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Satellite telemetry tracking of swordfish, *Xiphias gladius*, off the eastern United States

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Abstract Swordfish (*Xiphias gladius*) were tagged with satellite "pop-off" tags that release from the fish after a preprogrammed time, float to the sea surface, and transmit present position and archived temperature data. Swordfish were tagged on the "Charleston Bump," a topographic feature on the Blake Plateau east of South Carolina and Georgia. This feature is an important swordfishing ground and may be a spawning and nursery area. Swordfish were tagged in spring of 2000 to determine movements in relation to the Charleston Bump, and tags were programmed to pop off the fish at 30 days ($n=10$ tags), 60 days ($n=10$), and 90 days ($n=9$). Although four swordfish were found in the vicinity of the Charleston Bump up to 90 days after tagging, most moved considerable distances to the east and northeast and were subsequently located in association with offshore seamounts, submarine canyons of the Middle Atlantic Bight, and with thermal fronts of the northern wall of the Gulf Stream. The longest minimum (i.e., straight-line) distance tracked was 2,497 km, and maximum speed inferred from tracking was 34 km/day. Seawater temperature data archived by the tags reflected diel vertical migrations in swordfish.

Introduction

Swordfish (*Xiphias gladius*) occur worldwide from about 45°N to 45°S, giving it the broadest distribution of any billfish (Palko et al. 1981). The high commercial value of this species and trends toward reduced catch rates and smaller average fish size have led to concerns about the ability of the fishery to sustain itself at current exploitation rates. The biomass of the North Atlantic swordfish in 1999 was estimated to be at 65% of that needed to produce maximum sustainable yield (MSY; SCRS 1999). The biomass at MSY is the target stock size of the rebuilding program for North Atlantic swordfish. Reductions in quotas have been suggested to rebuild the stock to levels that would support MSY.

Data from mandatory longline vessel logbooks submitted to the U.S. National Marine Fisheries Service (NMFS) indicate a concentration of longline sets in the vicinity of a bottom topographic feature known as the Charleston Bump (Cramer 1996; Sedberry et al. 2001). The Charleston Bump is an area of high relief on the Blake Plateau located at about 31°30′N and 79°W. The bottom topography deflects the Gulf Stream offshore and sets up a series of frontal eddies, gyres, and upwelling zones that are important in the life history of several demersal and pelagic species (Govoni and Hare 2001; Sedberry et al. 2001). There are seasonally high occurrences of sublegal-sized swordfish in the vicinity of the Charleston Bump (Cramer 1996), and a high frequency of by-catch of other billfishes in the swordfish longline fishery (Sedberry et al. 2001). Although it is uncertain if these small swordfish and nontargeted billfishes are resident or transitory in the Charleston Bump area, a seasonal closure of the longline fishery (from February through April) has been recently implemented to reduce by-catch of nontargeted species and undersized swordfish.

The seasonal migration of swordfish is one of the most complex of the pelagic fishes (Palko et al. 1981), and time or area closures may not have a significant impact on reducing fishing effort on this overfished species if the fish migrate into areas that remain open to fisheries or remain resident in a temporally closed area and are subject to fishing when the temporal closure ends. Traditional tagging of highly migratory species such as swordfish has given some information regarding movements and growth of such species (Beckett 1974)

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but is not useful for determining residence times and short-term movements. In addition, reporting rates of highly migratory species tagged with traditional tags are low (2% of fish tagged on longline gear; Beckett 1974). Acoustic telemetry has been used to track short-term movements of swordfish and has demonstrated diel vertical migration in the species (Carey 1990). However, these transmitters are not appropriate for the estimation of residence times, as they can only transmit data for a relatively short period of time (24–48 h).

