Precipitous Declines in Northwest Atlantic Dusky Sharks

Author list

Supplementary Information

Data Sources

We attempted to consider all long-term series which satisfied the following conditions. First, we considered surveys in which methods had remained standard. For example, in the National Marine Fisheries Service (NMFS) apex predators program (*** ref ***), there has been a change from wire to monofilement leaders, which makes it difficult to distinguish long-term trends. Second, we only used data in which sharks were examined by scientifically trained observers. This included the one commercial series, the Crooke data series, in which a commercial fisher, Mr. Crooke, were trained by scientists at the Mote Marine Laboratory (Hueter 1991). Third, we only used data in which sharks were brought to very close contact with the scientifically trained observers, usually on board the vessel. This last step was considered necessary because of the difficulty of distinguishing dusky sharks from similar species, such as the sandbar shark.

Specifically, data on dusky shark abundance was obtained from four fishery-independent bottom trawl surveys (NMFS northeast U.S. offshore bottom trawl survey: 1966-2005, NMFS northeast U.S. inshore bottom trawl survey: 1974-2004, southeast U.S. SEAMAP bottom shrimp trawl survey: 1989-2003, northern Gulf of Mexico bottom shrimp trawl survey: 1972-2002), one fishery-independent longline survey [North Carolina Institute of

Comment [TDS1]: Need 2004 data

Marine Sciences longline survey (NC IMS): 1972-2002] and one commercial longline observer data set [Crooke: 1976-1989 (Hueter 1991)]. These data were collected along the coastal waters of east coast of the U.S. and the northern Gulf of Mexico, from the Gulf of Maine to Louisiana (Fig. 1). Although the NMFS offshore data set extends back to 1963, we limited the analysis of the data set to 1966 onward which maintained consistent spatial coverage. As well, after 199X, deeper water SEAMAP strata were no longer sampled. We did not consider these strata in our analysis.

Comment [TDS2]: Need to find what year this was.

Estimating trends in abundance

General modeling strategy

Trends in relative abundance of dusky sharks from each data source were analyzed using generalized linear models with a negative binomial error structure and a log link. The negative binomial error structure is appropriate for data with a large number of zero (no catch) observations. The log link allows the long-term trend in relative abundance to be characterized. All analyses were conducted using SAS v9.1 (SAS Institute Inc., Cary, NC, USA). The probability of catching C_i individuals of a given species in survey tow i was assumed to follow a negative binomial distribution with the mean μ_i,

$$p(C_i;k;\mu_i) = \frac{\Gamma\left(C_i + \frac{1}{k}\right)}{\Gamma(C_i+1)\Gamma\left(\frac{1}{k}\right)} \frac{(k\mu_i)^k}{(1+k\mu_i)^{C_i+\left(\frac{1}{k}\right)}}, \text{ for } C_i = 0, 1, 2, \ldots, \quad (1)$$

where Γ is the gamma function and k is the negative binomial dispersion parameter. The expected mean catch of a given species is then,

$$\log(\mu_i) = \boldsymbol{x}_i'\boldsymbol{\beta} + \log(\delta) \tag{2}$$

where $\boldsymbol{x}_i'$ is a vector of explanatory covariates for observation i, $\boldsymbol{\beta}$ is a vector of unknown coefficients for the explanatory variables and δ is the offset term.

Trawl surveys

For trawl surveys, considerable ancillary data existed which could be used as meaningful explanatory covariates. In general, these included temperature, depth, geographic location, and julian day. The NMFS surveys and the SEAMAP southeast US survey cover a large range of latitudes that are sampled up to three times each year. At the same time, dusky sharks are known to undertake large north-south migrations throughout the year (Bonfil 1997). To account for this, we assumed that the expected catch was dependent on the day of year (seasonal cycle), latitude and the interaction of the two. The seasonal cycle, q, was characterized by a series of sine and cosine terms, with periods, j, of ½ and 1 year as,

$$q(d_i) = \sum_{j=1}^{2}\left[\varsigma_j \cos\left(\frac{2\pi j d_i}{365.25}\right) + \sigma_j \sin\left(\frac{2\pi j d_i}{365.25}\right)\right] \tag{3}$$

where d_i is the sequential day of the year that observation i occurred in, and ς_i and σ_i are estimated parameters. This was included in the vector of explanatory covariates ($\boldsymbol{x}_i'$) for the NMFS surveys and southeast U.S. SEAMAP survey as,

