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research paper

Characteristics and trends in the nighttime and daytime United States Atlantic recreational swordfish fishery based on fishery-dependent data

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ABSTRACT.—Over the past two decades, the United States' recreational fishery for North Atlantic swordfish, *Xiphias gladius* Linnaeus, 1758, has grown along the coasts of the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico. Successful management and high recruitment during an historical period of low biomass contributed to rebuilding the North Atlantic swordfish stock, leading to sustainable harvest opportunities. Over time, fisheries have shifted fishing gears and techniques to increase access to swordfish, a crepuscular fish that occupies deep waters during the day and ascends to shallower depths at night. Particularly among recreational anglers, a decline in drift (surface) fishing and popularization of the deep-drop technique shifted much of the fishing activity from night to day. Private angler and for-hire (charter) self-reported data on swordfish landings (retained catch) from 2003 to 2014 illustrated this shift in recreational fishing, including trip, technique, and catch characteristics. The majority of the landings occurred off southeast Florida (88%), where 70% of the swordfish were caught on private trips. The shift in technique was observed in reports from 2008 to 2014, which revealed a nearly synchronous 40% increase in deep-drop fishing and decrease in drift fishing, shifting the peak hookup (bite) times from 21:00–23:00 to 10:00–13:00 hrs. The average size of drift- and deep-drop caught swordfish increased; however, deep-drop caught swordfish were, on average, larger than those caught while drift fishing. These summaries reflect a modern characterization of this fishery and potential areas of improvement to this data collection.

Fishery practices often change to accommodate the availability of marine resources and the invention of gear and fishing techniques that improve the catch of target species. The adoption of technological innovations and new gear has been well studied in fisheries anthropological literature (Acheson 1981). In a review of patterns of gear change in Maine fisheries, Acheson (1988) found that fishers are highly adaptive and regularly switch between target species, fishing techniques, or gear types to improve their catch and the likelihood of financial gain. Within Acheson's 5-yr study, >50% of the fleet increased their versatility by changing these strategies. Ditton et al.

(1978) explored the generalist approach of Texas charter fishing captains, who target multiple fish species, adjust fishing strategies to match the seasonality of species, and supplement their income with employment in other professions. Torres-Irineo et al. (2014) cited technological improvements in fish detection as one of several changes that increased catch for purse seiners in the eastern Atlantic Ocean. Holley and Marchal (2004) described the development of new strategies in French commercial offshore fleets when constraints were placed on traditional fishing techniques. Flexibility or adoption of multiple fishing strategies gives fishers a greater capacity to acclimate to uncertain circumstances (Martin 1979, Acheson 1981).

The adoption of new fishing strategies, technology, or gear can be gradual, and there are more documented cases where innovations have been rejected instead of accepted (Acheson 1981, Holley and Marchal 2004). Holley and Marchal (2004) found that offshore Atlantic fleets were slow to acclimate to new fisheries. Not only did vessels and gears require reconfiguration, but so did the markets to support the sale of new products. Acheson (1981) noted that fishers tend to be more conservative, working within familiar social networks to experiment with innovations before adopting new gears or fishing methodologies, and may gradually incorporate changes into their business (Acheson and Reidman 1982). Rogers and Burdge (1972) found that advantageous, uncomplicated, triable, or observable innovations were adopted at a faster rate than those that required new methods of unknown efficacy. Changes that are easy to make (e.g., minor adjustments to vessel infrastructure), which also allow for fishing in similar areas for the same target species, may take less time to adopt than those which require new vessels, major adjustments to vessel configuration, and different skill sets (Acheson 1988).

Identifying and characterizing the adoption of new fishing strategies and the emergence of new fishing practices can explain shifts in catch trends. Fishery managers would have little insight in the role of fisheries in stock assessments without a source of baseline information and recent changes in fishing effort, target species, and catchability. For example, the northwest Atlantic cod fisheries used various gears to target cod during seasonal migration and aggregative spawning, resulting in repeated fishing on the same stock through various points in its migratory life cycle. This, accompanied by improvements in fishing technology (e.g., boat design, engine power, mechanized hauling devices, navigational aids, sonar, improved gear durability), contributed to an eventual collapse of cod populations (Neis et al. 1999). Without considering shifts in fishing practices, management and regulations would prove less effective and unable to fully capture the needs of the stocks or the potential of the fisheries. It is therefore vital to examine changes in fishing practices when they occur and, if possible, ensure that data are being collected to inform management.

In this case, we consider the nature of the United States' North Atlantic swordfish (*Xiphias gladius* Linnaeus, 1758) recreational fishery, which has fluctuated in effort and catch over the last two decades. Swordfish are a particularly important component of commercial and recreational fisheries off southeastern Florida (McKenna 1997, Levesque and Kerstetter 2007, Lerner et al. 2013), and are often targeted in the Florida Straits due to a combination of physical and oceanographic features that make this area favorable and accessible habitat. Swordfish fishing locations off other parts of the east coast of the United States tend to be much farther offshore (Sedberry and Loefer 2001, Lerner et al. 2013). Tracks of individual swordfish with satellite tags suggest an affinity for thermal fronts, upwellings, and other oceanographic structures (Sedberry and Loefer 2001, Dewar et al. 2011), which supports the concept that high commercial fishery catch rates are often associated with Gulf Stream thermal fronts (Podestá et al. 1993). Therefore, the Florida Straits create a migratory bottleneck that concentrates fish in an area relatively close to shore, making the fishing grounds easily accessible [i.e., 30–60 km from ports between Fort Lauderdale and Lighthouse Point (approximately 18 km north of Fort Lauderdale)] to a large number of anglers concentrated in southeastern Florida (Levesque and Kerstetter 2007).

