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Survival of white marlin (*Tetrapturus albidus*) released from commercial pelagic longline gear in the western North Atlantic*

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Abstract—To estimate postrelease survival of white marlin (*Tetrapturus albidus*) caught incidentally in regular commercial pelagic longline fishing operations targeting swordfish and tunas, short-duration pop-up satellite archival tags (PSATs) were deployed on captured animals for periods of 5–43 days. Twenty (71.4%) of 28 tags transmitted data at the preprogrammed time, including one tag that separated from the fish shortly after release and was omitted from subsequent analyses. Transmitted data from 17 of 19 tags were consistent with survival of those animals for the duration of the tag deployment. Postrelease survival estimates ranged from 63.0% (assuming all nontransmitting tags were evidence of mortality) to 89.5% (excluding nontransmitting tags from the analysis). These results indicate that white marlin can survive the trauma resulting from interaction with pelagic longline gear, and indicate that current domestic and international management measures requiring the release of live white marlin from this fishery will reduce fishing mortality on the Atlantic-wide stock.

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White marlin (*Tetrapturus albidus* Poey 1860) is an istiophorid billfish species widely distributed in tropical and temperate waters throughout the Atlantic Ocean, including the Caribbean Sea. There is substantial international concern regarding the population levels of this species. The standing committee for research and statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) last assessed the Atlantic-wide stock of white marlin in 2002 and in its continuity-case assessment the committee indicated a total biomass of approximately 12% of that necessary to produce maximum sustainable yield. It was also estimated that the current international fishing mortality level for this species is equivalent to more than eight times the replacement yield, contributing to further decline of the overfished stock (ICCAT, 2005).

Both recreational and commercial fisheries contribute to the mortality of white marlin. A directed recreational fishery exists throughout the tropical and temperate Atlantic (with considerable effort off the coasts of Brazil and Venezuela), as well as off the U.S. mid-Atlantic coast, and there is a growing trend towards catch-and-release practices in all directed recreational billfish fisheries. In contrast to the catches by this directed recreational effort, white marlin are an infrequent bycatch or a retained incidental catch of the international pelagic longline fishery, which targets tunas (*Thunnus* spp.) and swordfish (*Xiphias gladius*). Although white marlin catches in the pelagic longline fishery are relatively rare, the fishery accounts for the majority of the total fishing mortality on this species simply because of the sheer magnitude of pelagic longline effort exerted throughout the Atlantic (ICCAT, 2005).

Both domestic and international management measures are currently in effect for white marlin. The U.S. recreational fishery is managed with a 66″ lower jaw-fork length federal minimum size and a binding ICCAT recommendation that limits the annual U.S. recreational landings to a total of 250 blue marlin (*Makaira nigricans*) and white marlin combined (ICCAT, 2000). U.S. commercial fishermen have been prohibited from landing or possessing white marlin since the implementation of the National Marine Fisheries Service (NMFS) Fishery Management Plan for Atlantic Billfish (NMFS, 1988). ICCAT has responded twice to the decreasing biomass of white marlin and blue marlin by adopting binding

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recommendations requiring reductions in commercial landings by both pelagic longline and purse seine gears (ICCAT, 2000, 2001a). However, these reductions in landings by themselves may ultimately be insufficient to rebuild these two marlin stocks. Goodyear (2002a) found that a reduction of 60% would be necessary to halt the decline of blue marlin, a species which is more abundant, larger, and presumably more robust to the trauma associated with commercial capture (Kerstetter et al., 2003). Given that white marlin are smaller animals, and that the stock is more depleted than that of blue marlin, even more drastic measures are likely necessary to achieve the same management goal for this species.

