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Abstract—Survivorship pop-up archival tags (sPATs) were attached to swordfish (*Xiphias gladius*) released from U.S. commercial pelagic longline vessels in the western North Atlantic Ocean. The purpose was to determine the postrelease survival of individuals less than the minimum retention size (119 cm in lower jaw fork length) established by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Between 2021 and 2023, 24 sPATs were deployed with a programmed duration of 30 d to measure depth, temperature, and ambient light. Temperature and depth were recorded as daily minimums and maximums, and light level was recorded as a daily change between minimum and maximum values. The final 5 d of depth information were also recorded at 10-min intervals prior to release to assess fine-scale movements consistent with survival. Nineteen tags transmitted data, with 16 tags having data sufficient for analysis. Of these tags, 9 sPATs (56.2%) transmitted data consistent with movements of a surviving swordfish. This survival rate is lower than those reported for previous studies that focused on rod-and-reel and swordfish buoy gear, indicating that capture with pelagic longline gear causes swordfish greater stress than those other gear types. This result, combined with those of prior studies of at-vessel mortality rates, indicates that the current ICCAT rule regarding the minimum retention size provides limited conservation benefits to swordfish stocks.

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Postrelease survival of undersized swordfish (*Xiphias gladius*) caught on pelagic longline gear in a U.S. commercial fishery in the western North Atlantic Ocean

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The swordfish (*Xiphias gladius*) is a large, highly migratory predator with a circumglobal range extending from temperate to tropical zones between 45°N and 45°S (Palko et al., 1981), although individuals have been reported as far north as 49°N in the Pacific Ocean (Haplin et al., 2018). In the western North Atlantic Ocean, adult swordfish migrate between temperate foraging grounds in summer and spawning grounds at subtropical latitudes in winter (Neilson et al., 2009; Braun et al., 2019), swimming at rates of up to 43 km/d (Canese et al., 2008). Swordfish undertake diel vertical migrations, generally staying within the mesopelagic zone during the day and moving into shallower waters to feed in the mixed layer during the night (Carey and Robison, 1981; Sedberry and Loefer, 2001; Abascal et al., 2010). These movements expose swordfish to a wide range of temperatures between 2.7°C (Braun et al., 2019) and 31.0°C (Fenton, 2012). The movements of juvenile swordfish appear to have similar but shallower diel patterns than those of adults (Fenton, 2012; Braun et al., 2019).

U.S. fisheries that target swordfish have operated in the western North Atlantic Ocean since the 1950s, although directed harpooning by commercial fishermen can be dated to the 1800s (Ellis, 2013) and indigenous Red Paint people harvested swordfish thousands of years ago in Maine (Bourque, 2012). Responding to a substantial decline in the North Atlantic swordfish stock, the International Commission for the Conservation of Atlantic Tunas in 1990 established a minimum size for retention (125 cm in lower jaw fork length [LJFL] with a 15% allowance for incidental catches) and restricted incidental catches to no more than 10% of the entire catch (Neilson et al., 2013). Additional regulations specific to the

U.S. fishery in the North Atlantic Ocean were later instituted, including an alternate lower retention size limit of 119 cm LJFL with a zero tolerance for retention of undersized swordfish in 1995 and a 10-year rebuilding plan involving a total allowable catch of 10,600 metric tons (t)/year (Neilson et al., 2013). Additionally, time-area closures were implemented by NOAA in 2000 to protect undersized swordfish (Neilson et al., 2013). In 2004, the use of circle hooks was made mandatory in the U.S. Atlantic pelagic longline fishery (Serafy et al., 2012). The North Atlantic swordfish stock was finally considered rebuilt in 2009 (Neilson et al., 2013).

Internationally, the fishery in the North Atlantic Ocean has had an average annual catch (landings of swordfish of a legal size combined with the number of undersized swordfish that were discarded) of around 10,400 t between 2012 and 2022 (ICCAT, 2023). The average number of undersized swordfish discarded, as a result of regulations based on a minimum size required for retention, was approximately 5844 individuals/year between 2017 and 2021 in the U.S. pelagic longline fishery alone (NMFS, 2022). Pelagic longline landings of swordfish have decreased since the 1990s because some fishermen in the U.S. waters of the Atlantic Ocean opportunistically target more valuable fish, such as tunas, or leave the fishery for economic reasons; however, swordfish are still targeted by fishermen that use buoy and rod-and-reel gears. Swordfish are also a common bycatch species in pelagic longline fisheries targeting tuna species, such as the bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) (ICCAT, 2019).

Several prior studies have reported postrelease survival rates for billfishes (family Istiophoridae) released from pelagic longline gear. Specifically, the survival of blue marlin (*Makaira nigricans*) was estimated at 77.8% (Kerstetter et al., 2003), the survival of sailfish (*Istiophorus platypterus*) was estimated at 88.2% (Kerstetter and Graves, 2008), and the survival of white marlin (*Kajikia albida*) was estimated at 63.0–89.5%, depending on inclusion or exclusion of tags that did not transmit data (Kerstetter and Graves, 2006). Similar results have been reported for recreational rod-and-reel fisheries, with white marlin having 65% survival on J hooks and 100% survival on circle hooks (Horodysky and Graves, 2005). A meta-analysis across istiophorid billfishes found postrelease survival for this family to be about 86%, with most mortalities occurring from just minutes to a few days after release (Musyl et al., 2015).

