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2001

Use of Pop-Up Satellite Tag Technology to Estimate Survival of Blue Marlin (Makaira nigricans) Released from Pelagic Longline Gear

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Recommended Citation

USE OF POP-UP SATELLITE TAG TECHNOLOGY TO ESTIMATE

SURVIVAL OF BLUE MARLIN (*MAKAIRA NIGRICANS*)

RELEASED FROM PELAGIC LONGLINE GEAR

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A Thesis

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

Master of Science

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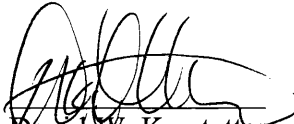
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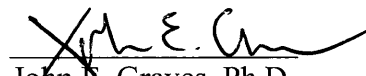
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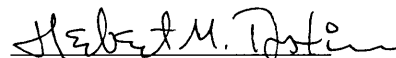
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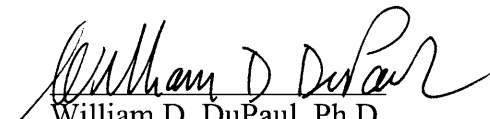
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DEDICATION

This thesis is dedicated to my grandmother, Jean Memmert Kerstetter (1922-2001).

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ABSTRACT

The most recent population assessment for Atlantic blue marlin (*Makaira nigricans*), conducted in 2000, suggests a highly overfished stock. Although approximately 50% of these fish are alive at capture on longline gear, the conservation impact of releases is unknown because little information exists about post-release billfish survival. Domestic and international management actions currently require the release of live blue marlin by commer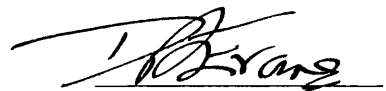cial longline vessels to reduce fishing mortality for the Atlantic-wide stock, despite protests that such measures have little conservation benefit. Pop-up satellite archival tags (PSATs) were used in the western North Atlantic Ocean to evaluate the potential impact of this management measure. Seven 5-day and two 30-day PSATs were deployed during normal longline operations from three commercial swordfish and tuna fishing vessels in waters off Bermuda, North Carolina, and the east coast of Florida.

Nine blue marlin were tagged with PSATs between July 2000 and September 2001. Prior to release, individual weights of tagged fish were visually estimated, and hooking location, physical condition, and the approximate position of the fish on the length of the longline recorded. Fish were released using the standard commercial protocol of cutting the gangion, leaving the hook in place. When possible, fish were also tagged using a conventional "spaghetti" tag from the U.S. National Marine Fisheries Service (NMFS). Deployment of PSATs from commercial longline vessels did not interfere with normal longline operations.

Seven of the PSATs (five 5-day and both 30-day tags) released from the blue marlin, floated to the surface, and transmitted data. Based on total net displacement, diving behavior measured by temperature and depth data, and consistent forward movement, at least seven of the tagged fish survived the tagging experience. Tag data indicate vertical displacement at least daily with dives to below 100 meters common. The deepest recorded dive was to a depth of 268 meters. Diving behavior was not strongly correlated to any specific time of day. Tagged fish appear to prefer habitat above 50 meters depth and temperatures above 22 degrees C. Data also indicate large-scale horizontal displacement away from the tagging locations (range: 142.6-242.2 km for 5-day tags, 1393.9 and 2796.6 km for 30-day tags). All six fish with transmitting tags along the east coast of the United States moved north or northeast following tagging, while the one fish tagged near Bermuda moved south-southeast.

It is unknown why only seven of the nine deployed tags transmitted data. All tagged fish appeared healthy at release. Non-reporting tags may indicate mortality, although other factors could account for a failure to report, including tag malfunction or mechanical damage to the tag. However, even the conservative estimate of seven surviving fish strongly suggests that many blue marlin captured as longline bycatch do survive capture and release from commercial longline vessels, demonstrating the conservation benefit of this management measure.

USE OF POP-UP SATELLITE TAG TECHNOLOGY TO ESTIMATE

SURVIVAL OF BLUE MARLIN (*Makaira nigricans*) RELEASED

FROM PELAGIC LONGLINE GEAR

INTRODUCTION

Populations of Atlantic billfish (Family Istiophoridae) are now considered to be severely depleted. Specifically, an assessment in 2000 by fishery scientists with the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated that the total biomass of Atlantic blue marlin (*Makaira nigricans*) is only about 40% of that necessary to produce the maximum sustainable yield (ICCAT, 2000). This species supports several important recreational fisheries in both the eastern and western Atlantic Ocean, contributes to the harvests of artisanal fisheries, and is part of the incidental landings of foreign commercial longline fishing vessels. Although billfish comprise only a fraction of total longline landings, commercial fishing operations have a disproportionately negative effect on blue marlin populations due to the sheer fishing effort throughout the Atlantic. Current international management measures to promote the release of live, incidentally caught billfish by commercial fishing vessels are intended to decrease the fishing mortality on these stocks; however, the effectiveness of these measures on commercial longline fishing vessels has not been studied.

U.S. commercial longline vessels are currently required by regulation to release all Atlantic billfish. Although approximately half of these fish are alive at capture

(Jackson and Farber, 1996), the conservation impact of releases is unknown because little information exists about post-release billfish survival. Results of acoustic tracking studies of blue marlin for up to several days after recreational capture suggest that mortality, when it occurs, usually happens within 48 hours of release (Pepperell and Davis, 1999). Pop-up satellite archival tags (PSATs), which have been used to study movements of other highly migratory species over time periods of days to several months, provide a potential tool to investigate post-release survival of billfish. A recent study using PSATs on recreationally caught blue marlin off Bermuda had positive returns from eight of nine tags, all of which indicated post-release survival of those animals for at least five days (Graves *et al.*, 2002).

Blue Marlin Biology

Blue marlin are globally distributed in tropical and sub-tropical marine waters.[1] In the Atlantic Ocean, the species is found from Canada to Argentina in the west and from the Azores Islands to South Africa in the east. The species is epipelagic and generally prefers warm oceanic waters.

A summary of blue marlin biology is included in Nakamura (1985). Blue marlin are large apex predators that travel as individuals rather than in schools or small pods. Adults average 100-175 kg in weight and are sexually dimorphic; females are generally larger than males and reach a much larger maximum size (Hopper, 1990). This species is one of the fastest growing teleost fishes. Prince *et al.* (1991) reported that blue marlin

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[1] Disagreement persists whether the Indo-Pacific blue marlin constitutes a separate species, *Makaira mazura*. Nakamura (1985) suggested that the difference in lateral line morphology was sufficient for such a determination, although genetic analyses (Finnerty and Block, 1994; Graves and McDowell, 2000) have disagreed with the separate species hypothesis. This thesis considers Atlantic

reach 24 cm lower jaw fork length (LJFL) in 40 days and 190 cm in 500 days. Blue

marlin attain sexual maturity between ages II and IV, and are believed to live 20-30 years

(Hill *et al.*, 1989). Gut content analyses have shown that blue marlin have a varied diet of

surface species, mostly scombrids, other pelagic fishes, and squids (Pimenta *et al.*, 2000)

as well as deepwater fishes (Nakamura, 1985). The size range of prey is similarly wide,

from post-larval surgeonfish to tunas greater than 50 kg (Erdman, 1962). Previous

acoustic tracking studies have shown that blue marlin engage in a diurnal movement

within the water column, possibly related to feeding behavior (Holland *et al.*, 1990).

Detailed migration patterns of blue marlin are unknown, although the capture of

ripe females and larvae suggest spawning areas in the eastern Caribbean Sea (Eric

Prince, NMFS, pers. comm.). Several groups in the United States participate in

conventional tagging programs, with the majority of tagged releases from the NMFS

Cooperative Tagging Center (from 1954-present) and The Billfish Foundation (1990-

present). The South Carolina Marine Resources Division (1974-1999) and the National

Marine Fisheries Service's Shark Tagging Program (1962-1999) have also participated in

tagging blue marlin. Between these four programs, 43,343 conventional tags have been

applied to blue marlin, of which only 587 (1.35%) had been returned as of the 2000

ICCAT billfish workshop. Most reported recaptures were from the area of initial release,

even after several years at liberty (SCRS, 2000). Many returns have inferred seasonal

movements by individual animals between the United States and Venezuela, although

these tag returns may reflect the increasing presence of recreational and charter fleets in

both countries. Some individuals have undertaken large-scale movements, including

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and Indo-Pacific blue marlin one globally distributed species, *Makaira nigricans.*

three trans-equatorial (north to south), 12 trans-Atlantic (west to east), and one inter-ocean movement from the Atlantic to the Indian Ocean (SCRS, 2000).

Atlantic blue marlin were historically separated into two stocks for management purposes, separated at 5° North latitude. This line corresponded to ICCAT statistical area delineations, which reflected, in turn, the early patterns of fishing effort by foreign longline fishing fleets. However, as the high seas longline fisheries expanded, it is now known that blue marlin are distributed throughout the year across the 5° N line (SCRS, 2000). Tagging studies have also demonstrated that there are movements across the 5° N latitude delineation, and high resolution molecular analyses provide no genetic basis for stock structure within the Atlantic (e.g., Graves and McDowell, 2000). Based on this combined tag-recapture and genetic information, Atlantic blue marlin are now managed as a single stock.

Longline Fishing and Other Bycatch Species

The primary commercial method of fishing for highly migratory species in the Atlantic Ocean is the pelagic longline, although many other gears are used globally, such as purse seines, harpoons, gillnets, and hook-and-line fishing. Blue marlin are generally not a target species of commercial longline fleets, but are retained as "sellable" incidental catch by many foreign longline vessels. These "retained by-catch" fisheries include vessels from Venezuela, Brazil, and Cuba, as well as the distant-water fleets of Japan, Chinese-Taipei,[2] and the People's Republic of China. Many of the developing coastal countries within the species' range also have low- to moderate-scale artisanal or

subsistence fisheries. While there are many modifications of pelagic longline gear that can affect the relative composition of the catch, fisheries that use longline gear are inherently multi-species fisheries. In addition to the commercial fisheries, important recreational fisheries for blue marlin exist in the Azores, Brazil, the Bahamas, Bermuda, Jamaica, Madeira, Venezuela, and the United States.

The basic configuration of pelagic longline gear includes several components (Figure 1). The primary line, the "mainline," is a braided, or more-commonly single-stranded monofilament, line up to 40 nautical miles in length.[3] At intervals along the mainline, lengths of line termed "gangions" or "dropper lines" of up to approximately 40 fathoms[4] are used as leaders for the hooks. Chemical light sticks are often used on these gangions when targeting swordfish (*Xiphias gladius*) and some tuna species. Other lines called "buoy drops" attach small foam floats, 3-meter long metal radar reflectors called "high flyers," and transmitting radio buoys to the mainline at regular intervals. The mainline is deployed from a deck-mounted reel out over the stern of the vessel. Retrieval, also called "haulback," of the mainline through pulley blocks to the reel is done from the hauling station, a small console on one side of the vessel (Figure 2). By holding one hand on the mainline and the other on the wheel and throttle, the captain is able to feel weight, indicating the presence of a caught fish, enabling the crew to prepare for landing (or releasing) the animal with gaffs and other tools.

Bait for longline gear depends in large part on the geographic location of the set.

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[2] Because of political sensitivities, Taiwan, Republic of China, is referred to as "Chinese-Taipei" at ICCAT.
[3] The Final FMP for Atlantic Tunas, Swordfish, and Sharks (NMFS, 1999) limits the length of longlines in waters of the U.S. Exclusive Economic Zone (EEZ) to 24 nautical miles during the period of August 1st to November 30th.
[4] A fathom equals six feet (1.8 meters). "Fathom" is still the term commonly used within the longline fleet to describe the lengths of leaders and buoy drops.

Figure 1. Basic pelagic longline gear configuration. Drawing is not to scale, and radar

buoys are not shown (from Arocha, 1996).

High-flyer

Buoys

gangions   Mainline   light-sticks

hooks
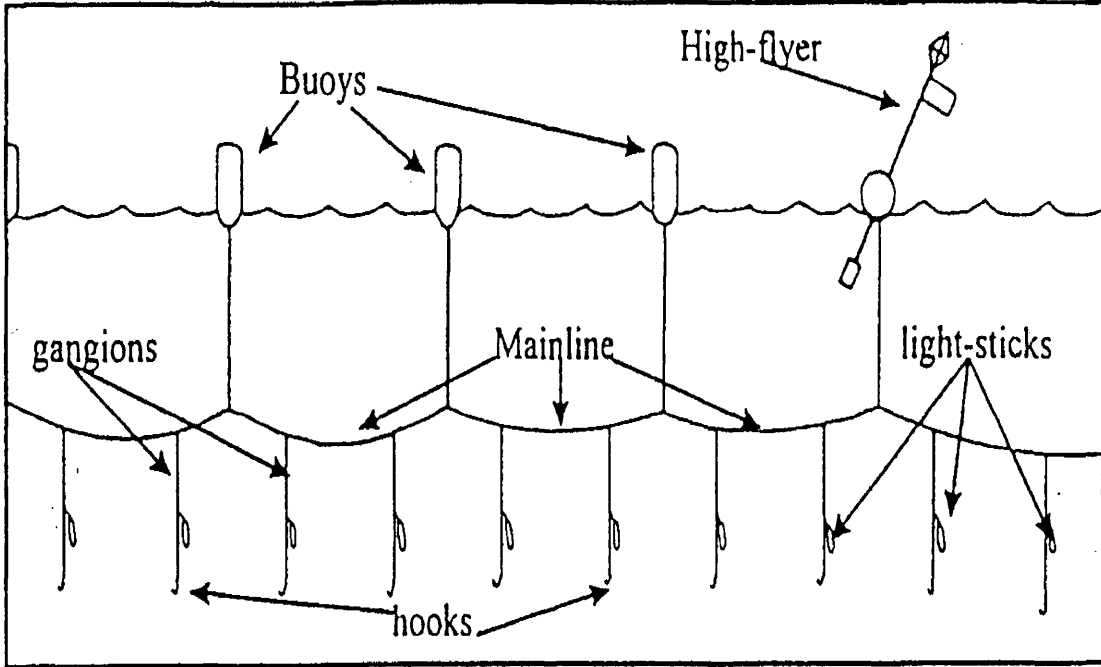
Figure 2. Deck layout of the F/V *Triple Threat*. Note large mainline reel in center of deck and hauling station on the portside gunwhale marked by the yellow rectangle. Marked by the green arrow, four "high-flyer" reflective marker buoys (topped with orange floats) can be seen on the vessel at left.

Although frozen squid (*Illex* sp. or *Loligo* sp.) is most common, frozen mackerel (*Scomber* sp.) is also occasionally used, especially by north Atlantic longline vessels targeting large swordfish. Many foreign (non-United States) vessels in the Caribbean Sea currently use live bait such as scad (*Decapterus* sp.), although this practice is now prohibited for all U.S. longline vessels in the Gulf of Mexico through a U.S. National Marine Fisheries Service (NMFS) regulation (65 F.R. 47213) due to concerns that live bait results in higher rates of billfish bycatch. (Prohibiting live bait by longline vessels in the Gulf of Mexico was expected to reduce blue and white marlin discards in the Gulf of Mexico by approximately 10 to 20 percent, and sailfish discards by up to 45 percent, depending upon the analytical procedure used.) Although technically permitted, no U.S. longline vessels outside the Gulf of Mexico are known to currently use live bait, in large part due to the logistical difficulties of keeping the bait alive over long periods of time.

Pelagic longline gear has many possible modifications for particular target species. The time of day that the gear is fished affects swordfish catch rates, for example, with higher catches at night reflecting the shallow nocturnal feeding habits of the species (Hoey, 1996). Swordfish catches are also much higher around the full moon, with many Grand Banks swordfish vessels deliberately scheduling their month-long trips to remain synchronized with the moon phase. By varying the lengths of the gangions and buoy drops, altering the speed at which the gear is deployed, and changing the lengths of mainline between floats, fishermen can choose the depths at which the gear fishes. Depth can be a crucial variable affecting catch rates with some deep-water tuna species such as bigeye tuna (*Thunnus obesus*). Deep-water sets generally use a combination of longer gangions and buoy dropper lines that place the baited hooks at depths greater than 150

meters. Other variables include setting along or across temperature and current breaks, horizontally curving the shape of the mainline to allow for different drift rates during the free-floating time of the set, and attaching chemical attractants between gangions (pers. observ.).

Longline vessels fishing for swordfish and tunas within the geographic range of blue marlin also capture many other incidental catch and bycatch species. Appendix 1 provides a partial list of those species taken concurrently with blue marlin in commercial longline sets. Several of these are considered "protected species" by NMFS through either the Marine Mammal Protection Act or Endangered Species Act. These acts require increasing regulatory management of these fisheries to reduce interactions of these protected species with the longline fleets.

Blue Marlin Management

Blue marlin are found throughout the Atlantic Ocean and its adjacent seas. This international range led to its inclusion within the purview of ICCAT, whose management mandate includes all "tuna and tuna-like" species in the Atlantic Ocean. ICCAT management measures are subsequently implemented in the United States by the NMFS Highly Migratory Species (HMS) Division. Acting under the mandates of the Sustainable Fisheries Act, and with the guidance of the Billfish Advisory Panel, the HMS Division is responsible for the promulgation of fishery management plans (FMPs) and other regulations for billfish, including blue marlin. Historically, both ICCAT and NMFS have worked on billfish issues under the scientific guidance of the ICCAT Standing Committee for Research and Statistics (SCRS) assessments.