In the mid-1990s, fishing effort was high and swordfish catch was declining (Arocha 1997). The stock biomass was 0.65 B/B_{MSY} (biomass over biomass at maximum sustainable yield); a level that could not sustain existing catch rates without leading to further stock declines. In 2001, the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS, or "NOAA Fisheries") closed the East Florida Coast area, which includes the Florida Straits, to commercial pelagic longline fishing. The closure was implemented to reduce bycatch, including the bycatch of undersized swordfish. These and other management measures, as well as a period of relatively good recruitment since 1997, contributed to an estimated 0.94 B/B_{MSY} in the 2002 the swordfish stock assessment, and an almost fully rebuilt stock in 2006 (NMFS 2003, Neilson et al. 2013). In 2007, the United States swordfish retention limits were increased (NMFS 2011), while the Florida Straits remained closed to commercial pelagic longline fishing, creating opportunities for revitalization of the recreational swordfish fishery in this area.

Recreational fishers employ several techniques to target swordfish, as the fish exhibit diel vertical movement patterns, including deep diurnal dives and shallow nocturnal ascent (Palko et al. 1981, Carey 1990, Dewar et al. 2011). Swordfish follow forage species to the upper water column at night (<100 m depth), moving vertically during crepuscular periods, and returning to depth (≥400 m) during the day, except when basking events at the surface are undertaken (Carey and Robinson 1981, Sedberry and Loefer 2001, Dewar et al. 2011, Lerner et al. 2013). Because shallower depths make fish more accessible, the traditional recreational swordfish fishery occurred primarily at night. Deploying the nighttime "drift" fishing technique, the vessel is allowed to drift while several rods deploy lines spread apart with floats, rigged with lights on the leaders, and weighted to fish in the upper 100 m of the water column (Levesque and Kerstetter 2007). In more recent years, the daytime swordfish fishing technique "deep-dropping" gained popularity, whereby the vessel is under power to maintain position while a lighted and heavily weighted line is deployed from an electric or manual reel to depths often exceeding 300 m (Suroviec 2007, MRIP and FWRI 2010, Conway 2014). This technique was originally developed by Reuben Jaen in Venezuela, where a submarine canyon is found close to shore (IGFA 2015), but has since been further adapted for fishing in the Florida Straits and elsewhere (e.g., Suroviec 2007, Conway 2014). Various baits, including live, dead, lure, or combination baits may be used. Field intercept surveys conducted by NOAA Fisheries and the state of Florida suggest that swordfish for-hire captains tend to use predominantly dead bait or artificial bait to target swordfish (MRIP and FWRI 2011). Occasionally, swordfish may be caught using other techniques, such as: trolling, whereby the boat is under power, towing baits in the upper water column; kite fishing, whereby the boat is often under power and baits are suspended from a kite; techniques targeting other fish (e.g., mackerel) that may have resulted in incidental catch of swordfish; or lesser known techniques.

To monitor the status of the North Atlantic swordfish stock, federal fishery managers have implemented a number of requirements in the recreational fishery. A highly migratory species (HMS) angling (recreational) permit or an HMS charter/headboat permit is required to fish for North Atlantic swordfish, and in 2014, the number of permits issued was 20,443 and 3801, respectively (NMFS 2014). To be retained, swordfish must meet a minimum length of 119.5 cm from the lower jaw to the fork of the tail (LJFL) or 63.5 cm from the cleithrum to caudal keel (CK) (50 CFR 635.20(f)). The trip retention limit is one swordfish per person, with up to 4 on private vessels, 6 on charter vessels, and 15 on headboats.

In addition to permitting requirements, all recreational swordfish landings must be reported to NOAA Fisheries within 24 hrs. A swordfish landing report includes the number of swordfish that were released on the trip; however, there is no report required of a purely catch-and-release swordfish fishing trip. Therefore, these reports consist solely of "successful" trips, wherein at least one swordfish was landed. As with all fishery-dependent data, the accuracy of each catch report is contingent upon the effort and proficiency of the angler completing it. Although reporting all swordfish landings is mandatory, compliance with this regulation has been of particular concern. Levesque and Kerstetter (2007) reported that, in 2002, southeast Florida fishers estimated about 10 recreational vessels target swordfish during the week and 30 recreational vessels target swordfish during the weekend (excluding activity in fishing tournaments). Since then, anecdotes from fishers to NOAA Fisheries staff suggest that these numbers could be greater. A field intercept (dockside) and random telephone survey conducted in 2009 of for-hire (charter and headboat) vessels in southeast Florida and the Florida Keys compared the number of fish observed in the survey to those reported to NOAA Fisheries (as required), finding that only 61.5% of the landed swordfish were reported (MRIP and FWRI 2011). A similar study was conducted from May 2008 to April 2009 with private anglers in Florida, finding that tournament and non-tournament recreational swordfish reports accounted for only 2/3 of the total number of fish landings estimated by the survey (MRIP and FWRI 2010).