Similar studies on swordfish are less common, and results have varied by gear type and size class. Tracey et al. (2023), who examined mortality of swordfish by recreational rod-and-reel gear, found that tagged adult swordfish had 86.4% survival, a rate that decreased to 44% when analysis included landed fish assessed as moribund, on the basis of a modified condition scale (Kerstetter et al., 2003) based on evaluations of overall activity, color, eyes, stomach eversion, and body musculature. However, in other studies, estimates of postrelease survival related to capture of swordfish on buoy gear ranged only from 57.9% (Rewis, 2023) to 64.3% (Fenton, 2012). A high mortality of undersized swordfish on pelagic longline gear was expected considering that the at-vessel mortality (fish that are dead at gear retrieval) for undersized individuals has been estimated between 78% and 88% across the various pelagic longline fisheries in the Atlantic Ocean (ICCAT, 2019). Because no literature has been published on the postrelease survival of undersized swordfish released alive from pelagic longline gear, the primary aim of this study was to fill this knowledge gap.

Materials and methods

Survivorship pop-up archival tags (sPATs) (model 407, Wildlife Computers Inc.[1], Redmond, WA), each with a medium-sized Domeier anchor (Wildlife Computers Inc.), were used to assess postrelease survival. This electronic tag automatically activates when its conductivity sensor detects seawater and its depth sensor detects that it is submerged below a programmed depth (10 m). The sPAT weighs 61 g and measures 11.8 by 3.8 cm, minus a flexible antenna. Tags were programmed for a 30-d deployment and had predetermined early release conditions for maximum depth (1700 m), as well as for the tag remaining at a constant depth (±2 m) or on the surface (depths of ≤1 m or for the wet-dry sensor indicating dry for over 50% of the time) for a period of more than 24 h. A constant depth would indicate death, with the carcass floating or sitting on the seafloor. Upon release from a fish and surfacing, each tag would transmit data to the Wildlife Computers Inc. portal through Argos system satellites (Argos Services, Ramonville-Saint-Agne, France). The sPAT has sensors that record daily minimum and maximum values for depth and temperature and the daily change between minimum and maximum light levels. Depth information from the final 5 d prior to pop off of each tag was recorded at 10-min intervals in addition to the daily minimum and maximum depths.

Swordfish were tagged aboard pelagic longline vessels of the U.S. commercial fishery, off the coast of South Carolina in the Charleston Bump region, off northeastern Florida in the vicinity of the Blake Escarpment, and off northeastern New Jersey around the Hudson Canyon (Fig. 1). Fishing took place between January 2021 and October 2023, when vessels were available. These vessels targeted albacore (*Thunnus alalunga*) and bigeye tuna using gangions with lines of approximately 12–20 m and 16/0 non-offset circle hooks baited with dead squid (*Illex* spp.), ballyhoo (*Hemiramphus brasiliensis*), or Atlantic mackerel (*Scomber scombrus*). The pelagic longline was deployed normally, with gear recovery starting after soak times of 8–12 h.