The ICCAT SCRS conducted its first assessment of blue marlin in the Atlantic in 1992. In both 1992 and 1996, the SCRS conducted assessments based on two scenarios: one for the two-stock hypothesis of northern and southern populations, and a second for a single, Atlantic-wide stock. Both assessment methodologies used ASPIC, a non-equilibrium surplus production model developed by Dr. Michael Prager of the NMFS Southeast Fisheries Science Center. This model uses several sets of time-series catch-per-unit-effort (CPUE) data from both commercial and recreational fisheries to parameterize the stock (see "Download Reports, Regulations, etc." at http://www.iccat.es for a further description of ASPIC). The 1996 assessment results of both stock models indicated similar total estimates of blue marlin stock production, as noted in Table 1.

Amendment 1 to the Atlantic Billfish Fishery Management Plan (Amendment 1) was published by the NMFS HMS Division in 1999 and effectively replaced the previous 1988 FMP that had been prepared by the South Atlantic Fishery Management Council with cooperation from four other Atlantic Fishery Management Councils. The 1988 FMP promulgated three major changes to billfish management in the United States: prohibiting both the sale and possession of Atlantic billfish by commercial longline and drift net vessels, establishing recreational size limits, and developing or expanding several recreational data reporting mechanisms. Amendment 1 also maintained the previous moratorium on the sale of Atlantic billfish, instituted increased size limits, and increased reporting requirements of the recreational fleet. An additional provision, expanding the NMFS management unit of billfish to include the entire Atlantic, reflected both the growing evidence of single, Atlantic-wide stocks for most billfish species and the increasing dispersal of the U.S. longline and recreational fleets.

Table 1. Historic assessment results from the 1992, 1996, and 2000 blue marlin stock assessments by the ICCAT SCRS (ICCAT, 1995; ICCAT, 1996; ICCAT, 2000). Yield units in metric tons (MT), the reporting unit for ICCAT statistics.

Year	1992			1996			2000
Area	North	South	Total	North	South	Total	Total
Maximum Sustainable Yield (MSY)	~1,700	~1,300	~3,600	1,963 (1,742-2,133)	n.p.	4,461 (4,096-4,787)	~2,000 (~2,000-3,000)
Current Yield	1990: 1,230	1990: 1,963	1990: 3,293	1996: 1,775	1996: 2,477	1996: 4,452	1999: 3,316
Replacement Yield	1990: 1,600	1990: 700	1990: 2,500	1996: 1,694	n.p.	1996: 1,920	1999: ~1,200 (~840-1,600)
Relative Biomass	B_{1990}/B_{MSY}: ~0.83	B_{1990}/B_{MSY}: ~0.34	B_{1990}/B_{MSY}: ~0.42	B_{1996}/B_{MSY}: 0.608	B_{1996}/B_{MSY}: n.p.	B_{1996}/B_{MSY}: 0.236	B_{2000}/B_{MSY}: ~0.4 (~0.25-0.6)
Relative Fishing Mortality	F_{1989}/F_{MSY}: ~1.1	F_{1989}/F_{MSY}: ~6.8	F_{1989}/F_{MSY}: ~2.5	F_{1995}/F_{MSY}: 1.21 (0.96-1.56)	F_{1995}/F_{MSY}: n.p.	F_{1995}/F_{MSY}: 2.87 (1.45-3.41)	F_{1999}/F_{MSY}: 4 (~2.5-6)

Notes:

- The symbol "~" indicates that the number is an approximate value reported by the ICCAT SCRS assessment.
- Values in parentheses indicate approximate 80% confidence intervals quantified by bootstrapping (ICCAT, 2000).
- The abbreviation "n.p." is for "not provided." The South Atlantic production model analysis in 1996 "could not be made to converge to a solution without fixing several parameters, thus making the assessment results unreliable. Because of the poor model fit, benchmark values are not provided in the summary table." (ICCAT SCRS, 1996)
- The total yield in 1996 includes a reported 200 MT catch from an "unclassified region," and hence is greater than the combination of the north and south reported catch.

Amendment 1 further established a rebuilding strategy that included the creation of a "foundation" to develop an international plan for rebuilding these billfish stocks in 10 years. This international strategy includes pursuing such options as catch restrictions, time and area closures, release of live billfish by commercial longline vessels, size limits, and implementing independent fisheries observers (NMFS, 1999). The development of an international strategy was required because the U.S. fishery component only harvests approximately five percent (1990-2000 average: 4.5 percent) of the reported Atlantic-wide blue marlin fishery (ICCAT, 2001). This cooperative international effort has been pursued by the United States through ICCAT and is generally supported by fellow ICCAT members Canada and the United Kingdom-Overseas Territories (Bermuda).

The tone of ICCAT management for Atlantic blue marlin changed following the 2000 SCRS stock assessment for the species. In that assessment, the SCRS estimated the current biomass to be approximately 40% of that required for production of the maximum sustainable yield (MSY) for the stock (ICCAT, 2000). This finding accompanied a downward revision in the estimate of MSY for the species, decreasing from 4,400 metric tons (MT) in 1996 to 2,000 MT in 2000. Furthermore, the 2000 assessment indicated that catch levels over recent years were almost double the replacement yield, or the amount of biomass that can be removed annually and have neither a decrease nor increase in the stock size, contributing to a further decline of the overfished stock (Figure 3). This is even more significant given that over-exploited pelagic stocks have, by definition, lower replacement yields than those that are fully exploited.

The combination of reduced estimates of stock size and increased landings

Figure 3. Total Atlantic Ocean catch of blue marlin in metric tons (SCRS, 2000).

N=North Atlantic, S=South Atlantic, and All=Combined N and S.

Dark horizontal line indicates the estimated MSY for the Atlantic-wide stock.

Year

Landings (metric tons)

Total - N
Total - S
Total - All
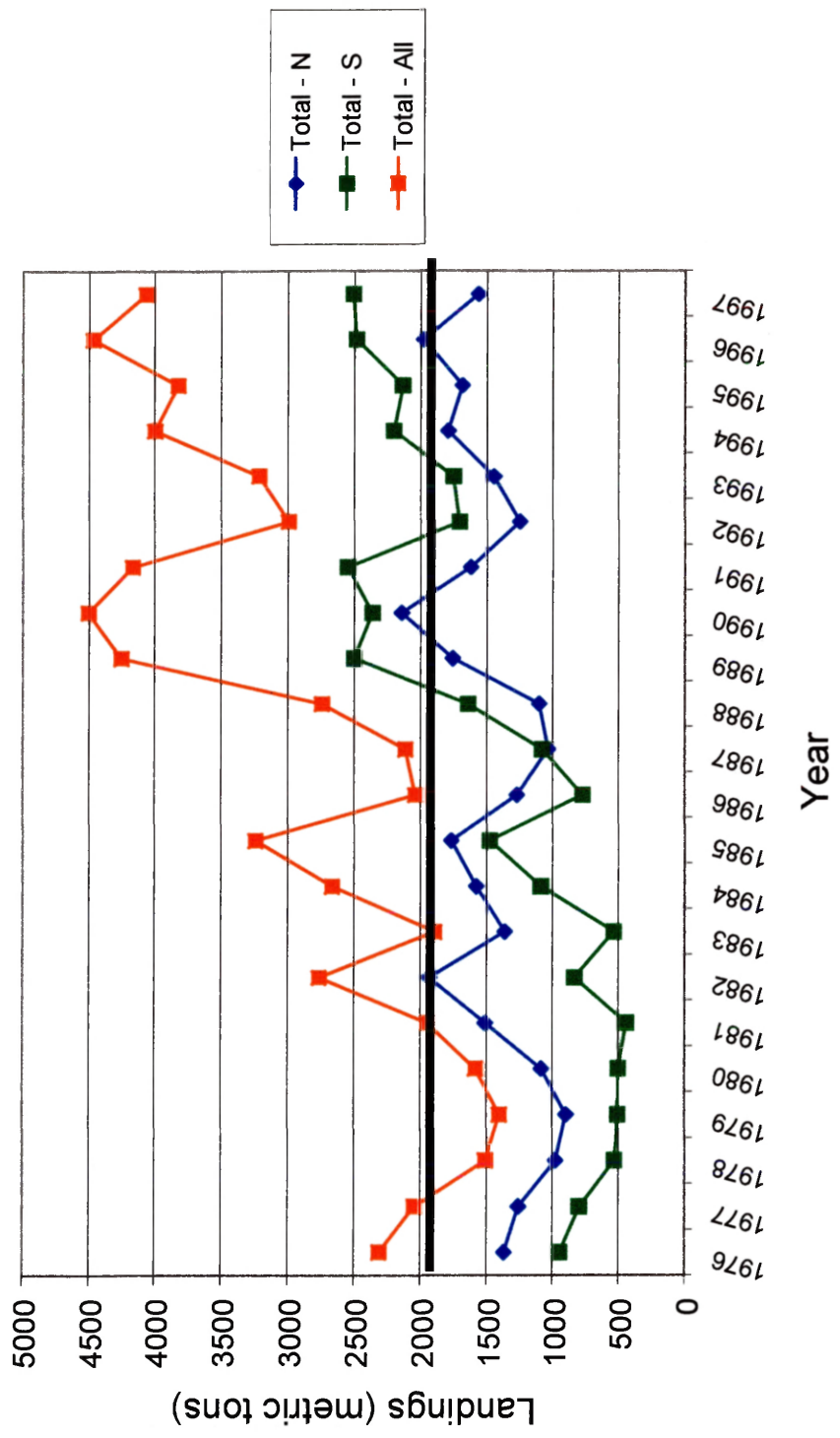
strongly suggested the need to reduce fishing mortality (F)[5] if the stock was to be rebuilt.

Amendment 1 to the U.S. Atlantic Billfish FMP noted in 1998 that a reduction in blue marlin fishing mortality of 43.4% would be sufficient to allow a rebuilding of the Atlantic stocks in 10 years (NMFS, 1998). The ICCAT SCRS additionally noted in 1999 "if perfectly implemented, this measure [requiring the release of live longline marlin bycatch] would reduce fishing mortality rates below F_{MSY} for this species" (ICCAT, 1999). The 2000 blue marlin assessment by the SCRS, however, indicated that this measure alone would not be sufficient to rebuild the blue marlin stock. In fact, the SCRS noted that a minimum reduction in fishing mortality of 60% would be necessary just to halt the decline in the stock biomass, with a further reduction in F required for any stock rebuilding (SCRS, 2000).

The greatest source of billfish mortality is the incidental catch by pelagic longline gear deployed for tunas and swordfish (ICCAT, 1997). These highly migratory fishes co-occur in the sub-tropical and tropical epipelagic environment and are vulnerable to non-selective fishing gear such as the pelagic longline. However, not all billfish are dead at the time of longline gear haulback; data from observers on vessels in the Venezuelan longline fishery indicate that about 50% of billfish caught on pelagic longline gear are alive at the time of haulback (Jackson and Farber, 1998). NMFS data from the U.S. Observer Program and mandatory pelagic longline logbook submissions indicate that 74.4% of blue marlin are released alive from commercial pelagic longline gear (NMFS,

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[5] "Fishing mortality" (F) describes the percentage of a stock that dies due to fishing activity, although there is disagreement on how far to extend the results of "fishing activity," i.e., it most often refers to direct deaths but there have been suggestions to also include delayed mortality effects due to habitat loss or degradation. NMFS and ICCAT both refer only to those mortalities directly resulting from fishing gear. F is a component of total mortality (Z), which also includes natural mortality (M). All of these mortality rates can either be an annual percentage or, more commonly, an instantaneous rate that expresses the amount of the stock dying at any given point in time. However, methodologies for estimating these parameters for blue marlin are imprecise, and "estimates of

1998), although no additional information on injuries or other condition parameters of released marlin are available.

The ICCAT SCRS has advised the Commission for many years that stocks of billfish in the Atlantic were overfished. The SCRS has also repeatedly commented that releasing all live billfish taken on longline gear would benefit the stocks by reducing billfish fishing mortality (ICCAT, 1993; ICCAT, 1995). This later became a specific management recommendation to the Commission (SCRS, 1997).[6] It was believed that such a management measure would be more acceptable to the Commission member states than an overall reduction in longline effort that would also reduce catches of target species.[7] Despite this precautionary management approach, representatives from several nations pointed out that the conservation benefits of post-release survival of billfish were questionable given the low recovery rates of conventional "spaghetti" streamer tags. Because of this low recovery rate, the conservation impact of a management recommendation requiring release could also not be evaluated. However, the 1996 SCRS stock assessment results were sufficiently dire to allow the passage in 1997 of a ICCAT binding recommendation to reduce blue and white marlin landings by 25% of 1996 levels by 1999. This measure was subsequently extended and amended in 1998 to hold landings in 2000 to the reduced levels to be achieved by 1999 (ICCAT, 1999).

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absolute F from surplus-production models [e.g., ASPIC] are known to be highly imprecise (Prager, 1994)" (ICCAT, 2000).

[6] This recommendation to the Commission was repeated in 2000, along with other suggestions such as reductions in fleet-wide effort and time-area closures (SCRS, 2000).

[7] ICCAT operates as a consensus-based organization, in which all members must (at least nominally) agree to a proposed management measure before it becomes applicable to all the Commission members. Proposed measures that have objectionable provisions are usually withdrawn rather than face a rarely-used voting process. In general, developing countries have been reluctant to support any measures that would reduce the harvests of their "developing" fisheries. Similarly, fisheries in the "developed" countries are hesitant to reduce their harvests in the face of uncertain scientific information. The Delegate from Japan to the 1992 ICCAT meeting commented on the U.S. domestic regulations requiring the release of all billfish. The Delegate commented on "... his country's view that all living marine resources, including billfishes, should be utilized for human consumption." He further suggested that "...perhaps [white marlin and blue marlin] fisheries were not important to all countries." Recent actions by Japan have suggested, however, an increased willingness to work within ICCAT to help recover these billfish stocks, even while

Additional data are needed to support or refute the hypothesis that the release of live billfish would significantly reduce the fishing mortality of blue marlin (Graves *et al.*, 1995). Determination of the survival rate of billfish caught and released from commercial pelagic longlines is necessary to evaluate the impact of current billfish management measures.

Previous Tagging of Pelagic Species

The use of various tag designs and tagging methods has vastly increased our understanding of the movements and habitat preferences of marlins and other pelagic fishes. Tag designs have included simple "spaghetti" streamer tags, ultrasonic telemetry tags, implanted archival tags, and the recently developed pop-up satellite archival tags. Each of these designs has specific advantages and limitations. Selected summaries of several previous electronic tagging projects and their respective tags are detailed in Tables 2 and 3.

Simple, non-transmitting streamer tags have been used for several decades. These tags can provide a substantial amount of information despite their simplicity, such as net displacement of the fish, the time at-liberty, and a growth estimate. Obviously, a returned tag also indicates post-release survival of the animal. While relatively inexpensive and easy to apply, the inherent limitation with this design is that the recaptured tag (or its information) must be returned to the tagging agency or group for analysis. Low recovery rates of billfish tagged with conventional tags and released from recreational and commercial fisheries (less than 2%; from Ortiz *et al.*, 1998) are consistent with high

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continuing to protest the SCRS assessment results during Commission meetings (e.g., ICCAT, 2000).

Table 2. Selected pelagic species electronic tagging programs and study parameters.

Project	Species	Study Area	Number Tagged	Capture Method	Tag Type	Time at Large (Range)
Yuen (1970)	Skipjack tuna	Main HI Islands	2 total	Recreational hook-and-line	Ultrasonic	2 and 7 days
Laurs et al. (1977)	Albacore	Monterey Bay, CA	6, but only 3 used for study	Commercial hook-and-line	Ultrasonic	2-50 hours
Jolley and Irby (1979)	Atlantic sailfish	Southeast FL	8 total	Recreational hook-and-line	Ultrasonic	2:56-28:21 (hours:minutes)
Carey and Robison (1981)	Swordfish	Baja CA and Hattaras, NC	5 Pacific and 1 Atlantic	Harpoon in Pacific and longline in Atlantic	Ultrasonic	1-5 days
Holland et al. (1985)	Yellowfin and bigeye tuna	Kona, HI	11 yellowfin and 2 bigeye tuna	Recreational hook-and-line	Ultrasonic	8 hours to 6 days
Carey and Scharold (1990)	Blue shark	Mid-Atlantic Bight	22 total	Recreational hook-and-line	Ultrasonic and multiplex ultrasonic	10-136 hours
Holland et al. (1990a)	Blue marlin	Kona, HI	6 total	Recreational hook-and-line	Ultrasonic	7-42 hours
Holland et al. (1990b)	Yellowfin and bigeye tuna	Kona, HI	11 yellowfin and 4 bigeye tuna	Recreational hook-and-line	Ultrasonic	5 hours to 6 days
Block et al. (1992)	Blue marlin	Kona, HI	6 total	Recreational hook-and-line	Multiplex ultrasonic	1-5 days
Brill et al. (1993)	Striped marlin	Hawaii	6 total	Recreational hook-and-line	Ultrasonic	4-51 hours
Cayré and Marsac (1993)	Yellowfin tuna	Southeast Indian Ocean	3 total	Not described	Ultrasonic	Not described
Block et al. (1998)	Bluefin tuna	Northwest Atlantic	37 total	Recreational hook-and-line	PSAT	Variable[1]
Pepperell and Davis (1999)	Black marlin	East Australia	8 total	Recreational hook-and-line	Ultrasonic	8-27 hours
Graves et al. (2002)	Blue marlin	Bermuda	9 total	Recreational hook-and-line	PSAT	5 days
This study	Blue marlin	Bermuda and Southeast U.S. Coast	9 total	Commercial longline	PSAT	5 and 30 days

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[1] This study used PSATs of varying release times as well as including several fish in another archival study.