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

The assessment of postrelease survival presents special problems for large pelagic fishes, which are rarely capable of being held in captivity (de Sylva et al., 2000). In general, recovery rates of billfish tagged with conventional streamer tags by commercial and recreational fishermen have been quite low (0.4–1.83%: Prince et al., 2003; Ortiz et al., 2003). Although this observation is consistent with high postrelease mortality, low recovery rates could also result from tag shedding and from tags that fail to transmit data (Bayley and Prince, 1994; Jones and Prince, 1998). The results of acoustic tracking studies of various billfish species (e.g., striped marlin [*Tetrapturus audax*]: Brill et al., 1993; blue marlin: Block et al., 1992; and black marlin [*Makaira indica*]: Pepperell and Davis, 1999) captured on recreational gear indicate that postrelease survival over periods of a few hours to a few days is relatively high, although mortalities have been observed in short-term tracking studies. Recently, pop-up satellite archival tag (PSAT) technology has proven especially useful to study postrelease survival in several larger istiophorid species, including blue marlin in the Atlantic (Graves et al., 2002; Kerstetter et al., 2003) and striped marlin in the Pacific (Domeier et al., 2003). Only recently have PSATs been attached to smaller (<40 kg) istiophorid billfishes. Horodysky and Graves (2005) used PSATs to evaluate the postrelease survival of white marlin from recreational (rod-and-reel) fishing gear and demonstrated that smaller billfish (≥16 kg estimated weight) can carry PSATs. Their work also suggested high postrelease survival rates in the recreational fishery, especially for fish caught on circle hooks. However, pelagic longline gear presents a different suite of stressors during capture of an animal than does recreational gear. These differences, including long "soak times" (the length of time in each deployment of the gear that the longline is fishing), may also affect postrelease survival rates. In our study, we applied PSAT technology to estimate the short-term mortality of white marlin released alive after capture on pelagic longline gear.

Materials and methods

Fishing operations

White marlin tagging took place off the east coast of Florida (FL), the southwest edge of Georges Bank (GB), the Yucatan Channel (YC), the Windward Passage (WP), and the Mid-Atlantic Bight (MA). These locations are all waters traditionally fished by the U.S. pelagic longline fleet. All tagging operations occurred opportunistically aboard the commercial pelagic longline fishing vessel FV *Carol Ann* (54′ length-over-all) between June 2002 and August 2004. This vessel is typical in size and is equipped for targeting swordfish, mixed swordfish, and tuna within the U.S. coastal pelagic longline fishery. Hook types and sizes were also typical for the fishery and included 7/0 and 9/0 offset J-style hooks (ca. 15º offset; Eagle Claw model no. 9016 or Mustad model no. 7698), 16/0 non-offset circle hooks (Mustad models no. 39660 or no. 39666), and 18/0 non-offset circle hooks (Lindgren-Pitman, Inc., Pompano Beach, FL). Adjusted seasonally, individual leader lengths were 7.5 fathoms (ca. 13.7 m) in the fall northern fishery targeting tuna and 15 fathoms (ca. 27.4 m) in the spring southern fishery for swordfish; this adjustment is standard practice within the fleet (O'Neill[2]). Individual leader lengths comprised a two-fathom "tail" separated from the rest of the leader by a 28-g leaded swivel—a configuration commonly used in this fishery to reduce tangles with other leaders or the mainline. Varying the length of the lines ("buoy drops") connecting the mainline with the small buoy floats on the surface also allows the gear to fish at different depths. Many captains will use two buoy drop lengths in the beginning of a trip to ascertain

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[1] Cramer, J. 2000. Species reported caught in the U.S. commercial pelagic longline and gillnet fisheries from 1996–1998. NMFS Sustainable Fisheries Division publication, SFD-99/00-78:1–33. NOAA/NMFS Southeast Fisheries Science Center, SFD, 75 Virginia Beach Dr., Miami, FL 33149.

[2] O'Neill, G. 2003. Personal commun. Carol Ann Sword Corporation. 629 NE 3rd Street, Dania Beach, FL 33004.

the most productive gear configuration. For our study, two buoy drop lengths were used in each set, and these drop lengths were alternated after every 30 hooks: usually 5- and 2.5-fathom (ca. 9.1 and 4.5 m, respectively) lengths in the fall and 10- and 12-fathom (ca. 18.3 and 21.9 m, respectively) lengths in the spring. Electronic hook-timers (Lindgren-Pitman, Inc.; Pompano Beach, FL) were also used during many of the sets to record the time at which an animal was hooked. Bait was usually frozen squid (*Illex* sp.), but occasionally included frozen Atlantic mackerel (*Scomber scombrus*) or a haphazard mixture of the two.

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

Tag models

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

The Microwave Telemetry, Inc. model PTT-100 HR satellite tag was used for the main study and constituted the majority of the PSAT deployments (n=22). This tag has similar physical attributes to those of the model PTT-100 tags previously described, but its functionality was increased by the addition of light and pressure (depth) sensors and an increased data storage capacity. The manufacturer preprogrammed all the PTT-100 HR model tags to detach themselves from the fish after ten days, and the tags were activated prior to attachment to the animal by removing a small magnet from the side of the tag. The tags sampled environmental data at approximately four-minute or two-minute intervals.