Satellite "pop-off" tags are a relatively new technology designed to provide a fishery-independent measure of distance traveled from tagging point to release point without the need to recapture the fish (Block et al. 1998). Because they do not require recapture of the tagged fish and return of the tag to the tagging agency, more information on movements can be obtained from fewer tagged fish. These tags can also archive temperature and other data while attached to the fish. Once the preprogrammed attachment interval has expired, a corrosive linkage releases the tag from the fish. The tag then floats to the surface and transmits its archived data as well as real-time temperature and tag inclination measurements continuously to satellites in the Argos system. This type of tag has been proven effective in tagging studies on bluefin tuna, *Thunnus thynnus* (Block et al. 1998), and blue marlin, *Makaira nigricans* (Graves et al. 2001).

Swordfish are believed to dive much deeper than blue marlin or bluefin tuna and are known to feed on benthic species in waters up to 595 m deep (Palko et al. 1981; Carey 1990). The satellite tags currently available are rated for a maximum depth of 650 m, so it is possible that swordfish may dive beyond this limit and render the tag inoperable. The objective of this study was to evaluate the use of satellite pop-off tags for tracking deep-swimming fishes such as swordfish and to track the movements of swordfish captured near the Charleston Bump, which has been suspected to be a resident feeding ground for small swordfish (Cramer 1996; Sedberry et al. 2001).

Materials and methods

Swordfish were captured aboard a commercial longline vessel during late April and early May 2000, in the Gulf Stream waters of the Charleston Bump area (Table 1; Fig. 1). The first 29 swordfish captured alive and in good condition were brought alongside the vessel and double tagged with a satellite pop-off tag and a conventional streamer tag. The satellite tags were approximately 15 cm in length (excluding the 15 cm antenna) with a 4 cm maximum diameter and weighed approximately 66 g. Each tag was attached to a double-barbed nylon dart tip with a heavy monofilament leader and was applied with a fiberglass tagging pole with a stainless steel tip (Graves et al. 2001). The tags were applied into the dorsal musculature, approximately 5 cm below the center of the

Table 1 *Xiphias gladius*. Tag and release data for all swordfish tagged during the study. *LJFL* Tip of lower jaw to fork of tail length. *NC* No contact from tag to satellite after pop-off date. *NP* No pop-off position recorded due to weak contact with satellites. Distance traveled is the minimum straight-line distance from tagging point to pop-off point

Pop-off delay (days)	Tagging date (month/day)	LJFL (cm)	Tagging position		Pop-off date (month/day)	Pop-off position		Distance traveled (km)
			Lat. (N)	Long. (W)		Lat. (N)	Long. (W)	
30	04/28	121.9	31°58.4′	78°29.4′	05/29	32°58.0′	76°48.1′	193.0
30	04/30	121.9	31°57.3′	78°33.9′	06/14	31°53.9′	78°38.9′	11.0
30	05/01	101.6	32°00.8′	78°32.9′	06/22	NP	NP	–
30	05/02	81.3	32°01.1′	78°18.7′	05/31	33°00.8′	73°30.0′	492.4
30	05/03	127.0	31°56.1′	78°50.0′	06/02	31°37.1′	68°54.4′	920.0
30	05/03	91.4	32°06.7′	78°43.5′	06/02	33°52.7′	62°45.1′	1,486.8
30	05/03	101.6	32°06.3′	78°42.1′	NC	–	–	–
30	05/03	86.4	32°05.2′	78°34.9′	06/07	31°09.5′	72°45.1′	563.8
30	05/06	96.5	32°05.3′	78°45.0′	NC	–	–	–
30	05/06	165.1	32°09.1′	78°19.0′	06/08	32°15.5′	77°58.3′	35.1
60	04/30	106.7	31°58.3′	78°37.6′	06/29	39°13.4′	57°44.9′	2,040.8
60	05/01	121.9	31°01.6′	78°40.1′	NC	–	–	–
60	05/01	106.7	32°00.2′	78°30.6′	07/03	33°21.7′	77°37.1′	173.0
60	05/02	182.9	32°00.2′	78°16.1′	NC	–	–	–
60	05/03	91.4	32°01.8′	78°46.9′	06/30	39°33.0′	51°45.4′	2,547.0
60	05/03	91.4	32°06.7′	78°43.3′	NC	–	–	–
60	05/03	71.1	32°06.1′	78°38.3′	07/03	33°15.7′	76°40.6′	223.7
60	05/03	91.4	32°04.9′	78°34.3′	NC	–	–	–
60	05/06	91.4	32°05.0′	78°29.5′	07/07	38°28.3′	72°07.4′	927.8
60	05/06	66.0	32°09.3′	78°42.2′	07/09	35°43.6′	71°03.4′	810.4
90	04/30	127.0	31°57.8′	78°35.4′	08/05	36°10.7′	69°12.7′	980.9
90	05/01	152.4	32°01.5′	78°40.3′	07/30	37°22.4′	73°44.8′	743.5
90	05/02	–	32°01.8′	78°23.9′	08/10	37°12.5′	71°33.2′	860.3
90	05/03	91.4	31°56.4′	78°50.1′	08/04	31°07.3′	78°15.2′	107.6
90	05/03	182.9	32°02.1′	78°45.6′	08/05	31°59.8′	78°32.6′	21.1
90	05/03	101.6	32°06.3′	78°42.3′	08/05	39°46.9′	52°26.9′	2,497.1
90	05/03	76.2	32°06.0′	78°38.1′	07/31	NP	NP	–
90	05/03	71.1	31°59.3′	78°30.8′	08/04	28°50.4′	74°02.5′	563.6
90	05/06	76.2	32°00.8′	78°20.7′	08/06	39°47.6′	45°52.0′	3,053.2