There is relatively little literature on the practices or historical prominence of the recreational swordfish fishery, likely due to its relatively minor impact on abundance of the stock when compared to that of the commercial fishery. While surveys have characterized other aspects of the fishery, the requirement to report all recreational landings of Atlantic swordfish makes it possible to examine trends in fishing strategies and catch. These data have not previously been analyzed in the peer-reviewed literature, and provide an opportunity to identify recent changes associated with the fishery. Here, we summarize the fishing-trip, technique, and catch trends of the United States' North Atlantic recreational swordfish landings reported by fishers from 2003 to 2014, and provide a discussion on further interpretation of the trends found in these data, the association of behavioral shifts with other aspects of the recreational fishery, and improvement of the recreational landings reporting program.

Methods

Swordfish landings reports from 2003 to 2014 were obtained from the Atlantic Catch Reporting System (ACRS) to summarize and compare variables associated with fishing trips and catch. Data included all reports from the United States Atlantic coast, including the Gulf of Mexico and Caribbean Sea, identifying information about the permitted vessel, trip [date(s) and times of departure and return, port, type of trip], released species and their disposition (dead or alive), retained fish (species and size), and the circumstances around the capture of the fish (fishing technique, hook type, bait type, time hooked, and fight time). Because deep-drop fishing was not a technique listed in the ACRS until the 2008 fishing year, temporal comparisons of the nighttime drift fishing and daytime deep-drop fishing trip characteristics were made between 2008 and 2014.

Data were georeferenced and displayed as scaled (i.e., size of point reflects the number of data points that fell within the polygon) centroids within the telephone area code associated with the port at which the swordfish was landed to show the spatial distribution of reported landings. Agency confidentiality policies prohibited the display of individual point data; therefore, data were aggregated to no fewer than three reports across a polygon. Polygons depicting city limits (excluding unincorporated areas), county, area code, or state boundaries were available. The area code of the landing port was selected because the polygons were large enough to encompass multiple cities and counties (thereby showing more data) and provide a higher spatial resolution than aggregations across entire states.

Temporal trends in landings reports from southeastern Florida were further analyzed using Marine Geospatial Ecology Tools (MGET), an ArcGIS toolbox developed by Duke University (Roberts et al. 2010; available from: http://mgel.env.duke.edu/mget). Specifically, the "Analyze Temporal Periodicity of Catch" tool was used to evaluate patterns in the temporal periodicity of swordfish landings reports (based on the geographic coordinates of the location of landing). The following description was summarized from the MGET help documentation on this tool in ArcGIS. Output produced from this tool included: (1) a periodogram plot created from a Fourier analysis on catch records extracted from the area of interest, which dictated whether repeating temporal patterns existed in the data; and (2) several orbital plots that aided in identification of annual, lunar, or diurnal cycles. To generate the periodogram, the Temporal Periodicity tool decomposed the overall pattern in the data into a series of sine waves with different frequencies and amplitudes. Each sine wave represented a temporal phenomenon in the data. The tool then summed together the sine waves and plotted a reconstructed line that contained multiple peaks, which correspond to the peaks in each of the individual sine waves, thereby reflecting all of the patterns observed in the data. The resulting plot, a periodogram, compared the period vs the spectral power (i.e., a measure of the strength of an individual wave or peak to an overall pattern) of the reconstructed line. The importance of a temporal phenomenon is indicated by the strength of its associated peak (i.e., spectral power; shown on the y-axis) relative to the overall pattern over time (x-axis). The output from this tool was visually interpreted by examining the periodogram to identify peaks with high spectral power, and then considering the radial plots for additional context on the timing of the observed phenomenon. For example, if the periodogram contained an observable peak at 365 d, this could have indicated an annual peak in reported swordfish landings for a particular fishery. Examination of the orbital plots associated with the tool would have provided an indication of when this peak might occur during the calendar year (MGET Help Documentation; MGET version 0.8a60, released July 23, 2015; http://mgel.env.duke.edu/mget). An MGET analysis of temporal periodicity of reported landings was conducted on data associated with three port of landing area codes spanning southeast Florida (roughly Palm Beach County to Key West, Florida) that contained the majority of the self-reported data.

Landings characteristics and release information were compared by fishery technique using the Analysis ToolPak in Microsoft Excel. A one-way ANOVA was conducted to compare log-transformed mean lengths of swordfish landed from drift fishing and deep-dropping. Because swordfish landings reports summarize "successful" trips, and do not include all trips that targeted but did not retain any swordfish, fishing effort (e.g., catch per hours fished) was not analyzed. The relationship between the number of vessels, trips, and fish reported across years was tested for covariance. Swordfish reported as released alive and dead on successful trips (2008–2014) were summarized. However, it should be noted that anglers only reported releases associated with successful trips. The regulations specify that reporting is mandatory only when fish are retained. The data set therefore does not accurately capture data associated with catch-release trips or unsuccessful trips, and results presented herein only characterize discard rates for successful trips.

Results

Trip Characteristics.—Analysis of the recreational swordfish landings reports characterized fishing trips based on trip type, technique, bait type, and hookup time (the time at which the fish bit the hook). Several trends emerged across the fishery from 2003 to 2014 (all years of available data), and for drift and deep-drop fisheries at times when anglers could distinguish between the two types of fishing in landing reports (2008–2014).