Table 3. Size comparison of tags used in pelagic species electronic tagging programs.

Project	Species	Individual Fish Weight	Tag Type	Tag Size (cm)[1]	Tag Weight (g)
Yuen (1970)	Skipjack tuna	40 and 44 cm (lengths only)	Ultrasonic	8.1*2, cylindrical	62 air
Laurs et al. (1977)	Albacore	8.2-13.6 kg	Ultrasonic	8.2*1.9, cylindrical	67 air/43 seawater
Jolley and Irby (1979)	Atlantic sailfish	7-30 kg	Ultrasonic	7.6 to 13*1.5 to 2.5, cylindrical	60.5-143.0 air
Carey and Robison (1981)	Swordfish	70-140 kg	Ultrasonic	14*4.5*3	250 air/90 seawater
Holland et al. (1985)	Yellowfin and bigeye tuna	Unknown	Ultrasonic	8*1.6, cylindrical	27.7 air/11.7 seawater
Carey and Scharold (1990)	Blue shark	198-300 cm (lengths only)	Ultrasonic and multiplex ultrasonic	14*4.7*3.3	750 air/90 water
Holland et al. (1990a)	Blue marlin	60-160 kg	Ultrasonic	8*1.6, cylindrical	27.7 air/11.7 seawater
Holland et al. (1990b)	Yellowfin and bigeye tuna	Unknown	Ultrasonic	8*1.6, cylindrical	27.7 air/11.7 seawater
Block et al. (1992)	Blue marlin	60-220 kg	Multiplex ultrasonic	18*4*2.2	190 air/78 seawater
Brill et al. (1993)	Striped marlin	37-57 kg	Ultrasonic	8*1.6, cylindrical	27.7 air/11.7 seawater
Cayré and Marsac (1993)	Yellowfin tuna	73-105 cm FL (lengths only)	Ultrasonic	Not described	Not described
Block et al. (1998)	Bluefin tuna	96-181 kg	PSAT	14.8*4, cylindrical	65-71 air
Pepperell and Davis (1999)	Black marlin	100-420 kg	Ultrasonic	22 and 32 mm diameter, length not described	Not described
Graves et al. (2002)	Blue marlin	150-425 lbs	PSAT	14.8*4, cylindrical	65-71 air
This study	Blue marlin	125-400 lbs	PSAT	14.8*4, cylindrical	65-71 air

[1] Tag size indicated does not necessarily include length of antennae or attachment leads.

post-release mortality of these tagged fish. However, factors such as tag shedding and failure to report tag recaptures could also account for low rates of tag returns (Bayley and Prince, 1994; Jones and Prince, 1998).

Working with Atlantic sailfish (*Istiophorus platypterus*), Jolley and Irby (1979) reported their belief that tagging mortality was minimal, but also suggested that further studies incorporating two tags on each released fish be conducted to achieve an overall estimate of tag shedding. Concerns over tag shedding led one recreational billfish angling group, The Billfish Foundation (TBF), to switch from metal tag heads to nylon (plastic) darts, which NMFS subsequently adopted for its own HMS tagging programs.

Acoustic (generally ultrasonic) transmitter tags emit high-frequency sound waves, which are then tracked by researchers following the fish in dedicated research vessels. These tags are implanted internally through ingestion (attempted by Laurs *et al.*, 1977, with albacore, *Thunnus alalunga*, and Carey and Scharold, 1990, with swordfish), affixed externally along either side of the dorsal ridge (e.g., Block *et al.*, 1992, with North Atlantic bluefin tuna, *Thunnus thynnus thynnus*), or attached with nylon bands (similar to plastic cable ties) through the pterygiophore bones and centered externally along the dorsal finlets posterior to the first dorsal fin (described fully in Holland *et al.*, 1985, with bigeye tuna and yellowfin tuna, *Thunnus albacares*). The effective range of these tags is highly dependent on factors such as battery strength and local oceanographic conditions (see Guy *et al.*, 1996, for a further discussion of the limitations of acoustic tagging).

The majority of acoustic tagging projects for pelagic fishes has used individuals obtained by recreational hook-and-line fishing methods (e.g., Yuen, 1970; Jolley and Irby, 1979; Brill *et al.*, 1984; Carey and Scharold, 1990; Holland *et al.*, 1990; Block *et*

al., 1992; Brill *et al.*, 1993), although Carey and Robison (1981) used both harpoon and longline gears to obtain specimens of Pacific and Atlantic swordfish.

Acoustic tracking studies designed to investigate billfish physiology and behavior have also provided insights into the post-release survival of billfish taken with recreational gear. Specifically, observed and inferred mortalities during the course of the acoustic tracks indicate that not all released billfish survive (reviewed in Pepperell and Davis, 1999). Unfortunately, it is not possible to accurately estimate levels of post-release mortality from previous acoustic tracking studies for several reasons. First, due to the high cost of ship and personnel time, relatively few individual animals have been investigated in acoustic tracking studies. Secondly, as ocean conditions can deteriorate quickly, many of the acoustic tracks were for less than 12 hours, providing a limited opportunity to observe mortality. Thirdly, billfish were caught and subsequently tracked under a variety of conditions at various locations, making comparisons between studies difficult. Finally, an estimate of post-release mortality rates resulting from acoustic studies may be biased because in several cases only healthy fish were selected to carry the transmitters (e.g., Carey and Scharold, 1990; Brill *et al.*, 1993).

The recent development of several different technologies allows for the use of archival tags on large pelagic fishes. These are relatively large tags, usually surgically implanted into the peritoneal cavity, that are capable of collecting data for up to several years. Recent designs have incorporated a light-sensing device that extends through the body cavity wall, registering light level data that permit the later calculation of latitude and longitude for a given time. An obvious drawback to this design is that the capturing vessel must return the tag for the data to be retrieved. Relatively large rewards for the

return of these tags (up to $5,000 USD) are thought to provide an ample incentive. However, recent experience regarding the difficultly of NMFS to retrieve a bluefin tuna archival tag from an artisanal fisherman in the Philippines suggests that there are still exceptions to this conventional wisdom (David Balton, U.S. Department of State, pers. comm.). Other researchers have had only parts of archival tags returned, in which case the data collected by these tags were unrecoverable (Block *et al.*, 2001). Finally, internal archival tags require surgical implantation, a procedure that would be both impractical and dangerous for the researchers on large billfish such as blue marlin.

While able to collect large quantities of data, the disadvantage of requiring the recovery and return of implanted archival tags prompted the development of pop-up satellite tag technology. These tags use a corrodible link between the tag body and a tether to the fish to detach under pre-determined conditions, float to the surface, and transmit stored data through the Argos satellite system. Although individually expensive, PSATs eliminate the need to use a dedicated tracking vessel to follow fish on the high seas or to rely on an unknown fisherman to return a tag. They are also able to record environmental parameters over predefined time intervals. These tags have been deployed primarily on Atlantic northern bluefin tuna for relatively long durations (30, 60, or 90 days) in order to determine movement patterns (Block *et al.*, 1998; Block *et al.*, 2001). Another study employed PSATs on Atlantic swordfish to examine horizontal and vertical movement patterns (Sedberry and Loefer, 2001). Non-tuna species, including great white sharks (*Carcharodon carcharias*) and ocean sunfish (*Mola* sp.), are also now beginning to be tagged with PSATs (Melinda Braun, Wildlife Computers, pers. comm.). Recovery rates of PSAT data in previous studies have been good, with researchers reporting

recovery rates of 79% (Sedberry and Loefer, 2001) and in excess of 90% (Block *et al.*, 1998).[8] In 1999, Graves *et al.* (2002) attached PSATs to recreationally caught blue marlin off Bermuda, with a recovery rate of 88% (8 of 9 deployed tags). These latest results further suggest the technology is well suited for shorter-term studies, including the determination of post-release survival.

Tagging Concerns

Despite rapid advances in both the size and sophistication of PSATs, several challenges remain for projects that utilize this technology. One is the size of the tag itself, since any device (electronic or otherwise) attached to a fish should incur an energetic cost to the individual. The various PSAT tag designs are fairly bulky and have therefore only been used on relatively large fish in order to minimize the potential interference of the tag with normal behavior. Another issue is whether the condition of the individual fish should be a deciding factor on whether or not to apply a tag. Finally, there remains a question of how accurately PSAT-generated data reflect post-release survival and how this estimate of survival relates to estimates of mortality.

The size of PSATs is directly related to the amount of data that can be stored and transmitted. Current PSAT models are necessarily large to compensate the battery weight with sufficient floatation to allow for post-release surfacing. Large animals are generally thought necessary for PSAT tagging studies in order to minimize the ratio of hydrodynamic drag imposed by the tag to thrust produced by the individual, hence

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[8] Reporting rate varied by location, with the eastern Atlantic and Mediterranean areas having a lower reporting rate than the western Atlantic. This is believed to be due to inadequate Argos coverage rather than differences in tags or tagging techniques (Roger Hill, Wildlife Computers, pers. comm. and Paul Howey, Microwave Telemetry, Inc., pers. comm.).

minimizing the probable effects of the tag on post-release behavior. This size requirement limits the species that can be tagged and may also potentially limit tagging to only one sex for sexually dimorphic species, such as blue marlin. The technological development of smaller batteries and other electronic components has allowed for smaller, less intrusive tags that present a lower hydrodynamic load for the tagged fish. Recent work by Dr. Eric Prince (NMFS, pers. comm.) in 2000 with recreationally caught sailfish off Central America has shown that an animal less than 75 pounds (34.1 kg) may be tagged successfully with current PSAT models.

Several previous studies utilizing acoustic tags used a condition standard for selecting fish to be electronically tagged. Acoustic tags are extremely expensive, as is the boat time required for tracking acoustically tagged fish. Therefore many projects have either used a simple condition index (Jolley and Irby, 1979) or explicitly stated that only fish meeting a minimum physical condition were used (Carey and Scharold, 1990; Brill *et al.*, 1993). However, even fish apparently dead at the time of release may survive; Holland *et al.*, (1990a) noted that fish number 8807 was "completely immobile and floating belly-up at the side of the boat when the transmitter was attached." This fish slowly sank for approximately 30 seconds after release before regaining normal, i.e., faster, movements. This individual was tracked for approximately 42 hours before the signal was lost in deteriorating weather conditions. Conventional tag returns have also indicated that the condition at release may not always be an accurate indicator of post-release survival.

Studies employing PSAT technology have noted that some tags did not report to the Argos satellite system after their programmed release time, which could result from

either fish mortality or tag failure. This latter category includes: failure of the tag electronics, mechanical destruction of the tag or its antenna (e.g., by the bite of a fish or other marine animal, or by a malevolent recapturing fishing vessel), and depth-induced tag crushing. In addition to these sources of PSAT non-reporting, there are also several possible sources of tagging error, such as tagging induced mortality (e.g., tagging along the lateral line or puncturing the peritoneal cavity) and tag shedding resulting from poor tag placement.

The larger issue of how accurately PSAT data reflect actual survival remains open for debate, as does the relationship of survival to mortality. Goodyear (1999) used a series of simulation analyses to evaluate the accuracy of PSATs to estimate billfish survival. Although examined from a recreational catch-and-release perspective, many of the conclusions remain valid for this commercial project as well. Specifically, he noted that, absent other information, tag shedding, the malfunction of the electronics, and possible tag damage would all be erroneously reported as mortalities. Any tagging-induced injuries may also cause additional mortality apart from the actual release. Finally, there remains a question of how long a fish must survive release relative to ongoing natural mortality, i.e., at what point will natural mortality rates interfere with the estimation of post-release fishing mortality. All of these factors involved in tagging experiments contribute error that would cause an upward bias in mortality estimates.

Finally, there is also the question of the sample size required for an Atlantic-wide estimate of post-release mortality given the need to account for different environmental conditions and geographic areas. The consensus appears to be that such a project would be so large that it would also be prohibitively expensive given current technological

constraints. A recent estimate of this larger project indicated a required minimum sample size approaching 100 deployed PSATs per location per gear type, although this estimate also varied with differing assumptions of the underlying natural mortality rate (Goodyear, 2000). The study by Graves *et al.* (2002) with recreationally released blue marlin in Bermuda affirmed that the PSAT technology is an appropriate and effective (albeit expensive) method for estimating post-release survival for this species. Although important, the recreational fishery contributes a smaller fraction of the total fishing mortality than the pelagic longline fishery. This current project thus evaluates the use of PSAT technology for assessing the survival of live-released blue marlin from commercial longline sets in the western Atlantic Ocean.

Project Objectives

This project had two objectives: one, to evaluate the feasibility of deploying PSATs on blue marlin under normal working conditions from commercial longline vessels, and two, to describe the behavior and survival of blue marlin released from commercial longline gear. The first objective will be described qualitatively and the second described quantitatively from the data obtained from deployed PSATs.

Previous deployments of PSATs on blue marlin have been done from two types of platforms, recreational fishing boats (e.g., Graves *et al.*, 2002; Eric Prince, NMFS, pers. comm.) and the Japanese government longline fisheries research vessel R/V *Shoyo Maru* (two deployed archival tags, Ziro Suzuki, Japanese Institute of Far-Seas Research, pers. comm.). Commercial longline vessels frequently have crowded deck spaces, small crews, and a strong profit motive. Even under current mandatory release management

measures, vessel operators have very little incentive to engage in labor-intensive billfish

release protocols such as resuscitation or hook removal.[9] By deploying PSATs from

longline vessels, a more accurate account of actual fishing practices will be obtained, as

well as documenting the required billfish release under real, albeit generally "best case,"

working conditions.

The post-release behavior of blue marlin was evaluated through data obtained

from the PSAT tags. This technology was used for several reasons. The first is the lack

of conventional tag returns. During 1996 and 1997, 1,715 blue marlin were tagged

through a tagging program organized by the joint NMFS-The Billfish Foundation

Cooperative Tagging Center (NMFS, 1999). During this same time, however, there were

only 39 reported recaptures, many of which were from fish tagged before that two-year

period. By utilizing the pop-up release technology, PSATs eliminate the need for the fish

to be recaptured and (perhaps even more importantly) reported back to the tagging

agency. The second factor is the amount of data that can be gathered on each

deployment. Conventional tags can only provide data on estimated growth and net

movement between the initial catch and recapture locations. In contrast, each PSAT

recorded at least temperature, while the 30-day model also recorded pressure and light

level data. Location data from the first transmission site allowed the calculation of net

displacement. Survival of released fish was ascertained through analyses of net

displacement and reported behavioral data. For the 5-day tags, fish showing consistent

forward motion (inclinometer data) and vertical movement within the water column

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[9] Several crewmembers of various longline vessels reported to the author that some captains and crew remove hooks from all caught fish species, including billfish, even if doing so likely kills the animal. Although unverifiable for all species and all longline fisheries, some species groups such as gempylids and small sharks are often casually killed to obtain the hook, despite an average

(temperature data) are assumed to have survived. The thirty-day tags do not have the inclinometer, but do have a direct pressure sensor as well as the temperature sensor to gauge depth.

Many of the blue marlin caught by commercial longline fishing gear are alive at haulback. Based on both the number of conventional tag returns from fish tagged by commercial longline fishermen and the survival of fish caught by longline for acoustic tracking research, it is highly likely that many of these released fish survive the interaction experience with this fishing gear. It is therefore the general working hypothesis of this project that the majority of blue marlin released from commercial pelagic longline gear will survive under the conditions of the standard release protocol.

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cost per hook of approximately $1.50.

MATERIALS AND METHODS

Locations

This project was conducted in six different areas of the western North Atlantic

Ocean. Locations are briefly described in Table 4. Most sets were deployed over fairly

deep waters (depths greater than 350 fathoms or approximately 616 meters), although

some sets in the north Florida Straits were over relatively shallow bottom relief (less than

200 fathoms or 110 meters).

Equipment and Vessels

Four commercial longline vessels in the western North Atlantic Ocean were used

for this study. The characteristics of these vessels are also noted in Table 4. All carried

approximately 20 miles (32 kilometers) of longline on one large spool centrally mounted

amidships. Gear was set off the stern and retrieved from a hauling station located on one

side of the vessel approximately amidships. This is a standard vessel configuration for

the U.S. Gulf of Mexico/East Coast swordfish fleet.

This project used standard, East Coast pelagic commercial longline gear. Various

gear configurations, i.e., different lengths of dropper lines or number of hooks between

floats, were used in attempts by the captains to increase billfish catch rates. Leader

Table 4. Characteristics of the fishing vessels used in this study. Note that home ports and vessel names are as of time of participation in study. All four vessels used diesel engines for main propulsion. Length over-all (LOA) is in feet, with meters in parentheses (NMFS, 2002).