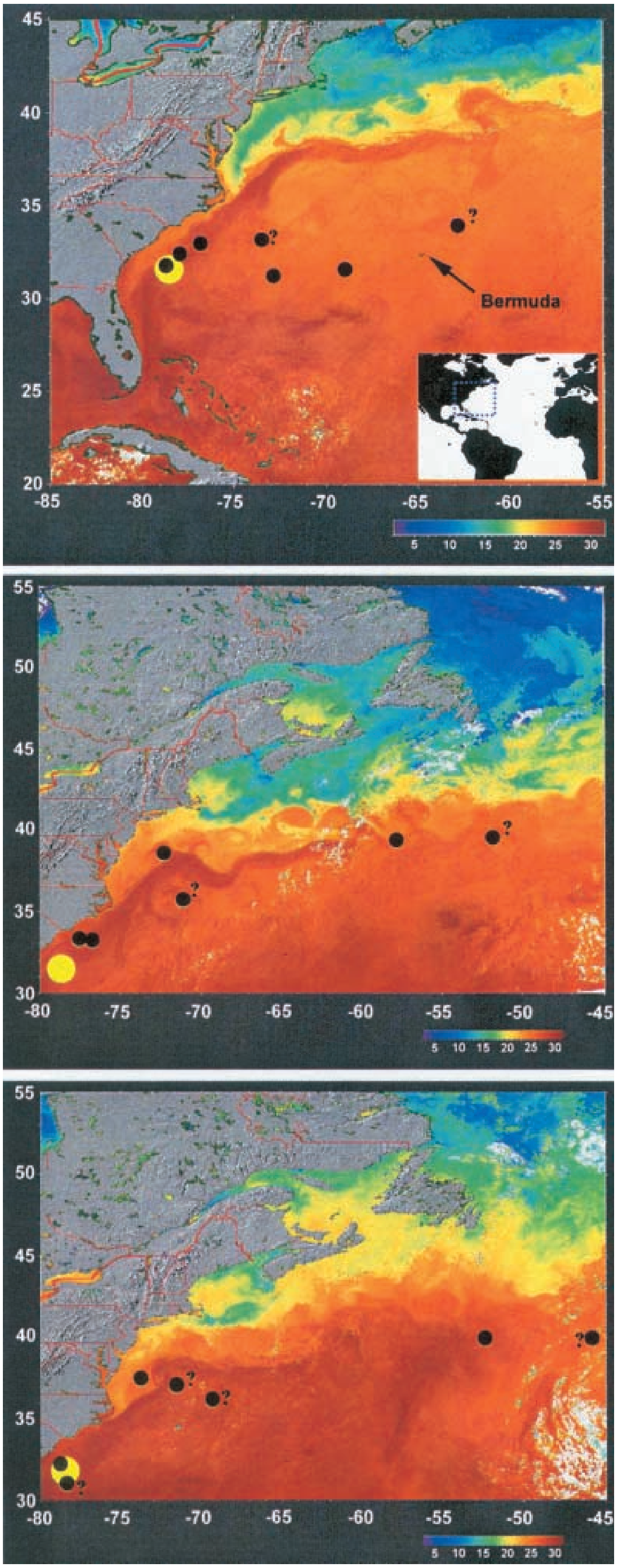

Fig. 1 *Xiphias gladius*. Movements of swordfish in relation to sea surface temperature (SST) features. Tag return locations with an associated question mark (?) reported questionable archived temperature data. *Top* Seven-day composite SST diagram for 5 June 2000 showing tagging and release points for 30-day satellite tags. Note the offshore deflection of the Gulf Stream by the Charleston Bump in the tagging area. *Middle* Seven-day composite SST diagram for 10 July 2000 showing tagging and release points for 60-day satellite tags. *Bottom* Seven-day composite SST diagram for 21 August 2000 showing tagging and release points for 90-day satellite tags. One tag reported from 497 km southeast of the tagging location, beyond the scope of the SST image

first dorsal fin. Water column temperature profiles were measured with a conductivity-temperature-depth (CTD) probe deployed from a research vessel working in the vicinity of the tagging locations, at approximately the same time.

The satellite tags (model PTT-100) were manufactured by Microwave Telemetry (Columbia, Md.) with preset attachment intervals of 30 days (ten tags), 60 days (ten tags), or 90 days (nine tags) and were deployed in alternating order by attachment interval (30, 60, 90, 30, 60, 90, etc.). Each tag recorded a single inclinometer measurement during the attachment interval, which gave a general estimate of the angle of the tag relative to vertical throughout the attachment time. The tags also contained enough memory to record 60 temperature readings during the attachment interval. The time interval between each temperature record was dependent on the duration of attachment (e.g., 60 temperature readings from a 30-day tag resulted in a temperature record every 12 h). Each temperature reading recorded into memory was an average of temperatures taken hourly since the end of the previous interval (if a temperature is recorded every 12 h, each record is an average of the previous 12 hourly temperature readings). Inclination