The majority of the landings reports from 2003 to 2014 were from private trips (70%), followed by charter trips (28%). Prior to the addition of the deep-drop fishing category to the ACRS in 2008, drift fishing was reported by private vessels for 78% of swordfish landings (n = 1111) and charter vessels for 69% of swordfish landings (n = 375). From 2008 to 2014, however, reports of drift fishing decreased from 61% to 22%, by an average of 2% yr^{-1}; conversely, reports of deep-drop fishing increased from 34% to 77%, by an average of 7% yr^{-1}. Over that period, private vessels reported deep-drop fishing for 58% of successful trips, and charter vessels reported deep-drop fishing for 80% of successful trips (Table 1, Fig. 1). Landings reports from 2003 to 2014 implied peak activity in the middle of the day and late in the evening. Reports submitted between 2008 and 2014 indicated that drift fishing hookup times ranged from 19:00 to 4:00 hrs, with most occurring between 21:00 and 23:00 hrs, while deep-drop hookup times ranged from 9:00 to 17:00 hrs, with most occurring between 10:00 and 15:00 hrs (Fig. 2). Between 2003 and 2014, hook ups were reported from dead bait (91%), combination baits and lures (6%), live bait (3%) (data not shown). From 2008 to 2014, the majority of all drift (84%) and deep-drop (92%) swordfish landings were caught using dead bait (squid, mackerel, or strip bait), although 14% of drift fishing trips used live bait [e.g., goggle eye, *Selar crumenophthalmus* (Bloch, 1793); blue runner, *Caranx crysos* (Mitchill, 1815); or other small "bait" fishes)] (Table 1). There was no significant change in the relationship between number of fish landed per vessel over time as the number of vessels, trips, and fish landed covaried overall; however, the mean number of swordfish caught per vessel was highest in 2012 (3.4 swordfish per vessel) (Table 2).

Table 1. Summary of private and charter swordfish landings reports (2008–2014): technique and bait type; percent values are rounded to the nearest whole integer.

				Bait type			
	Charter	Private	Total	Live	Dead	Lure	Combination
Total Landings	637	1,557	2,194				
Technique							
Deep Drop	80%	58%	1,412	1%	92%	0%	7%
Drift	19%	40%	746	14%	84%	0%	1%
Other	2%	1%	36	11%	82%	2%	5%
Bait type							
Live	4%	3%	71				
Dead	94%	90%	2,001				
Lure	0%	1%	12				
Combination	2%	6%	110				

Geospatial analysis of the distribution of self-reports suggested that the majority of landings (87%) occurred in ports located off southeastern Florida (>500 reports); however, a notable number of landings also occurred off the coast of central Texas (>100 reports) (Fig. 3). Smaller numbers of landings (26–100 fish) were reported from the Florida panhandle, Georgia, South Carolina, Virginia, New Jersey, and Rhode Island from 2003 to 2014.

Results of temporal periodicity analyses on the southeastern Florida drift fishery and deep-drop fishery (2008–2014) are shown in Figure 4. The deep-drop periodogram (Fig. 4B) contained a strong annual peak. The lack of any strong peaks on the deep-drop periodogram (Fig. 4B) for periods of time shorter than a year suggest minimal importance of shorter time scales on the periodicity of catch reports. In other words, the frequency of swordfish self-reporting in the deep-drop fishery may not be linked to shorter time cycles, such as moon phase. There was no single strong peak observable in the drift fishery data. The prevalence of multiple peaks on the drift

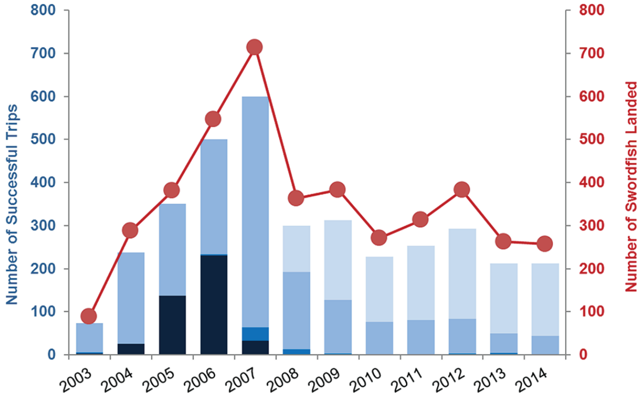

Figure 1. Number of (left axis) successful trips taken by technique (blue bars): deep-drop (lightest), drift (light), other (dark), and unreported (darkest); and (right axis) swordfish landed (red line and dots); 2003–2014. A “successful” trip means at least one swordfish was landed (retained and brought to land).