[1] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

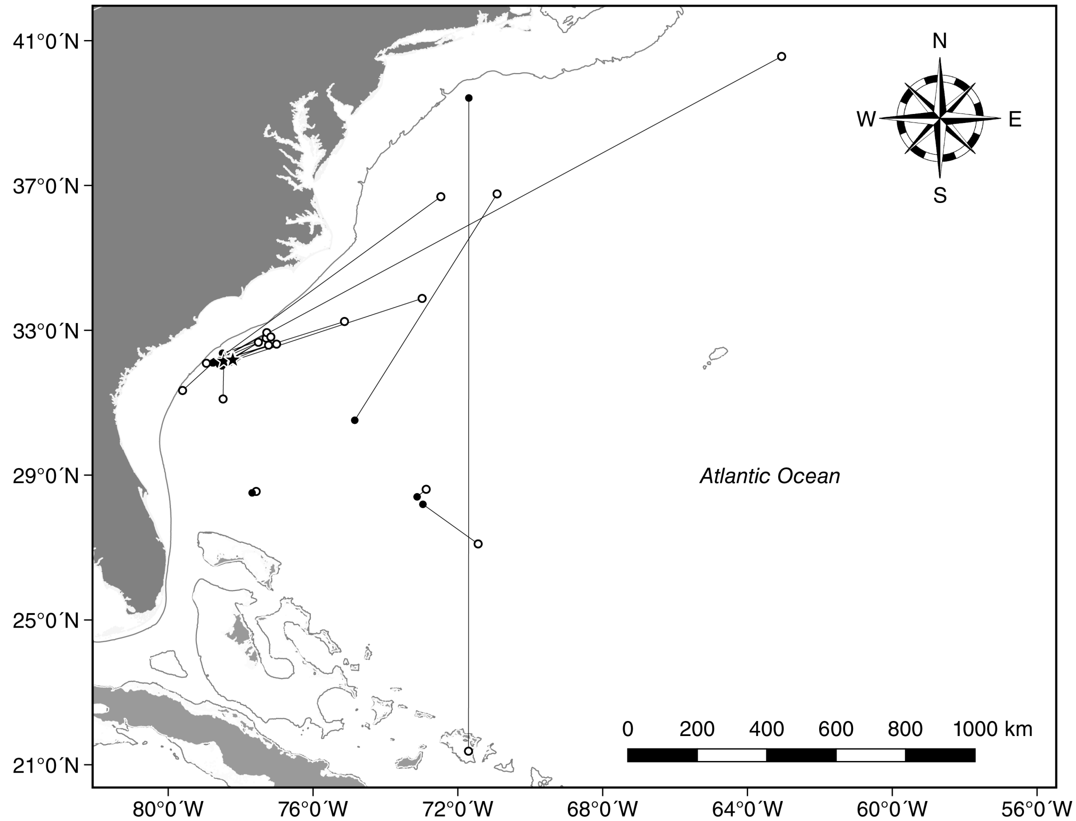

Figure 1

Map showing locations for survivorship pop-up archival tags (number of tags [*n*]=24) deployed on undersized swordfish (*Xiphias gladius*) released from pelagic longline gear in the western North Atlantic Ocean from January 2021 through October 2023. Net horizontal displacement for each of the tags that provided data (*n*=19) is shown as the straight line between the deployment location (black circles) and the first location where a tag transmitted data to the Argos satellite system following detachment from a swordfish (white circles). Black stars indicate deployment locations for tags that did not report data (*n*=5). The gray contour line indicates the shelf break at a depth of 140 m.

Size was visually assessed as straight LJFL, the straight-line distance between the tip of the lower jaw and the fork of the tail. Any swordfish between 74 and 119 cm LJFL (up to a visually estimated 120 cm) that was actively capable of swimming and had not sustained any mortal wounds (e.g., missing a caudal fin or significant chunks of the body) was considered a candidate for tagging. Smaller individuals (<74 cm LJFL) were not tagged because of concerns regarding the effect of tag size and the associated drag on and potential damage to fish from a tag (Grusha and Patterson, 2005), and larger individuals (>120 cm LJFL) could not be tagged because they were retained by crew for market. Size was estimated visually without removing fish from the water, although in instances when the size was close to either end of the size bracket, the fish was removed, measured, and tagged as quickly as possible. Tags were attached through the dorsal musculature such that the anchor would lock behind the pterygiophores below the dorsal fin midpoint. Tagging was conducted as quickly as possible, and the time taken never exceeding 1 min. Hooks were removed from individuals that were easily accessible, or the leader was cut as close to the hook as possible.

Survival of individuals was inferred by using the change in depth as well as changes in recorded environmental data (temperature and ambient light). Horizontal net displacement (HND) was also analyzed to support survival estimates and determine habitat utilization. Depth profiles were the primary means of determining mortality, and individuals whose movements included regular changes in depth over the course of the 30-d deployment period were considered to have survived their tagging. Depth time series were compared with those from Fenton (2012) and Lerner et al. (2013) to determine if behavior was normal (occupying the mesopelagic zone during the day and coming near the surface during the night) and to identify anomalies resulting from tag ingestion by a predator, such as a constant temperature despite increasing depth (e.g., Kerstetter et al., 2004). Both null movement (no depth changes within 24 h) and a steady increase in depth up to the maximum resulting in pop off of a tag were inferred as mortalities. The HND was calculated as the straight-line distance between the deployment location and the tag's first transmission to the Argos satellite system by using QGIS, vers. 3.30.2 (QGIS Development Team, 2023). Habitat preference was differentiated from mortality for short distances if the depth and environmental data did not indicate predation and the tag remained on the fish for the full 30-d period. A Kruskal–Wallis one-way analysis of variance was conducted to determine if there was a significant correlation ($P \leq 0.05$) between distance and direction traveled.

To analyze how the small sample size could have influenced the results of this study, a bootstrapping simulation was conducted by using Release Mortality (vers. 1.1.0), software developed by Goodyear (2002). This program was used to estimate the 90% confidence intervals of postrelease mortality over 10,000 simulations with a series of specified process, experimental, and decision variables. Initially, values of all variables except the release mortality fraction were set to zero, assuming no error sources (e.g., tag shedding or tags that did not transmit data). Then, 2 more simulations were conducted to analyze how outside errors may have influenced results. For these additional simulations, the variables were kept the same except for the decision variable *tags not reporting*. In the first simulation, tags that did not transmit data were included, and in the second simulation, such tags were excluded. Values for all process and experimental variables were based on results of this study or from prior research and were as follows: *tagging mortality fraction* (0.00; i.e., no assumption of tag-induced mortality), *tag failure probability* (0.25), *tag shedding probability* (0.04), and *natural mortality* (0.2, based on Griggs et al., 2005). The programmed duration from tagging to tag pop off was set to 30 d for all simulations, and the number of tags was set to 20 and doubled with every iteration until the confidence intervals were within 5% of the assumed true value. This procedure was similar to those used in prior studies (Goodyear, 2002; Fenton, 2012; and Rewis, 2023). For decision variables, data from tags reporting normally were included as data for surviving swordfish.

Maximum depth and time intervals taken from the final time series were qualitatively used in analysis of vertical habitat utilization for the 5 d prior to sPAT release to confirm individual swordfish survival. The time series from tags deployed on surviving fish were graphed to show depth variations over this interval. To avoid including in analysis of habitat utilization any atypical behaviors that may result from the capture and tagging of swordfish, only data recorded after 10 d was used (Hoolihan et al., 2015). Depth profiles from all tags were also evaluated for daily vertical movements, and a combined daily behavior trend line was created by using a generalized additive model. Statistical analyses in this study were conducted in RStudio, vers. 2023.03.0 (Posit Software PBC, Boston, MA). Daytime and nighttime intervals were determined by inputting the first location of tags after pop off into the web-based NOAA Solar Calculator (NOAA Earth System Research Laboratories, Global Monitoring Laboratory, available from website).

