Lagocephalus lagocephalus* (1), pelagic stingray *Dasyatis violacea* (1), scalloped hammerhead shark *Sphyrna lewini* (1), and Atlantic cutlassfish *Trichiurus lepturus* (1).

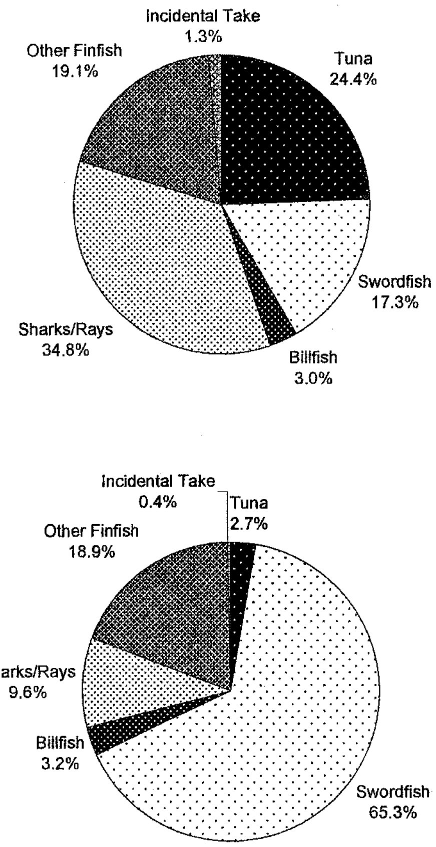
LIST OF FIGURES

Figure 6. Time-at-hooking for 64 undersized and 193 retainable swordfish caught with hook time recorders during 46 pelagic longline sets in the Gulf of Mexico and Caribbean (spring fishery; lower chart)..

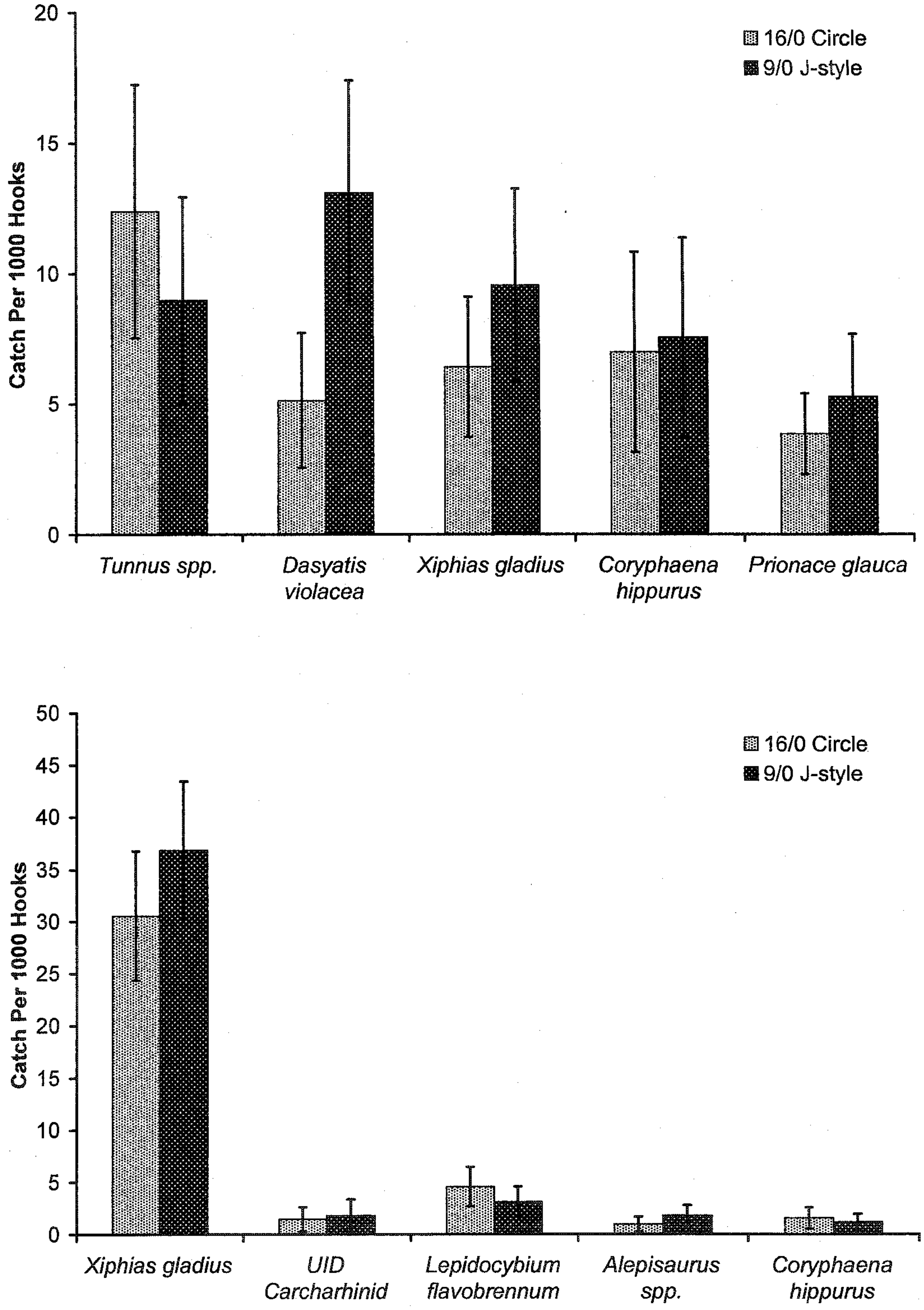
[Figure 1]


"Section" (90 hooks)
High-Flyer Radar Reflecting Float
Radio Beacon Buoy
"Basket" (5 hooks)
Buoy Float
Buoy Drop
Mainline
Leaded Swivel
Lightstick
D2:45
Hook-Time Recorder (HTR)
Temperature-Depth Recorder (TDR)

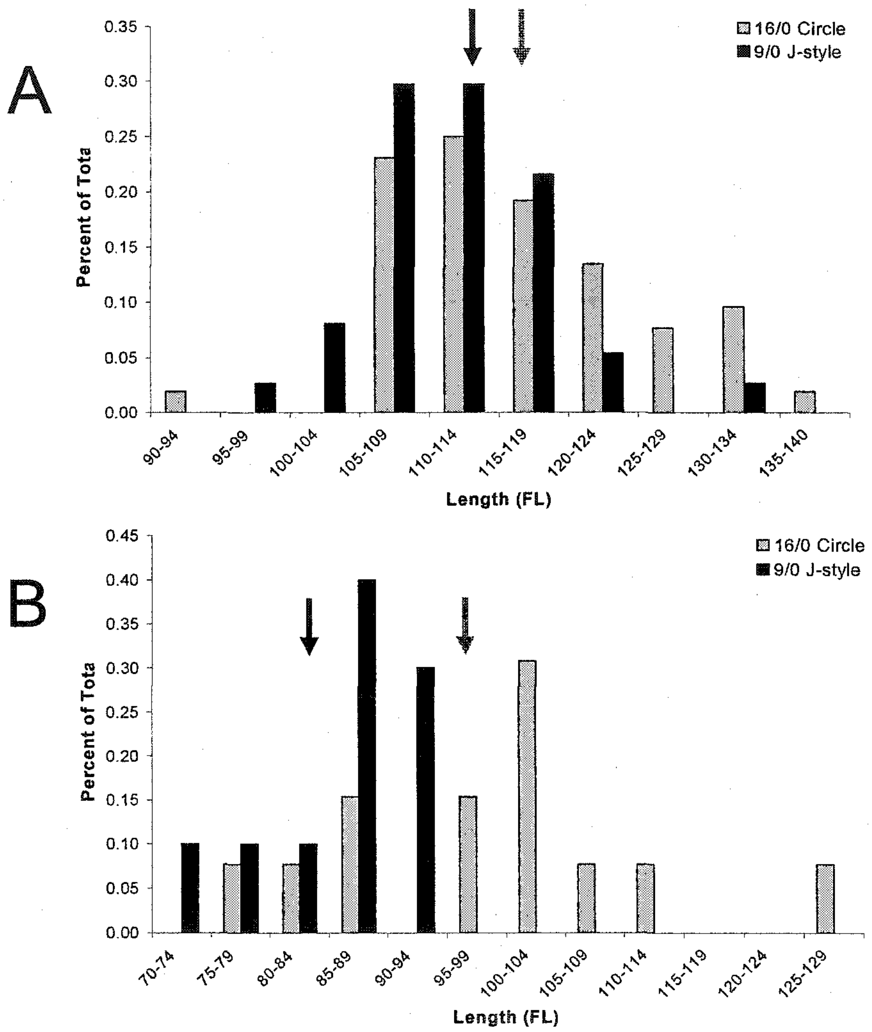
[Figure 2]


Incidental Take
1.3%
Other Finfish
19.1%
Tuna
24.4%
Swordfish
17.3%
Sharks/Rays
34.8%
Billfish
3.0%
Incidental Take
0.4%
Tuna
2.7%
Other Finfish
18.9%
Sharks/Rays
9.6%
Billfish
3.2%
Swordfish
65.3%

[Figure 3]


20
15
10
5
0
Catch Per 1000 Hooks
▨ 16/0 Circle
■ 9/0 J-style
Tunnus spp.
Dasyatis violacea
Xiphias gladius
Coryphaena hippurus
Prionace glauca
50
45
40
35
30
25
20
15
10
5
0
Catch Per 1000 Hooks
▨ 16/0 Circle
■ 9/0 J-style
Xiphias gladius
UID Carcharhinid
Lepidocybium flavobrennum
Alepisaurus spp.
Coryphaena hippurus

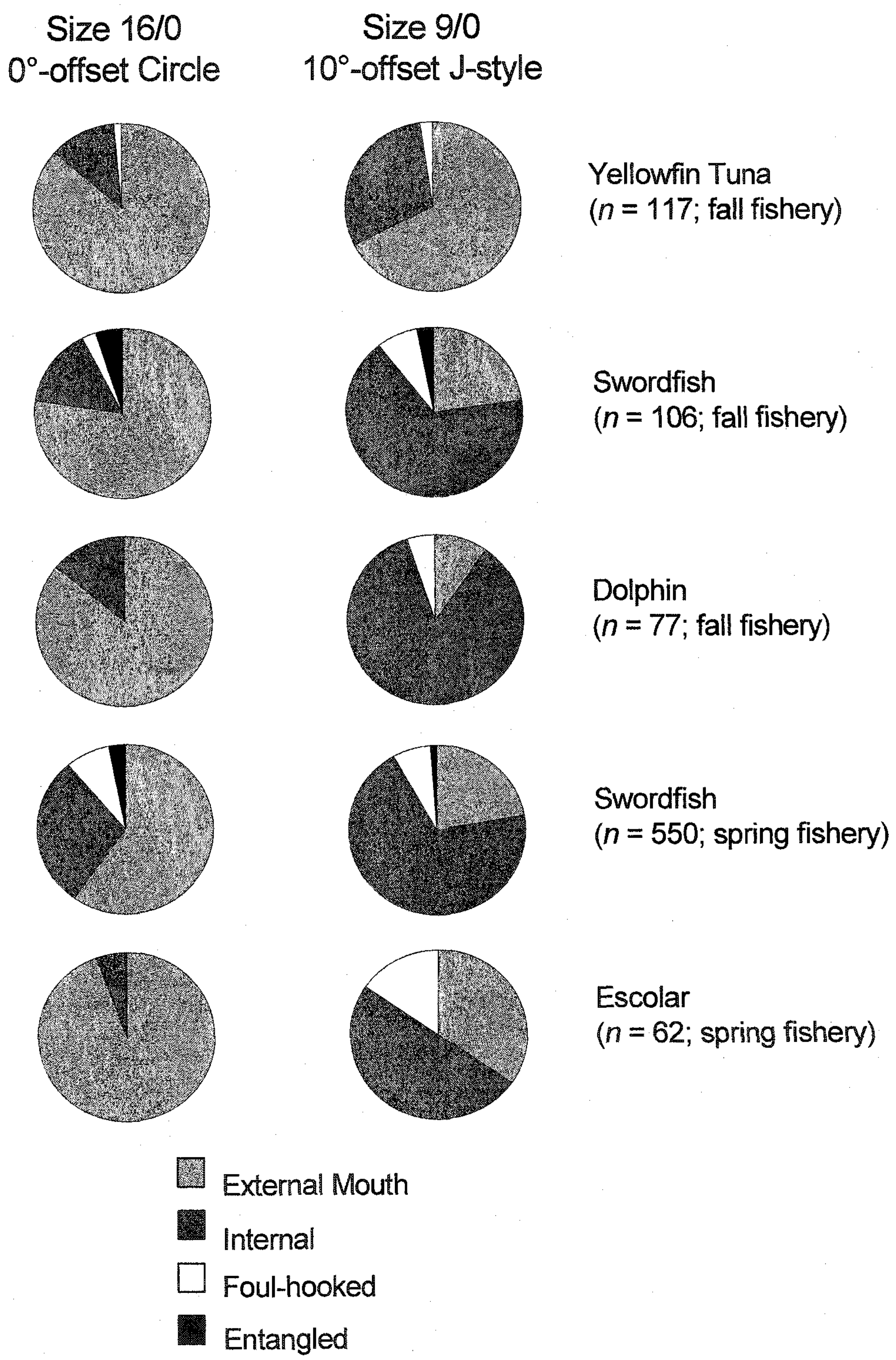
[Figure 4]