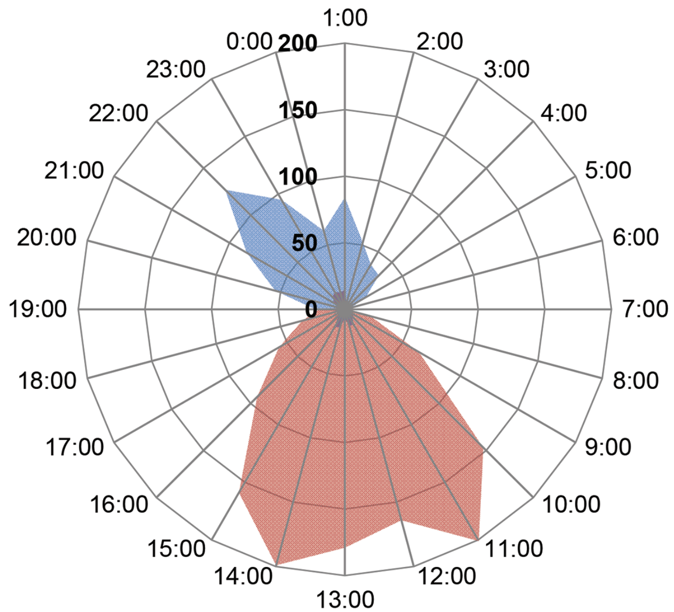

Figure 2. Fishing technique by time of hookup (2008–2014); blue (top) is drift fishing and red (bottom) is deep drop fishing; radial numbers indicate diel period; scale (0–400) indicates number of swordfish landing reports.

Table 2. Summary of swordfish landings reports from 2003 to 2014. *Total number of unique vessels that reported swordfish landings from 2003 to 2014.

	Total			Average		
Year	Vessels	Successful trips	Swordfish	Swordfish per trip	Successful trips per vessel	Swordfish per vessel
2003	36	74	89	1.2	2.1	2.5
2004	89	237	288	1.2	2.7	3.2
2005	126	350	381	1.1	2.8	3.0
2006	191	500	547	1.1	2.6	2.9
2007	254	597	714	1.2	2.4	2.8
2008	157	298	363	1.2	1.9	2.3
2009	158	311	383	1.2	2.0	2.4
2010	121	227	271	1.2	1.9	2.2
2011	109	248	313	1.3	2.3	2.9
2012	113	287	382	1.3	2.5	3.4
2013	98	207	263	1.3	2.1	2.7
2014	95	210	257	1.2	2.2	2.7
Average	129	296	354	1.2	2.3	2.8
Min	36	74	89	1.1	1.9	2.2
Max	254	597	714	1.3	2.8	3.4
Total	993*	3,546	4,251			

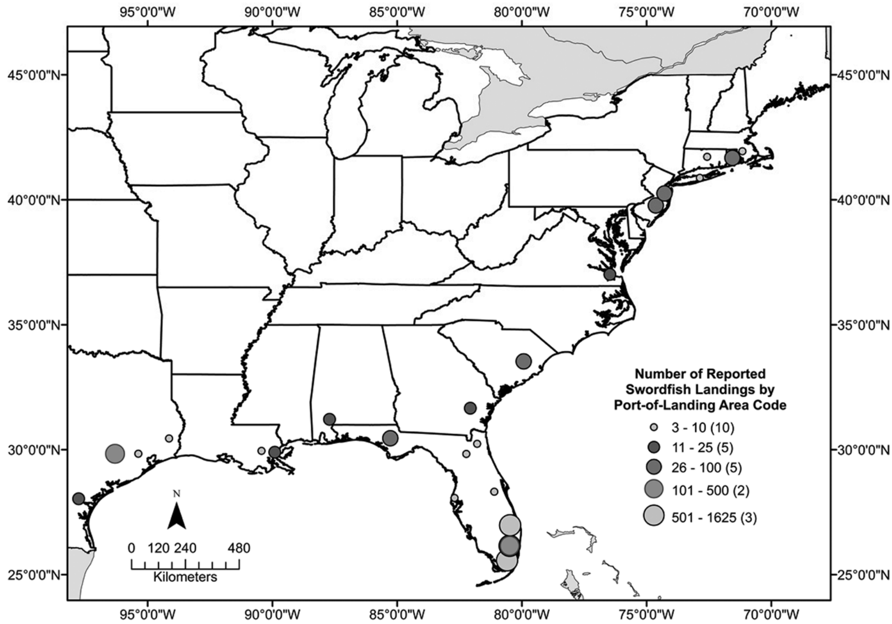

Figure 3. United States Atlantic self-reported recreational swordfish landings distribution by port of landing area code, 2003–2014 (n = 4251).

fishing periodogram of roughly the same magnitude (Fig. 4A) suggested that solar or lunar cycles in the data may not exist (MGET Help Documentation; MGET version 0.8a60, released July 23, 2015; http://mgel.env.duke.edu/mget). However, review of the monthly radial plots (Fig. 4C,D) indicated a possible peak with respect to the timing (month) of self-reporting in both fisheries. Self-reported drift fishery catch reports peaked in January, whereas self-reported deep-drop fishery catch reports peaked in the fall (September–November). Generally, it appeared that self-reporting

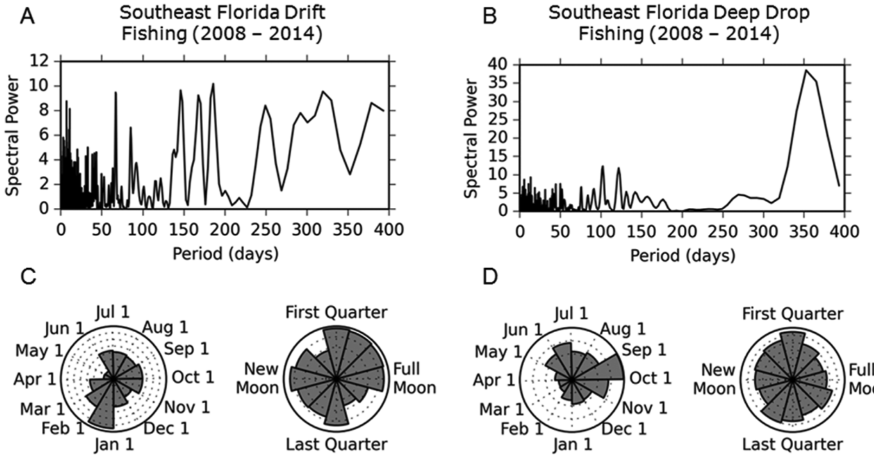

Figure 4. Temporal periodicity of self-reported catch data for the (A) recreational swordfish drift and (B) deep-drop fisheries.