and water temperature measurements gave an indication of the success of each tag, as tags floated vertically in the water when they were released (prematurely, or as programmed), and water temperature data can indicate a diel activity pattern in a vertically migrating fish such as swordfish. When the release time was reached, electrical current applied to a thin wire promoted rapid corrosion of the linkage and thus released the tag from the fish. The tag then floated to the surface and began transmitting data. Each transmission included the latitude and longitude, real-time sea surface temperature (SST), and current inclination of the tag, as well as a portion of the archived temperature and inclination data stored in memory. The entire archived data set was generally recovered after five to ten satellite contacts with the tag.

Tagging location and pop-off locations were plotted on bottom topography and SST images, with positions geo-referenced using the Image Analyst Extension (v. 1.0) for ArcView version 3.2a GIS software (ESRI 2000). Bottom topography images were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDS) web site (http://www.ngdc.noaa.gov). Sea surface temperature images from Advanced High Resolution Radiometry (AVHRR) satellites were 7-day composite images assembled from about the date of tag pop-off and made available courtesy of the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory web site (http://fermi.jhuapl.edu/avhrr/).

Results

The swordfish tagged for this study were juveniles or young adults, ranging in size from 71 to 183 cm (mean = 106.4; SD = 31.4) lower jaw fork length (LJFL; Table 1). Of the 29 satellite tags deployed during this study, 23 released successfully and made contact with the Argos system. Three of the 23 tags demonstrated weak or sporadic contact with the satellites, and the full archived temperature data set was not recovered. In addition, two of these weakly transmitting tags could not be triangulated by the satellites and thus no position was reported.