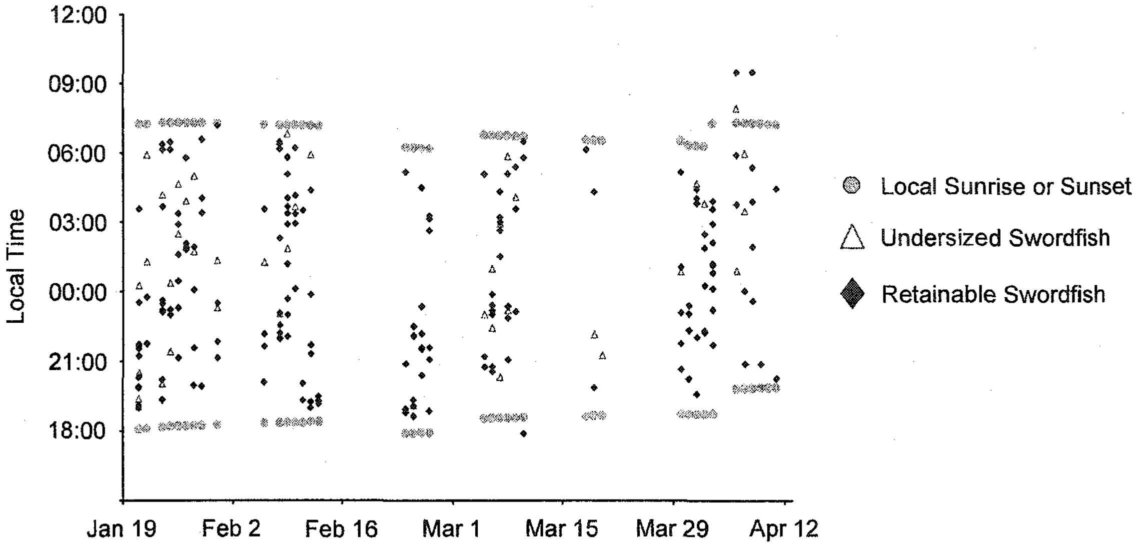
Yellowfin Tuna (*n* = 90)
MAB/NEC 2003

Dolphin (*n* = 23)
MAB/NEC 2003

[Figure 5]


Size 16/0
0°-offset Circle
Size 9/0
10°-offset J-style
Yellowfin Tuna
(n = 117; fall fishery)
Swordfish
(n = 106; fall fishery)
Dolphin
(n = 77; fall fishery)
Swordfish
(n = 550; spring fishery)
Escolar
(n = 62; spring fishery)
External Mouth
Internal
Foul-hooked
Entangled

[Figure 6]


12:00
09:00
06:00
03:00
00:00
21:00
18:00
Local Time
Jan 19
Feb 2
Feb 16
Mar 1
Mar 15
Mar 29
Apr 12
Local Sunrise or Sunset
Undersized Swordfish
Retainable Swordfish

Appendix 1. Locations and sea surface temperatures of sets taken on a commercial pelagic longline vessel during the fall MAB/NEC (2003) and spring GOM/CAR (2004) fisheries. Abbreviated location designations refer to NOAA Fisheries statistical areas. Bait type refers to "S" = squid *Illex* spp., "M" = mackerel *Scomber scombrus*, and "SM" = combination of squid and mackerel baits. "SST" is the sea surface temperature in degrees Celsius.

Set Number	Set Date	Location	Set Longitude	Set Latitude	Haul Longitude	Haul Latitude	Bait Type	SST -Set	SST - Haul
1	7/26/03	MAB	70.59° W	37.44° N	70.85° W	38.23° N	S	26.4	26.8
2	7/28/03	NEC	67.63° W	40.30° N	67.32° W	40.41° N	S	23.4	20.7
3	7/29/03	NEC	67.68° W	40.27° N	67.50° W	40.30° N	S	23.7	24.1
4	7/30/03	NEC	67.71° W	40.27° N	67.53° W	40.32° N	S	23.8	24.7
5	8/1/03	NEC	67.63° W	40.34° N	67.52° W	40.37° N	S	25.4	24.8
6	8/2/03	NEC	67.56° W	40.34° N	67.44° W	40.37° N	S	25.3	25.2
7	8/3/03	NEC	67.55° W	40.35° N	67.44° W	40.35° N	S	25.7	25.4
8	8/4/03	MAB	67.45° W	40.42° N	67.40° W	40.42° N	S	25.3	22.6
9	8/6/03	MAB	70.43° W	39.74° N	70.26° W	39.84° N	S	24.6	24.4
10	8/7/03	MAB	69.07° W	39.84° N	70.93° W	39.89° N	S	24.9	25.3
11	8/8/03	MAB	70.01° W	39.88° N	69.89° W	39.92° N	S	25.0	25.4
12	8/9/03	MAB	70.06° W	39.88° N	69.96° W	39.93° N	S	25.0	25.1
13	8/13/03	MAB	70.13° W	39.91° N	70.02° W	39.93° N	S	26.1	26.8
14	8/14/03	MAB	69.71° W	39.89° N	69.68° W	39.90° N	S	26.6	26.7
15	8/15/03	MAB	69.49° W	39.90° N	69.45° W	39.98° N	S	27.6	25.2
16	8/17/03	MAB	72.28° W	39.32° N	72.28° W	39.32° N	S	26.4	26.3
17	8/18/03	MAB	72.27° W	39.34° N	72.27° W	39.32° N	S	26.4	26.8
18	8/19/03	MAB	72.38° W	39.22° N	72.40° W	39.27° N	S	26.9	26.6
19	9/2/03	MAB	71.31° W	39.83° N	71.29° W	39.76° N	S	23.0	24.0
20	9/3/03	MAB	71.55° W	39.86° N	71.46° W	39.84° N	S	25.7	25.4
21	9/4/03	MAB	71.71° W	39.79° N	71.65° W	39.84° N	S	24.7	25.3
22	9/5/03	MAB	71.72° W	39.78° N	71.69° W	39.84° N	S	24.9	25.2
23	9/6/03	MAB	71.73° W	39.80° N	71.67° W	39.81° N	S	25.3	25.2
24	9/7/03	MAB	71.74° W	39.80° N	71.70° W	39.82° N	S	24.9	25.2
25	9/8/03	MAB	71.28° W	39.92° N	71.63° W	39.86° N	S	22.2	24.0
26	9/9/03	MAB	71.38° W	39.87° N	71.47° W	39.77° N	S	21.6	20.8
27	9/10/03	MAB	71.58° W	39.84° N	71.57° W	39.78° N	S	20.7	23.0
28	9/11/03	MAB	71.75° W	39.69° N	71.82° W	39.77° N	S	24.3	24.2
29	9/12/03	MAB	71.74° W	39.58° N	71.72° W	39.62° N	S	24.7	24.8
30	9/13/03	MAB	71.93° W	39.57° N	71.92° W	39.61° N	S	25.1	25.3
31	9/14/03	MAB	71.88° W	39.59° N	71.98° W	39.60° N	S	25.3	25.3
32	10/1/03	MAB	71.74° W	39.73° N	71.71° W	39.71° N	S	23.7	23.4
33	10/2/03	MAB	71.82° W	39.70° N	71.85° W	39.71° N	S	23.4	22.6
34	10/3/03	MAB	71.65° W	39.83° N	71.52° W	39.88° N	S	22.2	22.1
35	10/5/03	MAB	72.96° W	38.72° N	72.93° W	38.70° N	S	22.4	21.2
36	10/6/03	MAB	73.09° W	38.61° N	73.15° W	38.58° N	S	22.7	22.6

37	10/7/03	MAB	73.21° W	38.50° N	73.24° W	38.50° N	S	22.7	22.7
38	10/8/03	MAB	73.19° W	38.49° N	73.20° W	38.48° N	S	22.6	22.8
39	10/9/03	MAB	73.11° W	38.58° N	73.14° W	38.57° N	S	22.4	21.4
40	1/21/04	GOM	84.28° W	24.98° N	83.91° W	24.33° N	SM	26.6	26.6
41	1/22/04	GOM	84.27° W	24.95° N	84.16° W	24.76° N	SM	26.1	24.7
42	1/24/04	CAR	85.37° W	22.10° N	85.63° W	22.03° N	SM	26.4	26.5
43	1/25/04	CAR	85.38° W	22.04° N	85.59° W	22.07° N	SM	26.9	26.8
44	1/26/04	CAR	85.42° W	22.04° N	85.39° W	22.07° N	SM	27.1	27.1
45	1/27/04	CAR	85.40° W	22.06° N	85.54° W	22.13° N	SM	27.1	26.8
46	1/28/04	CAR	85.40° W	22.06° N	85.54° W	22.13° N	SM	26.9	26.7
47	1/29/04	CAR	85.59° W	22.04° N	85.64° W	22.15° N	SM	26.9	26.8
48	1/31/04	CAR	85.52° W	22.11° N	85.52° W	22.10° N	SM	26.7	26.6
49	2/6/04	CAR	85.40° W	22.04° N	85.49° W	22.13° N	SM	27.3	27.1
50	2/8/04	CAR	85.40° W	22.06° N	85.39° W	22.16° N	SM	26.7	26.6
51	2/9/04	CAR	85.37° W	22.13° N	85.36° W	22.25° N	SM	26.8	26.7
52	2/10/04	CAR	85.36° W	22.11° N	85.34° W	22.17° N	SM	27.1	26.7
53	2/11/04	CAR	85.45° W	22.37° N	85.43° W	22.73° N	SM	27.1	26.8
54	2/12/04	CAR	85.55° W	22.35° N	85.66° W	22.44° N	SM	27.1	26.9
55	2/13/04	CAR	85.63° W	22.31° N	85.63° W	22.43° N	SM	27.2	26.9
56	2/24/04	CAR	73.65° W	20.27° N	73.74° W	20.23° N	SM	26.5	26.3
57	2/25/04	CAR	73.67° W	20.44° N	73.78° W	20.39° N	SM	26.7	26.6
58	2/26/04	CAR	73.65° W	20.39° N	73.80° W	20.40° N	SM	26.9	27.8
59	2/27/04	CAR	73.53° W	20.18° N	73.75° W	20.23° N	SM	28.0	27.1
60	3/5/04	GOM	82.35° W	24.18° N	82.13° W	24.29° N	SM	25.6	25.1
61	3/6/04	GOM	82.70° W	24.23° N	82.65° W	24.16° N	SM	24.9	24.6
62	3/7/04	GOM	82.69° W	24.23° N	82.55° W	24.19° N	SM	24.4	24.1
63	3/8/04	GOM	82.70° W	24.23° N	82.55° W	24.22° N	SM	23.7	23.4
64	3/9/04	GOM	82.74° W	24.23° N	82.51° W	24.07° N	SM	23.6	23.1
65	3/10/04	GOM	82.74° W	24.73° N	82.25° W	23.56° N	SM	26.4	26.2
66	3/18/04	GOM	82.48° W	24.19° N	82.56° W	24.22° N	SM	25.7	24.8
67	3/19/04	GOM	82.70° W	24.22° N	82.84° W	24.25° N	SM	25.3	24.6
68	3/20/04	GOM	82.65° W	24.17° N	82.79° W	24.23° N	SM	25.1	24.1
69	3/30/04	GOM	82.36° W	23.94° N	82.21° W	24.15° N	SM	26.1	24.4
70	3/31/04	GOM	82.32° W	23.44° N	82.61° W	23.81° N	SM	26.5	25.8
71	4/1/04	GOM	82.27° W	23.39° N	81.77° W	23.69° N	SM	26.6	26.2
72	4/2/04	GOM	82.55° W	23.66° N	82.18° W	23.78° N	SM	25.0	25.3
73	4/3/04	GOM	82.36° W	23.40° N	81.88° W	23.71° N	SM	26.8	26.4
74	4/6/04	GOM	83.89° W	24.66° N	83.89° W	24.69° N	SM	23.4	23.3
75	4/7/04	GOM	83.99° W	24.36° N	83.95° W	24.80° N	SM	23.9	23.3
76	4/8/04	GOM	84.27° W	24.58° N	84.02° W	24.65° N	M	24.6	24.2
77	4/9/04	GOM	84.00° W	24.59° N	83.92° W	24.64° N	M	25.0	23.9
78	4/10/04	GOM	83.95° W	23.50° N	83.76° W	23.35° N	M	27.2	27.0
79	4/11/04	GOM	82.80° W	23.25° N	82.31° W	23.33° N	M	27.6	27.1
80	4/19/04	GOM	84.09° W	24.72° N	84.31° W	24.76° N	SM	24.6	24.8
81	4/20/04	GOM	84.29° W	24.97° N	84.65° W	24.54° N	SM	25.1	26.6
82	4/21/04	GOM	83.98° W	24.70° N	84.19° W	24.70° N	SM	24.5	25.9
83	4/22/04	GOM	83.25° W	24.32° N	83.02° W	24.16° N	SM	26.4	26.5
84	4/23/04	GOM	82.67° W	23.84° N	82.22° W	23.72° N	SM	26.4	26.4
85	4/24/04	GOM	82.05° W	23.49° N	82.23° W	23.44° N	SM	26.3	26.3