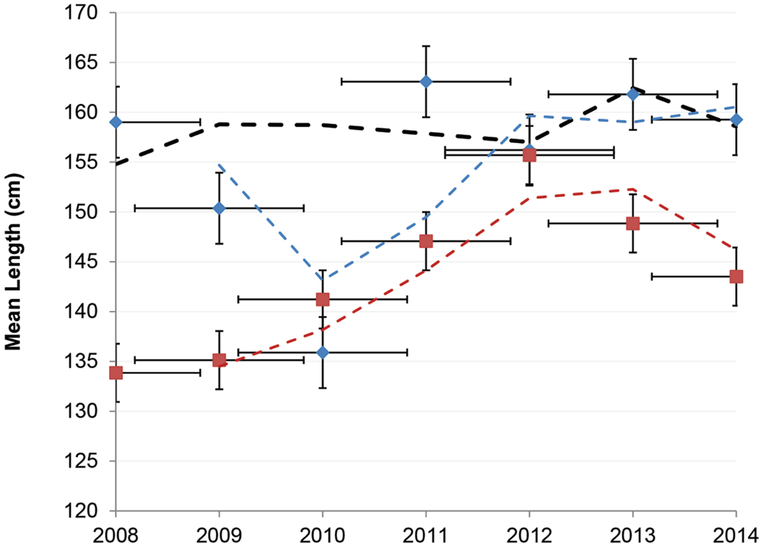

Figure 5. Mean length of swordfish landed by drift or deep-drop fishing over time (2008–2014); blue diamond is deep-drop fishing, red square is drift fishing; error bars are ± standard error; dashed blue (second from bottom) and red lines (bottom) are corresponding 2-pt moving averages; dashed bold black line is 2-pt moving average for all reports.

of swordfish catch occurred throughout the lunar cycle for both fisheries, but may be slightly biased toward first-quarter full moon in the drift fishery.

Landings and Discard Characteristics.—Recreational swordfish landings occurred across the Atlantic United States management area, but the majority of landings (89%) occurred off southeastern Florida (Fig. 3). Reported landings peaked in 2006 and 2007, and while lower, have since remained relatively consistent (Fig. 1).

The reported size of swordfish landed varied by time and technique. Overall, the mean size of reported swordfish increased from 2003 to 2014. While between the years of 2008 (when "deep-drop" was added as an option for fishing technique) and 2014, the mean reported swordfish lengths (LJFL) of those caught in the deep-drop and drift recreational fisheries varied significantly (one-way ANOVA of log-transformed data: $F_{1,12} = 5.92$, $P = 0.03$), there was no significant difference in size between swordfish caught while nighttime drift fishing vs day time deep-drop fishing (Fig. 5).

Most of the self-reported recreational discarded fish were released alive, regardless of the fishing technique. Between 2008 and 2014, recreational anglers reported the release of 1324 billfish on successful swordfish fishing trips (Table 3); of these, 240 animals (18%) were reported dead and 1084 (82%) were reported alive. Most of the reported releases were swordfish (Table 3); however, anglers also reported discards of blue marlin (*Makaira nigricans* Lacépède, 1802), white marlin [*Kajikia albida* (Poey, 1860)], sailfish [*Istiophorus platypterus* (Shaw, 1792)], and roundscale spearfish (*Tetrapturus georgii* Lowe, 1841). There were no significant differences in the proportions (Table 3) of swordfish discards that were reported dead for the drift fishery vs the deep-drop fishery.

Table 3. Summary of reported numbers and percentages of swordfish and Istiophorid billfish releases by fishing technique, disposition, and species during successful (at least one swordfish was landed) swordfish fishing trips from 2008 to 2014. * Kite, troll, or other fishing technique.

	Blue marlin		White marlin		Sailfish		Swordfish		Roundscale spearfish	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Reported numbers										
Deep drop	13	0	5	0	22	4	640	136	0	0
Drift	15	0	12	0	21	0	346	93	1	0
Other*	0	1	0	1	0	2	0	3	9	0
Percentages										
Deep drop	100%	0%	100%	0%	85%	15%	82%	18%	0%	0%
Drift	100%	0%	100%	0%	100%	0%	79%	21%	100%	0%
Other*	0%	100%	0%	100%	0%	100%	0%	100%	100%	0%