The data archived by the internal inclinometers demonstrated little or no deviation from vertical throughout all tag data sets. This indicated a slow average swimming speed for all fishes tagged during this study.

Archived temperature data from 30-day tags indicated daily movements through water temperatures between 10°C and 28°C (Fig. 2). Tags with longer attachment intervals (60 and 90 days) recorded a temperature average only once every 24 h or 36 h, respectively, so the temperatures reported by these tags did not vary as widely as those of the 30-day tags. The archived temperature data also indicated (by archiving temperatures that were consistent with continuous recording of SSTs) that either nine tags were shed from the fish prematurely, or the fish died and surfaced prior to the tag release date (Figs. 1, 3).

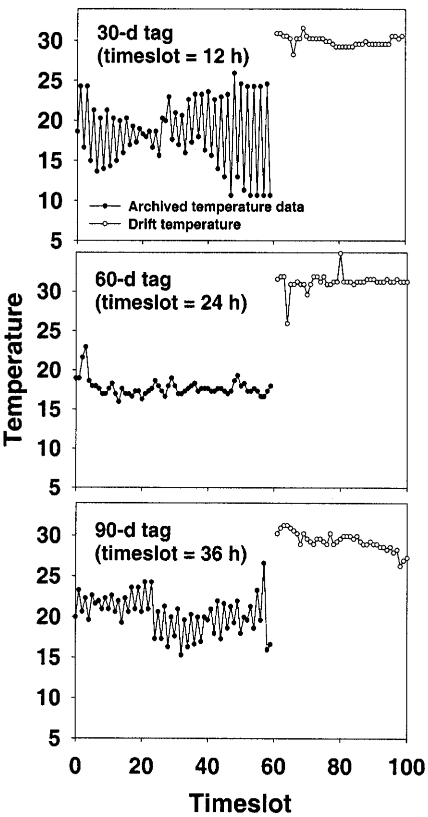

Fig. 2 *Xiphias gladius*. Examples of temperature data recorded by individual pop-off tags. *Top* Archived temperature data (*closed circles*) and drift temperatures (*open circles*) reported after release from a 30-day satellite tag. The archived temperature data demonstrates the pattern expected for an individual with a diel vertical migration pattern. The difference between the two data sets indicates that the tag remained attached to the fish the entire time at large. *Middle* Archived temperature data from a 60-day satellite tag. The overall consistency of temperatures lower than that of surface water temperatures in the tagging region fits the expected pattern for a tag archiving average water temperature surrounding a vertically migrating organism approximately every 24 h. *Bottom* Archived temperature data from a 90-day satellite tag. The reported temperatures fit the expected pattern for a tag archiving water temperature averages surrounding a vertically migrating organism approximately every 36 h

Temperature–depth profiles collected in the area of tagging (data not shown) were variable, reflecting the dynamic nature of currents in the area where the Gulf Stream is deflected offshore by the Charleston Bump. This complicated the use of the temperature data for estimation of the depth of swordfish diel migrations. The profiles indicated that forays into water as low as 10°C may have required dives of as little as 150 m, or greater than 350 m, depending on the exact location in the tagging area.

Tags that released after 30 days showed that those fish moved in an easterly direction, toward Bermuda (Fig. 1). Of these, the fish that moved the farthest was located near the Muir Seamount (Fig. 3), 260 km northeast of Bermuda, or 1,490 km east-northeast of the Charleston Bump. Tags that popped off after 60 days, however, showed movement to the north and northeast along the Gulf Stream, and some of these fish were found near other seamounts or near submarine canyons (Figs. 1, 3). One was found near Wilmington Canyon (930 km from tagging site). Tags that popped off after 90 days showed that these fish also moved north and northeast. Two were also found near submarine canyons (Norfolk Canyon, 750 km from tagging site) and others were found along the "north wall" of the Gulf Stream (Figs. 1, 3). Though there were two to five tags in each group demonstrating questionable archived temperature data, the release locations of these tags did not contradict the general movement trends indicated by tags without questionable data.