White marlin tagging procedures

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

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

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

Table 1

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

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

Data analysis

Survival of tagged animals was inferred from three types of environmental data provided by the tag: water temperature changes, depth changes, and ambient light intensity. Frequent short-scale (<1 hour) variations in both depth and temperature were used as indicators of a live white marlin. The survival of individual fish was also supported by the net displacement, calculated as the distance from the location of the vessel at the time the white marlin was released to that of the first good transmission from the free-floating PSAT to the ARGOS satellite system. The precision of reported location estimates was based on the attitude of the receiving satellite, and transmissions were generated through the ARGOS system (Service Argos, Inc., Largo, MD) and categorized into seven location accuracy codes. Locations were considered "good" for our study if the ARGOS system reported an accuracy code that corresponded to a distance of less than 1000 meters. If a good position was not obtained directly from ARGOS, an average of all location code "0" readings from the first 24-hour period of transmission was used as a proxy location. All distances were calculated with PROGRAM INVERSE (NGS[3]).

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

Results

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

Catch rates (catch per 1000 hooks) for target and bycatch species varied by season and location. Swordfish catch rates for retained animals ranged from 1.6 (mid-Atlantic, summer 2005) to 23.9 (Caribbean and Gulf of Mexico, spring 2004). Retained tuna (yellowfin [*Thunnus albacares*]; bigeye, *T. obesus*; and albacore [*T. alalunga*]) catch rates ranged from 0.8 (Caribbean and Gulf of Mexico, spring 2004) to 44.2 (mid-Atlantic, summer 2004). Istiophorid billfishes (blue marlin, white marlin, longbill spearfish [*Tetrapturus pfluegeri*], and sailfish [*Istiophorus platypterus*]) represented approximately 3% of the catch by number, and the overall mean catch rate of white marlin was 1.87 per 1000 hooks. Proportions of white marlin dead at the time of haulback varied among sets, trips, seasons, and locations. The lowest observed proportion dead was 34.4% (mid-Atlantic, summer 2005) and the highest was 50%

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[3] NGS (National Geological Survey). 1975. Version 2.0, modified by M. Ortiz, NOAA/NMFS Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

Table 2

Summary information for tagged white marlin (*Tetrapturus albidus*) released from commercial pelagic longline gear in the western North Atlantic Ocean, June 2002–August 2004. "D/NV" refers to hooks that were deep and not externally visible at the time of tagging. Y=yes; No=no. L=live; PR=premature release; D=dead. —=not available. MSLD=minimum straight line distance (distance between the point where the animal was released and the area where the tag began transmitting data.)

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

(Caribbean and Gulf of Mexico, spring 2004). The average proportion of white marlin dead at haulback across all seasons and trips was 35.4%.

PSATs were applied to 28 white marlin at the time of haulback. All live white marlin brought to the vessel were tagged regardless of physical condition until the supply of tags available on that trip was exhausted (i.e., if a fish was evaluated as being alive, it was tagged). Estimated weights of tagged fish ranged from 14–27 kg (30–60 pounds) and detailed information for each individual tagged (including hook location, fate, and minimum straight-line distance) is presented in Table 2. Three white marlin tagged with PSATs were caught on leaders attached to electronic hook-time recorders, allowing us to determine the length of time the animal was on the hook before release. Two fish (YC-04-01 and WP-0401) struck the bait in the early morning after local sunrise (7:32 and 8:13 a.m. local time, respectively) and were on the line only for approximately 1.5 hours before release. The third fish (MA-03-01) was caught during haulback at 9:52 p.m. local time on one of the few sets retrieved at night and was hooked for only 11 minutes.

Tag performance

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

White marlin survival

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

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

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

The tags that did not transmit data may or may not represented mortalities of the tagged white marlin. These resulting calculated mortality rates therefore depend on whether or not the tags that did not transmit data are included as evidence of mortality. Combining both hook types, the overall mortality rate was 10.5% (95% CI: 0.0–26.3%) if nontransmitting tags were excluded and 37.0% (95% CI: 18.5–55.6%) if nontransmitting tags were included as mortalities.