Results

Data from 16 of the 24 tags deployed (Table 1) were used for analysis of mortality, with 9 tagged fish surviving for the 30-d recording period. Five tags transmitted no data or began recording prior to deployment and did not provide relevant data. Additionally, 2 tags did not provide data, and 1 tag was shed. Habitat utilization was analyzed for the 9 fish that did not die. However, data from one of these tags was excluded from HND analysis because of an inaccurate pop-off location (tag 199973), and data from 2 tags indicate that fish experienced depths considered outlier values (tags 199966 and 199973). Multiple data points in the time series from tag 199966 indicate that the fish stayed at or near the surface for hours after sunrise. Although this trend was recorded only for this individual, it could be evidence of "basking" behavior that has been described previously (Carey and Robinson, 1981; Abascal et al., 2010; Fenton, 2012). Data from the last 4 d of the time series from tag 199973 indicate abnormal behavior, with the fish staying during night at increasingly deeper depths that were below the depths recorded by tags on other individuals.

Over the 30-d deployment period, 9 (56.2%) of the 16 fish for which data were analyzed survived. Between surviving individuals, HND varied from 22 to 783 km (mean: 367 km). The minimum average daily swimming speed varied between 1 and 26 km/d (mean: 12 km/d). Size of individual fish did not significantly influence the distance traveled (df=3, P=0.85). The orientation of HNDs was generally parallel to the coastline, with 6 of the tagged fish traveling northward and 2 tagged fish moving southward (Fig. 1). The 2 individuals that moved southward experienced the shortest HNDs, traveling only 22 and 116 km, whereas the northward moving fish all traveled a minimum distance of 168 km. There was a significant difference between the directional movement and distance traveled (df=1, P=0.05). Tagged swordfish inhabited the mesopelagic zone during the day and the epipelagic zone at night (Suppl. Fig. 1). The range of daytime depths was approximately 350–900 m, with an average of 544 m (standard deviation 154). Swordfish began to ascend approximately 2.6 h before dusk, then would begin to descend back to mesopelagic depths about 1.2 h before dawn. A generalized additive model of the daily movements from 7 of the surviving swordfish was constructed, explaining 74.5% of the variation in occupied depth (Suppl. Fig. 1).

Of the 7 tags on swordfish that died, 5 tags sank to the seafloor within hours of tagging, 1 tag remained at the surface with the fish making a brief dive midway through the second day before returning to the surface, and 1 tag recorded abnormal movement for multiple days before ceasing to capture any sort of intentional vertical

Table 1

Summary of movement and mortality assessments, based on data from 24 survivorship pop-up archival tags, for undersized swordfish (*Xiphias gladius*) released from pelagic longline gear deployed in the western North Atlantic Ocean during January 2021–October 2023. Horizontal net displacement (HND) was recorded to support survival estimates and determine habitat utilization. Mortality categories include alive, tag not reporting (NR), dead, premature release (PMR), and not determined from available data (ND). An asterisk (*) indicates that the length is an actual measurement of an individual removed from water, rather than a visual estimate.

Tag ID	Date tagged	Length (cm)	HND (km)	Days at liberty	Mortality
199947	2021-05-30	110	770.74	30	Alive
199948	2021-06-03	120	–	–	NR
199950	2021-06-03	90	120.58	1	Dead
199951	2021-05-30	110	169.61	30	Alive
199952	2021-06-03	115	–	–	NR
199954	2021-05-30	120	363.76	30	Alive
199955	2021-05-30	100	116.00	30	Alive
199956	2021-05-31	100	140.82	1	Dead
199957	2021-05-30	110	167.82	30	Alive
199958	2021-06-02	100	119.24	1	Dead
199959	2021-05-30	122	1690.45	30	ND/PMR
199960	2021-01-21	118*	11.68	3	Dead
199961	2021-05-31	115	–	22	ND
199962	2021-05-31	100	–	–	NR
199963	2021-06-03	90	–	–	NR
199966	2021-06-02	90	543.00	30	Alive
199967	2021-01-30	119*	193.25	5	ND/PMR
199973	2021-06-02	90	110.62	30	Alive
199975	2021-06-05	80	134.77	1	Dead
199986	2021-05-30	100	170.14	1	Dead
199987	2021-01-31	110*	33.66	1	Dead
199989	2021-05-30	100	22.19	30	Alive
199993	2023-10-08	80*	2000.00	30	ND
199994	2023-05-30	100	783.38	30	Alive

movement indicative of a swimming fish and floating to the surface. All recovered depth profiles from tags are provided in Supplementary Figure 2.

The results of the analyses done with the Release Mortality software indicate that some 1200 tags would be needed to verify the precision of the mortality estimate to 5% above or below the confidence interval, with a true mortality rate of 43.8% (90% confidence interval: 29.2–58.3%) (Suppl. Fig. 3). The addition of variables, such as *tag failure probability*, *tag shedding probability*, and *natural mortality*, led to a widened 90% confidence interval of 27.8–66.7%.

Discussion

The expense of satellite archival tags and their deployment continues to present barriers to collecting data from fish tags in numbers large enough to allow rigorous analysis across multiple condition strata, such as accumulated hooking time. One of the many challenges faced during this study was that the concentrations of undersized swordfish and other bycatch in the catch of cooperating vessels could not be known in advance, making it difficult to reliably tag undersized individuals on any given trip. The tags deployed in this study were few in number. However, results of the bootstrapping analyses indicate that the number of deployments needed for more precise confidence intervals are not practical because of both the cost of tags and the logistical effort necessary.