SURVIVAL OF WHITE MARLIN (TETRAPTURUS ALBIDUS) RELEASED FROM COMMERCIAL PELAGIC LONGLINE GEAR IN THE WESTERN NORTH ATLANTIC

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ABSTRACT

To estimate postrelease survival of white marlin caught incidentally to regular commercial pelagic longline fishing operations targeting swordfish and tunas, short-duration pop-up satellite archival tags (PSATs) were deployed on captured animals for periods of 5 - 43 days. Twenty of 28 (71.4%) tags transmitted at the pre-programmed time, including one tag that became detached from the fish shortly after release and was omitted from subsequent analyses. Transmitted data from 17 of 19 tags were consistent with survival of those animals for the duration of the tag deployment. Estimates of postrelease survival range from 63.0% (assuming that all non-reporting tags were mortalities) to 89.5% (excluding non-reporting tags from the analysis). The results of this study indicate that white marlin can survive the trauma resulting from *interaction with pelagic longline gear, and suggest that current domestic and international management measures requiring the release of live white marlin from this fishery will reduce fishing mortality on the Atlantic-wide white marlin stock.*

INTRODUCTION

White marlin (*Tetrapturus albidus* Poey 1860) is an istiophorid billfish species widely distributed in tropical and temperate waters throughout the Atlantic Ocean, including the Caribbean Sea. There is substantial international concern regarding the population levels of this species. The Standing Committee for Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) last assessed the Atlantic-wide stock of white marlin in 2002 and the continuity-case assessment indicated a total biomass of approximately 12% of that necessary to produce maximum sustainable yield. It was also estimated that the current international fishing mortality for this species is equivalent to more than eight times the replacement yield, contributing to further decline of the overfished stock (ICCAT, 2004).

Both recreational and commercial fisheries contribute to the fishing mortality on white marlin. A directed recreational fishery exists throughout the tropical and temperate Atlantic with considerable effort in Brazil, Venezuela, and the U.S. mid-Atlantic coast, and there is a growing trend towards catch-and-release practices in all directed recreational billfish fisheries. In contrast to the catches by this directed recreational effort, white marlin are an infrequent bycatch or retained incidental catch of the international pelagic longline fishery, which targets tunas (*Thunnus* spp.) and swordfish (*Xiphias gladius*). Although white marlin catches in the pelagic longline fishery are relatively rare, the fishery accounts for the majority of the total fishing mortality on this species simply due to the sheer magnitude of pelagic longline effort exerted throughout the Atlantic (ICCAT, 2004).

Both domestic and international management measures are currently in effect for white marlin. The U.S. recreational fishery is managed with a 66" lower jaw-fork length federal minimum size and a binding ICCAT Recommendation that limits the annual U.S. recreational landings to a total of 250 blue marlin and white marlin combined (ICCAT, 2000). U.S. commercial fishermen have been prohibited from landing or possessing white marlin since the implementation of the National Marine Fisheries Service (NMFS) Fishery Management Plan for Atlantic Billfish (NMFS, 1988). ICCAT has responded twice to the decreasing biomass of white marlin and blue marlin (*Makaira nigricans*) by adopting binding recommendations requiring reductions in commercial landings by both pelagic longline and purse seine gears (ICCAT, 2000; ICCAT, 2001a). However, these landings reductions by themselves may ultimately be insufficient to rebuild these two marlin stocks. Goodyear (2002a) found that a reduction of 60% would be necessary to halt the decline of blue marlin, a species which is more abundant, larger, and presumably more robust to the trauma associated with commercial capture (Kerstetter et al., 2003). Given that white marlin are smaller animals, and that the stock is more depleted than that of blue marlin, even more drastic measures are likely necessary to achieve the same management goal for this species.

Because the pelagic longline fishery accounts for the majority of white marlin mortality, understanding the nature of billfish interactions with this gear is critical to developing effective strategies to reduce fishing mortality. Jackson and Farber (1998) reported that 56% of white marlin caught in the Venezuelan longline fishery between 1987 and 1995 were alive at the time of haulback. Data from the U.S. observer program and mandatory pelagic longline logbook records indicate that 71% of white marlin were released alive from U.S. commercial pelagic longline gear between 1996 and 1998[1]. ICCAT has long been encouraging the release of live white marlin through both non-binding Resolutions (ICCAT, 1995; ICCAT, 1996). More recently the Commission has approved binding Recommendations that require the release of all live white marlin caught by purse seine and pelagic longline vessels (ICCAT, 1997; ICCAT, 2001b). However, those animals released alive must have a reasonable probability of survival for such management measures to be ultimately effective.

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[1] Cramer, J. 2000. Species reported caught in the U.S. commercial pelagic longline and gillnet fisheries from 1996-1998. NMFS Sustainable Fisheries Division publication, SFD-99/00-78.

The assessment of postrelease survival presents special problems for large pelagic fishes, which are rarely capable of being held in captivity (de Sylva et al., 2000). In general, recovery rates of billfish tagged with conventional streamer tags by commercial and recreational fishermen have been quite low (1.3%: Ortiz et al., 2003). While this observation is consistent with high postrelease mortality, low recovery rates could also result from tag shedding and non-reporting of recovered tags (Bayley and Prince, 1994; Jones and Prince, 1998). The results of acoustic tracking studies of various billfish species (e.g., striped marlin: Brill et al., 1993; blue marlin: Block et al., 1992; and black marlin: Pepperell and Davis, 1999) captured on recreational gear suggest that postrelease survival over periods of a few hours to a few days is relatively high, although mortalities have been observed in short-term tracking studies. Recently, pop-up satellite archival tag (PSAT) technology has proven especially useful to study postrelease survival in several larger istiophorid species, including blue marlin in the Atlantic (Graves et al., 2002; Kerstetter et al., 2003) and striped marlin (*Tetrapturus audax*) in the Pacific (Domeier et al., 2003). Only recently have PSATs been attached to smaller (< 40 kg) istiophorid billfishes. Horodysky and Graves (2005) used PSATs to evaluate the postrelease survival of white marlin from recreational (rod-and-reel) fishing gear and demonstrated that smaller billfish (≥ 16 kg estimated weight) can carry PSATs. This work also suggested high postrelease survival rates in the recreational fishery, especially for fish caught on circle hooks. However, the experience of being caught by pelagic longline gear presents a different suite of stressors for the animal than recreational gear, potentially affecting postrelease survival rates. In this study we apply PSAT technology to estimate the short-term mortality of white marlin released alive after capture on pelagic longline gear.

MATERIALS AND METHODS

Fishing Operations

White marlin tagging took place off the east coast of Florida (FL), the southwest edge of Georges Bank (GB), the Yucatan Channel (YC), the Windward Passage (WP), and the Mid-Atlantic Bight (MA). These locations are all waters traditionally fished by the U.S. pelagic longline fleet. All tagging operations occurred opportunistically aboard the commercial pelagic longline fishing vessel F/V *Carol Ann* (54' LOA) between June 2002 and August 2004. This vessel is typical in size and targeting strategies within the U.S. coastal pelagic longline fleet. Hook types and sizes were also typical for the fishery and included 7/0 and 9/0 offset J-style hooks (ca. 15° offset; Eagle Claw model #9016 or Mustad model #7698), 16/0 non-offset circle hooks (Mustad models #39660 or #39666), and 18/0 non-offset circle hooks (Lindgren-Pitman, Inc., Pompano Beach, FL, USA). Adjusting seasonally, individual leader lengths were 7.5 fathoms (ca. 13.7 m) in the fall northern fishery targeting tuna and 15 fathoms (ca. 27.4 m) in the spring southern fishery for swordfish, a standard practice within the fleet (G. O'Neill, pers. comm.). Individual leader lengths included a two-fathom "tail" separated from the rest of the leader by a 28 g leaded swivel, a practice commonly used in this fishery to reduce tangles with other leaders or the mainline. Varying the length of the lines ("buoy drops") connecting the mainline with the small buoy floats on the surface also allows the gear to fish at different depths. Many captains will use two buoy drop lengths in the beginning of a trip to ascertain the most productive gear configuration. This study used two buoy drop lengths in each set, alternating every 30 hooks: usually 5- and 2.5-fathom (ca. 9.1 and 4.5 m, respectively) lengths in the fall and 10- and 12-fathom (ca. 18.3 and 21.9 m, respectively) lengths in the springtime. Electronic hook-timers (Lindgren-Pitman, Inc.; Pompano Beach, FL, USA) were also used during many of the sets to record the time that an animal was hooked. Bait was usually frozen squid (*Illex* sp.), but occasionally included frozen Atlantic mackerel (*Scomber scombrus*) or a haphazard mixture of the two.

This project consisted of both a preliminary and a main study. The pilot study occurred off the east coast of Florida during June 2002 and included deployments of five PTT-100 tags (Microwave Telemetry, Inc.; Columbia, MD, USA) and one PAT (Wildlife Computers; Redmond, WA, USA) tag. The main study was conducted between August 2002 and August 2004, and used only the PTT-100 HR model tags (Microwave Telemetry, Inc.).

Tag Models

The physical characteristics of all PSAT tag models used in this work were similar and included a microprocessor, a transmitter, and various environmental sensors, all contained within a resin-filled carbon fiber tube. The tag is made positively buoyant by a spherical, glass bead-embedded float at the base of the antenna. It measures approximately 38 cm in length by 4 cm diameter (including antenna), and weighs between 65-75 g (air weight). Tags were rigged with approximately 16 cm of 400-pound test Momoi® brand (Momoi Fishing Co.; Ako City, Japan) monofilament attached to a large hydroscopic nylon intramuscular tag head per Graves et al. (2002). The earlier model PTT-100 tags were identical to those used by Graves et al. (2002) and Kerstetter et al. (2003) and recorded one temperature data point for every two hour period during their five-day ($n = 3$) or 30-day ($n = 2$) deployments, as well as a pre- and post-deployment inclinometer value. The PAT tag recorded environmental data every minute during its 43-day deployment (programmed to release on 30 July 2002), but transmitted data as summary histograms rather than discrete data points. The PAT tag possessed emergency release software as well as a mechanical device (RD-1500; Wildlife Computers) for early emergency release prior to crush depth.

The Microwave Telemetry, Inc. model PTT-100 HR satellite tag was used for the main study, constituting the majority of the PSAT deployments ($n = 22$). This tag has similar physical attributes as the previous model PTT-100 tags previously described, although it differed in capability through the addition of light and pressure (depth) sensors and increased data storage capacity. The manufacturer pre-programmed all of the PTT-100 HR model tags to release from the fish after ten days, and the tags were activated prior to attachment to the animal by removing a small magnet from the side of the tag. The tags sampled environmental data at approximately four-minute or two-minute intervals.

White Marlin Tagging

Preparations for tagging operations were made before each haulback of the gear. Tags were either activated prior to haulback or during haulback immediately following the tagging of a fish in preparation for another animal. Regardless of the time of external tag activation, all PSATs were allowed to cycle through their full ten-minute computerized internal activation process prior to application on a fish. The captain of the vessel identified incoming white marlin on the line during the morning haulback of the gear and fish were evaluated as live or dead based on movement (or lack thereof) alongside the vessel. All live white marlin were tagged, regardless of physical condition.

