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Bycatch estimates of lemon shark in the shark bottom longline fishery

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Introduction

In 2021, per a request by the Office of Sustainable Fisheries, the Southeast Fisheries Science Center (SEFSC) determined that an external assessment of the lemon shark stock in the western North Atlantic (Hansell et al. 2020) represented the best scientific information available and can be used for management purposes. The SEFSC also concluded that the overall stock status was overfished with overfishing occurring. As such, the Atlantic Highly Migratory Species (HMS) Management Division's staff need projections, which were not provided in the assessment, in order to develop a rebuilding plan and determine when overfishing can be expected to stop. A memo sent from the Office of Sustainable Fisheries to the SEFSC and Northeast Fisheries Science Center (NEFSC) requests that they develop projections for rebuilding lemon sharks and confirm if overfishing is not occurring based on recent catch levels. Estimates of discards (live and dead) are a required since the terminal year of the stock assessment (2017) to develop these projections and determine if overfishing will end.

Currently about 200 United States (US) fishers are permitted to target sharks (excluding dogfish) in the Atlantic Ocean and Gulf of Mexico, with an additional number of fishers (<250) permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan based on stock assessments have eliminated the major directed shark fishery in the US South Atlantic (NMFS 2007). These amendments also implemented a shark research fishery, which allows the National Marine Fisheries Service (NMFS) to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments. Since 2008, only commercial shark fishers participating in the shark research fishery are allowed to land sandbar sharks, *Carcharhinus plumbeus*, and must carry an observer on 100% of all trips (compared to a coverage level of 4-6% outside the research fishery). Fishers not participating in the research fishery are permitted to land 45 non-sandbar large coastal sharks (including lemon shark, *Carcharhinus limbatus*, bull shark, *Carcharhinus leucas*, lemon shark, *Negaprion brevirostris*, nurse shark, *Ginglymostoma cirratum*, silky shark, *Carcharhinus falciformis*, spinner shark, *Carcharhinus brevipinna*, tiger shark, *Galeocerdo cuvier*, great lemon, *Sphyrna mokarran*, and scalloped lemon, *Sphyrna lewini*) per trip in the South Atlantic region.

Bottom longline landings and fishing effort of commercial vessels operating in the South Atlantic are

reported to NMFS through the Coastal Fisheries Logbook Program (CFLP, conducted by the NMFS Southeast Fisheries Science Center). The program collects landings and effort data by fishing trip from vessels that are federally permitted to fish in a number of fisheries managed by NMFS and South Atlantic Fishery Management Council. The coastal logbook program began in 1990 with the objective of a complete census of coastal fisheries permitted vessel activity, with the exception of Florida, where a 20% sample of vessels was selected to report. Beginning in 1993, reporting in Florida was increased to include all vessels permitted for federally managed coastal fisheries.

Commercial shark longline vessels operating in the US South Atlantic and Gulf of Mexico are also required to carry fishery observers to monitor catch and bycatch. Fishery observers are trained in fishery and biological data collection, biological sampling, and teleost and elasmobranch species identification. Observers are required to record and measure all species captured, their disposition (e.g. kept, discarded dead, used for bait, etc.) and effort (e.g. number of hooks, gear characteristics, set and haul times).

Herein, bycatch estimates are developed for lemon sharks captured in the shark bottom longline fishery.

Methods

Dead and live discards were reported separately for the shark research fishery and the shark bottom longline fishery. As vessels in the shark research fishery are monitored 100%, no extrapolations of the dead and live discards were needed. For vessels outside the shark research fishery (i.e. shark bottom longline fishery), observer- reported lemon shark discard rates from 2018-2022, along with self reported commercial fishing effort data, were used to calculate lemon shark discards for the shark bottom longline fishery in the US South Atlantic and Gulf of Mexico.