Four swordfish apparently did not move away from the Charleston Bump, even after 90 days (two of the four). These fish may have ranged away from the Bump during the time at large but were in the vicinity of the tagging location when the tags released, indicating that some swordfish prefer the area of the Charleston Bump. Most swordfish, however, moved great distances from the tagging site. The longest minimum straight-line distance (from tagging point to pop-off point, only tags with reliable archived temperature data considered) was 2,497 km, covered in 90 days (about 27 km/day). The fastest fish moved 2,041 km in 60 days (about 34 km/day). Although the tagged fish ranged in length from 71 to 183 cm LJFL, there was no statistical relationship between distance traveled and size of the fish (ANOVA, $R^2 = 0.11$, $n = 20$, $P = 0.159$).

Discussion

The archived inclination readings reported by the tags deployed in this study demonstrated little or no deflection from vertical for any tag in the sample. This suggested that the large amount of vertical movement undertaken during the daily diel migrations of swordfish precluded proper function of the inclination sensors,

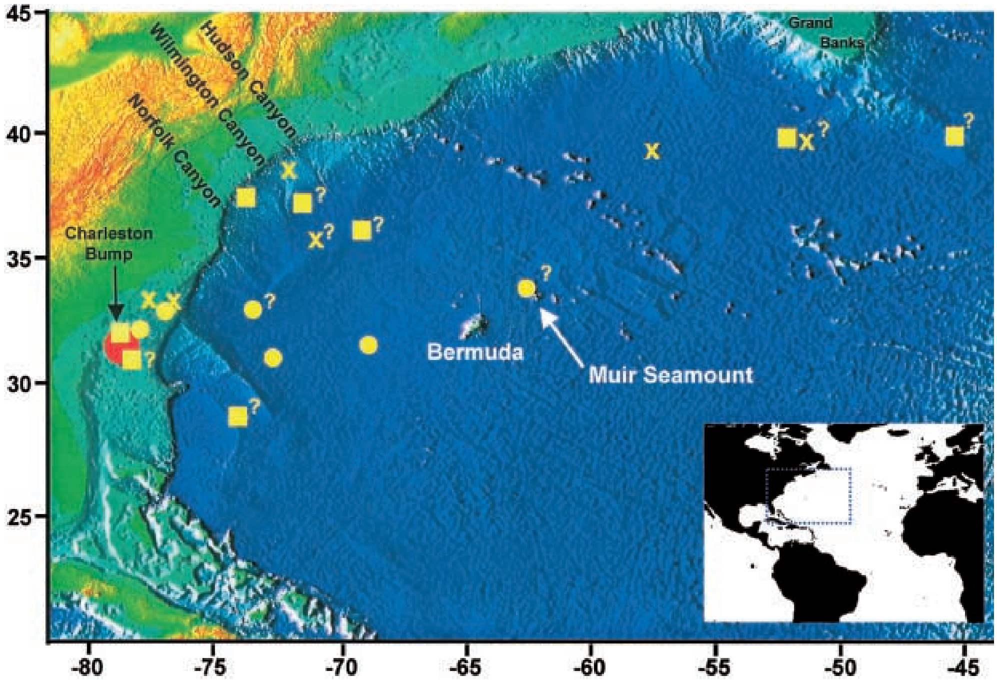

Fig. 3 *Xiphias gladius*. Topographic image of the western North Atlantic showing swordfish tagging and release points for all pop-off tags in the study. The *red circle* indicates the tagging area. Each release point is indicated by a *circle* for 30-day tags, an X for 60-day tags, and a *square* for 90-day tags. Tag return locations with an associated question mark (?) reported questionable archived temperature data

which were designed to give an indication of rapid horizontal swimming.