Fish were manually brought alongside the vessel just aft of the hauling station along the rail and held briefly by the leader until calm. The average distance between the top of the rail and the fish (free-board) on the F/V *Carol Ann* was approximately one meter, requiring the use of a tagging pole of approximately 2 m length to reach the fish over the gunwhale. The nylon anchor to the PSAT tether was carefully inserted about 5-10 cm below the midpoint of the anterior dorsal fin to a depth of about 5 cm. This location on the fish provides an opportunity for the nylon tag head to pass through the pterygiophore bones without approaching the coelemic cavity (Prince et al., 2002a). For most white marlin in this study (93%), a conventional streamer tag was also attached well posterior of the PSAT.

White marlin were released as soon as possible after tagging by the standard commercial protocol of cutting the leader near the hook unless the hook was readily accessible for manual removal. No animals were resuscitated after tagging. Prior to release, hook type was noted and fish lengths and weights were estimated. Disposition ("live" vs. "dead") and hook location data were collected from all white marlin caught in 2003 and 2004. For the purposes of this study, "internal" hook locations were those in which the barb of the hook was lodged posterior to the esophageal sphincter, while "external" hook locations were noted with more specificity (e.g., "upper jaw"). Hooking on the body away from the mouth ("foul hooking") was considered an "external" hook location. In addition to noting hooking location, a rapid visual examination of each fish was conducted using the five-point "ACESS" scale of activity, color, eye condition, stomach status, and body state (see Kerstetter et al., 2003). The tagging operation, from positive species identification to actual release from the gear, lasted less than 10 minutes. All data, including the time of day, vessel location, and surface water temperature were recorded immediately after tagging.

Data Analysis

Survival of tagged animals was inferred from three types of environmental data provided by the tag: water temperature changes, depth changes, and ambient light intensity. Frequent short-scale (< 1 hour) variations in both depth and temperature were used as indicators of a live white marlin. The survival of individual fish was also supported by the net displacement, calculated as the distance from the location of the vessel at the time the white marlin was released to that of the first good transmission from the free-floating PSAT to the ARGOS satellite system. The precision of reported location estimates is based on the attitude of the receiving satellite, with transmissions through the ARGOS system categorized into seven location accuracy codes. Locations were considered "good" for this study if the ARGOS system reported an accuracy code corresponding to within 1,000 meters. If a good position was not obtained directly from ARGOS, an average of all location code "0" readings from the first 24 hour period of transmission was used as a proxy location. All distances were calculated with PROGRAM INVERSE (NGS, 1975; modified by M. Ortiz, NMFS-SEFSC, Miami, FL).

Estimates of white marlin postrelease survival were calculated both including non-reporting tags as mortalities and with non-reporting tags excluded. The 95% confidence intervals associated with these estimates were calculated using the RELEASE MORTALITY version 1.1.0 software developed by Goodyear (2002b). These confidence intervals were based on 10,000 simulations with assumed underlying postrelease mortality rates derived from the transmitted data with no error sources (e.g., no premature releases or tag-induced mortality). For the purpose of these simulations, natural mortality was also assumed to be zero because of the relatively short duration of the tagging deployment period. Unless otherwise noted, all statistical analyses for this study were conducted using SAS version 8.3 (SAS Institute, Cary, NC, USA).

RESULTS

Eight trips (n = 112 sets) were taken between June 2002 and August 2004 on the F/V *Carol Ann*, a U.S.-registered commercial pelagic longline vessel that operated during the winter and spring in the Caribbean Sea targeting swordfish and during the summer and fall in the mid-Atlantic and Georges Bank region targeting both tuna and swordfish. A summary of these trips and sets is provided in Table 1. Sets were typically made overnight, with gear deployed at dusk and retrieved at dawn.

Catch rates (catch per 1000 hooks) for target and bycatch species varied by season and location. Swordfish catch rates for retained animals ranged from 1.6 (mid-Atlantic, summer 2005) to 23.9 (Caribbean and Gulf of Mexico, spring 2004). Retained tuna (yellowfin, *T. albacares*; bigeye, *T. obesus*; and albacore, *T. alalunga*) catch rates ranged from 0.8 (Caribbean and Gulf of Mexico, spring 2004) to 44.2 (mid-Atlantic, summer 2004). Istiophorid billfishes (blue marlin, white marlin, longbill spearfish, and sailfish) comprised approximately 3% of the catch by number, and the overall mean catch rate of white marlin was 1.87 per 1,000 hooks. Mortality of white marlin at the time of haulback varied among sets, trips, seasons and locations. The lowest observed mortality during commercial fishing operations was 34.4% (mid-Atlantic, summer 2005) and the highest was 50% (Caribbean and Gulf of Mexico, spring 2004). The average mortality of white marlin at haulback across all seasons and trips was 35.4%.

PSATs were applied to 28 white marlin alive at the time of haulback. All live white marlin brought to the vessel were tagged regardless of physical condition until the supply of tags available on that trip was exhausted (i.e., if a fish was evaluated as being alive, it was tagged). Estimated weights of tagged fish ranged from 14 - 27 kg (30 - 60 pounds) and detailed information for each individual tagged (including hook location, fate, and minimum straight-line distance) is presented in Table 2. Three white marlin tagged with PSATs were caught on leaders attached to electronic hook-time recorders, allowing us to determine the length of time the animal was on the hook before release. Two fish (YC-04-01 and WP-0401) struck the bait in the early morning after local sunrise (7:32 and 8:13 a.m. local time, respectively) and were only on the line for approximately 1.5 hours before release. The third fish (MA-03-01) was caught during haulback at 9:52

p.m. local time on one of the few sets retrieved at night and was hooked for only 11 minutes.

Tag Performance

In the pilot study, four of six tags (67%) transmitted archived data as programmed. One reporting tag prematurely released several hours after deployment and the data from this tag were omitted from subsequent analyses. For each of the three reporting early model PTT-100 tags, 100% of the 63 archived data points were received, while approximately 33% of the summary data were received from the PAT tag. In the main study, 16 (72.7%) of the 22 PTT-100HR tags reported to satellites in the ARGOS system as programmed, and an average of 51% (range 4.4 - 86.1%) of each tag's archived data was transmitted. Two PTT-100 HR tags were found on shore after their transmission period and returned to us, allowing for a full recovery of the archived data from each tag.

White Marlin Survival

Transmitted temperature and depth data from 17 of 19 reporting tags (89.5%) indicated the released white marlin survived for the time periods over which the tags were programmed to collect data. Of the two confirmed mortalities in this study, one fish (GB-02-01) died within one hour after release and sank to the bottom at 145 meters depth. It remained there for approximately 10 hours before the tag and presumably the carcass were scavenged by a shark (Kerstetter et al., 2004). The second mortality (MA-03-04) occurred approximately 24 hours following release. After tagging, the animal remained between 0 – 26.9 meters depth before it was inferred to be the victim of a shark predation event based on an abrupt change in behavior and light level (Kerstetter et al., 2004).

The net displacement of all reporting tags was used as an additional line of evidence to assess postrelease survival of white marlin. All of the tags from putatively surviving animals demonstrated net movements that cannot be explained by surface currents alone. For the 14 surviving fish with PTT-100 HR tags, the average minimum straight-line movement was 246.2 nautical miles (nmi) over the ten-day period, but there was a wide range of net displacement among individuals (80.4 - 631.5 nmi). Eight of the nine white marlin tagged approximately 350 miles east of Ocean City, Maryland, in summer 2004 moved generally east to northeast, with the exception being one animal that went 304.9 nmi to the northwest.

All but one of the tags employed in this study lacked hardware or software that would cause the tag to release prematurely if a moribund fish descended below a critical depth. Consequently, non-reporting tags could result from an animal that died and sank in waters deeper than the pressure capacity of the tags. All eight white marlin tagged with PSATs that did not report were released in or near areas with depths in excess of 2000 meters, the manufacturer's suggested pressure limit of the tags.

The non-reporting tags may or may not represent mortalities of the tagged white marlin and the resulting calculated mortality rates vary on the consideration of these eight tags. Combining both hook types, the overall mortality rate was 10.5% (95% CI: 0.0 - 26.3%) if non-reporting tags were excluded and 37.0% (95% CI: 18.5 - 55.6%) if non-reporting tags were included as mortalities.

Hook Performance

Two general hook types, circle and J-style, were used by the crew of the longline vessel in this study. Nineteen white marlin tagged with PSATs were caught on circle hooks, two of which (10.5%) were lodged internally and 17 (89.5%) externally in the jaw or mouth (Figure 1). Neither of the two PSATs on animals hooked internally with circle hooks reported. Two PSATs attached to the 17 fish caught with circle hooks externally failed to report, and only one fish caught with a circle hook externally was a confirmed mortality. Nine white marlin tagged with PSATs were caught by J-style hooks. Two fish caught with J-style hooks were hooked internally (22.2%) and seven externally (77.8%). Of the two hooked internally, one tag did not report while the other (fish GB-02-01) was a confirmed mortality. Three of the remaining seven tags on fish caught externally with J-style hooks did not report. Comparisons of hook type and postrelease survival were not significant (Fisher's exact; $P > 0.16$). For the 10° offset J-style hooks, the mortality rate was 20.0% excluding non-reporting tags, and 55.6% if non-reporting tags were included as mortalities. The 0° offset circle hooks had a 7.1% mortality rate if non-reporting tags were excluded and 27.7% if these non-reporting tags were included as mortalities.

Nine white marlin were hooked in or near the eye. Seven fish were hooked on either circle or J-style hooks through the eye socket (with no visible damage to the eyeball) and all survived for the 5- or 10-day PSAT deployments. Two PSATs were attached to animals that had been hooked with a circle hook through the eye itself. One transmitted data consistent with survival, while the other tag did not report. Only one white marlin tagged in this study was foul-hooked, caught in the ventral musculature by a size 18/0 circle hook. The PSAT attached to this fish released prematurely.

DISCUSSION

The amount of data archived and transmitted varied greatly among the three models of satellite tags, as well as among the 16 reporting PTT-100 HRs. The early model PTT-100 tags only archived 63 data points, but 100% of the archived information was transmitted, providing sufficient information to infer survival (Graves et al. 2002; Kerstetter et al. 2003). In contrast, the newer PTT-100 HR tags archived either 4500 or 9145 data points, but not all archived data were transmitted. In this study most of these tags transmitted a relatively large percentage of the archived data, facilitating determination of the fate of the released white marlin. However, one tag (MA-04-08) had an unusually low data reporting rate of 4.4%, representing 315 data points over the ten day tagging period. Because these data were transmitted in blocks encompassing periods of 11 minutes (approximately 9 data points), they often included short-duration movements to depths. As the transmitted blocks of data were distributed haphazardly over the entire ten-day tagging period, it was possible to determine postrelease survival from a high-resolution tag with a low data recovery rate.

Prior studies of postrelease survival have used different lengths of time to ascertain the effects of capture. These have included studies focused on postrelease survival as well as others addressing long-term behavior, movements, and habitat preferences. Graves et al. (2002) justified a five-day deployment period for blue marlin by citing reports of blue marlin recaptured within five days after being released with conventional tags from the recreational fishery, thus demonstrating a return to feeding. Kerstetter et al. (2003) adopted a similar position, although their study on blue marlin also included the deployments of two PSATs for 30 days to evaluate the possibility of delayed mortality. Domeier et al. (2002) used a variety of deployment periods (1 – 12 month durations) to assess postrelease survival in striped marlin. However, the longer the PSAT deployment period, the more susceptible the animal becomes to both fishing (i.e., recapture) and natural mortality such as predation, biasing upwards the estimate of postrelease mortality (Goodyear, 2002b).

In this study, we primarily used tags with a ten-day deployment period and believe that this period is sufficiently long to document short-term mortality. Five of seven white marlin mortalities reported in Horodysky and Graves (2005) occurred within the first six hours of release, while the other two died less than three days later. All of the mortalities inferred for the closely related striped marlin by Domeier et al. (2002) occurred within six days of release, with 75% of these mortalities happening in less than two days. The two documented mortalities in the present study (GB-02-01 and MA-03-04) occurred within 24 hours of release.