Adding to the difficulty of obtaining significant sample sizes is the potential for tags to fail to report usable data. Scientists encounter several challenges in deployment of electronic tags on pelagic fish species, and tags not reporting data is a common occurrence in studies involving satellite tags on swordfish (Canese et al., 2008). Tags can fail to report for several reasons, including biofouling (accumulation of aquatic organisms) that can prevent a tag from surfacing and transmitting data, battery drain over extended periods prior to deployment (Hays et al., 2021), entanglement with debris (Fenton, 2012), and damage due to predation (Kerstetter et al., 2004). In addition to tags that do not report data, the premature release of tags due to detachment either of the anchor or a break of the wire between the tag and the anchor, tag shedding, can also reduce sample sizes even though tags that are released early do report some data. Tag shedding is common in studies of istiophorid billfishes (e.g., Canese et al., 2008). One tag (tag 199967) was deemed to have prematurely shed on the basis of the normal behavior of the fish prior to tag release. Because the fate of the fish after tag 199967 was released is unknown, mortality cannot be determined, even if the behavior inferred from the data is that of a healthy individual.

It is likely that mortalities observed in this study were related to exposure to stressors incurred over the extended pelagic longline soak times, given the short time span between release and apparent mortality events. However, it is not practical to attach electronic timers that record the duration of hooking across the hundreds of hooks deployed in a standard pelagic longline set. Mortality occurred within hours for all but one fish, which died 3 d after tagging, appearing to be unable to stay at depth and not following the movement patterns typical for swordfish. Pelagic longline gear likely subjects swordfish to greater post capture stress than other gear types, because of the higher potential for swordfish to be on the line for extended periods due to the length of time that longlines need to be deployed. Indeed, previous research indicates that at-vessel mortality of undersized swordfish within the U.S. Atlantic fleet has been 65–79% since the implementation in 2004 of the requirement for the use of circle hooks (ICCAT[2]). High mortality rates have been reported throughout the Atlantic Ocean for other pelagic longline fleets, such as the fleet that operates in Portugal and has a reported at-vessel mortality of 87.8% (Coelho and Muñoz-Lechuga, 2019). Mortality is influenced by several factors, including vessel practices, seasonality, and hooking location and therefore varies temporally and between fleets. For example, Serafy et al. (2012) found that the required adoption of circle hooks in U.S. pelagic longline and recreational tournament fisheries has led to an 8% reduction in mortality for billfishes and may explain why these U.S. fisheries have lower mortality rates than other fleets that deploy J hooks.

The survival rates of undersized swordfish caught on pelagic longline gear is lower than that reported for other gear types. Tracey et al. (2023) tagged swordfish exclusively caught on rod-and-reel gear with angling times typically of only around 1 h and reported a postrelease survival rate of 44% (when including moribund individuals deemed not suitable for tagging). Fenton (2012) reported survival rates of 64.3% for swordfish caught on buoy and recreational rod-and-reel gears and reported no at-vessel mortality prior to tagging. However, at-vessel mortality might be expected to be lower given that these gear types are deployed for shorter durations than pelagic longlines and are more closely monitored by vessels. As such, individual fish do not spend as much time on these other gear types compared to pelagic longlines, which soak in the water for 10–14 h (NMFS, 2022) and then take additional hours to fully retrieve. The results of our study also indicate that swordfish have lower postrelease survival on pelagic longlines than istiophorid billfishes, whose survival typically is around 86% on this gear type (reviewed by Musyl et al., 2015). Although the reason for this difference in survival is not clear, it is possible that the biology of swordfish differs from that of istiophorids such that the species is less capable of recovering from catch-induced stress.

Within the context of commercial pelagic longline fisheries, most undersized swordfish do not survive capture events. Given the 65–79% (ICCAT[2]) at-vessel mortality of undersized swordfish in U.S. fisheries and the estimated 43.8% postrelease mortality determined in our study, the total mortality for undersized swordfish would likely fall between 80% and 88%. Such a result calls into question the overall effectiveness of the current minimum size required for retention and its effect on fish biomass and stock conservation. To put this range of total mortality into perspective, consider that, of the 5844 undersized swordfish caught per year on average between 2017 and 2021 (NMFS, 2022), 4675–5143 swordfish too small to retain likely died in that period within the U.S. fishery alone. Although this amount is small in comparison to actual retained catches (Fig. 2), it represents a substantial level of mortality of unharvested fish.

Regulations that mandate the discard of all individuals that do not meet the minimum size for retention have discouraged the targeting of small swordfish, given that the reported percentage of landed swordfish that were undersized between 2000 and 2015 internationally was reduced from 33% to 23% (ICCAT, 2019). Revisiting the International Commission for the Conservation of Atlantic Tunas management rule that was used from 1990 to 2004, an alternative of a larger minimum size with retention of a percentage of undersized swordfish, could reduce the number of dead swordfish discards without incurring additional mortality in the stock. However, such a measure would need to be approached with caution. An overcorrection could undo decades worth of stock rebuilding and incur opposition from other domestic swordfish fishery stakeholders. The results of this study do not provide clear support for any proposed management policy changes.