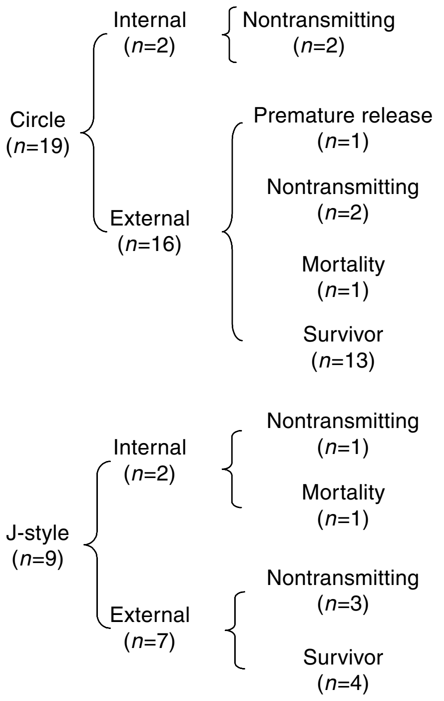

Figure 1

Fate of each white marlin (*Tetrapturus albidus*) tagged with PSAT tags and released from commercial pelagic longline gear in the western North Atlantic Ocean, June 2002–August 2004.

Hook performance

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

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

Discussion

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

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

In our study, we primarily used tags with a ten-day deployment period and believe that this period is sufficiently long to document short-term mortality. Five of seven white marlin mortalities reported in Horodysky and Graves (2005) occurred within the first six hours of release, and the other two died less than three days later. All of the mortalities inferred for the closely related striped marlin by Domeier et al. (2003) occurred within six days of release, and 75% of these mortalities happened in less than two days. The two documented mortalities in the present study (GB-02-01 and MA-03-04) occurred within 24 hours of release.

Direct comparisons of estimates of postrelease survival of billfishes among previous acoustic and PSAT studies are problematic. Many acoustic tracking studies had relatively short observation periods and low sample sizes, and often fish in marginal physical condition were not tagged (reviewed in Domeier et al., 2003). Even among PSAT tagging studies, nontransmitting tags have been addressed with different protocols by various authors. Neither Graves et al. (2002) nor Kerstetter et al. (2003) directly observed mortalities of PSAT-tagged blue marlin. However, in both studies a conservative approach was adopted to estimate postrelease survival by considering nontransmitting tags as representing mortalities; this approach was adopted in part because of a lack of emergency release software or mechanisms on the tags themselves that would release the PSAT prior to its sinking with a dead fish below the depth at which the tag would be crushed. Some new models of satellite tags possess such emergency release software or physical mechanisms, such as glass implosion devices (Domeier et al., 2003) or the RD-1500 metal guillotine from Wildlife Computers (Redmond, WA) that sever the tether of the tag prior to reaching the depth limit of the tag. New generations of tags are also rated to greater crush depths (ca. 2000 m) than earlier models. The PSATs used in our study, with the exception of the one PAT tag, did not possess emergency release software or physical mechanisms. Because all the animals in this study were tagged over or near waters deeper than the crush depths of the tags, any deaths of tagged white marlin could have resulted in the PSATs being destroyed prior to transmitting data while the tag remained attached to the sinking, moribund fish.

There are several reasons why PSATs may not report even with emergency releases, including recovery of the tag by a noncooperative fishing vessel, internal malfunction, or biological activities. Kerstetter et al. (2004) reported on three PSAT tags that were presumably ingested by sharks during predation or scavenging and suggested that a number of nontransmitting tags in all PSAT studies could result from biological activity. Goodyear (2002b) noted that including nontransmitting tags as mortalities would bias mortality estimates upwards if the failure to transmit data was due to causes other than mortality.

The combination of physically more robust tags, emergency release capabilities, and demonstrated mortalities has led authors (e.g., Domeier et al., 2003) to specifically exclude tags that do not transmit data from subsequent analyses. Because it was not possible to estimate how many such tags in this study could have been due to malfunction versus individual mortality events, we chose to conservatively estimate two postrelease mortality rates: one that includes all nontransmitting tags as mortalities and another that excludes nontransmitting tags. The expensive nature of PSAT technology resulted in relatively small sample sizes and hence large confidence intervals for the estimated postrelease mortality rates. However, as with Horodysky and Graves (2005), simulations with the observed rates in the present study have shown that very large sample sizes (over 200 tags for each hook type) under ideal conditions would be required to reduce these estimates to within ±5% of the true value. The advent of newer tag models with features such as an emergency release will presumably result in lower nontransmitting rates for PSATs and hence more accurate estimates of postrelease survival.