Vessel Name	Home Port	Hull Composition	Year Built	Horsepower	LOA
F/V *Ark Angel*	Hamilton, Bermuda	Steel	1968	320	70.4 (21.5)
F/V *Deliverance*	Wanchese, NC	Fiberglass	1976	375	48.1 (14.7)
F/V *Triple Threat*	Miami, FL	Fiberglass	1982	318	49.7 (15.2)
F/V *Carol Ann*	Miami, FL	Fiberglass over wood	1979	174	48.8 (14.9)

lengths ranged from 5 to 20 fathoms (9.2 to 36.6 meters), while the buoy drops generally

were 10 to 15 fathoms (18.3 to 27.5 meters). An average "section" of gear had five hooks

between "bullet floats", then ten bullet floats between large "polyballs." Every second or

third polyball also had a "high flyer" attached to it. Transmitting radio buoys were

attached to the lead end of the line and replaced every other high flyer, so that the average

set included three radio buoys spaced throughout the line.

Pop-up Satellite Tags

Microwave Telemetry, Inc. (MWT) and Wildlife Computers (WC) pop-up

satellite archival tags were used in this study (see Table 5 for tag characteristics). The tag

design of these two models is very similar: they are both positively buoyant, measure

approximately 38 cm by 4 cm diameter (including antenna) and weigh between 65-75

grams (air weight minus attachment leader and tag head). The tag is composed of a

lithium-composite battery, a microprocessor, various sensors, and a 0.150 watt (MWT) or

0.5 watt (WC) satellite transmitter packaged within a resin-filled carbon fiber tube. The

antenna is attached to a bulbous top end of buoyant glass bead-embedded resin. In

external appearance, the largest difference between the two tag types is the color; the WC

tag is off-white while the MWT tags are black (Figure 4). The WC tag also has a small

metal emergency release mechanism on the attachment leader. All tag models used in

this project can withstand a maximum pressure equivalent to a depth of about 1000

meters (3,280 feet), which is well below the depth of previously documented blue marlin

migrations in the water column (Block *et al.*, 1992).

PSATs were attached to blue marlin with an approximately 20 cm length of

Table 5. Comparison between two tag models used in study.

Model	Make	Duration	Inclinometer	Temperature Sensor	Pressure Sensor	Light Sensor	Emergency Release
PTT-100	MWT	5 days	Yes	Yes	No	No	No
PAT	WC	Variable	No	Yes	Yes	Yes	Yes

Figure 4. The MWT PTT-100 model tag. The WC PAT tag model is almost

identical in size and shape, although the color of the tag body is a light grey

and the bulbous float is white. Also not shown is the release device (RD-1500)

used on the WC PAT tag that is positioned on the light colored segment of

tether between the two sections of black heat shrink tubing. The horizontal

black bar shown above the tag for scale is approximately six inches.
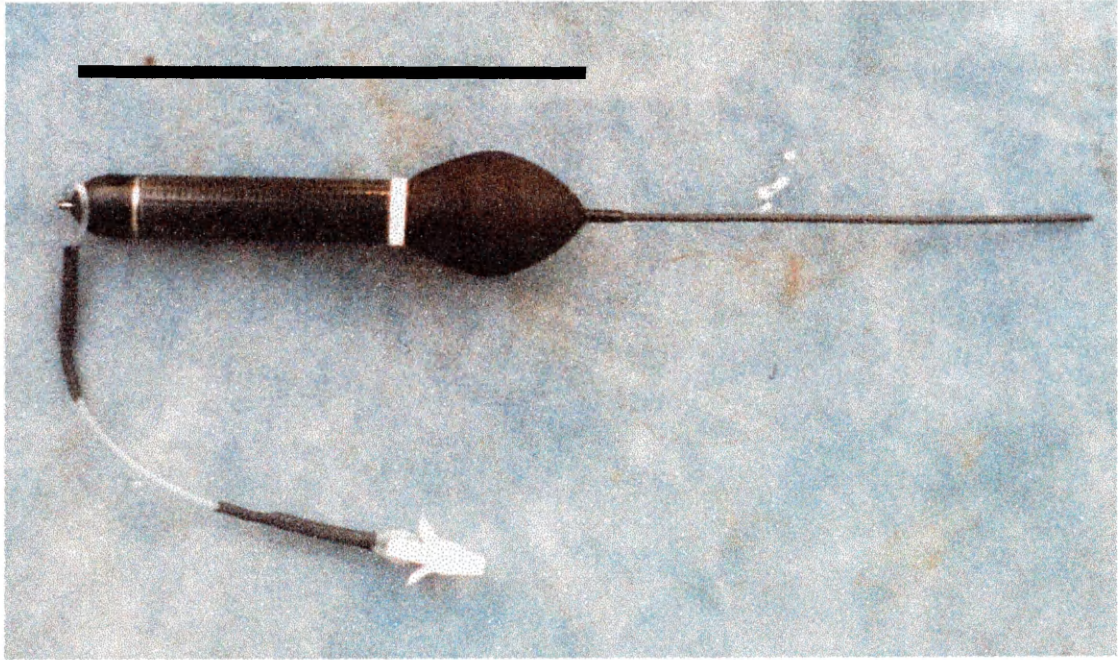
300-pound-test Moimoi® brand monofilament. This attachment was constructed by hand using a large hydroscopic, surgical-grade nylon tag head held in place with double metal crimps. The Billfish Foundation developed this tag head during cooperative research with NMFS (TBF, 2000). Designed as an intramuscular tag, this model eliminates the need to precisely place the tag between the pterygiophore bones, as was the case with metal tag heads. Testing indicates that muscle tissue adheres to the tag head over time, likely eliminating some tag shedding (TBF, 2000). Two double metal crimps were used to secure the attachment leader to the tag, and both sets of double crimps were covered with heat-shrink tubing to minimize potential abrasion along the fish body. Complete tags, including attachment leaders, were constructed prior to embarking on the vessels.

Drag effect of the PSAT

Previous researchers have suggested that the MWT and WC tags are sufficiently small as to not impose a major drag on large marine organisms such as blue marlin and bluefin tuna (Block *et al.*, 1998), although there are few ways to directly measure this effect while the tag is still attached to the fish. The following section describes the experimental calculation of this effect and whether such a force is significant relative to the known energetics of a large pelagic fish.

Any body moving through the water experiences a drag force, which can be either a viscous drag or a pressure drag (or both) depending on several factors such as Reynolds number (which affects the drag coefficient value), the size of the object, and relative velocity. The external attachment nature of the PSAT to a blue marlin inherently results in a drag force to the fish. This drag may constitute an energetic penalty to the fish that

may be significant for smaller fish, although this drag is believed by most researchers

(e.g., Block *et al.*, 1998 and Graves *et al.*, 2001) to be insignificant for large pelagic

species such as adult billfishes.

At the heart of this analysis is an examination of the drag coefficient. Although

there are two components of drag force, resulting from steady or accelerating flow, this

analysis will only focus on the steady component. The steady drag force, measured in

Newtons (N), is calculated as follows:

drag (N) = $\frac{1}{2}*\rho*S*U^2*C_D$,

$$\text{where: } \rho = \text{density of fluid (seawater in kg/m}^3\text{)}$$
$$S = \text{projected or wetted area of object (m}^2\text{)}$$
$$U = \text{relative velocity through the fluid (m/s)}$$
$$C_D = \text{drag coefficient (dimensionless)}[10]$$

This analysis makes several assumptions, all of which are to be considered "worst

case" scenarios. The first concerns ρ; given the varying temperatures evidently

encountered by these tagged fish, the value of 1024 kg/m^3 is used, which corresponds to

the ρ for 34‰ salinity at 20° C (Vogel, 1994). The second concerns S; because the shape

of the PSAT is irregular, the least hydrodynamic solid shape – the sphere – is used as a

proxy. The measurement for calculating the projected surface area of the sphere is from

the widest cross-section point. The third assumption regards the dimensionless drag

coefficient C_D, which is based on the shape, here the sphere, for a value of 0.47. Finally,

for the relative velocity term U, the highest velocity (distance/time) seen among all the

tagged fish in this study is used as a maximum proxy. This was seen in the second fish

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[10] There are two forms of C_D used in scientific literature. The first refers to the total "wetted" area, while the second only refers to the projected surface area, i.e., the forward-facing area of the object.

tagged in 2001, which traveled at an average speed of 1.035 m/s during the days between tagging and tag release.

Finally, power (energy/time) needed to move the tag through the water is the product of force (drag) * velocity (U), resulting in a new equation:

$$power = \frac{1}{2} * \rho * S * U^3 * C_D$$

This power term is in units of Nm/s or joules/s (watts or W). Given these assumptions, the power needed to carry the tag is:

$$power = \frac{1}{2} * 1024 \text{ kg/m}^3 * 0.00159 \text{ m}^2 * (1.044 \text{ m/s})^3 * 0.47$$
$$power = 0.40 \text{ W}$$

However, it should be noted that this 0.40 W estimate is based on the maximum relative velocity value seen in the study; calculating out the minimum relative velocity results in a value of only 0.03 W. The average value over all seven tags is 0.19 W, although this analysis will continue to use the 0.40 W value as a worst-case proxy.

The metabolic power generated by billfishes has never been measured, and calculations for the needed swimming power in watts are therefore based on that of yellowfin tuna (Dewar and Graham 1994). In this paper, the empirical power calculation for locomotion is described:

$$\text{Swimming power} = VO_2 - SVO_2 \text{ (mg O}_2\text{/kg/h)} * (1 \text{ W/kg})/256 \text{ mg O}_2\text{/kg/h} * W_{fish},$$

where: VO_2 = metabolic rate at speed

SVO_2 = standard metabolic rate

W_{fish} = weight of the fish (kg)

The $VO2$ term changes with the swimming speed of the fish, which the Dewar and Graham (1994) study found to range in yellowfin tuna from 300 mg O_2/kg/hr at 25 cm/s

to approximately 650 mg O_2/kg/hr at 100 cm/s. As noted by Bennett and Ruben (1979), the maximum aerobic capacity ($VO_{2\,MAX}$) for most fishes approaches 10 times the SVO_2, allowing a back calculation from the Dewar and Graham (1994) results of this maximum aerobic capacity to arrive at an estimated SVO_2 value of approximately 250 mg O_2/kg/hr for yellowfin tuna.

The swimming power equation was used to calculate upper and lower boundaries for the varying weights of the fish in this study under the assumption that blue marlin have energetic requirements somewhere between these two extremes, although given their overall biology, the lower estimate is the more probable. The results are shown in Figure 5. There are other methods for calculating SVO_2 rates, although subject to error given the differences in shapes and swimming mechanics between yellowfin tuna and blue marlin.

One question that remains is whether there is a body size effect in billfishes with regard to SVO_2 rates. In general, tunas show a mass-specific exponent for SVO_2, indicating that SVO_2 decreases with body mass (e.g., yellowfin: Dewar and Graham, 1994; skipjack: Brill, 1987). Other fishes do not, however; Videler (1993) reports that most fishes have a SVO_2 directly proportional to mass. He suggests that, based in part on the findings of Brett and Groves (1979) who compared total body mass with relative muscle, larger fishes generally have more muscle with an accordingly higher standard metabolic energetic cost. Further study would be needed to clarify whether such a body size effect exists in billfishes.

The results of this brief analysis show that the drag of the PSAT tag, albeit under worst-case assumptions, is a small part of the total cost of swimming. For the smallest

Figure 5. Estimates of swimming power for blue marlin.
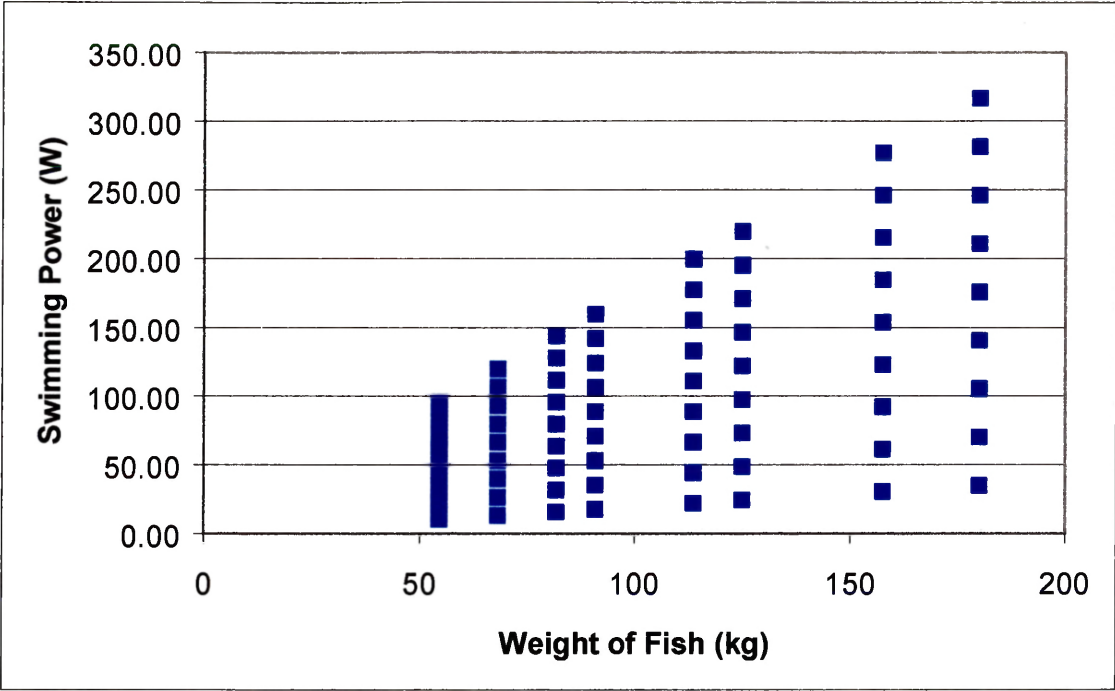
fish under the worst assumptions, the maximum calculated drag would be a 3.75 percent load. The actual value is likely less, although this will not be known without additional research into billfish-specific metabolic rates and processes. However, it is known that the billfish are among the fastest growing teleost fishes, showing a high scope for growth, especially as juveniles. Given the short length of time that these tags were attached to these medium-sized fish, it is likely that some of this scope for growth was instead shunted to counter the energetic drag of the PSAT, but that this energetic shift was not detrimental to the long-term health of the fish.

PSAT Programming

Seven MWT PTT-100 Pop-up Tags (PTT-100) were programmed to take a water temperature measurement (resolution: ± 0.2°C) every hour and store them as an average of two one-hour temperature readings. In addition, an inclinometer value was taken every two minutes. If the tag was inclined at an angle greater than 30 degrees relative to horizontal (i.e., little or no forward movement by the fish), the tag added "1" to "128," the starting value for the tag. If the inclination was less than 30 degrees relative to horizontal (i.e., relatively fast forward movement), the tag subtracted "1" from the value. This resulted in a possible minimum value of 0 and a possible maximum of 255 for the final inclinometer reading. The PTT-100 tag model returned two values for the inclinometer: one pre-release and one post-release.

The WC PAT tag allows the end user to program the tag within several parameters, including measurement intervals, using manufacturer-supplied connectors and the patHost computer program (version 2.06, Wildlife Computers, 2001). The PAT

has several advantages over the PTT-100, including direct pressure for depth (up to 1,000 meters, resolution: 0.5 meters). The PAT allows the tag user to set 12 pressure and temperature (resolution: ± 0.05° C) bins prior to deployment. Readings are taken at user-set intervals and stored as the percent of time that the tag was within each of the 12 pre-set bins. The PAT tag takes light level measurements every minute, and these data are used to calculate a mathematical mid-day time. This derived value is then used to calculate daily position estimates using the WC patTemplate analysis spreadsheet program (rev.6 version, Wildlife Computers, 2001).

The PAT also includes emergency pre-release software that allows the user to program the tags to release early if held at a constant depth for an extended period of time. Finally, and although not part of the tag itself, Wildlife Computers also includes the RC-1500 emergency release mechanism on all tags. This metal device is placed on the attachment leader and automatically severs the leader if the fish (and presumably the tag) descends below a depth of 1,500 meters, thereby eliminating tag crushing as a reason for the tag not to report (WC, 2001).

For this project, both available oceanographic data from published literature and the suggestions of two longline vessel captains were used to develop the data recording parameters. Tag 16122-01 was programmed on July 21, 2001 with a release date of August 25, 2001. Tag 24519-01 was programmed on August 30, 2001 with a release date of October 1, 2001. Based on suggestions from Wildlife Computers to avoid possible transmission conflicts, transmission repetition rates were 59 seconds for tag 16122-01 and 60 seconds for 24519-01. Both tags were programmed to sample depth and temperature every minute, and these values were binned in one-hour segments. The

programmed tag parameters are found in Table 6. For the emergency release software

component, both tags were programmed to release from the fish if it maintained a

constant depth (± 5 meters) for 48 continuous hours. The programming software

generated a report for each tag that listed all of the programmed parameters. Both tag

reports are included as Appendix 2. All the PTT-100 tags were programmed by the

manufacturer to release after five days at large, while the PAT tags were programmed on-

site to release after 32 days.

Upon release from the fish, the tags floated to the surface and transmitted the

stored data to the Argos satellite monitoring system. This system uses receivers placed

on satellites in circular, polar, sun-synchronous orbits at 850 kilometers altitude (Argos,

2001). At least two satellites are in operation at any given time, with the host satellites

operated by the U.S. National Oceanic and Atmospheric Administration (NOAA).