If, after further research, the requirement of a minimum size for retention is deemed to insufficiently reduce stock mortality, additional policies could be implemented in U.S. fisheries to further reduce catch rates of undersized swordfish or to improve their survivorship. The mandate for the use of circle hooks in the U.S. pelagic longline fleet has led to an 8% reduction in mortality within swordfish fisheries (Serafy et al., 2012), but many international fleets resist

[2] ICCAT (International Commission for the Conservation of Atlantic Tunas). 2022. Report of the 2022 ICCAT Atlantic swordfish stock assessment (online, 20–28 June 2022), 96 p. ICCAT, Madrid, Spain. [Report on stock assessment meeting held by ICCAT.] [Available from website.]

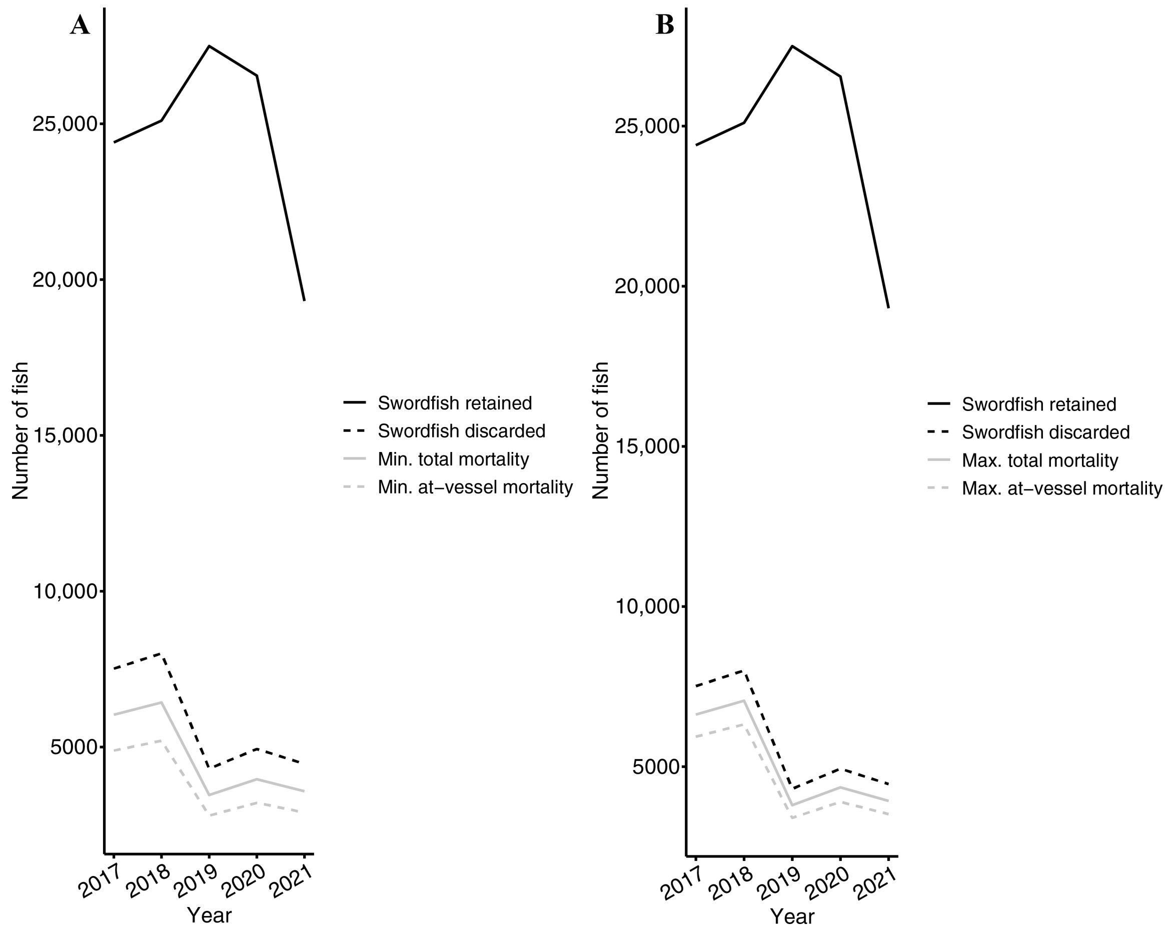

Figure 2

Estimated numbers of swordfish (*Xiphias gladius*) retained and discarded in the U.S. pelagic longline fishery during 2017–2021, based on the assumption of (**A**) minimum (65%) and (**B**) maximum (79%) estimates of at-vessel mortality from the stock assessment meeting held in 2022 by the International Commission for the Conservation of Atlantic Tunas. Total mortality represents the combination of at-vessel mortality and the 43.8% postrelease mortality found in this study. Data for captured swordfish that were discarded because they were smaller than the size required for retention (119 cm in lower jaw fork length) and that were retained in the fishery are from the stock assessment and fishery evaluation report for Atlantic highly migratory species published by the National Marine Fisheries Service in 2022. The difference between panels in values shown is the addition of the numbers of retained swordfish in panel B.

regulation regarding the use of circle hooks. Limiting soak times could reduce the physiological stress on caught fish and decrease mortality, but it also could likely lead to a reduction in target species yield, which would result in an increase in fishing effort to maintain current catch levels. An increase in hook size could reduce interactions with undersized swordfish (Kerstetter[3]) but may also reduce catch of smaller target species, such as bigeye tuna and yellowfin tuna. A combination of measures to reduce the mortality of undersized swordfish should continue to be examined.