In this study, PSATs attached to some white marlin in marginal physical condition at the time of release returned data consistent with postrelease survival. These included fish MA-04-03, which was hooked through the right eyeball, and fish WP-04-01, which displayed poor, faded color and was moving so little at haulback that it initially appeared dead until careful inspection. Both internal hooking and stomach eversion have been suggested as predictors of subsequent mortality for billfishes (Domeier et al., 2003). Horodysky and Graves (2005) found a 40% mortality rate for internally hooked white marlin, and Domeier et al. (2003) found a 63% mortality rate for similarly hooked striped marlin. We tagged four internally hooked animals, and the one reporting tag (GB-02-01) indicated mortality shortly after release for that fish. Three white marlin with everted stomachs at haulback were tagged in this study, but only one (MA-03-04) remained attached for the duration of the deployment period and transmitted data consistent with mortality. However, the survival of a white marlin (Horodysky and Graves, 2005) and a striped marlin (Holts and Bedford, 1990) with everted stomachs indicates that billfish with everted stomachs can survive if released.

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

The majority of white marlin caught with circle hooks in the present study were hooked in the mouth or jaw (n=23) rather than internally or by foul hooking on the body (n=5), as was also noted by Horodysky and Graves (2005) for white marlin caught in the directed recreational fishery. In the present study, low numbers of animals caught on either hook types prevented robust comparisons of postrelease survival rates by hook type. More balanced comparisons of postrelease survival among hook types were precluded by both a limited number of expensive PSATs and the imposition of a domestic management measure that prohibited the use of J-style hooks in the U.S. pelagic longline fishery as of 5 August 2004 (FR, 2004). Although beyond the scope of this study, any additional changes in the fishing practices of this fishery, such as the varying lengths of “soak time” between overnight sets (swordfish) and daylight sets (tunas), may also affect the rates of postrelease survival of white marlin.

Ultimately, hooking location may be a more important factor than hook type for predicting postrelease survival. Three of the four PSATs attached to internally hooked animals in this study did not transmit data, although Prince et al. (2002b) reported encapsulated hooks from istiophorid viscera, indicating that internal hooking events are not necessarily fatal. The large percentage of white marlin (35.7%) hooked through the upper lateral palate into the eye or eye socket raises some concern. Istiophorid billfishes are considered to be primarily visual predators (Rivas, 1975) and damage to an eye would be expected to negatively affect the foraging ability of the animal. Billfish are known to have specialized muscle tissue that allows individuals to maintain elevated brain and eye temperatures (Block, 1986), and recent work has revealed color vision in some istiophorids (Fritsches et al., 2003). Dissections of sailfish have revealed that hookings in the eye socket often cause damage to the optic nerve and surrounding ocular musculature (Jolley[4]). The one fish caught with a circle hook through the eye socket in Horodysky and Graves (2005) survived for the entire 10-day deployment period, and in the present study, the seven animals hooked through the eye socket also all survived for their entire deployment periods, as did one white marlin caught with a circle hook through the eyeball. A tagged striped marlin in Domeier et al. (2003) with a punctured eye also survived for ten days, suggesting that this condition is not necessarily fatal over short durations, and healthy swordfish have been observed

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[4] Jolley, J. W. 1977. The biology and fishery of Atlantic sailfish *Istiophorus platypterus*, from southeast Florida, 31 p. Fla. Mar. Res. Pub., contribution no. 298. Florida Dep. Natural Resources, Marine Research Laboratory, 100 Eighth Avenue SE, St. Petersburg, FL 33701.

with one healed ocular cavity (D. W. Kerstetter, personal observ.).