Service Argos, Inc., an Argos subsidiary located in Largo, Maryland, transmits received

data to the end-user via the Internet. Although past PSAT models transmitted data

continuously, recently introduced models now incorporate advanced software so that data

transmission will only occur during times of favorable transmission, i.e., when a satellite

receiver is at a high angle in relation to the floating tag, thus maximizing the quantity of

data that can be transmitted (Paul Howey, MWT, pers. comm.).

Tag Deployment

PSATs were attached to all blue marlin caught by commercial pelagic longline

gear that passed a basic condition standard. To be eligible for tagging a fish must: weigh

more than approximately 100 pounds (45.0 kg) and be in relatively good physical

Table 6. Programmed tag parameters from WC 30-day PAT tags. Bins record data in a "top-down" manner based on the sensitivity of the measuring instrument. Depth has a 0.05 meter precision; therefore bin 2 includes all depths from –0.5 (surface) to 2.5 meters and bin 3 from 2.55 to 5 meters. For depth, any measurement over 1,000 meters would be included in bin 12.

Depth Bins (meters)

Tag Number	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
16122	-1	2.5	5	10	15	25	50	100	250	500	750	1000
24519	-1	2.5	5	10	15	25	50	100	250	500	750	1000

Temperature Bins (degrees Celsius)

Tag Number	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
16122	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	60
24519	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	60

condition, e.g., no large or viscera-related wounds. Although this may have imposed a bias in the analysis of post-release survival, financial prudence dictated that at least a minimal physical standard be met. Of the ten blue marlin caught during this study, all but one passed this minimum standard (the one fish that was rejected arrived at the side of the vessel missing the posterior half of its body due to several large bites, assumed by the captain to be the result of sharks).

Tags were attached using a modified conventional tagging applicator pole from TBF, approximately two meters long. On all three vessels, tagging was done just aft of the hauling station along the rail. Although the F/V *Ark Angel* had a removable section of rail to facilitate bringing fish aboard, reaching the fish on the other two vessels required leaning out over the rail. The average distance between the top of the rail and the fish was approximately one meter. The tags were placed near the base of the dorsal fin about mid-way down the length of the fin. Tagged fish were released as soon as possible after tagging by the standard commercial release protocol of cutting the gangion near the hook and allowing the hook to remain in the fish. Approximate weights were estimated for each tagged fish, and time, date, longline location, hook location, and the surface water temperature recorded immediately after tagging.

One of the factors believed important in the determination of post-release survival is the physical condition of the fish. Previous studies have only described this condition in a simple, descriptive way. A condition index based on the pediatric APGAR scale was therefore developed for this study to describe the state of billfish caught and released. This scale provides a standard against which other fish can be more objectively measured.

As a review, Dr. Virginia Apgar, an anesthesiologist, developed this simple, non-

invasive test in the 1950s. The human infant APGAR scale concerns five areas: 1) Activity (muscle tone), 2) Pulse, 3) Grimace (reflex), 4) Appearance (color), and 5) Respiration. Each of the individual category scores for human infants is measured against a standard scale of responses (pregnancyweekly.com, 2001) to minimize subjectivity. The standard scale then assigns a score of 0-2 within the category, then the category scores totaled for a range of 0-10.

Such a scale for marlins and other billfish would involve an even higher degree of subjectivity. However, such a scale was believed to have some applicability in setting a condition standard. Based on research notes and observations, an "ACESS" score was developed for these fishes: overall Activity, Color, condition of the Eyes, whether the Stomach was everted, and the general State of the body musculature (Table 7). These scores reflect various forms of trauma possible after interaction with the longline gear.

Low scores may not necessarily be fatal; marlins, for example, are known to be able to evert their stomachs to rid them of foreign matter, and then apparently swallow them back without ill effect (pers. obs.). Lacerations are also known to occur even without contact with fishing gear (e.g., bites from cookie cutter sharks, *Isistius* sp.), and healed scars on many billfish indicate that such trauma is not fatal. Although not comprehensive, one of the of the prime considerations in developing this scale was the need to be able to quickly assess the condition of the fish during the extremely short period of time between tagging and subsequent release.

Table 7. ACESS score criteria. Numerals 0-2 indicate the number of points assigned to each condition in each of the five categories, for a total score ranging from 0-10.

Category	0	1	2
Activity	Inactive	Slightly moving	Very active
Color	Grey	Blue-grey	Bright blue
Eye status	Both eyes lacerated	One eye lacerated	Both eyes intact
Stomach eversion	Everted and lacerated	Everted, no lacerations	Not everted
State of body musculature	Obvious deep lacerations	Some lacerations, none deep	No obvious lacerations

Analyses

The seven deployed PT tags were programmed to release five days after activation. Following release, the positively buoyant tags floated to the surface and transmitted data to satellites in the Argos satellite system. Position information and sections of the temperature and inclinometer data were captured with each satellite pass, transmitted to a ground station, and ultimately to VIMS via the Internet.

Data were analyzed to determine net movement from the point of release, which was assumed to be roughly equivalent to the point of first good Argos satellite contact.[11] Because the tags cannot record detailed horizontal tracks of these fish and do not take into account vertical movements, all distances are described as "minimum straight-line distances," or the minimum possible distance traveled. These distances are calculated by comparing the location at which the fish was tagged with the location of the first transmission by the PSAT to the Argos satellite system. Location coordinates were recorded at tagging from the GPS receiver in each vessel's wheelhouse. Because of the orbital pattern of the Argos satellite receivers, the resolution of the transmission location varies with the altitude and attitude of the satellite in relation to the floating tag. Distances were calculated with the PROGRAM INVERSE computer program, version 2.0 (NGS, 1975; modified by O. Mortiz, NMFS SEFSC, 1999).

The two 30-day archival PSATs were programmed to release after 32 days in order to allow for possible delays in tagging and to allow a full 30 days of data collection.

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[11] Argos satellites calculate the location of the transmitter through an analysis of the Doppler shift in transmissions. Generally, four transmissions within a given pass of a satellite, two approaching the transmitter and two moving away, are needed for the three highest degrees of accuracy. Regardless of the number of transmissions, the Argos service categorizes the accuracy of the location estimate into seven categories: 3 ($\leq$150m), 2 (<350m), 1 (<1,000m), A and B (no accuracy estimate), 0 (> 1,000m), and Z (invalid location). For this project, only positions with accuracy scores of 1,2, or 3 were used to calculate minimum straight line distances.

Post-release tag behavior and data transmission are identical to that of the PT tags. Data from these tags were supplied from Argos in hexadecimal format, which were changed to standard text files before using them as input in the WC analysis programs PatDecoder.5 and patTemplate. Light level data was analyzed for longitude using the patTemplate program. Similar to the MWT 5-day tags, the point of the first satellite data transmission was used as a proxy for determining minimum straight-line distance.

RESULTS

Nine PSATs were deployed on blue marlin during the 2000 and 2001 field seasons (Table 8). These deployments were made during six trips on four vessels, ranging from one to eleven fishing days each, off Bermuda, North Carolina, and Florida. On these trips, seven PTT-100 PT and two PAT tags were attached to blue marlin. In addition, 25 conventional spaghetti tags were deployed on various billfish and swordfish (Table 9). Seven of the nine deployed PSATs returned data, although none of the conventional tags have been returned to date.

Longlining Trips

A summary of the longline trips during 2000 and 2001 is included in Table 10. Because of the small size of the longline vessels (and the fact that a crewmember did not show up for the first trip in Bermuda), I served as a full crewmember for all trips with the exception of the trip in July 2001. Target species were nominally yellowfin tuna (*Thunnus albacares*) and swordfish, with gear deployments varying between day and night sets. Most were relatively shallow sets. The combination of leaders and buoy drops resulted in estimated maximum hook depths of 20 to 35 fathoms. Estimated depths have up to an approximately 10 fathom variance due to sagging of the mainline between

Table 8. PSAT tagging summary. Non-reporting tags are in bolded type.

Year	Tag number	Soak time (hours)	Approximate weight of fish in pounds (kilograms)	ACESS Score	Did tag report?
2000	16122	11	200 (90.9 kg)	10	Yes
2000	24029	12	325 (146.3 kg)	10	Yes
2000	**24519**	**13**	**250 (113.6 kg)**	**10**	**No**
2000	24520	14	180 (81.8 kg)	8	Yes
2000	24522	16	150 (68.2 kg)	9	Yes
2000	**24523**	**19**	**275 (125 kg)**	**8**	**No**
2000	24527	9	120 (54.5 kg)	10	Yes
2001	16122	6	400 (180 kg)	10	Yes
2001	24519	35	350 (157.5 kg)	9	Yes

Table 9. Conventional tagging during study. These tags are also called "streamer" or "spaghetti" tags due to their shape and were provided by both NMFS and TBF. All nine blue marlin tagged with a PSAT tag during this study also received a conventional tag in case of eventual recapture. All swordfish tagged were juveniles.

Year	Vessel Name	Blue Marlin Tagged	Sailfish Tagged	White Marlin Tagged	Swordfish Tagged
2000	F/V *Ark Angel*	1	0	3	1
2000	F/V *Deliverance*	0	1	0	0
2000	F/V *Triple Threat*	6	3	0	5
2001	F/V *Carol Ann*	1	0	3	0
2001	F/V *Triple Threat*	1	2	1	6
	Total	**9**	**6**	**7**	**12**

Table 10. Summary data from longline fishing trips conducted during study. Due to factors such as broken and tangled leaders, breaks in the mainline, and weather difficulties, counts of total deployed hooks for each set of the gear varied in precision. Reported values are estimates based on a count of the number of hooks set and hauled and the number reported by the respective vessel captain.

Vessel Name	Month and Year	Approximate Location	Total Number of Hooks Deployed	Number of Blue Marlin Caught	Number of Blue Marlin Tagged
F/V *Ark Angel*	July 2000	Argus Bank, Bermuda	~1,050 (~350 *3 sets)	1	1
F/V *Deliverance*	August 2000	Outer Banks, North Carolina	~2,000 (~500*4 sets)	0	0
F/V *Triple Threat*	September 2000	North Florida Straits, Florida	~5,600 (~800*7 sets in 2 trips)	6	6
F/V *Carol Ann*	July 2001	Outer Banks, North Carolina to Eastern Shore, Virginia	~5,120 (17 total sets of varying length)	1	1
F/V *Triple Threat*	August 2001	North Florida Straits, Florida	~1,200 (~200*6 sets)	0	0
F/V *Triple Threat*	September 2001	North Florida Straits to Cape Hattaras, North Carolina	~1,460 (460+~500*2 sets)	2	1
Total			**~16,430**	**10**	**9**

buoys and vertical movement due to currents or other physical oceanographic conditions

(David Kolesar, former captain of F/V *Triple Threat*, pers. comm.). None of the vessels

used a line-thrower or other setting device that would cause the line to fish deeper in the

water column.

The blue marlin catch during these trips was very low for both the season and the

location. Of the four trips in 2000, the average catch-per-unit-of-effort (CPUE)[12] for blue

marlin was approximately 0.08 fish per 100 hooks (7 blue marlin/8,650 estimated total

hooks). For all billfish, excluding swordfish, the CPUE for was 0.17 (7 released blue

marlin, 4 white marlin, and 5 sailfish/8,650 estimated total hooks). This value is

comparable to the reported billfish CPUE of 0.12 for the NMFS southeast statistical

region for the third quarter of 1998 (Cramer, 2000). For the three trips in 2001, the

CPUEs were 0.04 for blue marlin (3 blue marlin/7,780 estimated total hooks) and 0.18 for

all billfish (3 blue marlin, 8 white marlin, and 3 sailfish /7,780 estimated total hooks).

There was little interference between PSAT tagging procedures and the normal

longlining operations. In all cases, the captain allowed the crew approximately 30

minutes between wake-up and haulback. This was usually sufficient time to both activate

and test the tags prior to each day's operations, as well as prepare the NMFS spaghetti

tags on a second tagging stick (the use of a second tag applicator made the double tagging

of each fish much faster). Both tagging sticks were loaded and kept within close

proximity of the haulback station. Each individual tagging took less than ten minutes

from the point of recognizing the fish as a blue marlin to actual release. Because many of

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[12] CPUE values for longlining are in units of catch per 100 hooks, e.g., a catch of five sailfish over a 1,000 hook set would calculate out to a CPUE of 0.05.

these same actions would have been done for a normal billfish release even without PSAT tagging, the tagging operations did not greatly interfere with normal fishing activity.

The conditions of the individual fish were evaluated using the ACESS scale. Based on a 10-point maximum, the blue marlin tagged during this research – excluding the one partial blue marlin – ranged from 8 to 10 (see Table 8). Of the fish that received a score of less than 10, the primary factor was color, followed by body musculature lacerations. Although these vessels used both "J" and circle hooks in their gear, all the blue marlin caught during this study were hooked in the jaw.

The term "soak time" usually refers to the approximate length of time that the baited hooks were in the water, reflecting the actual "fishing time" of the whole set. This research, however, needed a more precise estimate of time potentially on the hook. Therefore, during these trips, the location of each marlin on the longline set was used to calculate an approximate (± 1 hour) soak time for each fish and particular hook rather than for the entire set.

PSAT Performance

The two PSAT models used for this study reflect the rapidly developing technology in this field. Each tag model recorded different types and amounts of data. These differences presented an apparent trade-off between the resolution of the data and the probability of recovering (i.e., receiving uncorrupted) all the data recorded. The 5-day tags stored far fewer data points, but cleanly transmitted all of them. In contrast, the 30-day tags captured far more detailed data, yet only transmitted a fraction of them

because of technological constraints such as battery strength.

The 30-day tags recorded data into one-hour bins, which were then transmitted via satellite. In addition to the battery limitations, the sheer volume of data resulted in many of these messages becoming corrupted during transmission. Although a representative of the tag manufacturer described the amount of data returned from these two tags as "fairly clean" (Melinda Braun, WC, pers. comm.), less than half of the 744 possible hourly bins were present and uncorrupted after the final processing (46.5% for tag 24519-01 and 47.6% for tag 16122-01). Of the reported bins that were uncorrupted, there was a fairly consistent reporting across hours of the day, with an average of 14.75 records (range: 6-23) per hour of the day for tag 16122-01 and 14.42 (range: 8-21) for tag 24519-01 (Figure 6).

Net Displacement

The first reporting location of each tag was used to calculate a distance of net movement from the point of release. These distances are listed in Table 11 and shown in Figure 7. Movement patterns varied between fish. The Bermuda release moved away from the islands in a southeasterly direction. The fish tagged in Florida during 2000 showed a different dispersal pattern that roughly corresponds to the movement of the Gulf Stream as it exits the Florida Straits. The fish with the 30-day tags also undertook significant movements, one to the north almost to the Grand Banks and the other to the northeast toward the central North Atlantic.

The WC PAT tag has a separate light level measurement sensor, and allows for the direct calculation of latitude and longitude prior to the release of the tag at the end of

Figure 6. Hourly bin reporting of the WC PAT tags by hour of day. Only uncorrupted

data are represented. Midnight is "0:00."
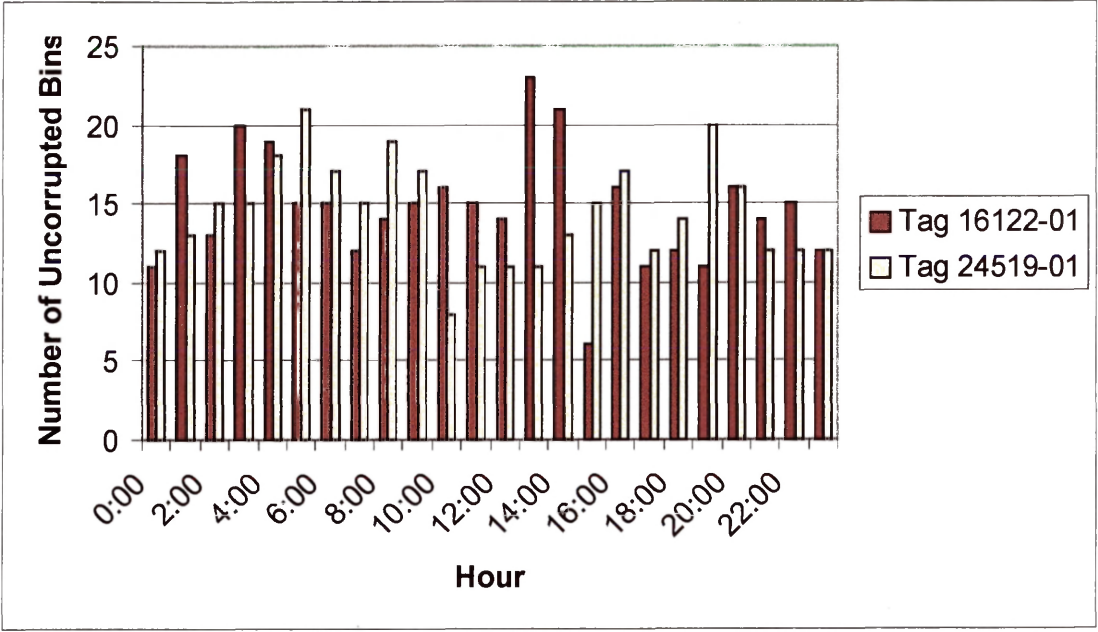
Table 11. Tagged fish locations and minimum straight-line displacement distances. Distances are in nautical miles (nm), kilometers (km) are in parentheses. (Distance per day for 5-day tags is calculated as x distance/122 hours*24 hours/day = y distance/day, distance for 30-day tags is calculated as x distance/31 days that tag was on fish = y distance/day.)