Direct comparisons of estimates of postrelease survival of billfishes among previous acoustic and PSAT studies are problematic. Many acoustic tracking studies had relatively short observation periods and low sample sizes, and often did not tag fish in marginal physical condition (reviewed in Domeier et al., 2003). Even among PSAT tagging studies, non-reporting tags have been addressed with different protocols by various authors. Neither Graves et al. (2002) nor Kerstetter et al. (2003) directly observed mortalities of PSAT-tagged blue marlin. However, both studies adopted a conservative approach to estimate postrelease survival by considering the non-reporting tags as mortalities, in part because of the lack of emergency release software or mechanisms on the tags themselves that would detach the PSAT prior to its sinking with a dead fish below the crush depth of the tag. Some new models of satellite tags possess such emergency release software or physical mechanisms, such as glass implosion devices (Domeier et al., 2003) or the RD-1800 metal guillotine from Wildlife Computers that sever the tether of the tag prior to reaching the depth limit. New generations of tags are also rated to greater crush depths (ca. 2000 m) than earlier models. The PSATs used in this study, with the exception of the one PAT tag, did not possess emergency release software or physical mechanisms. Because all of the animals in this study were tagged over or near waters deeper than the crush depths of the tags, any deaths of tagged white marlin could have resulted in the PSATs being destroyed at depth prior to transmitting while remaining attached to the sinking, moribund fish.

There are several reasons why PSATs may not report even with emergency releases, including recovery of the tag by a non-cooperative fishing vessel, internal malfunction, or biological activities. Kerstetter et al. (2004) reported on three PSAT tags that were presumably ingested by sharks after predation or scavenging and suggested that a number of non-reporting tags in all PSAT studies could result from biological activity. Goodyear (2002b) noted that including non-reporting tags as mortalities will bias mortality estimates upwards if such non-reporting is due to causes other than mortality. The combination of physically more robust tags, emergency release capabilities, and demonstrated mortalities has led several authors (e.g., Domeier et al., 2003) to specifically exclude non-reporting tags from subsequent analyses. Because it is not possible to estimate how many of the non-reporting tags in this study could be due to malfunction versus individual mortality events, we chose to conservatively estimate two postrelease mortality rates, one that includes all non-reporting tags as mortalities and another that excludes non-reporting tags.

In this study, PSATs attached to some white marlin in marginal physical condition at the time of release returned data consistent with postrelease survival. These include fish MA-04-03, which was hooked through the right eyeball, and fish WP-04-01, which displayed poor, faded color and was moving so little at haulback that it initially appeared dead until careful inspection. Both internal hooking and stomach eversion have been suggested as predictors of subsequent mortality for billfishes (Domeier et al., 2002). Horodysky and Graves (2005) found a 40% mortality rate for internally hooked white marlin, while Domeier et al. (2002) found a 63% mortality rate for similarly hooked striped marlin. We tagged four internally hooked animals, and the one reporting tag (GB-02-01) indicated mortality shortly after release for that fish. Three white marlin with everted stomachs at haulback were tagged in this study, but only one (MA-03-04) remained attached for the duration of the deployment period and transmitted data consistent with mortality. However, the survival of a white marlin (Horodysky and Graves, 2005) and a striped marlin (Holts and Bedford, 1990) with everted stomachs suggests that billfish with everted stomachs can survive if released.

White marlin captured with circle hooks demonstrated a trend of lower postrelease mortality than those hooked with J-style hooks, but this relationship was not significant. This trend in mortality rate versus hook type was independent of whether non-reporting tags were included as mortalities or excluded from analyses. Horodysky and Graves (2005) observed a significant decrease in mortality for white marlin caught on circle hooks relative to J-style hooks (0% versus 35% for J-style hooks). Domeier et al. (2003) also noted a trend for a lower mortality rate among animals hooked with non-offset circle hooks (12.5% versus 29.4% for offset J-style hooks), although this relationship was not significant. The lower mortality rate trend on white marlin caught by circle hooks relative to J-style hooks presented here is also consistent with the results in several other studies of pelagic fishes, such as Prince et al. (2002b) with recreationally caught billfish and Skomal et al. (2002) with recreationally caught Atlantic bluefin tuna (*Thunnus thynnus thynnus*), which based predictions of post-release survival on likely injury resulting from specific hooking locations on the animals.

The majority of white marlin caught with circle hooks in this study were hooked in the mouth or jaw ($n = 23$) rather than internally or foul hooking on the body ($n = 5$), a relationship also noted by Horodysky and Graves (2005) for white marlin caught in the directed recreational fishery. In the present study, low numbers of animals caught on both hook types barred robust comparisons of postrelease survival rates by hook type. More balanced comparisons of postrelease survival among hook types were precluded by both a limited number of expensive PSATs and the imposition of a domestic management measure that prohibited the use of J-style hooks in the U.S. pelagic longline fishery as of 5 August 2004 (69 F.R. 40733).

Ultimately, hooking location may be a more important factor than hook type for predicting postrelease survival. Three of the four PSATs attached to internally-hooked animals in this study did not report, although Prince et al. (2002b) reported encapsulated hooks from istiophorid viscera, indicating that internal hooking events are not necessarily fatal. The large percentage of white marlin (35.7%) hooked through the upper lateral palate into the eye or eye socket raises some concern. Istiophorid billfishes are considered to be primarily visual predators (Rivas, 1975) and damage to an eye would be expected to negatively affect the foraging ability of the animal. Billfish are known to have specialized muscle tissue that allows individuals to maintain elevated brain and eye (Block, 1986), and recent work reported color vision in some istiophorids (Fritsches et al., 2003). Dissections of sailfish (*Istiophorus platypterus*) have revealed that hookings in the eye socket often caused damage to the optic nerve and surrounding ocular musculature (Jolley, 1977). The one fish caught with a circle hook through the eye socket in Horodysky and Graves (2005) survived for the entire 10-day deployment period, and in this study, the seven animals hooked through the eye socket also all survived for their entire deployment periods, as did one white marlin caught with a circle hook through the eyeball. A tagged striped marlin in Domeier et al. (2003) with a punctured eye also survived for ten days, suggesting that this condition is not necessarily fatal over short durations, and healthy swordfish have been observed with one healed ocular cavity (D. Kerstetter, pers. obs.).

This study observed a high percentage of white marlin hooked with associated eye damage, specifically in conjunction with circle hooks. In contrast, Horodysky and Graves (2005) noted only one animal out of 40 hooked through the eye with a circle hook. The difference between studies may be a factor of the hook sizes used in the fisheries, with the recreational fishery generally using much smaller circle hooks than the commercial pelagic longline fishery (7/0 and 9/0 sizes versus 16/0 and 18/0). Jolley (1977) observed 134 of 848 (15.8%) sailfish caught recreationally with J-style hooks with the barbs exiting near the eyes, noting that the distal lateral regions of the istiophorid mouth roof (those areas underlying the eyes) are thinly-covered muscle tissue rather than bone. A hook would therefore presumably pass much more easily through this tissue to the eye than if it encountered the lower jaw. Prince et al. (2002b) considered hooking through the upper palate potentially lethal, not only from the opportunity for the hook to penetrate the occipital orbit, but also because of the tendency for J-style hooks in that location to compromise the integrity of the cranium, making it more susceptible to infection. Two non-reporting tags in this study were attached to fish caught with J-style hooks in the center of the upper palate. Working with blue sharks wounded by fishing hooks, Borucinska et al. (2002) noted that a perforating injury may also result in systemic debilitation over longer time intervals than that typically measured by PSAT tagging.

The postrelease mortality rates obtained for white marlin from Horodysky and Graves (2005) and this study also allow the estimation of total U.S. fishing mortality for this species. For the U.S. directed recreational fishery, the white marlin postrelease mortality rate (35% for J-style hooks; Horodysky and Graves, 2005) was applied to estimated yearly catch data and added to "best estimates" of the U.S. recreational landings (Goodyear and Prince, 2003). For the pelagic longline fishery, catch and condition at release data were obtained from the NMFS Pelagic Observer Program database (D. Lee, NMFS, pers. comm.). White marlin released alive were subjected to the 55.5% postrelease mortality rate (J-style hooks, non-reporting tags as mortalities; this study) and estimated dead fish were added to the reported dead discards. Average underestimates of the actual white marlin fishing mortality to recreational fishery reported landings or commercial fishery dead discards during this ten-year period were 88.6% and 61.6% respectively. Our analysis also suggests that the directed recreational fishery may generate higher levels of white marlin fishing mortality than the pelagic longline fishery in some years simply due to greater numbers of animals caught (see Fig. 2). Because we chose the postrelease mortality estimates based on the historic terminal gear choices of J-style hooks, these results do not account for the probable decrease in total postrelease mortality resulting from mandated (pelagic longline) and voluntary (recreational) changes in the U.S. fisheries from J-style hooks to circle hooks.

The results of this study clearly demonstrate that white marlin are capable of surviving the trauma associated with capture by pelagic longline fishing gear. Short-term survival of released white marlin was relatively high whether one discounted non-reporting tags (89.5% survival) or considered non-reporting tags to be mortalities (62.9% survival). These estimates are similar in magnitude to that found for the larger blue marlin released from pelagic longline gear (79% survival; Kerstetter et al., 2003). The documented survival of white marlin indicates that current domestic and international management measures requiring live release from commercial pelagic longline gear will reduce fishing mortality on this species.

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Table 1. Summary of locations, trips, and individual sets taken on a commercial pelagic longline vessel between June 2002 and August 2004 during tagging activities. Location refers to NOAA Fisheries statistical areas: FEC = Florida East Coast, NEC = Northeast Coastal, MAB = Mid-Atlantic Bight, GOM = Gulf of Mexico, and CAR = Caribbean. For hook type, OS = offset and NOS = non-offset.

	2002		2003	2004	
Months	June	August	July-September	January-February	August
Location	FEC	NEC	MAB	GOM and CAR	MAB
Number Tagged	6	2	6	2	12
Sets with Tagging	5	1	5	2	3
Bait Type	frozen squid	frozen squid	frozen squid	frozen squid, frozen mackerel, or mixture	frozen squid, frozen mackerel, or mixture
Hook Type	OS 9/0 J-style and NOS 18/0 circle	OS 9/0 J-style and NOS 16/0 circle	OS 9/0 J-style and NOS 16/0 circle	OS 9/0 J-style and NOS 16/0 circle	NOS 16/0 circle

Table 2. Summary information for tagged white marlin (*Tetrapturus albidus*) released from commercial pelagic longline gear in the western North Atlantic Ocean, June 2002-August 2004. "D/NV" refers to hooks that were deep and not externally visible at the time of tagging.