The study described herein is the first assessment of the postrelease survival rate of undersized swordfish caught on pelagic longline gear, information that could be used to provide a correction factor for future stock assessments. Although the sample size was small, the postrelease survival rate of 56.2% is both lower than that for several istiophorid billfishes released from pelagic longline gear in U.S. fisheries and lower than that for swordfish released from buoy gear or recreational rod-and-reel gear. Future research should focus on increasing the number of tags deployed to refine this preliminary estimate of survival, and this work should include analysis of variables such as temperature, time hooked on gear, and hook type, as well

[3] Kerstetter, D. W. 2004. Preliminary gear comparison between 16/0 and 18/0 sizes non-offset circle hooks in the Southeastern U.S. coastal pelagic longline directed swordfish fishery. VIMS Mar. Resource Rep. 2004-07, 19 p. Va. Inst. Mar. Sci., Coll. William Mary, Gloucester Point, VA. [Available from website.]

as associated physiological stress responses. Although a majority of tagged individuals survived release in this study, this result combined with the high at-vessel mortality rates estimated in previous studies for swordfish caught by pelagic longline gear indicates that minimum retention lengths may not have substantial conservation benefits beyond discouraging targeting. Management policies could be altered without biological detriment to the stock to allow some incidental retention of undersized swordfish while also discouraging the targeting of undersized individuals, but such options are very likely to be controversial among current stakeholders of the swordfish fishery.

Resumen

Se colocaron marcas archivadoras desplegables de supervivencia (sPAT) a peces espada (*Xiphias gladius*) liberados en palangreros pelágicos comerciales estadounidenses en el océano Atlántico Norte occidental. El propósito era determinar la supervivencia después de la liberación de individuos de talla inferior a la talla mínima de retención (119 cm de longitud mandíbula inferior-furcal) establecida por la Comisión Internacional para la Conservación del Atún Atlántico (CICAA). Entre 2021 y 2023, se colocaron 24 sPAT con una duración programada de 30 días para medir la profundidad, la temperatura y la luz ambiental. La temperatura y la profundidad se registraron como mínimos y máximos diarios, y el nivel de luz se registró como un cambio diario entre los valores mínimos y máximos. Los últimos 5 días de datos de profundidad también se registraron a intervalos de 10 minutos antes de la liberación para evaluar los movimientos a escala fina coherentes con la supervivencia. Diecinueve marcas transmitieron datos, y 16 de ellas tenían datos suficientes para el análisis. De estas marcas, 9 sPAT (56.2%) transmitieron datos consistentes con los movimientos de un pez espada superviviente. Esta tasa de supervivencia es inferior a las registradas en estudios anteriores utilizando caña con carrete y boyas para pez espada, lo que indica que la captura con palangre pelágico causa un mayor estrés al pez espada que esos otros equipos de pesca. Este resultado, combinados con estudios previos sobre las tasas de mortalidad a bordo, indica que la norma actual de CICAA sobre la talla mínima de retención ofrece beneficios limitados para la conservación de las poblaciones del pez espada.

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Literature cited

Abascal, F. J., J. Mejuto, M. Quintans, and A. Ramos-Cartelle.
2010. Horizontal and vertical movements of swordfish in the southeast Pacific. ICES J. Mar. Sci. 67:466–474. Crossref

Braun, C. D., P. Gaube, P. Afonso, J. Fontes, G. B. Skomal, and S. R. Thorrold.
2019. Assimilating electronic tagging, oceanographic modelling, and fisheries data to estimate movements and connectivity of swordfish in the North Atlantic. ICES J. Mar. Sci. 76:2305–2317. Crossref

Bourque, B.
2012. The swordfish hunters: the history and ecology of an ancient American sea people, 158 p. Bunker Hill Publishing, Piermont, NH.

Canese, S., F. Garibaldi, L. Orsi Relini, and S. Greco.
2008. Swordfish tagging with pop-up satellite tags in the Mediterranean Sea. Collect. Vol. Sci. Pap. ICCAT 62:1052–1057. [Available from website.]

Carey, F. G., and B. H. Robison.
1981. Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. Fish. Bull. 79:277–292.

Coelho, R., and R. Muñoz-Lechuga.
2019. Hooking mortality of swordfish in pelagic longlines: comments on the efficiency of minimum retention sizes. Rev. Fish Biol. Fish. 29:453–463. Crossref

Ellis, R.
2013. Swordfish: a biography of the ocean gladiator, 296 p. Univ. Chicago Press, Chicago, IL.

Fenton, J.
2012. Post-release survival and habitat utilization of juvenile swordfish in the Florida Straits. M.S. thesis, 106 p. Nova Southeastern Univ., Fort Lauderdale, FL. [Available from website.]

Goodyear, C. P.
2002. Factors affecting robust estimates of the catch-and-release mortality using pop-off tag technology. Am. Fish. Soc. Symp. 30:172–179.

Griggs, L., M. Francis, and C. Ó. Maolagáin.
2005. Growth rate, age at maturity, longevity, and natural mortality rate of swordfish (*Xiphias gladius*). N.Z. Fish. Assess. Rep. 2005/56, 27 p. Minist. Fish., Wellington, New Zealand. [Available from website.]

Grusha, D. S., and M. R. Patterson.
2005. Quantification of drag and lift imposed by pop-up satellite archival tags and estimation of the metabolic cost to cownose rays (*Rhinoptera bonasus*). Fish. Bull. 103:63–70.