Tag Number	Release Location	Transmission Location	Minimum Straight-line Distance: nm (km)	Minimum Straight-line Distance per 24-hour day: nm (km)
16122	64.99°W, 31.99°N	64.10°W, 30.35°N	107.8 (199.7)	21.2 (39.3)
24520	79.48°W, 28.59°N	78.37°W, 29.45°N	77.0 (142.6)	15.1 (28.0)
24522	79.41°W, 28.58°N	77.48°W, 28.91°N	103.7 (192.0)	20.4 (37.8)
24527	79.54°W, 28.69°N	78.09°W, 29.77°N	100.0 (185.2)	19.7 (36.4)
24029	79.16°W, 28.64°N	79.48°W, 30.81°N	130.8 (242.2)	25.7 (47.6)
16122-01	74.62°W, 36.79°N	62.10°W, 35.96°N	~752.7 (~1393.9)	~24.3 (~45.0)
24519-01	74.61°W, 34.67°N	50.08°W, 40.30°N	~1510.2 (~2796.6)	~48.7 (~90.2)

Figure 7. Horizontal displacement of PSAT tags. Nautical mile distances are in

parentheses next to the individual tag number. Note that tag numbers

16122-01 and 24519-01 were WC PAT tags with 30-day deployment periods.

Labels on map:

CANADA

New York

Norfolk

Jacksonville

Gulf of Mexico

THE BAHAMAS

CUBA

JAMAICA

HAITI

DOM. REP.

Caribbean Sea

24519-01 (1510.2)

16122-01 (752.7)

BERMUDA

16122-00 (107.8)

24029-00 (130.8)

24527-00 (100.0)

24520-00 (77.0)

24522-00 (103.7)
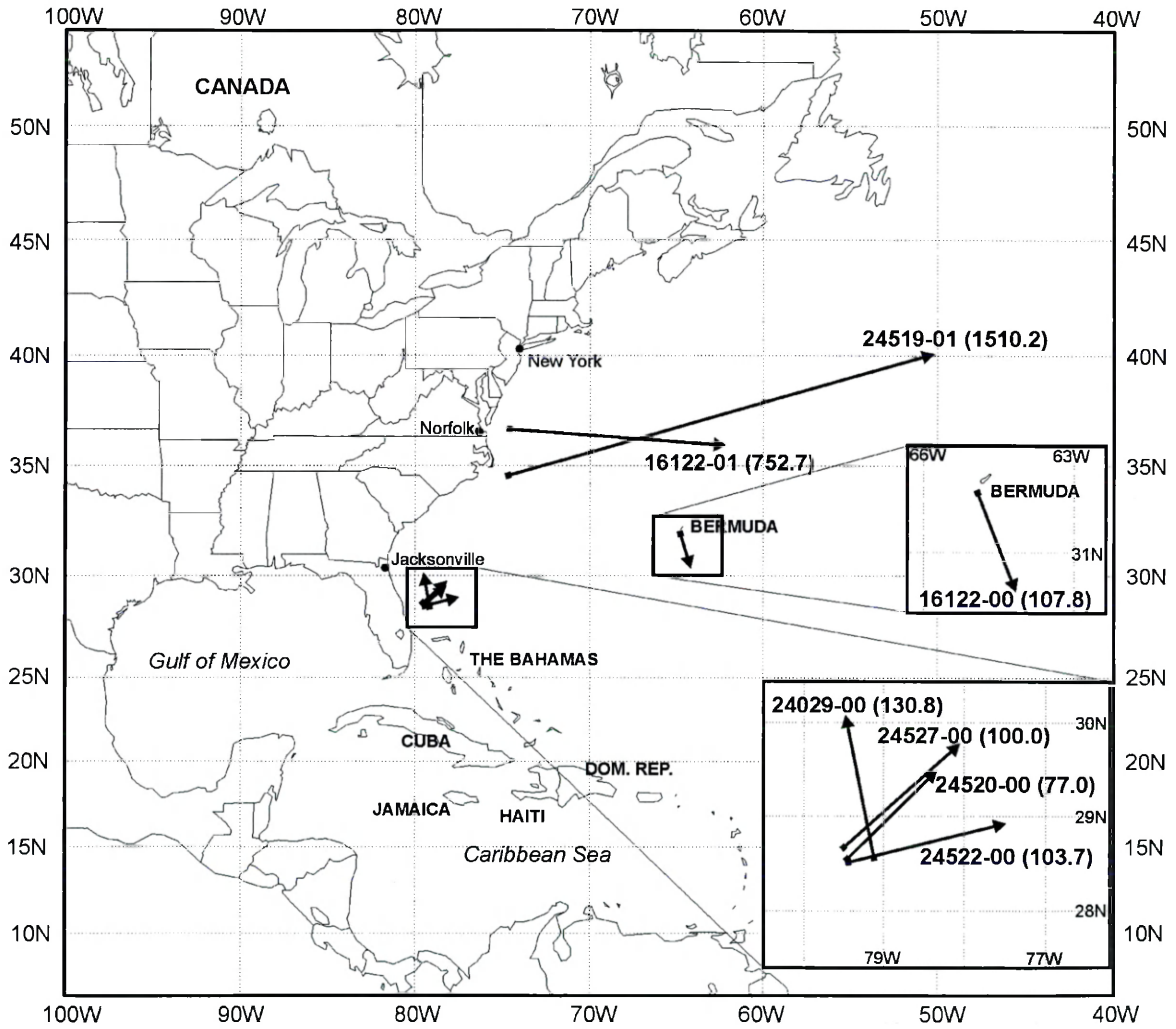
the 30-day data-recording period. Although the estimated positions for the two WC tags have a large error due to the proximity to the summer solstice, especially for latitude, the resulting longitude positions generally support the straight-line direction estimates regarding direction of movement (see Figure 8 for the estimated positions of the two WC tags during the deployment period).

Following release, the tags continue to transmit data for several days until the battery power is depleted. Many of these transmissions are duplicate data segments that are subsequently removed during analysis. However, the receiving Argos satellite continues to include a position estimate of the floating tags, making them in effect drifting position data loggers. Argos gives the latitude and longitude of the free-floating PSAT in the same manner, and with the same accuracy estimates, as the original data transmissions. Three of the PTT-100 tags deployed in Florida during 2000 became entrained in a persistent gyre formation north of the Bahamas in an area locally known for its high concentration of tunas and billfish, while the fourth entered the Gulf Stream and proceeded northward (Figure 9).

Depth and Temperature

The temperature data of the 5-day tags indicated numerous vertical migrations into colder water for each fish, demonstrated by the corresponding shifts in recorded temperature. Combined results are shown in Figure 10. For each tag, the maximum temperature was equivalent to or slightly greater than the sea surface temperature (SST) recorded for that day at liberty by available SeaWIFS satellite imagery data (SST Satellite Image Archive, University of Rhode Island, 2001). The slightly higher temperature is

Figure 8. Estimated positions from WC PAT (30-day) tag number 16122-01. Position

calculations from WC patTemplate program (rev6 version) are based on light level data

taken by the tags during deployment. (Graphic from Carlos Rivera, NMFS, pers. comm.)
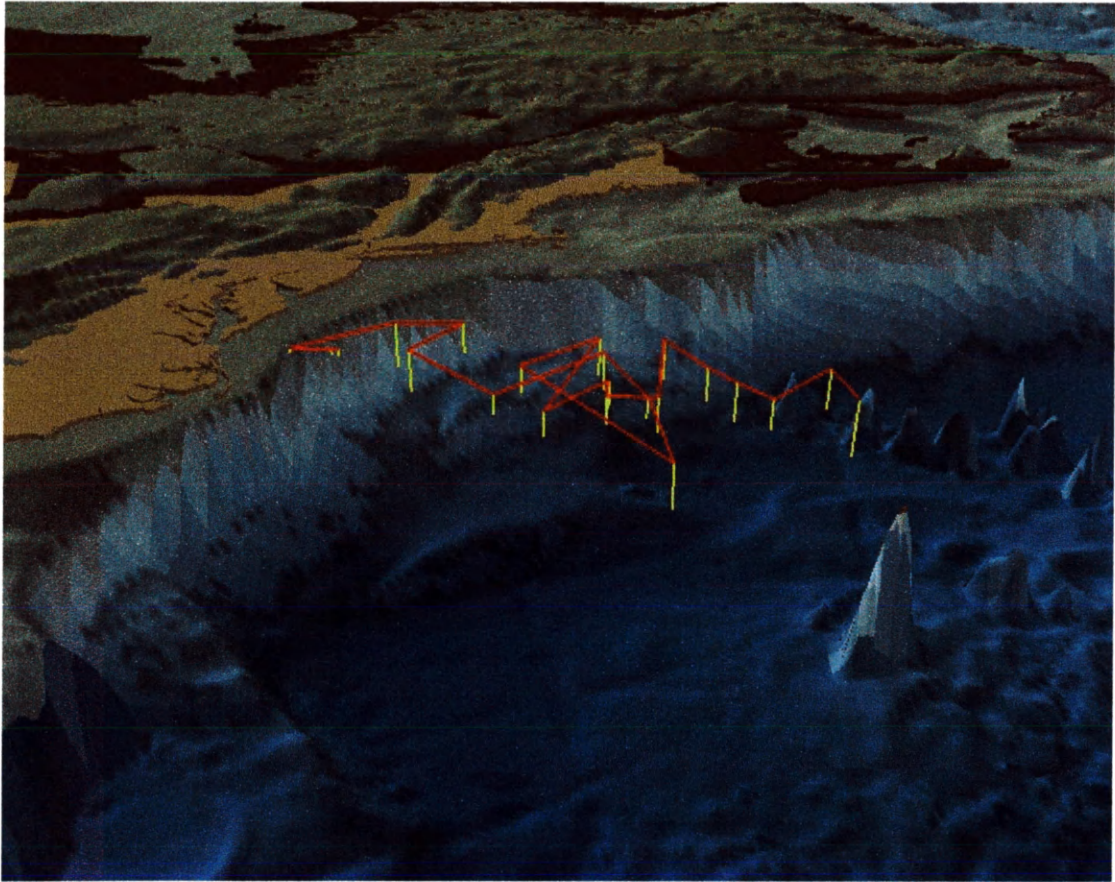
Figure 9. Drifting tag tracks of MWT PTT-100 (5-day) tags.

The first dot of each color is the location of initial release from fish.

Tag 24029: September 25 - October 22

Tag 16122: July 14 - August 13

Tag 24520: September 16 - October 20

Tag 24522: September 16 - October 17

Tag 24527: September 23 - October 21

Figure 10. Vertical displacement in 5-day tags. Black bars indicate hours of darkness. Tag numbers 24520 and 24522 are included within the same graph due to deployment of both tags within two hours. Numbers on the x-axis refer to the two-hour bin number. Temperatures are in degrees Celsius.

Tag 16122

Tag 24520

Tag 24522

Tag 24527

Tag 24029

likely an artifact due to the 5-day tag's black coloration, which could allow it to absorb heat while at the surface. The tracks also indicated in every fish a downward movement behavior immediately following release exhibited by other acoustic tracking studies (e.g., Brill *et al.*, 1993; Holland *et al.*, 1990).

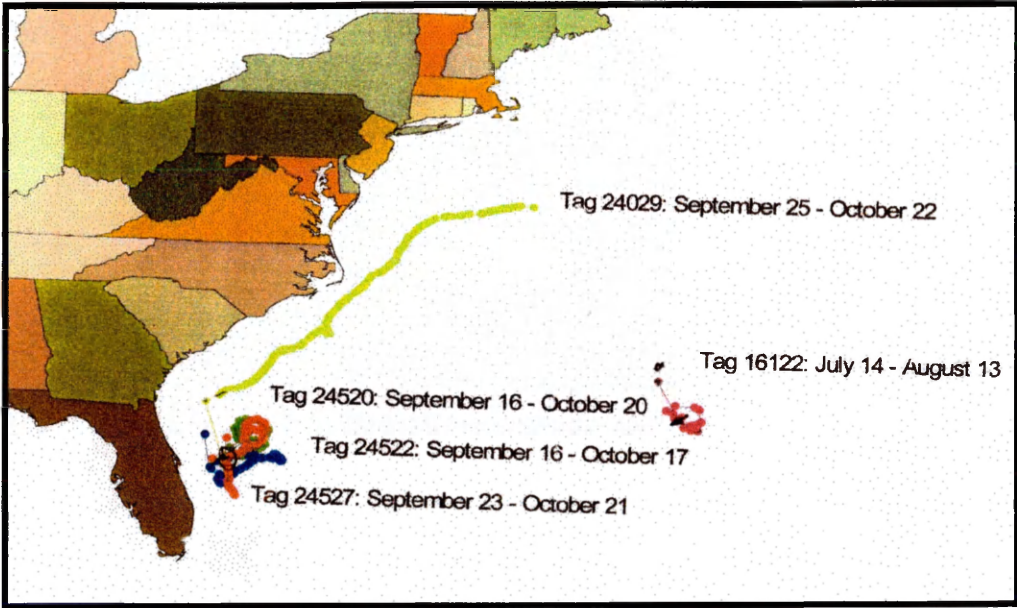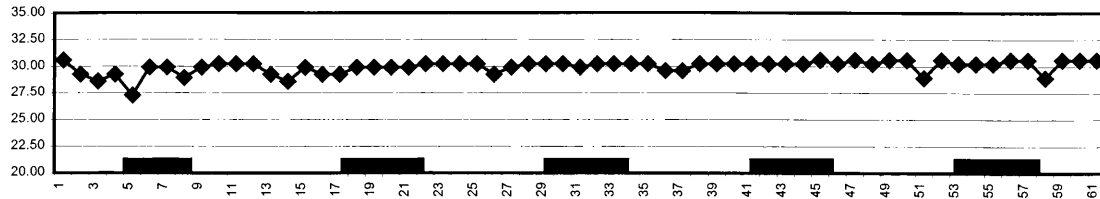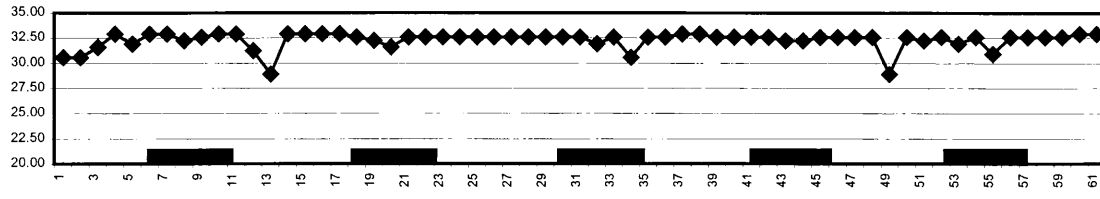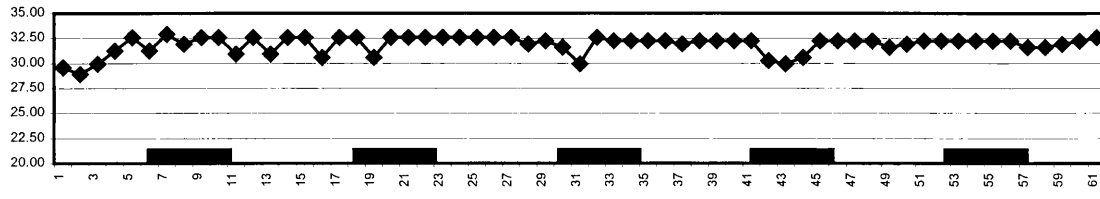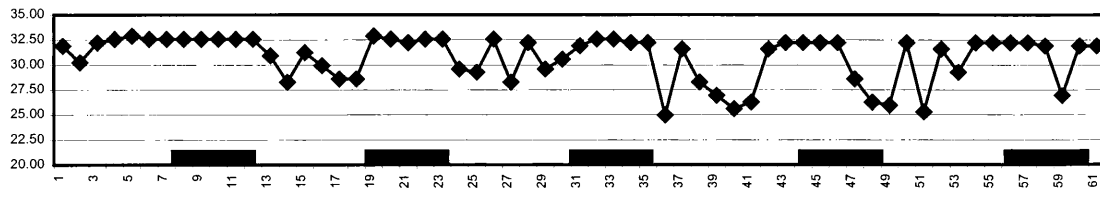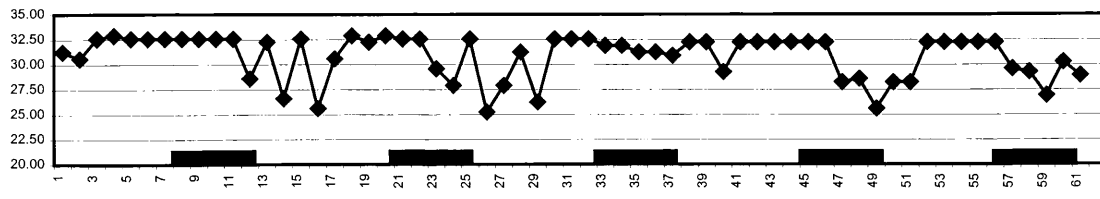The temperature data indicate several vertical movements for each fish, as well as differences between individuals. The values reported by the 5-day tag on the Bermuda fish stayed within two degrees C (28.58-30.58° C) for 98.6% of the time. The 5-day tags on the four Florida fish exhibited far more vertical behavior, but even these reported temperature values remained within a 6.5 degrees C range. All four fish also displayed vertical movements during the morning hours, especially the two with tags 24522-00 and 24029-00. There was also a significant difference in temperature readings between day and night periods. For the Florida fish in 2000 (because of the different temperature regimes between Florida and Bermuda, tag 16122-00 was excluded from this part of the analysis), there was a significant difference between night and both day and a composite dawn/dusk period of one hour pre- and post-sunrise or sunset (p=0.0003, 2 d.f., one-way ANOVA). Removing the overlapping dawn/dusk periods resulted in a stronger statistical difference between day and night (p=0.0002, 1 d.f.).