Discussion

The recreational deep-drop swordfish fishery is relatively new, and there is minimal information available in the scientific literature on this fishery; however, some information published about this fishery is in the gray literature (e.g., Conway 2014). The summary of landings data from the ACRS presented in the present study indicates a temporal shift from nighttime drift fishing to daytime deep-drop fishing in the recreational swordfish fishery over the past decade. Analyses on the for-hire fishery conducted by NOAA Fisheries and the state of Florida between 2008 and 2009 grouped deep-drop fishing in an "other" category (approximately 24% of trips), suggesting that, at least for the sampled pool of vessels, the primary techniques for targeting swordfish were either trolling or drift fishing (MRIP and FWRI 2011). Gradual increases in the utilization of the deep-drop method are not surprising. The deep-drop method requires modification of fishing gear and some training before it can be successfully employed, and may not be appropriate under some environmental conditions. It is evident that the deep-drop fishery has only partially been adopted by the recreational fishery, and expansion in the use of the technique is expected. The shift in fishing technique is more pronounced with charter vessels, which may be due to the nature of for-hire trips vs private angling trips. Deep-dropping is a method that can be employed during traditional daytime business hours and can provide access to swordfish fishing to vacationing clients that might not wish to embark on nighttime fishing trips. Anglers taking private trips on personal vessels may have greater flexibility in the duration and timing of their trips than those dependent on the schedules of charter companies. MRIP and FWRI (2011) reported that nearly 93% of swordfish charter trips are full-day trips (e.g., lasting >7 hrs and returning before 8:00 hrs the next day), with the mean trip length ranging between 7 and 8 hrs. MRIP and FWRI (2010) reported that the majority of private angler swordfish trips were single-day trips, but that approximately half (50.4%) were overnight or next-day trips returning within 24 hrs of departure. Additional evaluation of fishing technique from other data sources [e.g., Marine Recreational Information Program (MRIP)] may provide further insight into the shift from drift fishing to deep-drop fishing, since use of the deep-drop method was not a reportable option in the ACRS until 2008.

The growth in popularity of the deep-drop technique expanded the swordfish fishery, as it was previously limited to nighttime fishing trips. A switch from nighttime drift fishing to daytime deep-drop fishing may have provided access to fish that previously did not interact with the swordfish fishery (e.g., certain individuals remained too deep to be captured by the nighttime drift fishery). An overall increase in mean length could be considered a result of decreased commercial fishing pressure in important areas such as the Florida Straits, supporting the growth of the rebuilt North Atlantic swordfish stock; however, because swordfish are highly migratory, and their movement patterns are not yet fully understood, the effect of a localized fishing closure on fish size is unclear.

The southeastern Florida recreational fishery tends to fish multiple HMS by season. Private anglers and the charter fleet principally target sailfish in the winter, tuna and marlin in the spring and summer, and swordfish in the summer and fall (MRIP and FWRI 2010, 2011). Swordfish are present in the Florida Straits year-round (Taylor and Murphy 1992), but ACRS data suggest seasonal peaks in the timing of anglers submitting reports for deep-drop and drift fishery swordfish. Periodicity analyses suggest that a large number of recreational anglers report deep-drop caught swordfish in the fall, while drift fishers tended to report large numbers of swordfish in the early winter. This may be due to an increase in the abundance of swordfish off southeast Florida during the fall as these animals undertake seasonal migrations through the Florida Straits. Strong trends in periodicity on smaller time scales were not apparent in the deep-drop fishery. The periodogram for the drift fishery did not indicate a clear pattern; however, seasonal trends were noted. Help documentation for the Temporal Periodicity tool suggested that multiple peaks of similar magnitude may indicate the lack of a lunar or solar cycle in the data. Rerunning the analysis after additional years of drift fishery data have been collected may yield a more statistically robust (and clear) indication of cyclic patterns and resolve the discrepancy between the lack of strong patterns identified in the periodogram and the observed seasonal peak in reports shown in the radial plot. Other research does suggest strong associations between behavior and lunar cycles. Lerner et al. (2013) found that swordfish behavior is influenced by lunar cycles, noting strong positive relationships between depth and amount of lunar illumination from satellite tagged swordfish. A relationship between depth and the moon phase in pelagic longline fisheries was also observed, as commercial fishers set hooks deeper with increasing illumination to accommodate the behavioral responses of fish to the lunar cycle (Lerner et al. 2013). Recreational drift fishers are also known to modify fishing practices, deploying gear deeper during the full moon, when the best fishing is reported to occur (Levesque and Kerstetter 2007). Periodicity analyses also revealed an increase in the amount of self-reporting by the drift fishery in early winter. This peak may be related to the timing of permit renewals. Recreational anglers must renew annual permits at the end of each calendar year, which may serve as a reminder of reporting requirements.

Some constituents have expressed concern about the increased use of the deep-drop fishing technique and potential for harvest of larger swordfish in the Florida straits, which could remove more fecund animals from the population. The analyses completed here suggest that the overall difference in mean reported size between the drift and deep-drop fisheries was not large (10 cm difference in mean length). However, these conclusions are only based on landed fish and may not reflect the total population of swordfish that encounter each fishery. Therefore, it is important to continue monitoring the fishing practices across these fisheries; moreover, the recreational fishery is only a small portion of the overall United States and international swordfish fisheries. Between 2010 and 2014, annual recreational landings averaged 1.7% of total United States landings (NMFS 2015) and the United States fishery is part of the overall international fisheries for swordfish.