Following Xhang et al. (2022), the mean and variance of discard rates were calculated using the delta-lognormal method (Pennington, 1983). The method assumes a lognormal distribution of the positive bycatch rate observations. Effectively, the estimates are constructed as a product of the proportion of successful occurrences of an event and the average rate at which the event occurs for those successful events. The variance is a function of the variability of the positive bycatch rates as well the number of successful and unsuccessful sets. The delta estimator is more appropriate than the simple ratio estimate because catch rates are generally log-normally distributed and bycatch events (i.e., positive sets) are rare. The unit of effort in this analysis is the number of sets. Due to small number of sets in which a non-zero bycatch of the species group was observed (positive sets), observed sets are pooled by each observed year. The annual mean discard rate is based on the pooled observed sets for each observed year.

$$C = \frac{m}{n} e^{L} G_m \left(\frac{s^2}{2}\right)$$

When number of sets in which a non-zero bycatch was observed (positive sets) is greater than 1, the mean discard rate, *C*, is calculated as:

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m is number of sets in which a non-zero bycatch was observed (positive sets),
n is total number of sets observed,
L is the mean of the log-transformed number of animals taken per set for the positive sets,
s^2 is the variance of the log-transformed number of animals taken set hooks for the positive sets, and

$G_m(\frac{1}{2}s^2)$ is the cumulative probability function from the Poisson distribution given as:

$$G_m(\frac{1}{2}s^2) = 1 + \frac{m-1}{m}(\frac{1}{2}s^2) + \sum_{j=2}^{\infty} \frac{(m-1)^{2j-1}}{m^j(m+1)(m+3)...(m+2j-3)} \text{x} \frac{(\frac{1}{2}s^2)^j}{j!}$$

The series was computed numerically over j terms until meeting a convergence criterion of a change in the function value of < 0.001 with additional terms (j). The variance of the delta estimator is:

$$\text{var}(C) = \frac{m}{n}(e^{2L})\left[\frac{m}{n}G_m^2(\frac{s^2}{2}) - \frac{m-1}{n-1}G_m(\frac{m-2}{m-1}s^2)\right]$$

When number of sets in which a non-zero bycatch was observed (positive sets) is equal to 1, the mean discard rate reduces to the simple mean rate where:

$$C = \frac{e^L}{n} \quad (4)$$

and the variance of the delta estimator is:

$$\text{var}(C) = (\frac{e^L}{n})^2$$

When number of sets in which a non-zero bycatch was observed (positive sets) is equal to 0, the mean discard is:

$$C = 0$$

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and the variance of the delta estimator is:

$\text{var}(C) = 0$

When number of sets in which a non-zero bycatch was observed (positive sets) is greater than or equal to 1, the coefficient of variation for the mean discard rate is taken as:

$$CV = \frac{\sqrt{\text{var}(C)}}{C}$$

The *C* calculated above gives either the annual mean or the grand mean number of animals caught per set for the observed sets. To estimate annual discards, *N*, these rates are multiplied by the annual total number of sets. With an assumption of effort (*number of logbook sets*) being a known constant, the coefficient of variation for the annual (or grand) mean discard rate is the same as the coefficient of variation for the annual discards. Approximate 95% confidence intervals (95% CI) were calculated assuming a log- normal distribution of annual discards as *Nk* and *N/k* for the upper and lower confidence bounds respectively where:

$$k = e^{\left[1.96\sqrt{\ln(1+CV^2)}\right]} \quad (9)$$

Fishing effort data were available from the coastal logbook program for the years 2018-2022 (Figure 1). Beginning in 1993 all commercial vessels with Federal fishing permits (other than those for swordfish, tunas, and shrimp) was required to report landings and effort to the coastal logbook program. Available coastal logbook data were filtered to include only bottom longline data and to remove records missing effort information (number of sets, number of hooks per set). Coastal logbook data were additionally filtered to remove likely erroneous records; for example, data from trips that reported fishing more than 24 sets per 24 hours. Those data that exceeded the 99.5 percentile of the data for any variable used to calculate effort (number of sets, number of hooks) were also excluded. Such outliers in the data set usually resulted from data entry errors. After data filtering, effort data from only those trips that targeted sharks (defined as trips with reported landings of 2/3 shark by weight) were included in the analysis.

Results and Discussion

Lemon shark dead and live discards (in numbers of sharks) from the commercial shark bottom longline fishery and the shark research fishery are provided in Tables 1-4. In all the estimates, data were pooled by observed year without considering strata due to the sparse nature of the bycatch events and the fact that logbook data are reported by sampling grid (see Figure 1).

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Table 1. Yearly calculated dead discards of lemon sharks for the shark bottom longline fishery by year. Discards are reported as number.

Year	Number Observed Sets	Extrapolated take	Lower confidence limit	Upper confidence limit
2018	52	13.3	2.6	67.8
2019	39	0.0		
2020	6	0.0		
2021	35	0.0		
2022	0	0.0		

Table 2. Yearly calculated live discards of lemon sharks for the shark bottom longline fishery by year. Discards are reported as number.