Interpreting the MWT 5-day tag data is challenging due to the necessary inference of depth from temperature. However, if one defines the surface as the top four temperature readings in a fashion similar to the 30-day tag data, fish were near the surface for a majority of the time (Figure 11). Further analyses of the temperature data suggest that these fish were at or near the surface during daylight hours for 73.3% of the readings (range among all five tags: 61.1 to 83.3%) and during night, near the surface for 76.0% of

Figure 11. Time at temperature histogram for MWT PTT-100 (5-day) tags.
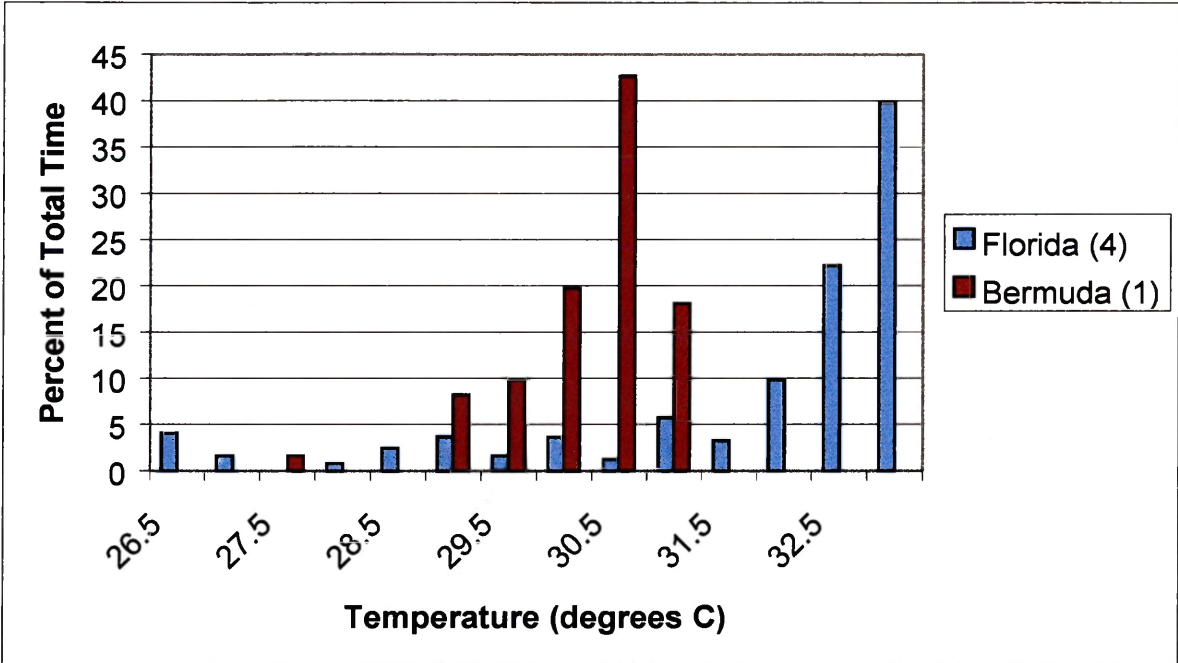
the readings (range: 56.0 to 92.0%).

The 30-day WC PAT tags provide a time signal with each hour-long temperature and depth bin, allowing for a more precise calculation of time of day against the resulting data. The vast majority of time for these two fish was spent within the upper five meters of the water column (65.4% for tag 16122-01 and 81.5% for tag 24519-01) (see Figure 12). This pattern is strongly supported by the accompanying temperature data. The apparent shift toward warmer water in tag 24519 is likely due to the warmer surface temperatures off Florida rather than a behavioral difference. These two tags also recorded a broader range of temperatures (tag 16122-01: 29.6-17.8 °C and tag 24519-01: 30.6-16.6 °C) and depths (tag 16122-01: 0-192 m and tag 24519-01: 0-268 m) than the fish from 2000. Examination of the maximum depth values by hour of day suggests a correlation between movement at depth and daylight (Figure 13).

The results from the two 30-day tags clearly indicate short-term diving behavior. Each hour-long bin includes both the maximum and minimum depths for the hour interval as well as the percentage of time spent within each predetermined depth bin. For example, during the hour between 10:00 and 11:00 a.m. on 25 July, tag 16122-01 reported the following data: a maximum depth of 28 m, a minimum depth of 0 m, and time at depth data (as a fraction of the hour-long bin) for the six depth bins encompassing these two depth ranges. Based on these percentages, the fish during this hour spent 42 minutes between 0 and 2.5 m, only 72 seconds between 3 and 15 m, and almost 17 minutes between 15.5 and 28 m.

Figure 12. Histogram of time at depth for WC PAT (30-day) tags.
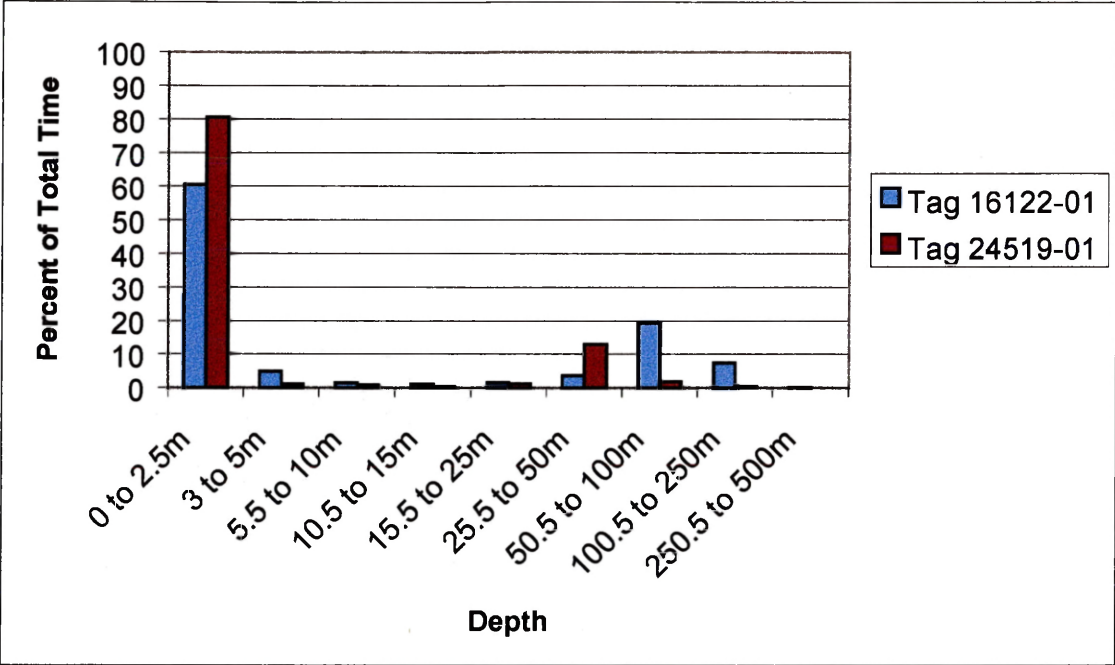
Figure 13. Maximum recorded depths as a function of hour past local

midnight (e.g., "15" equals 3:00 p.m.). Hour scale ranges from 0 to 23.

Tag 16122-01

Hour Past Local Midnight

Tag 24519-01

Hour Past Local Midnight

Forward Movement and Inclinometer Data

The MWT 5-day tags report two average inclinometer values that can be used to test for forward movement by the fish. The inclinometer values for each reporting PSAT tag indicated forward movement for an average of 47.25% of the five day tagged period (range: 46.77-47.74%) (Table 12). These values are consistent with both Graves *et al.* (2002), who reported forward movement more than 40% of the tagging duration and with the net displacement data. Inclinometer values following release were all consistent with the tag floating in an upright position.

Other Tagging

Almost all the live billfish caught on the longline gear during this research, including several undersized swordfish, were tagged with either a NMFS or TBF streamer tag and released, although some fish broke the leader prior to tagging. Depending on the provider of the streamer tag, the tagging information was sent to either The Billfish Foundation (Fort Lauderdale, Florida) or the NMFS Cooperative Tagging Center at the NMFS Southeast Fisheries Science Center (Miami, Florida) following the completion of each trip. A summary of the tagging for non-blue marlin bycatch is included in Table 9.

Table 12. Pre- and post-release inclinometer readings from five reporting MWT PTT-100 tags deployed in 2000. The "percent of time less than 30 degrees above horizontal" indicates the percentage of time that the fish was actively moving forward at enough velocity to depress the tag from its normal vertical position.

Tag Number	Pre-release Inclinometer Value	Percent of Time Less Than 30 Degrees above Horizontal	Post-release Inclinometer Value
16122	245	46.77	254
24520	245	46.77	254
24522	229	47.72	254
24527	227	47.29	255
24029	223	47.74	254

DISCUSSION

Deployment of nine PSATs in this project indicates that commercial longline vessels are adequate deployment platforms for PSAT tagging, and demonstrated that tags can be deployed with minimal interference on normal deck operations. The tag return data of seven of nine tags with "normal" movement patterns also provide strong evidence that blue marlin released from commercial pelagic longline gear do survive if promptly released using the minimum precautionary handling techniques required by the NMFS billfish regulations. The knowledge that longline-caught fish can survive release supports the conservation benefit of the live release management measures implemented by ICCAT in recent years. The additional detail of daily movements captured by the PSAT tag data increases our knowledge of the overall behavior of blue marlin in terms of habitat preferences, movement patterns, and possible feeding strategies. All of these factors may be used for better stock assessments and, possibly, for the development of strategies or technologies to reduce billfish bycatch in the longline fishery.

Behavior

Both PSAT tag models demonstrated vertical movements by blue marlin either through temperature or pressure (depth) changes. All fish initially moved downward

after release from the longline for several hours before returning to shallower depths, a movement pattern consistent with the acoustic observations of Holland *et al.* (1990). However, short-term movement inferences are difficult to make from the 5-day PSAT tag data. Each temperature reading for the 5-day tags was taken as an average of two one-hour interval "snapshot" measurements, compared with the hour-long time-at-depth profiles from the 30-day tags based on measurements taken every two minutes. The 5-day tag data may simply not capture the shorter duration vertical movements that were seen with the 30-day tags.

The WC 30-day tags recorded temperature, depth (via pressure), and light levels. The two fish tagged with the 30-day tags exhibited a variety of behaviors. Both animals exhibited a preference for water less than 100 meters in depth, with a large portion of their time spent within 50 meters of the surface. This may relate to the inferred sight feeding strategies of this species on other epipelagic (0-100 m depth) species such as dolphin (*Coryphaena hippurus*) and small tunas such as skipjack (*Katsuwonus pelamis*). However, the 2001 PSAT data also indicate that blue marlin frequently dive to depths of 150 meters, and one fish was recorded diving to a depth of 268 meters. Plotting depth against the hour of the day for both 30-day tags indicates that these fish were shallower at night. While the PSAT tags do not record actual feeding events, the depth preference may reflect diurnal behavior related to mesopelagic (200-1,000 m depth) feeding. Previous stomach content analyses of Pacific blue marlin have found deep-water fishes such as the squirrelfish (*Holocentrus laeteoguttatus*), gempylids, and bigeye tuna, while Atlantic studies have found swordfish, bigeye tuna, and the bioluminescent "swallower" fish (*Pseudoscopelus* spp.) (Krumholtz and de Sylva, 1958 and Erdman, 1962). Many of

these prey fishes are also known or believed to have diurnal vertical movements.

All of the tagged fish moved significant distances from the tagging location, although movement patterns varied among individuals. The blue marlin tagged and released off Bermuda moved away from the islands in a southeasterly direction. This is generally consistent with the results of Graves *et al.* (2002) who reported that the eight tagged blue marlin moved away from the islands in all directions. The fish tagged in Florida during 2000 showed a different pattern that roughly corresponds to the dispersing movement of the Gulf Stream as it exits the Florida Straits. Of the two fish tagged in 2001, one (tag 16122-01) moved northeast toward the central north Atlantic, while the other (tag 24519-01) moved north toward the Grand Banks. Tagged fish in this study moved at an average of 25.0 nm/day (range: 15.1 to 48.7), which is slightly faster, but similar to the values reported in Graves *et al.* (2001). In that study of recreationally caught blue marlin, tagged fish moved at an average rate of 17.6 nm/day (range: 10.9 to 26.4). Both studies are consistent with the swimming velocities of 1-2 nm/hour reported in the acoustic tracking of Pacific blue marlin by Holland *et al.* (1990).

Blue marlin tagged off Florida, North Carolina, and Virginia all moved north to northeast rather than south, as might be expected during fall migrations of this species to the warmer waters of the Caribbean Sea. The 2001 season fish with tag 16122-01 was near the Grand Banks when the tag released, perhaps as a result of becoming entrained within a warm-core ring coming off the Gulf Stream. (Due to the partial coverage of the SeaWIFS satellite imagery, the sea surface temperatures near the tag release location near the Grand Banks could not be verified.) The other 30-day tag from 2001 released in the central North Atlantic; although unexpected, the presence of blue marlin in this area

(from bycatch records) is consistent both from a recent bluefin tuna longline survey (Brian Luckhurst, Bermuda Division of Fisheries and Molly Lutcavage, New England Aquarium, pers. comm.) and long-term (1960s to present) ICCAT SCRS records of longline catches by species (SCRS, 2001). Other research has shown that swordfish also move into the north Central Atlantic after leaving waters off the southeast coast of the United States (Sedberry and Loefer, 2001).

Commercial Vessels as PSAT Platforms

This project represents the first deployment of PSATs on blue marlin from commercial platforms. Although the Japan National Far Seas Research Institute (NFSRI) deployed two PSAT tags during 2000 off the R/V *Shoyo-Maru*, this ship is a combination research and training vessel, not a commercial longliner. With only two tags deployed (of which one tag reported), there are insufficient data in the NFSRI project to estimate post-release survival. It is also inappropriate to compare deployment platforms as this ship was not a commercial longline vessel.

In contrast, this study deployed tags from commercial longline vessels during normal fishing operations. Specifically, the fish were never removed from the water nor retained any longer than absolutely necessary to attach the PSAT tag. The hooks were left in place as required by Amendment 1 to the Billfish FMP, thereby minimizing potential stress at the side of the vessel. Most importantly, this research (with the possible exception of the trip on the F/V *Carol Ann*) did not interfere in any way with normal commercial longline operations, thereby minimizing potential criticism that the conditions were not an accurate representation of normal commercial fishing procedures.

Overall, the longline trips for this project did not encounter large numbers of billfish. The 2001 trip on the F/V *Carol Ann* was chartered by NMFS to specifically fish in a manner maximizing potential blue marlin bycatch. During this trip, the vessel set gear within the grounds frequented by the Outer Banks, North Carolina, recreational charter fleet, which was catching blue marlin, albeit with a very different gear type. The captain on this trip also tried several different combinations of gear (i.e., setting shallow, deep, or a combination of the two), as well as varying the time of set (i.e., daylight, night, and dawn/dusk) and presence or absence of lightsticks on nighttime sets.

It is also worth noting that, at the request of the vessel owner, both captains of the vessel F/V *Triple Threat* made a conscious decision to fish in an area of high billfish bycatch – locally called the "Marlin Hole." This should have resulted in a higher billfish bycatch than is normal for the vessels that fish the mid-Florida offshore waters (David Kolesar, former captain of F/V *Triple Threat*, pers. comm.). This was not the case, however, and both the captains that fished this location for the project were surprised at the lack of billfish, especially blue marlin, bycatch on the longline. This project even obtained a NMFS Exempted Fishing Permit (HMS-EFP-01-004) to fish within the area along the east coast of Florida now closed to all commercial longlining. Despite expectations, longlining in this protected area produced few billfish and no blue marlin.