Archived temperature data indicated that satellite pop-off tagging of swordfish was successful in most cases. Varying patterns in the temperature data should be expected, as swordfish move vertically through different temperature regimes. Variability patterns in temperature data that showed a diel pattern would indicate an active swordfish migrating vertically from warm surface waters at night to cooler waters at depth during the day. The temperatures archived in each tag varied according to the time period between temperature recordings. For example, a 12-h temperature averaging and archiving period (such as in the 30-day tags) should demonstrate averages that alternate between warm and cold, as this time scale would record and average temperatures for every half of a diel cycle. However, the point in the diel cycle at which the 12-h sampling cycle was initiated (i.e., what time of day the tag was initially activated) could affect the amplitude of the temperature readings. Therefore, the temperature averages recorded by a 60-day tag (once every 24 h) should not be affected by this amplitude variation and will thus be fairly constant regardless of the time of activation, as each temperature record is an average of the water temperatures inhabited by the fish for a full diel cycle. It would also be expected that a 90-day tag, which records an average temperature once every 36 h, should show the same general pattern of variation as a 30-day tag, but this variation will be muted, as temperature averages were recorded every one-and-a-half diel cycles (the temperature ranges of the full diel cycle will have a buffering effect on the variation in the half diel cycle). Tags of all three deployment lengths demonstrated temperature data very similar to these expectations. As a result, the 30-day tags provided the most insight into the diel migration of swordfish. Carey (1990) used acoustic telemetry to demonstrate the diel migration patterns of swordfish, which consisted of a rise to the surface at sunset to waters as warm as 27°C, followed by dives to as low as 5°C at sunrise. Our data from satellite tags indicated swordfish preferred average temperatures as low as 10°C during the day and rose to near surface waters of up to 28°C at night. Considering that the temperature measurements of the former study are discrete, and of the latter, averages, the results appear quite similar.

The results of this study indicate that the pop-off satellite technology originally developed for bluefin tuna works on swordfish as well. However, a previous study on bluefin tuna (Block et al. 1998) found that only 5% of deployed tags failed to release and make satellite contact, whereas the current study demonstrated a failure rate of 21% (6 of 29). This is the first time satellite tags have been used on a species that makes such deep diel migrations. It is therefore possible that swordfish may occasionally exceed the 650 m depth limit of the satellite tags (at which the tag is crushed by hydrostatic pressure). Even if this maximum depth is not exceeded, the frequent and substantial changes in pressure resulting from the daily migrations demonstrated by swordfish may fatigue the tag casing during the attachment interval, leading to occasional leakage and failure.

The results of this study also demonstrated that 9 of the 23 tags that released successfully presented archived temperature data that suggested the tag was floating on the sea surface during all or part of the attachment interval. Though the availability of only a single data parameter (temperature) greatly limits our ability to ascribe a cause to each of these "floaters," there are two possibilities: the nylon tag head my have been shed from the flesh of the animal prior to the release date; or the fish my have died due to stress from capture, natural mortality, or recapture by fishing operations (there was confirmed recapture of a swordfish fitted with a 30-day tag during the last 12 h prior to tag release). Since either nonreporting tags or "floaters" may indicate fish mortality, it is possible that up to 52% of swordfish released alive during this study did not survive until the tag release deadline.

Swordfish migration is known to be complex and multidirectional (Palko et al. 1981), and this study indicated no definite trend toward fish moving progressively farther away from the tagging location with increased time of tag release. Although the longest straight-line travel (2,497 km) was demonstrated by a fish with a 90-day tag, two other 90-day tags reported from within 100 km of the tagging location. In fact, all three tag groups demonstrated a broad range of distances traveled from the tagging location. These results are at odds with previous studies using conventional tags. Beckett (1974) reported a maximum distance of 288 km between tag and recapture points based on 13 tag returns from swordfish tagged in Canadian waters. These fish were recaptured in subsequent years following tagging, but at around the same time of year they were tagged, which suggests that the fish were recaptured near the same point in their seasonal migration, rather than being resident at the tagging site.