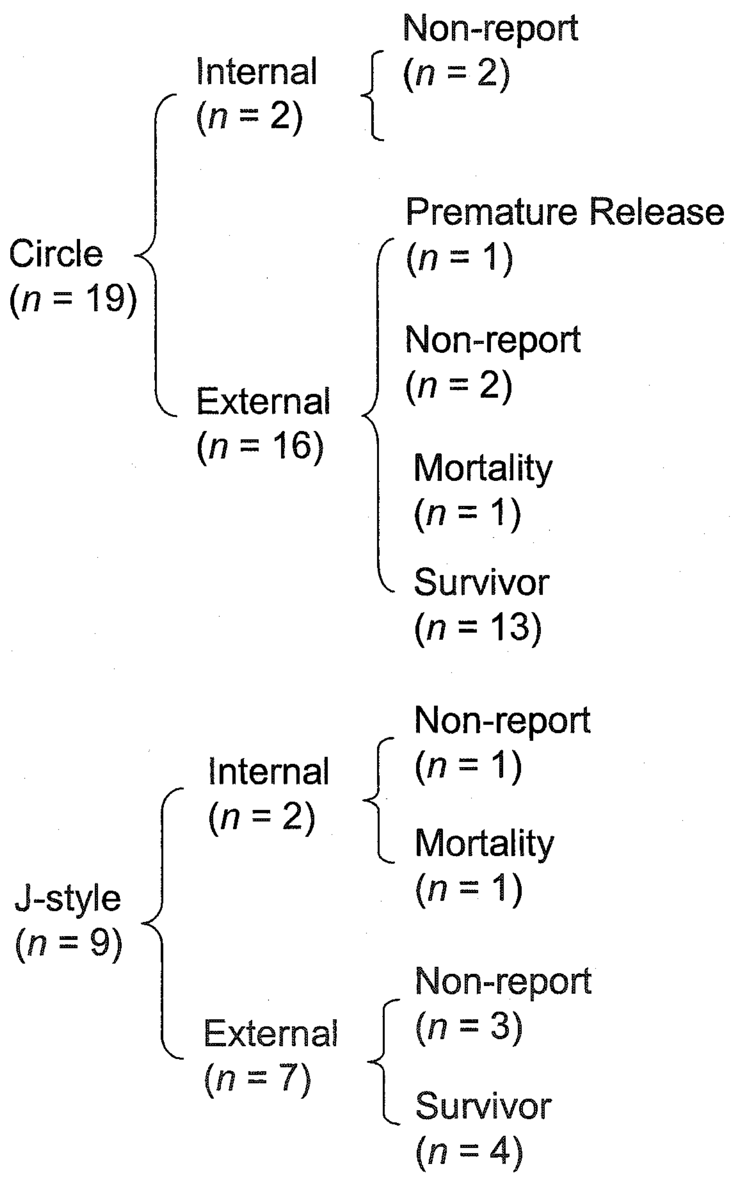
Tag Number	Deployment Duration	Tag Model	Hook Type	Hook Location	Est. Weight (kg)	Report?	Fate?	% Data	MSLD? (nmi/km)
FL-02-01	5-day	PTT-100	18/0 circle	eye socket	18	Y	L	100	42/78
FL-02-02	5-day	PTT-100	9/0 J-style	jaw	27	N	--	--	--
FL-02-03	5-day	PTT-100	9/0 J-style	jaw	20	Y	L	100	26/48
FL-02-04	30-day	PTT-100	18/0 circle	foul	18	Y	PR	n/a	--
FL-02-05	30-day	PTT-100	9/0 J-style	roof	20	N	--	--	--
FL-02-06	43-day	PAT	18/0 circle	eye socket	16	Y	L	33.4	806/1493
GB-02-01	10-day	PTT-100 HR	7/0 J-style	D/NV	20	Y	D	81.5	--
GB-02-02	10-day	PTT-100 HR	16/0 circle	eye socket	23	Y	L	100	109/202
MA-03-01	10-day	PTT-100 HR	9/0 J-style	D/NV	23	N	--	--	--
MA-03-02	10-day	PTT-100 HR	9/0 J-style	eye socket	25	Y	L	85.1	136/252
MA-03-03	10-day	PTT-100 HR	9/0 J-style	jaw	20	Y	L	67.5	80/149
MA-03-04	10-day	PTT-100 HR	16/0 circle	jaw	25	Y	D	57.3	--
MA-03-05	10-day	PTT-100 HR	9/0 J-style	roof	23	N	--	--	--
MA-03-06	10-day	PTT-100 HR	9/0 J-style	roof	25	Y	L	86.1	161/298
YC-04-01	10-day	PTT-100 HR	16/0 circle	jaw	16	N	--	--	--
WP-04-01	10-day	PTT-100 HR	16/0 circle	corner	23	Y	L	100	60/110
MA-04-01	10-day	PTT-100 HR	16/0 circle	eye socket	20	Y	L	44.1	525/973
MA-04-02	10-day	PTT-100 HR	16/0 circle	D/NV	20	N	--	--	--
MA-04-03	10-day	PTT-100 HR	16/0 circle	eye	16	Y	L	16.4	301/557
MA-04-04	10-day	PTT-100 HR	16/0 circle	eye socket	25	Y	L	70.5	632/1170
MA-04-05	10-day	PTT-100 HR	16/0 circle	eye	25	N	--	--	--
MA-04-06	10-day	PTT-100 HR	16/0 circle	eye socket	23	Y	L	22.8	332/615
MA-04-07	10-day	PTT-100 HR	16/0 circle	D/NV	18	N	--	--	--
MA-04-08	10-day	PTT-100 HR	16/0 circle	jaw	14	Y	L	4.4	81/149
MA-04-09	10-day	PTT-100 HR	16/0 circle	jaw	20	Y	L	48.3	436/807
MA-04-10	10-day	PTT-100 HR	16/0 circle	jaw	20	Y	L	17.6	250/463
MA-04-11	10-day	PTT-100 HR	16/0 circle	jaw	23	Y	L	51.0	89/164
MA-04-12	10-day	PTT-100 HR	16/0 circle	jaw	27	Y	L	18.8	255/473

LIST OF FIGURES

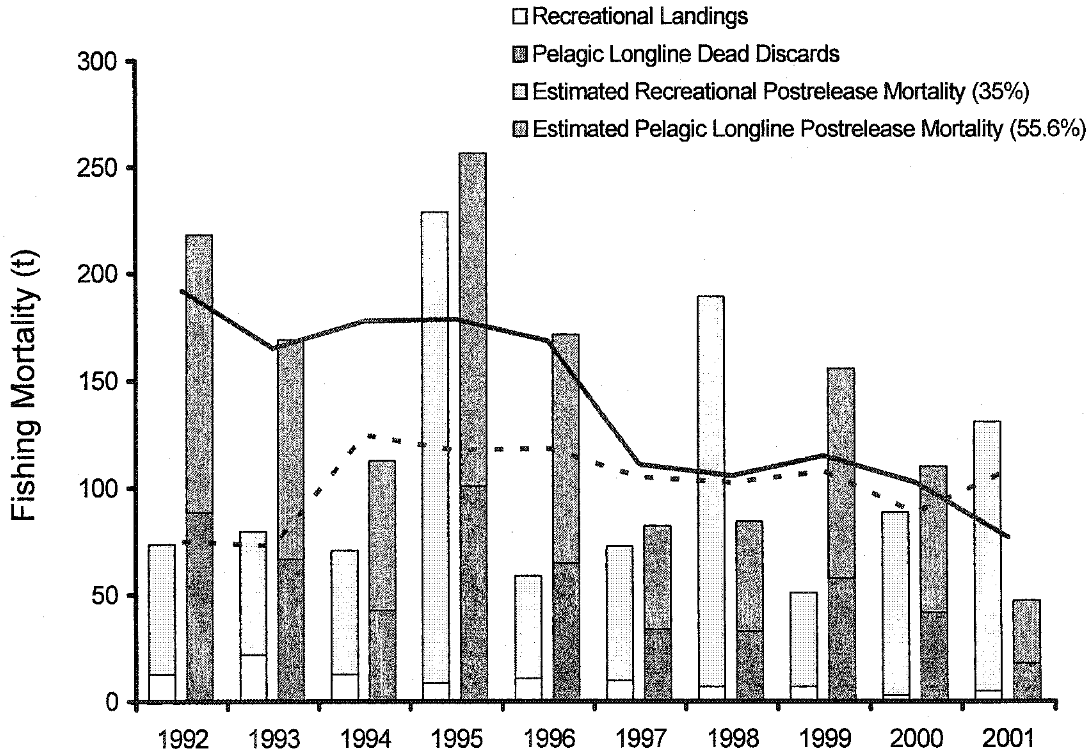
Figure 1. Results by hook type and hook location for 28 white marlin (*Tetrapturus albidus*) tagged with PSAT tags and released from commercial pelagic longline gear in the western North Atlantic Ocean, June 2002 – August 2004.

Figure 2. Calculated white marlin fishing mortality estimates in metric tons (mt) for the recreational and pelagic longline fisheries of the United States. The bottom part of each bar represents the reported mortality in each fishery (recreational landings and commercial dead discards, respectively), while the top part of the bar represents the possible additional fishing mortality based on conservative assumptions of 35% postrelease mortality using J-style hooks for the recreational fishery (Horodysky and Graves, 2005) and 55.6% postrelease mortality for J-style hooks in the commercial pelagic longline fishery (this study). The solid line is the three-year running average for estimated total recreational mortality (reported and estimated postrelease mortality), while the dashed line is the estimated total commercial pelagic longline mortality.

[Figure 1]


Circle
(*n* = 19)
Internal
(*n* = 2)
Non-report
(*n* = 2)
External
(*n* = 16)
Premature Release
(*n* = 1)
Non-report
(*n* = 2)
Mortality
(*n* = 1)
Survivor
(*n* = 13)
J-style
(*n* = 9)
Internal
(*n* = 2)
Non-report
(*n* = 1)
Mortality
(*n* = 1)
External
(*n* = 7)
Non-report
(*n* = 3)
Survivor
(*n* = 4)

[Figure 2]


Recreational Landings
Pelagic Longline Dead Discards
Estimated Recreational Postrelease Mortality (35%)
Estimated Pelagic Longline Postrelease Mortality (55.6%)
Fishing Mortality (t)
300
250
200
150
100
50
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

Evidence of shark predation and scavenging on fishes equipped with pop-up satellite archival tags

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Over the past few years, pop-up satellite archival tags (PSATs) have been used to investigate the behavior, movements, thermal biology, and postrelease mortality of a wide range of large, highly migratory species including bluefin tuna (Block et al., 2001), swordfish (Sedberry and Loefer, 2001), blue marlin (Graves et al., 2002), striped marlin (Domeier and Dewar, 2003), and white sharks (Boustany et al., 2002). PSAT tag technology has improved rapidly, and current tag models are capable of collecting, processing, and storing large amounts of information on light level, temperature, and pressure (depth) for a predetermined length of time before the release of these tags from animals. After release, the tags float to the surface, and transmit the stored data to passing satellites of the Argos system.

A problem noted by several authors using early PSAT models was the occasional occurrence of tags that did not transmit data. Clearly, a tag attached to a moribund fish that would sink to a depth exceeding the pressure limit of the tag casing would be destroyed. To prevent the loss of tags due to mortality events, tag manufacturers and researchers have developed mechanisms that release tags from dead or dying fish before the structural integrity of the tag is compromised at depth. These mechanisms include both mechanical devices that sever the monofilament tether that attaches the tag to the fish upon reaching a given depth and internal software subroutines that activate the normal electronic release mechanism if the tag either reaches a certain depth or maintains a constant depth for a predetermined length of time.

Despite the addition of these release mechanisms to PSATs, some tags still fail to transmit data. Such failure could result from any of the following events or conditions: mechanical failure of a critical tag component; destruction by fishing crews unaware of or not participating in the present research; excessive epifaunal growth that makes the tag negatively buoyant or prevents the tag from floating with the antenna in a vertical position; or fouling of the tag on the fish, fishing gear, or flotsam. Another cause of failure is that the tags could be lost as a result of ingestion. For example, a free-swimming white marlin (*Tetrapturus albidus*) was observed mouthing and almost swallowing a free-floating PSAT off the Dominican Republic in May 2002 (Graves, personal observ.). Alternately, the tag could be ingested incidentally with part of the tagged fish, as described by Jolley and Irby (1979) who reported that an acoustic tag on a sailfish (*Istiophorus platypterus*) was eaten along with the fish by an undetermined species of shark. In this note, we present data from PSATs deployed on two white marlin in the western North Atlantic Ocean and on an opah (*Lampris guttatus*) in the central Pacific; the data from these tags indicate that the tags were consumed by sharks.

Materials and methods

White marlin 1 (WM1)

At approximately 10:00 am local time on 1 September 2002, a white marlin was observed on pelagic longline gear set during the night near the southeastern edge of Georges Bank. The fish, which had been caught on a slightly offset, straight-shank J-style hook (size 9/0), was manually guided with the leader alongside the vessel. A PTT-100 HR model PSAT (Microwave Telemetry, Inc., Columbia, MD) was attached to the dorsal musculature approximately 5 cm below the base of the dorsal fin with a large nylon anchor according to the procedure and tether design described in Kerstetter et al. (2003). The tag was activated shortly after the white marlin was first identified, although approximately one hour is required following activation for this tag model to begin collecting data. The tag was programmed to record point measurements of temperature, light, and pressure (depth) in four-minute time intervals and to detach from the animal after 10 days. After release from the fish, the positively buoyant tag was expected to float to the surface and transmit stored and real-time data. For both white marlin

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Table 1

Comparison of depths and temperatures recorded by three pop-up satellite archival tags (PSATs) before and after the tags were ingested by an organism.

	Before ingestion					After ingestion				
Animal	Depth range (m)	Depth mean (SD)	Temp. range (°C)	Temp mean (SD)	*n*	Depth range (m)	Depth mean (SD)	Temp range (°C)	Temp mean (SD)	*n*
WM1	145.2	145.2 (±0.00)	11.6–11	11.7 (±0.07)	179	0–564.9	130.0 (±237.80)	12.1–26.5	24.1 (±0.84)	2755
WM2	0–26.9	5.9 (±4.44)	19.8–27.8	24.7 (± 0.91)	207	0–699.3	131.0 (±162.61)	18.9–29.5	27.3 (±1.20)	1683
Opah	22–456	221.81 (±92.20)	8–25.6	16.68 (±4.21)	360	0–524	170.56 (±133.83)	26.2–30.6	28.64 (±0.67)	168

tags, minimum straight-line distances were calculated between the point of release and the first clearly transmitted location of the tag following its release (pop-off) (Argos location codes 0–3).