Year	Number Observed Sets	Extrapolated take	Lower confidence limit	Upper confidence limit
2018	52	13.3	2.6	67.8
2019	39	10.3	2.1	52.7
2020	6	0.0		
2021	35	0.0		
2022	0	0.0		

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Table 3. Yearly observed dead discards of lemon sharks from the shark research fishery for all areas combined. Discards are reported as number.

Year	Number Observed Sets	Total Dead Discards
2018	65	0
2019	59	0
2020	34	0
2021	35	1
2022	65	0

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Table 3. Yearly observed live discards of lemon sharks from the shark research fishery for all areas combined. Discards are reported as number.

Year	Number Observed Sets	Total Live Discards
2018	65	0
2019	59	2
2020	34	0
2021	35	1
2022	65	0

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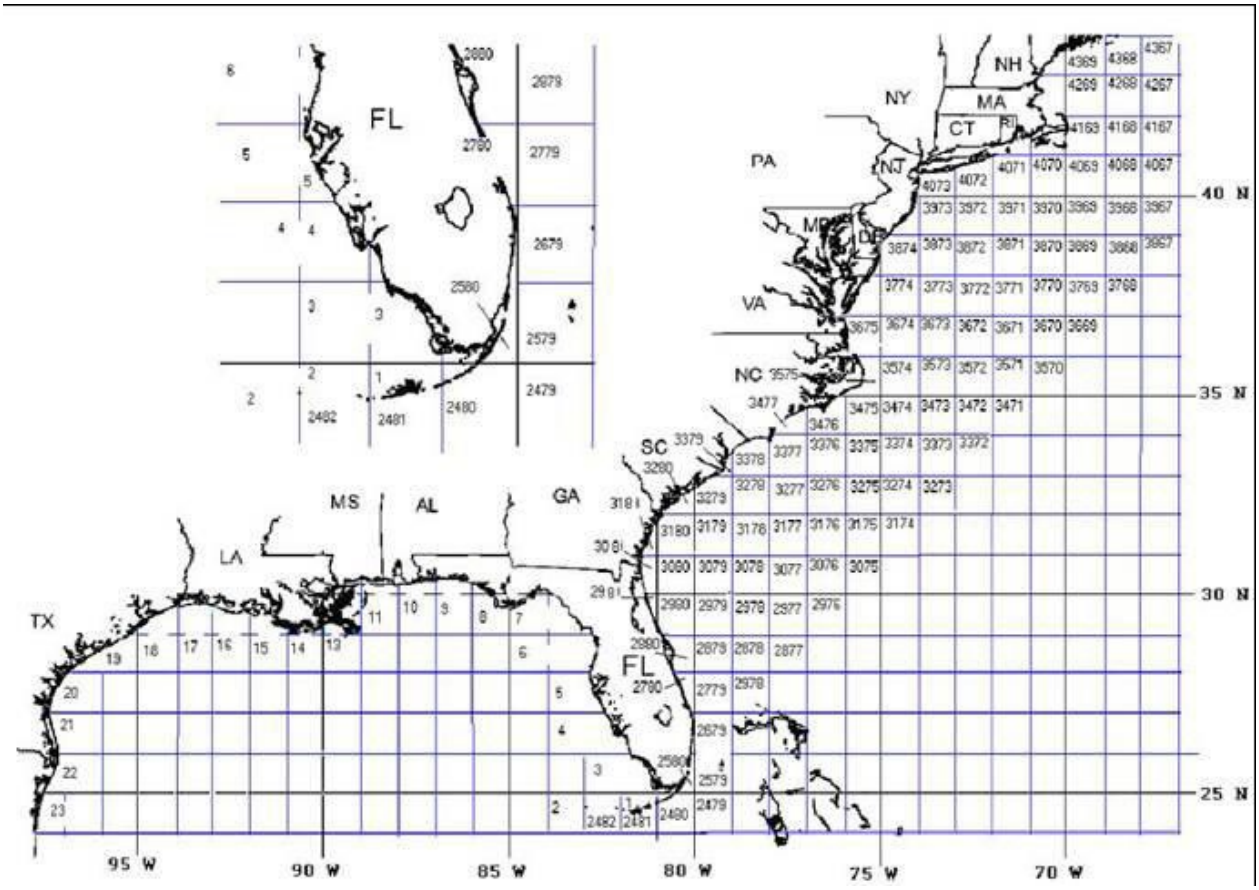

Figure 1. Coastal logbook statistical areas.