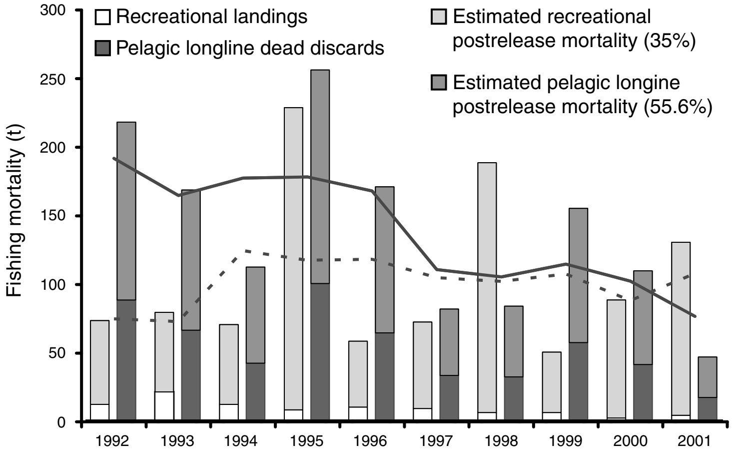

Figure 2

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

We observed a high percentage of hooked white marlin with associated eye damage, specifically in conjunction with circle hooks. In contrast, Horodysky and Graves (2005) noted only one animal out of 40 hooked through the eye with a circle hook. The difference between studies may be a factor of the hook sizes used in the fisheries; the recreational fishery generally uses much smaller circle hooks than the commercial pelagic longline fishery (7/0 and 9/0 sizes versus 16/0 and 18/0). Jolley[4] observed that for 134 (15.8%) of 848 sailfish caught recreationally with J-style hooks, the barbs exited near the eyes, noting that the distal lateral regions of the istiophorid mouth roof (those areas underlying the eyes) are thinly-covered muscle tissue rather than bone. A hook would therefore presumably pass much more easily through this tissue to the eye than if it encountered the lower jaw. Prince et al. (2002b) considered hooking through the upper palate potentially lethal, not only because of the opportunity for the hook to penetrate the occipital orbit, but also because of the tendency for J-style hooks in that location to compromise the integrity of the cranium, making it more susceptible to infection. Two tags that did not transmit data in our study were attached to fish caught with J-style hooks in the center of the upper palate. Borucinska et al. (2002) noted that for blue sharks (*Prionace glauca*) wounded by fishing hooks, an injury caused by a perforating hook may lead to systemic debilitation over longer time intervals than that typically measured with PSAT tags.

The postrelease mortality rates obtained for white marlin from Horodysky and Graves (2005) and this study also allowed the estimation of total U.S. fishing mortality for this species. For the U.S. directed recreational fishery, the white marlin postrelease mortality rate (35% for J-style hooks; Horodysky and Graves, 2005) was applied to estimated yearly catch data and added to "best estimates" of the U.S. recreational landings (Goodyear and Prince, 2003). For the pelagic longline fishery, catch and condition at release data were obtained from the NMFS Pelagic Observer Program database (Lee[5]). The 55.6% postrelease mortality rate (J-style hooks, nontransmitting tags as mortalities; present study) was applied to the number of white marlin released alive to obtain an estimate of the number of fish that died following release. Average underestimates of the actual white marlin fishing mortality to recreational fishery reported landings or to commercial fishery dead discards during this ten-year period were 88.6% and 61.6%, respectively.

Our analysis indicates that the directed U.S. recreational fishery may generate higher levels of white marlin fishing mortality than the U.S pelagic longline fishery in some years simply due to greater numbers of animals caught (Fig. 2). Because we chose the postrelease mortality estimates based on the historic terminal gear choices of J-style hooks, these results do not account for the probable decrease in total white marlin postrelease mortality resulting from mandated (pelagic longline) and voluntary (recreational) changes in the U.S. fisheries from J-style hooks to circle hooks. However, even this estimated magnitude of actual mortality incurred as the result of the U.S. recreational or pelagic longline fisheries results in the international pelagic longline fishery remaining the largest source of total white marlin fishing mortality in the Atlantic (ICCAT, 2005).

The results of this study clearly demonstrate that white marlin are capable of surviving the trauma associated with capture by pelagic longline fishing gear. Short-term survival of released white marlin was relatively high whether one discounted nontransmitting tags (89.5% survival) or considered nontransmitting

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[5] Lee, D. 2004. Personal commun. NOAA/NMFS Southeast Fisheries Science Center, 75 Virginia Beach Dr., Miami, FL 33149.

tags to represent mortalities (62.9% survival). These estimates are similar in magnitude to that found for the larger blue marlin released from pelagic longline gear (79% survival; Kerstetter et al., 2003). The documented survival of white marlin indicates that current domestic and international management measures requiring live release from commercial pelagic longline gear will reduce fishing mortality on this species.

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