At the time of tagging, the longline hook used to capture the fish was not visible in the mouth of the white marlin. The leader was therefore cut as close as possible to the fish before the fish was released, following the standard operating procedure for the domestic pelagic longline fleet. The fish was maintained alongside the vessel for less than three minutes for the application of the PSAT and a conventional streamer tag. Although the white marlin was initially active at the side of the vessel, some light bleeding from the gills was noted. After release, the fish swam away slowly under its own power.

White marlin 2 (WM2)

At 9:05 am on 2 August 2003, a white marlin was observed on pelagic longline gear with the same configuration in the same approximate area of Georges Bank as WM1. The fish was caught by a circle hook (size 16/0) in the right corner of the mouth, and although the stomach was everted, the fish appeared to be in excellent physical condition. A PTT-100 HR tag had been activated at 6:30 am that morning, and was therefore collecting data at the time of tagging. After the fish was brought to the side of the vessel, both the PSAT and a conventional streamer tag were attached to this fish in less than three minutes by using the same protocol as that described for WM1, and the fish swam strongly away from the vessel after release without any evident bleeding.

Opah

At 5:52 pm local time on 21 November 2002, a female opah was observed on pelagic longline gear set during the day east of the Island of Hawaii. The fish was brought to the side of the fishing vessel and a Wildlife Computers (Redmond, WA) PAT2 model tag was attached through the dorsal musculature with a Wildlife Computers titanium anchor. The tag was programmed to record the temperature and depth occupied by the fish in binned histograms, and the minimum and maximum temperatures and depths for 12-hour time periods. However, these 12-hour bins encompassed both day and night periods. The tag was programmed to be released six months after deployment. In the event of a premature release, the tag was programmed to begin transmitting stored data if it remained at the surface for longer than three days. The opah was lively and quickly dived after it was released.

Results

WM1

Release of the PSAT was expected to occur on 10 September 2002 and the tag was expected to begin transmitting data on that date, but the first transmission was not received until almost two days later. At the time of first transmission, the PSAT was 81.3 km (43.9 nmi) west-southwest of the tagging location. A total of 81.5% of the archived light level, temperature, and pressure (depth) data was recovered.

The light level, temperature, and pressure (depth) readings over time are presented in Fig. 1 (A–C) and summarized in Table 1. The first light level measurements indicated that the fish was already in relatively dark waters within one hour following its release. Light levels continued to drop to almost zero during the next ten hours and remained at that level for the next nine days (Fig. 1A). During the next seven-day surface transmission period, the tag recorded real-time day and night differences in light levels, which indicated that the light sensor was functioning properly.

Sea surface temperatures in the area where the gear was set and hauled back, varied from 25.2° to 26.7°C (D. Kerstetter, unpubl. data) and the first temperature

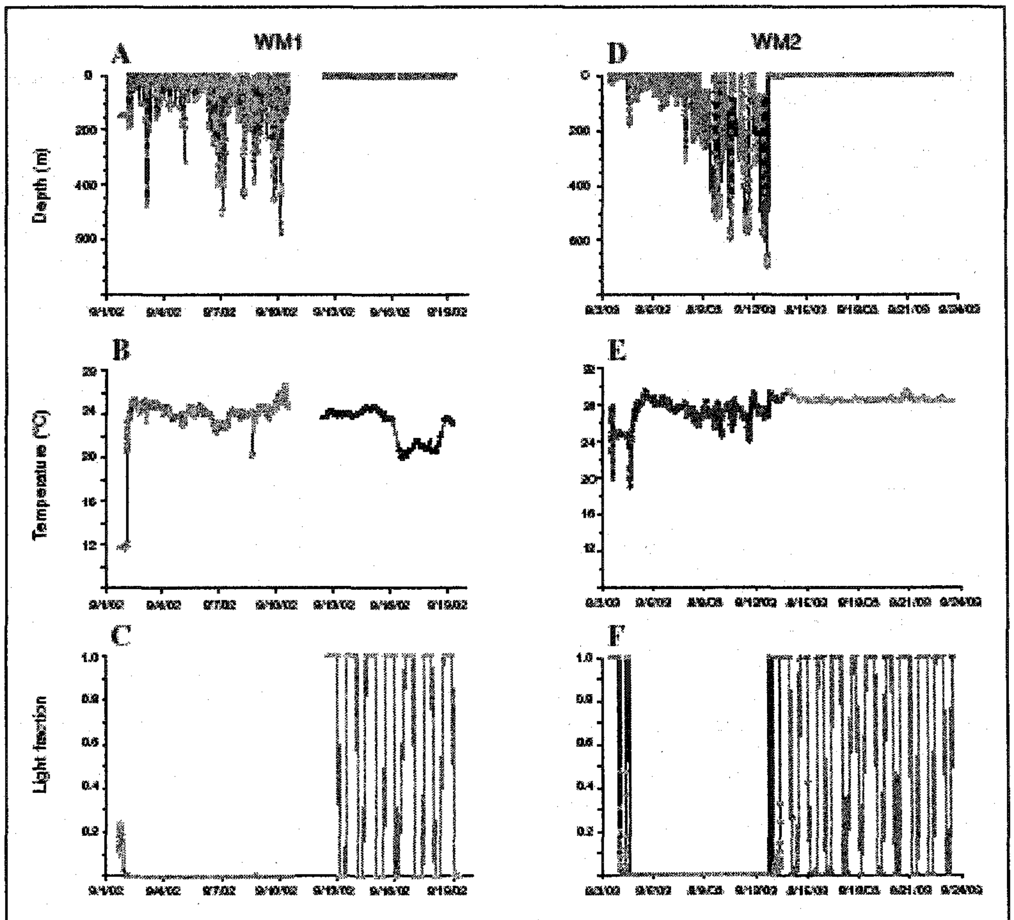

Figure 1

Graphs of data on and depth (A and D), temperature (B and E), and light index (C and F) for tags WM1 and WM2. Lighter lines and points are prior to programmed release date, whereas darker lines and points are "real-time" surface condition measurements transmitted by the tag in addition to the archived data.

recording by the PSAT (one hour after activation) was 11°C (Fig. 1B). The temperature remained fairly constant at 11°C for a period of approximately ten hours after which there was a rapid rise to 25°C. The temperature of the PSAT remained between 22.5° and 26.5°C for the next nine days (until the programmed release date), with the exception of one brief decrease to 20°C on 8 September. When the tag began transmitting on 12 September, the real-time surface temperature was 23.6°C.

The pressure data (Fig. 1C) indicated that the tag was at a depth of approximately 145 m at one hour following release. The PSAT remained at this depth for a little more than ten hours after which the data suggested that there was a rapid rise to the surface. For the next nine days, the tag reported considerable vertical movement between the surface and depths to 565 m. The tag was at the surface when it began transmitting both archived and real-time data on 12 September.

WM2

The tag reported data as expected on 13 August 2003 and transmitted 57.3% of the archived data. At the time of first transmission, the PSAT was 600.1 km (324.0 nmi) east-southeast of the tagging location. Summary depth and temperature data recorded by the PSAT are included in Table 1.

From the depth and temperature data, it appears that the fish survived for approximately 24 hours after release, at which point the light readings dropped to zero (see Fig. 1D) and remained at that level for the next eight days. The depth record following this change in light level was marked by several discrete diving events, and depths (see Fig. 1F) ranged between the surface and over 699 m. Recorded temperatures for this period varied between 18.9° and 29.5°C, although sea surface temperatures in the area where gear was set and hauled back varied from 20.9° to 26.0°C (Kerstetter, unpubl. data). On 12 August, the light level returned to its maximum value and the tag remained at the surface for approximately one day until its scheduled release date (13 August) when it began transmitting data.

Opah

The PAT2 satellite tag was expected to pop-up 6 months after deployment, but the first transmission was received after only 34 days from a location about 330 km (178 nmi) northwest of the deployment site. All the archived binned light level, temperature, and pressure (depth) data from this period were recovered (see Table 1). This tag model collected eight temperature and depth samples during each 12-hour period, resulting in 16 values per day or 528 total values for the deployment period. The two 12-hour blocks were removed from all analyses to more accurately represent the differences in data between specimens: 1) the 12-hour block after tagging in order to allow for the recovery of the animal, and 2) the 12-hour block during which the predation event putatively occurred in order to clarify the potentially distant depth and temperature characteristics of the ingesting animal.

The measured sea surface temperature during the tagging of the opah was 25.9°C. The ranges of dive depths, temperature, and light based on minimum and maximum values over the 12-hour day and night periods showed two distinct patterns (Fig. 2). During the first period (23 days), the dive depths ranged from about 32 to 456 m (Fig. 2A). Water temperatures encountered by the tag during this period ranged from 8.0° to 25.6°C (Fig. 2B) and the light index values ranged from about 50 to 150 (Fig. 2C). During the second period (11 days), the dive depths ranged from 0 to 524 m, temperature ranged from 26.2° to 30.6°C (higher than the 24.2–24.8°C SST recorded by the tag after it was released from the fish), and the light index recorded persistently low values.

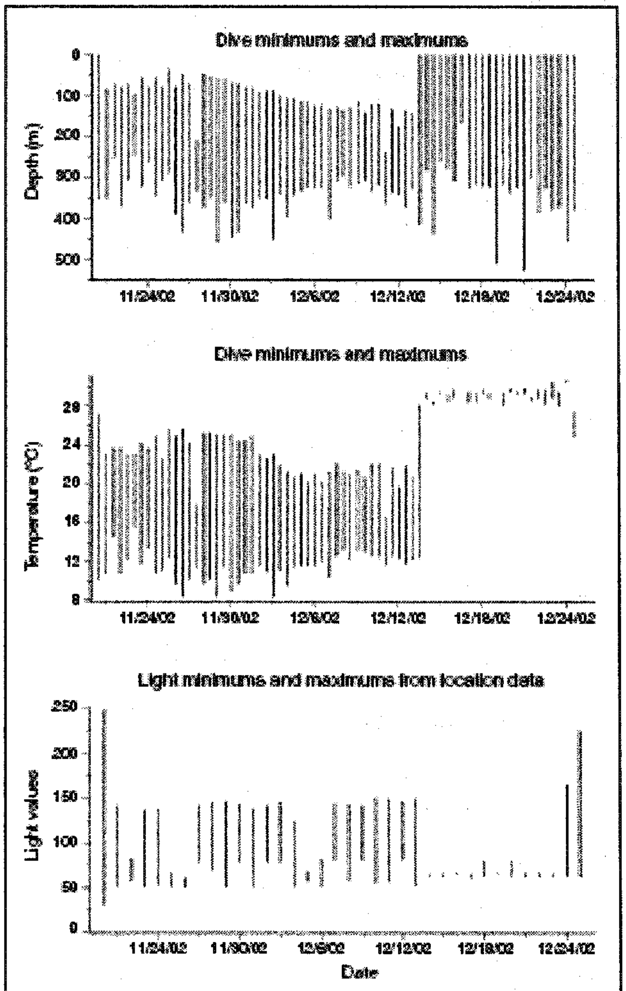

Figure 2

Graphs of depth (A), temperature (B), and light index (C) for the opah PAT tag from deployment until transmission.

Discussion

WM1

Our interpretation of these data is that the PSAT on WM1 was ingested by an animal scavenging the marlin carcass. The first PSAT readings for WM1, recorded about one hour after its release, indicated that the marlin was already dead or moribund by that time and was descending to the ocean floor. For the next ten hours, the tag and carcass remained at a constant depth of 145 m (the depth of the nearest sounding at the site of release, according to NOAA depth chart 13003 [1998], was approximately 160 m) and at a temperature of 11°C. The light level steadily decreased at approximately 4:30 pm, corresponding to changes in ambient light from the setting of the sun. At approximately 9:00 pm local time, there was a dramatic change in conditions when temperature rapidly rose to near 26°C and depths began to vary between the surface and 600 m.

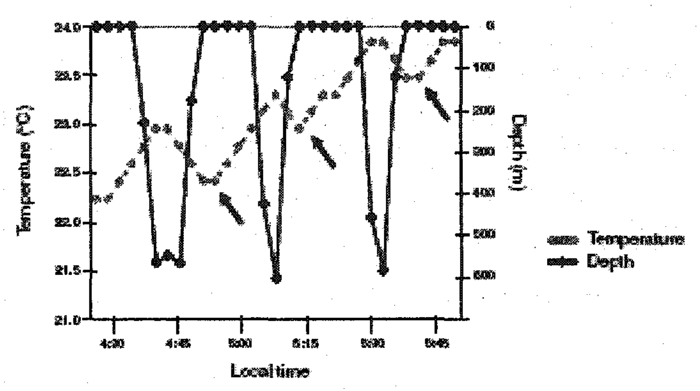

Figure 3

Delayed temperature changes recorded by tag WM1 following deep dive events on the morning of 2 September 2002. Arrows indicate the lowest temperatures recorded in association with a movement of the animal to depth; note that these temperatures were often recorded while the animal was at or near the surface and therefore represent a delay between depth and temperature.