Haplin, L. R., M. Galbraith, and K. H. Morgan.
2018. The first swordfish (*Xiphias gladius*) recorded in coastal British Columbia. Northwest. Nat. 99:63–65. Crossref

Hays, G. C., J.-O. Laloë, A. Rattray, and N. Esteban.
2021. Why do Argos satellite tags stop relaying data? Ecol. Evol. 11:7093–7101. Crossref

Hoolihan, J. P., J. Luo, D. Snodgrass, E. S. Orbesen, A. M. Barse, and E. D. Prince.
2015. Vertical and horizontal habitat use by white marlin *Kajikia albida* (Poey, 1860) in the western North Atlantic Ocean. ICES J. Mar. Sci. 72:2364–2373. Crossref

Horodysky, A. Z., and J. E. Graves.
2005. Application of pop-up satellite archival tag technology to estimate postrelease survival of white marlin

(*Tetrapturus albidus*) caught on circle and straight-shank ("J") hooks in the western North Atlantic recreational fishery. Fish. Bull. 103:84–96.

ICCAT (International Commission for the Conservation of Atlantic Tunas).
2019. SWO-ATL—Atlantic swordfish. *In* Report of the Standing Committee on Research and Statistics (SCRS) (Madrid, Spain, 30 September to 4 October 2019), p. 164–187. ICCAT, Madrid, Spain. [Available from website.]
2023. SWO-ATL—Atlantic swordfish. *In* Report of the Standing Committee on Research and Statistics (SCRS) (Hybrid/Madrid (Spain) 25–30 September 2023), p. 173–193. ICCAT, Madrid, Spain. [Available from website.]

Kerstetter, D. W., and J. E. Graves.
2006. Survival of white marlin (*Tetrapturus albidus*) released from commercial pelagic longline gear in the western North Atlantic. Fish. Bull. 104:434–444.
2008. Postrelease survival of sailfish caught by commercial pelagic longline gear in the southern Gulf of Mexico. North Am. J. Fish. Manag. 28:1578–1586. Crossref

Kerstetter, D. W., B. E. Luckhurst, E. D. Prince, and J. E. Graves.
2003. Use of pop-up satellite archival tags to demonstrate survival of blue marlin (*Makaira nigricans*) released from pelagic longline gear. Fish. Bull. 101:939–948.

Kerstetter, D. W., J. J. Polovina, and J. E. Graves.
2004. Evidence of shark predation and scavenging on fishes equipped with pop-up satellite archival tags. Fish. Bull. 102:750–756.

Lerner, J. D., D. W. Kerstetter, E. D. Prince, L. Talaue-McManus, E. S. Orbesen, A. Mariano, D. Snodgrass, and G. L. Thomas.
2013. Swordfish vertical distribution and habitat use in relation to diel and lunar cycles in the western North Atlantic. Trans. Am. Fish. Soc. 142:95–104. Crossref

Musyl, M. K., C. D. Moyes, R. W. Brill, B. L. Mourato, A. West, L. M. McNaughton, W.-C. Chiang, and C.-L. Sun.
2015. Postrelease mortality in istiophorid billfish. Can. J. Fish. Aquat. Sci. 72:538–556. Crossref

Neilson, J. D., S. Smith, F. Royer, S. D. Paul, J. M. Porter, and M. Lutcavage.
2009. Investigations of horizontal movements of Atlantic swordfish using pop-up satellite archival tags. *In* Tagging and tracking of marine animals with electronic devices (J. L. Nielsen, H. Arrizabalaga, N. Fragoso, A. Hobday, M. Lutcavage, and J. Sibert, eds.), p. 145–159. Springer, Dordrecht, Netherlands.

Neilson, J., F. Arocha, S. Cass-Calay, J. Mejuto, M. Ortiz, G. Scott, C. Smith, P. Travassos, G. Tserpes, and I. Andrushchenko.
2013. The recovery of Atlantic swordfish: the comparative roles of the regional fisheries management organization and species biology. Rev. Fish. Sci. 21:59–97. Crossref

NMFS (National Marine Fisheries Service).
2022. Stock assessment and fishery evaluation report: Atlantic highly migratory species 2022, 254 p. Highly Migr. Species Manag. Div., Off. Sustainable Fish., Natl. Mar. Fish. Serv., Silver Spring, MD. [Available from website.]

Palko, B. J., G. L. Beardsley, and W. J. Richards.
1981. Synopsis of the biology of the swordfish, *Xiphias gladius* Linnaeus. NOAA Tech. Rep. NMFS Circ. 441, 21 p.

Rewis, C.
2023. Evaluating post-release survival and distribution of juvenile swordfish (*Xiphias gladius*) caught on buoy gear within the Gulf of Mexico and the Florida Straits. M.S. thesis, 146 p. Nova Southeast. Univ., Fort Lauderdale, FL. [Available from website.]

Sedberry, G. R., and J. K. Loefer.
2001. Satellite telemetry tracking of swordfish, *Xiphias gladius*, off the eastern United States. Mar. Biol. 139:355–360. Crossref

Serafy, J. E., E. S. Orbesen, D. J. G. Snodgrass, L. R. Beerkircher, and J. F. Walter.
2012. Hooking survival of fishes captured by the United States Atlantic pelagic longline fishery: impact of the 2004 circle hook rule. Bull. Mar. Sci. 88:605–621. Crossref

QGIS Development Team.
2023. QGIS Geographic Information System. Open Source Geospatial Foundation project. [Available from website, accessed May 2023.]

Tracey, S. R., J. Pepperell, and B. Wolfe.
2023. Post release survival of swordfish (*Xiphias gladius*) caught by a recreational fishery in temperate waters. Fish. Res. 265:106742. Crossref