Swordfish appear to be attracted to complex high-relief bottom structure and complex thermal structure consisting of fronts where warm Gulf Stream waters meet cooler shelf, slope, and Labrador Current waters. The topographic relief of the Charleston Bump is an area of high swordfish catch frequency (Sedberry et al. 2001), and higher catches have been noted along the western wall of the Gulf Stream in the vicinity of thermal fronts (Podestá et al. 1993). Our tagging data indicate that some swordfish remained in the vicinity of the Charleston Bump, probably attracted to the great topographic relief (exceeding 100 m of steep scarps in depths of 375–700 m) and numerous thermal fronts generated by deflection of the Gulf Stream and subsequent formation of meanders, frontal eddies, gyres, and upwelling of cooler waters. Because the Charleston Bump results in increased frequency and abundance of thermal fronts, the Bump provides additional habitat for swordfish. Swordfish that moved away from the Charleston Bump were frequently found associated with seamounts, submarine canyons, and the Gulf Stream front as the Stream turned eastward across the North Atlantic.

The Charleston Bump appears to be an important habitat for swordfish and also functions as a stepping stone along the path of seasonal migration of the swordfish. Satellite tagging technology is increasing in sophistication and the amount and types of data that can be archived and transmitted. Additional studies, including tagging of swordfish with "second generation" satellite tags that have increased memory capacity and are able to store data on depth and ambient light are needed to further define the activity patterns and migratory behavior of swordfish and other highly migratory species in the western North Atlantic.

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References

Beckett JS (1974) Biology of swordfish, *Xiphias gladius* L., in the northwest Atlantic Ocean. In: Shomura RS, Williams F (eds) Proceedings of the International Billfish Symposium, part 2. Review and contributed papers. (NOAA Tech Rep NMFS SSRF-675) U.S. Government Printing Office, Washington, D.C., pp 103–106

Block BA, Dewar H, Farwell C, Prince ED (1998) A new satellite technology for tracking the movements of Atlantic bluefin tuna. Proc Natl Acad Sci U S A 95:9384–9389

Carey FG (1990) Further acoustic telemetry observations of swordfish. In: Planning the future of billfishes. Proceedings of the Second International Billfish Symposium, part 2. Contributed papers. National Coalition for Marine Conservation, Savannah, Ga., pp 103–122

Cramer J (1996) Recent trends in the catch of undersized swordfish by the U.S. pelagic longline fishery. Mar Fish Rev 58:24–32

ESRI (2000) ArcView version 3.2a. Environmental Systems Research Institute, Redlands, Calif.

Govoni JJ, Hare JA (2001) The Charleston Gyre as a spawning and larval nursery habitat for fishes. In: Sedberry GR (ed) Island in the stream: oceanography and fisheries of the Charleston Bump. (American Fisheries Society Symposium 25) American Fisheries Society, Bethesda, Md., pp 123–136

Graves JE, Luckhurst BE, Prince ED (2001) An evaluation of pop-up satellite tag technology to estimate post-release survival of blue marlin (*Makaira nigricans*). Fish Bull, in press

Palko BJ, Beardsley GL, Richards WJ (1981) Synopsis of the biology of the swordfish, *Xiphias gladius* Linnaeus. (NOAA Tech Rep) NMFS Circ 441:2–11

Podestá GP, Browder JA, Hoey JJ (1993) Exploring the association between swordfish catch rates and thermal fronts on U.S. longline grounds in the western North Atlantic. Cont Shelf Res 13:253–277

SCRS (1999) Report of the standing committee on research and statistics, 16th regular meeting of the commission, executive summary, October 12, 1999. International Commission for the Conservation of Atlantic Tunas (ICCAT), Rio de Janeiro, Brazil

Sedberry GR, McGovern JC, Pashuk O (2001) The Charleston Bump: an island of essential fish habitat in the Gulf Stream. In: Sedberry GR (ed) Island in the stream: oceanography and fisheries of the Charleston Bump. (American Fisheries Society Symposium 25) American Fisheries Society, Bethesda, Md., pp 3–24