We cannot attribute these changes to a resuscitation of the fish for three reasons. 1) The measured light levels indicated that the tag was in complete darkness for a period of ten days, even though it was at the surface during daylight hours. A malfunctioning light sensor cannot explain this observation because the tag recorded day and night differences in light levels at the surface during the seven-day transmission period after it was released from the fish. 2) After a rapid increase, the temperature remained relatively constant, between 23° and 26°C, even when the tag was at depths in excess of 300 m. Although dive behavior may be affected by location-specific conditions, previous PSAT observations of more than 20 other white marlin indicated that temperature ranges of individual dive events rarely exceed 8°C when, it is assumed, animals make foraging dives to depth (Horodysky et al., in press). 3) The PSAT recorded several dives in excess of 400 m, and previous observations of white marlin have revealed no dives in excess of 220 m (Horodysky et al., in press). Finally, the PSAT was scheduled to be released from WM1 after ten days on 10 September. Although archiving of light, temperature, and pressure data ceased on that date, the tag did not begin transmitting until 12 September.

WM2

The shallow dive patterns reported by this fish may indicate that it survived for approximately 24 hours following its release. Between 12:45 and 3:07 pm (local time), the light level fell abruptly from the maximum light level value to zero. At 3:08 pm, the temperature was 19.8°C at 166 m depth; by 4:37 pm, the temperature was above 24°C and remained above this value for the remainder of the deployment period. At 5:58 pm on 12 September, the light levels returned to maximum strength from zero—an indication that the tag had likely been egested. For the 19 hours remaining of the programmed deployment period prior to pop-off, the depth, light, and temperature data all indicated that the tag was floating at the surface.

Opah

Based on recovered data, our conjecture is that the tag was attached to the live opah for the first 23 days. Then, sometime during the 12-hour period from 2:00 pm 13 December to 2:00 am 14 December the tag was ingested. From our data, we cannot discern whether 1) the tag was detached prematurely from the opah and was floating on the surface when it was ingested, 2) an animal attacked the opah and ingested the tag incidentally, or 3) an animal ingested the tag alone. However, it is unlikely that the opah died, sank to the ocean floor, and was scavenged because the ocean floor in the area where the opah was tagged is below 2000 m. We have observed from other tags on opahs what we believe are mortalities; these occur shortly after tagging and show that the tag reaches depths in excess of 1000 m before detaching when the emergency pressure release in the tag is triggered. We did not observe depths below 600 m at any time during this record, and therefore the pressure-induced detachment mechanism on the tag was not triggered.

The ingestion hypothesis for the failure of these three tags to transmit data is supported by several lines of evidence. First, the light level readings were consistent with a tag residing in the complete darkness of an alimentary canal. Second, although temperature variations occurred during the deployment period, the delay in temperature changes during dives to depths indicates that the tags were not directly exposed to ambient water (see Fig. 3 for an example from WM1, as well as the comparisons in Table 1) and further may indicate that the scavenger was either endothermic or of large enough size to mitigate heat loss at depth.

There are several organisms that could have eaten these PSATs, whether by scavenging a carcass or attacking a moving fish. Clearly, each of these organisms was sufficiently large to ingest the tag without seriously damaging it. It is unlikely that a cetacean was responsible for any of these events because internal temperatures for odontocete whales (including killer whales, *Orcinus orca*) range between approximately 36° and 38°C (Whittow et al., 1974)—well above the range of temperatures recorded by the PSATs.

The only other natural predators of large pelagic fishes are various species of sharks. Several species of lamnid sharks maintain elevated body temperatures, including the shortfin mako (*Isurus oxyrinchus*) and the white shark (*Carcharodon carcharias*), both of which are found in the area of Georges Bank (Cramer, 2000) and the Central Pacific (Compagno, 1984). Several shortfin makos were caught by the same longline vessel during the week following each white marlin PSAT deployment (WM1: $n=4$, 95–189 cm FL; WM2: $n=3$, 94–199 cm FL) (Kerstetter, unpubl. data). The opah tag record closely resembles the relatively constant temperature noted for lamnid sharks, despite the independence of stomach temperature with ambient water for these endothermic sharks as reported by Carey et al. (1981). It is also interesting to note that although precipitous temperature fluctuations were generally absent, a rapid drop in temperature from 24° to 20°C was observed with tag WM1 on 8 September at 32.3 m depth—a fluctuation that could have resulted from another feeding event that brought cool food matter into the stomach. Similar reductions in stomach temperatures due to feeding have been noted for white sharks (McCosker, 1987). The range of temperatures recorded by each of the two white marlin tags appears rather broad for an endothermic shark, however, and although the temperature at depth was not measured, the delay in stomach temperature closely resembles the pattern of blue shark internal temperatures (*Prionace glauca*) measured in the Mid-Atlantic (Carey and Scharold, 1990).

The diving behavior recorded by the three tags also corroborates ingestion of the tags by sharks. Carey et al. (1982) reported that a tagged white shark off Long Island, New York, made frequent dives to the bottom during a 3.5-day acoustic tracking period. White sharks are known to dive to depth while scavenging whale carcasses (Dudley et al., 2000; Carey et al., 1982). A juvenile white shark also tracked by Klimley et al. (2002) spent far more extended times at depth than either white marlin tag. Although the programming of the tag on the opah precludes such fine-scale analyses of diving behavior, the available data are not inconsistent with the mako tracks in the study of Klimley et al. (2002). However, the short duration dives with frequent returns to the surface seen with the two white marlin tags most closely resemble those of blue sharks (Carey and Scharold, 1990) and were notably missing from the tracks of three shortfin makos observed by Klimley et al. (2002).

If sharks were indeed the scavenging animals, it is likely that the tags were regurgitated, rather than egested through the alimentary canal, whereupon the PSAT floated to the surface and was able to transmit the archived data. The narrow diameter of the spiral valve in the elasmobranch gastrointestinal tract would likely be too narrow to allow the undamaged passage of an object the size of a PSAT, even for a large shark. Although the available literature describing regurgitation abilities of pelagic sharks is rather limited, Hazin et al. (1994) reported that 35% of blue sharks brought aboard for scientific study had everted and protruding stomachs. Economakis and Lobel (1998) also stated their belief that regurgitation of ingested ultrasonic tags was the primary cause of lost tracks for grey reef sharks (*Carcharhinus amblyrhynchos*) on Johnston Atoll in the central Pacific Ocean.

Conclusions

The temperatures and dive depths recorded by the opah tag and both white marlin tags after apparent ingestion share similarities, yet also contain sufficient information to indicate the different identities of the ingesting organisms. The dive depths in all cases ranged from the surface to over 500 m, whereas the temperatures remained relatively constant at several degrees above the background SST, even during deep dive events. Temperature ranges alone strongly indicate sharks rather than odontocete whales were the ingesting organisms. However, limited literature on the internal stomach temperatures of the various pelagic sharks forces us to rely on telemetered diving behavior data for further species identification, which we used in the present study to suggest that blue sharks ingested the two white marlin tags (on account of the broad range of recorded temperatures) and that an endothermic shark ingested the opah tag.

It is not possible to account for all of the factors that may result in the failure of satellite tags to transmit data, but the results from these three PSATs indicated that biological activities such as predation and scavenging may play an important role. We believe that the most consistent explanation for the data transmitted by these three tags is that they were ingested by large sharks. One cannot calculate the probability that a tag could be engulfed whole without physical damage to the tag, survive for several days in the caustic environment of a digestive system, and be regurgitated with sufficient battery power to transmit data to the Argos satellites, but we suspect that the probability is not very great. We expect that a far greater number of tags may have had similar fates, that is to say, they were damaged by predation or scavenging and digestion processes or were regurgitated later in the transmission cycle, when the PSAT batteries had insufficient remaining power for successful data transmission. The failure of satellite tag to transmit data is frequently considered to be the result of internal tag malfunction or user error. However, these three data sets clearly indicate that the failure of PSATs to function may also be due to predation or scavenging events.

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CONCLUSION

The coastal pelagic longline fishery of the Unites States is an evolving entity, with the various segments developing into a fairly unified front when involved with management and research. This fishery remains politically important, despite the reduction by over half in numbers of active vessels and the total elimination in the late 1990s of the longline fishery for swordfish off the east coast of Florida, because of its combination of local economic and historical importance. The combination of an appreciation of fisheries science and a willingness to work cooperatively with government and academic scientists has made it arguably one of the most proactive commercial fisheries in the United States with regards to management.

The management of this fishery is complicated by the interaction of domestic and international regimes for the highly migratory target and bycatch species. For example, U.S. management is legally obligated to consider scientific populatioin benchmarks, endangered bycatch species interactions, and economic impacts which may not be required of managers in other countries. However, there exist several unique programs within the U.S. domestic management regime that are designed to facilitate research between commercial fisheries and scientists to address pressing management needs. These research programs formed the genesis of the work described in this dissertation.

The U.S. pelagic longline fishery has been recently confronted with several important issues, and bycatch remains one of the largest problems. For example, concerns with juvenile swordfish bycatch led ultimately to the closure of traditional longline grounds in the Gulf of Mexico and the east coast of Florida, and high interaction rates with sea turtles also resulted in the temporary closure of the seasonal Grand Banks fishery. Despite these management actions, little was known about the fishery interactions, especially regarding the coastal longline fleet. Determining the nature of these interactions included investigations into the behavior of the gear, the impacts of mandatory terminal gear changes, and the impacts on total mortality of the various species interacting with the gear. This dissertation was designed around these management needs to provide answers to four specific applied questions: the behavior of the pelagic longline gear, the impacts of a switch in terminal tackle to circle hooks, the time at hooking for target and bycatch species, and the post-release survival rates of white marlin.

This work found many important results with clear management implications. For example, shallow coastal longline gear is highly variable with regards to depth, regardless of specific float line and leader length combinations. This information suggests that factors other than gear configuration are more important for determining actual fishing depths, and that previous modeling of the gear results in an overestimation of hook depth. Determining the actual fishing depths of the gear will affect future population assessments by more accurately describing the range of interactions between the gear and the various pelagic species. With regards to terminal gear types, this study found few differences in catch rates between circle hooks and J-style hooks, suggesting that the current management requirement to use circle hooks will likely have limited impact on total fleet-wide revenue. More importantly, this work concurred with the preliminary results of other studies that showed a decreased rate of hooking internally with circle hooks, which resulted in lower mortality rates at haulback for many species. The release of live, longline-caught bycatch species could promote the recovery of depleted stocks by reducing fishing mortality, while the survival at haulback of target species results in a higher-value fisheries product. Analyses of time at hooking found that swordfish almost exclusively were caught by this shallow coastal gear during nighttime, although bycatch species did not show such a clear pattern. Finally, the results of the PSAT tagging of white marlin demonstrated survival for the majority of those individuals released alive, indicating that current management measures requiring release of these animals will reduce fishing mortality on this species.

The results of this study addressed these four goals, but certainly did not answer all of the questions regarding the interactions of fishes with pelagic longline gear. While the most comprehensive data to date on the behavior and effective fishing depths of coastal pelagic longline gear, the results presented here should not be considered representative for the entire fishery throughout the Atlantic. Varying gear configurations and oceanographic conditions may affect the gear differently. Other work, such as the cooperative research program between several academic researchers (including the author), scientists with the National Marine Fisheries Service, and the Fisheries Research Institute (a group of participating longline industry vessels) to study the effectiveness of bycatch reduction technologies, many be able to elaborate these results with greater precision and geographic range. More importantly, other cooperative research programs will allow the diffusion and evaluation of these bycatch reduction technologies to the pelagic longline fleets of developing states, such as Brazil.

The pelagic longline remains an economically viable gear type throughout most of the world. The results of this and previous studies demonstrate that environmental concerns such as bycatch can be addressed through relatively minor changes in the physical gear or deployment strategies. The species groups targeted by this gear type are among the most valuable in the marine environment and these economic pressures will continue to encourage further development in these target fisheries. Unfortunately, this fishery development will also catch more of the bycatch species that may be least robust to additional fishing mortality. The international management of this fishery is already challenged by the need to effectively control effort and ultimately harvest levels. One method to reduce fishing mortality on bycatch species is to disperse these bycatch reduction methodologies throughout the pelagic longline fleets. Fostering scientific collaborations between scientists and the commercial fishery, such as this dissertation work, remains a powerful tool for both discovering and dispersing additional bycatch reduction methodologies.

VITA

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