The longline trips had several non-target species of note. The first trip in Bermuda caught several gempylids, both Roudi escolar (*Promethicthys prometheus*) and oilfish (*Ruvettus pristiosus*) (Smith-Vaniz et al., 1999), and blue sharks (*Prionace glaucus*), as well as four white marlin (one dead on retrieval) and very small numbers of other species. A different variety of species interacted with the gear on the second trip off

the Outer Banks of North Carolina, including a large leatherback sea turtle (*Dermochelys coriacea*) of approximately seven feet total length, a sailfish, a bigeye thresher shark (*Alopias superciliosus*), and a pilot whale (*Globicephala* sp.) found entangled in the mainline. The sailfish was tagged with a TBF tag and released. Both the leatherback and the pilot whale were also released alive, although the pilot whale had several lacerations near the flukes as a result of contact with the mainline. The third and fourth trips off Florida set the gear in the relatively warmer waters of the Gulf Stream as it exited the Florida Straits. As a result, the species interactions were slightly different. The largest bycatch (assuming swordfish and yellowfin tuna were both target species) by number was of small oilfish, followed closely by juvenile swordfish. Other bycatch species included several sailfish, several dolphinfish, three great barracuda (*Sphyraena barracuda*), a leatherback sea turtle, a blackfin tuna (*Thunnus atlanticus*), and a large oarfish (*Regalecus glesne*) of approximately 12 feet total length. This oarfish specimen was subsequently donated to the Harbor Branch Oceanographic Institution in Fort Pierce, Florida (Sandra Brooke, HBOI, pers. comm.). The trips in 2001 on the F/V *Carol Ann* and the F/V *Triple Threat* resulted in bycatch similar to the 2000 longlining, although with a higher catch rate of white marlin. As expected, fishing within the Florida closed area on the F/V *Triple Threat* also resulted in a very high (more than 20 per set) bycatch of juvenile swordfish.

Billfish Survival

Seven of the nine deployed tags in this project reported data. The two non-reporting tags may be the result of mortality or other factors, including tag malfunction or

mechanical damage to the tag. However, this minimum survival rate of 78% compares favorably with 89% (8 of 9 reporting PSAT tags) reported for recreationally caught blue marlin by Graves *et al.* (2002). The relatively small number of deployed tags limits the general applicability of these results given the diversity of oceanographic conditions, gear modifications, and seasons that may affect catch and survival rates. The general conclusions of post-release survival by blue marlin are therefore essentially qualitative in nature.

All tagged fish appeared healthy at the time of release, with ACESS condition index scores from 8-10. The results of this index also indicate that the majority of billfish caught by the longline were in relatively good condition, with 94% of the tagged billfish having scores of 8 or higher. The weight of the individual fish did not correlate with tag reporting, nor did the physical condition of the fish. The fish in 2000 that received tag 24519-00 was jaw hooked, in good condition, and actively swam away from the vessel, while the fish that received tag 24523-00 was also jaw hooked and swam away from the vessel, albeit more slowly than several of the others. It is worth noting that this fish also had an orange spaghetti tag attached to it from a previous capture, although neither time nor the physical layout of the vessel allowed its retrieval without compromising the release protocol.

This project demonstrated that most billfish released from pelagic longline gear survive release for a minimum of 5-30 days. However, this must be interpreted with several caveats. One, the tagging procedure was designed to mimic that of the commercial U.S. longliner crewman. While this was intended to be as accurate a representation as possible of the actions by U.S. vessels, it may not be representative of

other nation's fleets. Two, the small number of tags deployed limits the power of the

hypothesis testing, although the relatively small sample size was certainly not from lack

of effort. Third, longline gear is deployed throughout tropical and sub-tropical waters,

especially in the tropical Caribbean and central Atlantic. The areas covered by this study

only comprise a fraction of the total ocean. Finally, not all tags report, and non-reporting

tags may be inadvertently described as mortalities when mechanical or technological

problems are actually at fault. However, new technologies such as emergency release

mechanisms are currently being developed that will act to reduce the uncertainty in non-

reporting tags.

The sample size required for an Atlantic-wide estimate of post-release mortality

would be large given the need to account for different environmental conditions and

geographic areas. The consensus appears to be that the size of such a project would be

prohibitively expensive given current technological (and budgetary) constraints. A recent

estimate of this larger project indicated a required minimum sample size approaching 100

deployed PSATs per location per gear type, although this estimate also varied with

differing assumptions of the underlying natural mortality rate (Goodyear, 2000).

The results of the 30-day tags answer several other questions, such as whether

PSAT tags can be easily and effectively deployed from commercial vessels. This study

has demonstrated that they can. Most importantly, the use of the 30-day tags tests the

underlying assumption that 5-day tags are of sufficient duration to allow an estimation of

post-release survival. The results indicate common behavior among all seven individuals

in terms of diving and temperature preferences. When the horizontal displacements with

the 5-day tags are compared with the longitude estimates from the 30-day tags, movement

speeds and expected distances traveled are also similar. Further use of 30-day tags may also begin to answer questions regarding movement patterns and spawning behavior.

The data collection interval of the 30-day tags has an additional cost in terms of eventual data recovery, and that data needs be evaluated against these limitations. Should only a minimum estimate of behavior be necessary to evaluate survival, the data resolution provided by the 5-day tags may be sufficient. The validation of the 5-day tags with 30-day tags suggests that the five-day period is appropriate for determining post-release survival. As with the study of recreationally caught blue marlin by Graves *et al.* (2002), this project with commercially caught fish found that PSAT technology was an effective and appropriate means to evaluate post-release survival. Although important, the recreational fishery contributes a smaller fraction of the total fishing mortality than the pelagic longline fishery. Specifically, this project found that releasing live blue marlin from commercial longlines would benefit the stock by reducing fishing mortality.

Billfish Management Implications

The United States has been relatively proactive regarding billfish management, but this perspective is not roundly shared internationally. In the Atlantic, ICCAT has never been particularly supportive of billfish management and conservation, which is hardly surprising given that the stated goal of the Convention is to "ensure maintenance of the populations of tuna and tuna-like fishes in the Convention area at levels which will permit the maximum sustainable catch and which will ensure the effective exploitation of these fishes in a manner consistent with this catch" (ICCAT, 1966). The ICCAT charter does not specify the allocation of this catch between recreational or commercial (or even

conservation) interests. The organization is, and probably will always be, primarily concerned with maximizing the catch of tunas and swordfish, not preserving the populations of species with low economic importance to the majority of its members.

The consequence of this reticence to act is that the stocks of Atlantic billfish have fallen to their lowest levels since records and assessments have been conducted. Some species of billfish, such as the longbill spearfish (*Tetrapturus pfleugeri*), have never been assessed due to their inherent rarity, and their population status remains unknown (the SCRS currently assumes that the population is relatively stable based solely on CPUE values from the Atlantic longline fishery). Lacking scientific advice, the Commission has consistently taken the view that better data are needed before taking management action.

Despite the historic lack of proactive management, there have been attempts to force the Commission to consider the conservation aspect of the charter as it applies to billfish. There have also been clear distinctions between the advice offered by the SCRS and those management actions taken by the Commission. As early as 1992, the SCRS Chairman suggested that releasing "live [bill]fish pulled along side longline vessels may be one approach to reduce the mortality rate. If the survival rate of marlin released from longline vessels is sufficiently high, then this approach may be one practical method to reduce mortality on those species" (ICCAT, 1993). Other warnings about the status of the blue marlin stock came early as well: Dr. J.L. Cort, the SCRS Chair in 1993, warned the Commission that the latest stock assessments – the first done since the mid-1980s – suggested that this stock was "at least fully-exploited and likely over-exploited by about 1980" (ICCAT, 1993).

Specific countries have had fairly consistent strategies for addressing concerns about both billfish bycatch and assessments. Some fishing nations, like Spain (later represented by the European Community), have taken the position that while the data are insufficient to trigger any management action, they are "actively monitoring" the problem (however, consistent reported captures of 100 MT per year for several years stretches credulity). Japan has often taken the approach that the available data are both misleading and insufficient for any kind of management requirement, and that any action to be taken should be done so voluntarily. Japan also frequently generates good will by financing research programs related to those species in question. In 1992, Japan took the disingenuous argument that any "pain" should be borne equally across user groups, i.e., that the recreational fisheries should be forced to reduce their landings as well (ICCAT, 1992). Ironically, this is the same approach taken by some U.S. longliners during the debate over closing the east coast of Florida to all commercial longlining, even though the U.S. recreational fleet had already reduced its annual take by approximately 90%.

The United States has maintained a conservation-oriented strategy for billfish since the early 1990s. Since 1994, the U.S. delegation has proposed every year that ICCAT members require the release of all live billfish caught by pelagic longlines. (See ICCAT, 1995.) The adoption in 1997 of a recommendation to reduce landings of marlins by 25% and promote voluntary live release was rightfully seen as a large step by the Commission.

The 2000 annual ICCAT meeting in Marrakech, Morocco, coincided with a new and more pessimistic SCRS stock assessment for both blue and white marlin. These stock assessments clearly stated that blue and white marlin populations would not recover

under the 1997 Recommendation measures. To counter objections that live release would have negligible benefits to the stocks, the United States qualitatively used the preliminary data obtained during this project in 2000 (i.e., the survival for five days of 5 of 7 blue marlin released from longline gear). The new recommendation adopted by the Commission in 2000 made significant progress toward slowing the decline of the blue and white marlin stocks.

This resulting recommendation mandated several measures, including reducing landings by longline and purse seine vessels of blue marlin by 50% and white marlin by 67% of the 1999 levels. These did not apply to those marlin dead at haulback that would not be sold, i.e., intended for artisanal fisheries and local consumption. The United States also accepted several restrictive provisions, including limiting its landings to 250 combined blue and white marlin and increasing tournament observer coverage to 10%, yet these provisions were basically implemented domestically anyway. Finally, the recommendation called for additional data collection and monitoring, with a new assessment and stock rebuilding alternatives tentatively scheduled to be conducted by the SCRS in 2002.

Conclusion

Billfish are vital resources in the Atlantic, both economically and biologically. Large recreational fleets depend on sufficient populations to support fishing interest, and although relatively minor, billfish contribute to the landings of several artisanal fisheries in the tropical Atlantic. Many of the trophic interactions between pelagic fishes are still relatively unknown. The complex behavior exhibited by the fish tagged in this study

clearly suggests that additional research is needed to evaluate the interactions of this species with longline fishing gear, perhaps to eventually determine methods or technologies designed to avoid interactions. Large apex predators such as blue marlin may have served a controlling role for populations of smaller pelagic species. The potential loss of billfish in the Atlantic should be of concern to all.

This research demonstrates that commercial longline vessels are suitable platforms for the deployment of pop-up satellite archival tags. More importantly, this research also demonstrates that blue marlin do indeed survive interactions with pelagic longline gear under release protocols now currently used by U.S. vessels. While ultimately not enough to solve the problem of the declining stock, mandating the release of live blue marlin is certainly an important component of any rebuilding scenario.

Appendix 1. Catch species compositions from longline sets.

Study	Years	Location	Target Species	Catch Composition (only reported for bycatch species with catch percentages greater than 0.5)
Falterman and Graves (2000)	1999	Venezuela	Yellowfin tuna	Yellowfin tuna (60.0), albacore tuna (4.85), wahoo (4.85), bigeye tuna (4.24), gempylid (4.24), oilfish (3.63), sailfish (3.64), dolphinfish (2.42), longbill spearfish (2.42), pelagic stingray (1.82), swordfish (1.82), great barracuda (1.82), pelagic puffer (1.21), horse-eye jack (0.61), skipjack tuna (0.61), blue shark (0.61)
Cramer (1996)[1]	1987	SE Coastal[2]	Varied	Swordfish (59.5), other shark (12.0), yellowfin tuna (8.3), dolphinfish (3.5), blue shark (3.5), bigeye tuna (3.3), hammerhead sharks (2.4), sailfish (2.1), blue marlin (1.1), wahoo (0.7), tiger shark (0.7), mako shark (0.6), white marlin (0.6)
	1988	SE Coastal	Varied	Swordfish (67.9), other shark (8.0), yellowfin tuna (7.2), dolphinfish (3.0), hammerhead sharks (2.4), sailfish (2.4), blue marlin (1.8), bigeye tuna (1.8), blue shark (1.5), wahoo (0.8)
	1989	SE Coastal	Varied	Swordfish (61.2), dolphinfish (9.7), yellowfin tuna (7.9), other shark (7.6), hammerhead sharks (2.6), bigeye tuna (2.1), blue marlin (2.0), sailfish (1.9), wahoo (0.9), blackfin tuna (0.8)
	1995	SE Coastal	Varied	Swordfish (55.5), dolphinfish (14.6), yellowfin tuna (5.9), silky shark (4.5), sandbar shark (3.4), night shark (1.7), blue marlin (1.6), smooth hammerhead shark (1.4), sailfish (1.2), wahoo (1.2), blacktip shark (1.1), scalloped hammerhead shark (1.0), blackfin tuna (0.9), tiger shark (0.6), dusky shark (0.6), spinner shark (0.6), bigeye thresher shark (0.6)
Cramer (2000)[3]	1996-1998	SE Coastal	Varied	Swordfish (59.9), yellowfin tuna (7.9), dolphinfish (7.2), bigeye tuna (5.6), silky shark (4.1), sailfish (2.1), sandbar shark (1.5), blue marlin (1.3), blackfin tuna (1.1), blue shark (1.0), oilfish (0.7), wahoo (0.7), white marlin (0.5)

[1] Bycatch species reported for the third quarters only, roughly corresponding to the study range and months.
[2] This is a NMFS statistical area, roughly corresponding to 35°N to 22°N and 71°W to 82°W. Technically, Bermuda falls within the "Offshore South" area, although the presence of the Gulf Stream through the Bermudian fishing grounds suggests a closer similarity with the "Southeast Coastal" area catches.
[3] Bycatch species reported for the third quarters only, roughly corresponding to the study range and months.

Appendix 2. Tag programming reports. These are the output files generated by the WC PAT tags after programming. Note that tag number 24520 (code-named "BOROFIJI2") repeatedly malfunctioned during programming on board the longline vessel; hence tag number 24519 ("BOROFIJI3") was deployed instead.

PAT Tag 16122:

Report for Recorder: 00-0990; named: ... by user:
    Dept. of Fisheries Science
    The Virginia Institute of Marine Science
    School of Marine Science
    Gloucester Point, Va 23062

Password is BOROFIJI1
Argos PTT: 16122 (0FBE90 hex) with repetition rate: 60s
Hardware version: 2.00; Software version: 2.06a; Bootcode version: 4
Host Date: 21 Jul 2001 at 13:34:58
PAT tag Date: 21 Jul 2001 at 17:25:47
PAT tag release Date: 25 Aug 2001 at 00:00:00

Channel 1 is Depth, measured over the range: -40 to 1000m, with resolution = 0.5m
    -20m to -10.5m is saved with resolution of 2m
    -10m to 9.5m is saved with resolution of 0.5m
    10m to 49.5m is saved with resolution of 2m
    50m to 789.5m is saved with resolution of 4m

    Depth correction tables verified
    Depth Temp-Compensation tables verified

Channel 2 is Temperature, measured over the range: -40 to 60C, with resolution = 0.05C
    -2.50C to 22.45C is saved with resolution of 0.1C
    Internal Temperature correction tables verified

Channel 3 is Light Level, measured over the range: 0 to 255 LLU, with resolution = 1 LLU
    Light Level correction tables verified

Sample:
    Depth: every 1 minute
    Temperature: every 1 minute
    Light Level: every 1 minute
    RTC Temperature: never
    Battery Voltage: never
    Depth Temperature: never

1-hour Histogram Limits:

Depth	Temp	Profile
-1	5	
2.5	7.5	
5	10	
10	12.5	
15	15	
25	17.5	
50	20	
100	22.5	
250	25	

```
500     27.5
750     30
1000    60
```

57 Kbytes are allocated for histograms/PDTs/Locations, 903 Kbytes will be used to store sampled data.
Status message will be sent every 30 transmissions.
Premature Release detection is enabled
PAT will release before designated release date if depth remains constant +/- 5m
for 48 hours. 10 outliers are ignored.

PAT Tag 24519:

Report for Recorder: 00-0992; named: ... by user:
    Dept. of Fisheries Science
    The Virginia Institute of Marine Science
    School of Marine Science
    Gloucester, Point Va 23062

Password is BOROFIJI3
Argos PTT: 24519 (07F1F7 hex) with repetition rate: 59s
Hardware version: 2.00; Software version: 2.06a; Bootcode version: 4
Host Date: 30 Aug 2001 at 07:18:17
PAT tag Date: 30 Aug 2001 at 11:05:01
PAT tag release Date: 01 Oct 2001 at 00:00:00

Channel 1 is Depth, measured over the range: -40 to 1000m, with resolution = 0.5m
    -20m to -10.5m is saved with resolution of 2m
    -10m to 9.5m is saved with resolution of 0.5m
    10m to 49.5m is saved with resolution of 2m
    50m to 789.5m is saved with resolution of 4m

    Depth correction tables verified
    Depth Temp-Compensation tables verified

Channel 2 is Temperature, measured over the range: -40 to 60C, with resolution = 0.05C
    -2.50C to 22.45C is saved with resolution of 0.1C
    Internal Temperature correction tables verified

Channel 3 is Light Level, measured over the range: 0 to 255 LLU, with resolution = 1 LLU
    Light Level correction tables verified

Sample:
    Depth: every 1 minute
    Temperature: every 1 minute
    Light Level: every 1 minute
    RTC Temperature: never
    Battery Voltage: never
    Depth Temperature: never

1-hour Histogram Limits:
```
Depth   Temp    Profile
-1      7.5
2.5     10
5       12.5
```

10	15
15	17.5
25	20
50	22.5
100	25
250	27.5
500	30
750	32.5
1000	60

53 Kbytes are allocated for histograms/PDTs/Locations, 907 Kbytes will be used to store sampled data.
Status message will be sent every 30 transmissions.
Premature Release detection is enabled
PAT will release before designated release date if depth remains constant +/- 5m
for 48 hours. 10 outliers are ignored.

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