Compliance with billfish and swordfish reporting requirements is an issue of strong concern for NOAA Fisheries, and has implications for this analysis. A lack of reporting compliance means that less data are available for analysis and raises the risk for misrepresentation; therefore, the fishery as described here may not be fully representative of its participants. Additionally, in some years the numbers of reported swordfish landings are not large, and the influence of reports from an individual angler could significantly affect the results (see Table 2). For example, in 2014, there were a total of 257 self-reported swordfish logged in the ACRS. However, during that year a single charter-headboat captain provided 50 reports of landed swordfish (approximately 19% of the total reported landings). These data are not shown or discussed in great detail due to NOAA Fisheries data confidentiality requirements; however, it is not unusual for a small number of individuals to contribute a sizable proportion of the landings data within a given year. On the other hand, NOAA Fisheries has no reason to believe that these individuals (both private anglers and charter-headboat captains) are not representative of other fishery participants. Improved reporting compliance would reduce the risk that the characterization of the fishery is really a description of a sub-population of fishery participants. This is particularly important given the interest in the deep-drop fishing technique. NOAA Fisheries has anecdotal evidence that the deep-drop fishery is expanding outside of southeastern Florida. However, unless these participants actively report their participation in the fishery, then any future management actions, or engagement and outreach activities conducted by NOAA Fisheries, would be based on the known deep-drop fishery (which occurs within a limited area). Improvements in reporting compliance would necessitate a new analysis and characterization of the fishery, which is desirable, as a more robust data set would be less likely to reflect activity of a sub-population of participants (e.g., southeast Florida) and be more reflective of trends across the United States North Atlantic fishery.

Lack of reporting also has management implications for the United States. Swordfish are managed according to international treaty obligations and the provisions of the Atlantic Tunas Convention Act and the Magnuson-Stevens Fishery Management and Conservation Act. A lack of reporting could have consequences as the United States is currently underharvesting its swordfish quota issued by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Reporting data to NOAA Fisheries ensures that ICCAT consider an accurate quantity of swordfish that are needed for the United States' recreational and commercial swordfish fisheries. In addition, recreational landings are an important component of the data that are provided for ICCAT stock assessments.

The limitations of these analyses speak immediately to improvements that could be made in the recreational reporting system. Anglers are only required to report landed swordfish, bluefin tuna [*Thunnus thynnus* (Linnaeus, 1758)], and Istiophorid billfishes; therefore, a reliable estimate of effort or of numbers of discarded fish cannot be determined from this database as trips (or fishing hours) during which these species were not landed, are not included. Lack of zero-catch reports has historically been a problem in commercial sport fisheries, and was discussed in context of swordfish and billfish fisheries as early as 1972 at the International Billfish Symposium (Shomura and Williams 1975). The rate of successful swordfish trips is known to be higher for the charter fleet (20%–50%) than for private anglers (20%–30%) (MRIP and FWRI 2010, 2011). Incorporation of a simple no-catch report, perhaps made less burdensome through the development of mobile reporting applications, could aid in understanding the recreational fishery and conducting more robust statistical analyses; however, requiring anglers to submit such reports would involve thorough feasibility and environmental evaluation. The majority of billfish and swordfish bycatch from successful trip data in the ACRS was reported to have been released alive; however, this data set cannot be used to develop bycatch rates as it does not include data for catch-and-release trips or for unsuccessful trips. Fenton (2012) estimated post-release mortality of 35.7% for 16 juvenile swordfish captured off southeastern Florida in recreational drift fisheries. If this same percentage was applied to the live releases from successful trips in the drift fishery reported in Table 3, then an additional 124 fish (rounded up to the nearest fish) could be considered mortalities following the release events.

Absence of fishing effort data limits the ability to evaluate the cause of variations in swordfish landings data. For example, variability in the time ranges which characterize catches by the fishery may be influenced by changes in the amount or timing of fishing effort. In other words, the peak times for hookups reflect when the most lines are out on the water. Anglers are also not required to report the location of hookup; therefore, any geospatial analyses are limited to land-based assignments from the reported location of landing. For the present study, we used area codes to assign a geo-referenced location to landing ports; however, area codes often change and reference their source location on land. Further, recreational anglers that have access to waterfront may not always land catch in an incorporated city, or may elect to utilize water access in locations such as state parks and national seashores, and therefore report the nearest city as the port of landing. Automation or selection from drop-down menus in the ACRS would remove some of the potential for user error, inaccuracies, and inconsistencies in the data entry. Moreover, incorporating an interactive spatial grid on which the angler could select the landing location could provide more robust data for future geospatial analyses.

Changes in the recreational swordfish fishery, such as variations on fishing techniques or bait types, as well as technological advances, will continue to occur as anglers strive to improve catch rates. Data collected from recreational reporting of swordfish has previously only been used in fisheries management for quota monitoring and reporting purposes. Despite some limitations in how the data can be used, an analysis of this database can still provide useful information for future management options and long-term policy planning and implementation. NOAA Fisheries has undergone a number of policy, scientific, and management exercises concerning the recreational fisheries in recent years; in particular, the development and implementation of regional recreational action plans, the development of an HMS Recreational Action Plan, and various improvements to recreational data collection through MRIP. Summaries of characteristics and trends in the recreational swordfish fishery, as provided by fishery reporting programs, provide valuable insight into the potential effects that change (e.g., technological advances, changes in management measures, etc.) might have on the fishery. Improved understanding of the various recreational fisheries will help ensure that adequate consideration or evaluation of these fisheries is undertaken, and that the practices, trends, and economics of these fisheries are well represented in decision-making by NOAA Fisheries.

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