$$\boldsymbol{x}_i' = y_i + o_i + o_i^{\,2} + t_i + t_i^{\,2} + l_i + q(d_i) + l \cdot q(d_i) \quad (4)$$

where y_i is the year that observation *i* occurred in, o_i is the depth, t_i is bottom temperature and l_i is latitude. We used this vector of covariates in equation 2 along with trawl width (NFMS surveys) or swept area (southeast U.S. SEAMAP survey) as the offset term (δ) to estimate the vector of parameters,

$$\boldsymbol{\beta} = \beta_y + \beta_o + \beta_{o^2} + \beta_t + \beta_{t^2} + \beta_l + \beta_{q(d)} + \beta_{l \cdot q(d)} \quad (5).$$

Estimates from the northern Gulf of Mexico bottom shrimp trawl survey were previously derived (Shepherd and Myers 2005) from a model with non-significant factors removed. The final northern Gulf of Mexico model included year and depth as parameters. To assess the robustness of our choice of covariates for the trawl surveys, we constructed an alternate series of ecologically sensible models from various combinations of covariates. From each of these models, we calculated Akaike Information Criterion (AIC), which is a measure of model parsimony. The models we used (eq. 4 & 5) had either the lowest or very near the lowest AIC (Table 1). Regardless of the models used, estimates of instantaneous rate of change in abundance were similar.

Crooke data series

Due to a lack of covariates, parameterization of models used in the analyses of the crooke data were limited to year (β_y) and seasonal cycle ($\beta_{q(d)}$). Although Mr. Crooke kept excellent records, there are two limitations with the data set. First, during the first years of the survey, he appeared to be learning the best places and time to fish, and his catch rates may be have reflected abundance. Second, he did not record fishing sets where he did not catch any sharks. The first problem was investigated by using different start dates for the analysis (Table 2). Using different start dates did have a small effect on estimates of trends in abundance. Using a later start date resulted in larger rates of decline, likely because catch rates increased slightly over the first three years as Mr. Crooke became better at catching sharks. We choose to use 1976 as a start date as a trade off between the effect of Mr. Crooke becoming a better fisher of sharks and the chance of overestimating declines.

The second problem, i.e. no zero sets, is not as large a problem as it might first appear because dusky sharks were not a large part of the overall catch (xx %). Thus, most of the zero catches for dusky shark are present in any case. Furthermore, as the overall catch rate declined, Mr. Crooke, increased the number of hooks fished from 15 to 20. The difficulty of the lack of records when a longline was set, and no sharks were caught (or reported) was dealt with by first fitting, a truncated negative binomial model to the data. The zeros were inputted using the fit to the data. For robustness, we also examined the consequence of assuming that there were no missing zeros. Trends in relative abundance for models which assumed there were no missing zeros were somewhat more positive than models with inferred zeros, but not significantly so (Table 2). We feel the models with inferred zeros is a valid option since the assumptions of no zeros is obviously in error and because the differences between the two sets of models were relatively small.

Comment [TDS3]: Need to calculate this

Comment [TDS4]: I don't really understand this arguement

North Carolina Institute of Marine Sciences longline survey

For the NC IMS survey, ancillary data was limited to the year (β_y) and seasonal cycle ($\beta_{q(d)}$) and a fixed sampling station effect (β_f), where *f* is the fixed station identifier where observation *i* occurred.

Model Robustness

We also verified the robustness of our models to assumptions of error structure and model form. Along with our original generalized linear models with negative binomial error structures, we also fit delta loggamma and delta lognormal models using each data source. Trends in relative abundance were similar among all three models (Table 3). Further, the negative binomial error assumption produced the most conservative estimates of decline for the southeast U.S. SEAMAP survey, the NC IMS survey and the Crooke commercial data. For the NMFS trawls surveys negative binomial error assumption produced estimates between those for the delta loggamma and delta lognormal error assumptions.

Likelihood profiles

The generalized linear models allow estimation of the instantaneous rate of change in abundance (β_y) and symmetrical errors. We take the approach of examining the log-likelihood profiles of β_y , which allows for non-symmetrical errors and estimation in cases with few data points. For the data source, we produced log-likelihood profiles for the instantaneous rate of change in relative abundance through time. Meta-analytic estimates were generated by summing across all likelihood profiles.

Comment [TDS5]: Need some more info about this technique.

Effectiveness of management measures

We examined trends in abundance for change since the implementation of the NMFS Atlantic Sharks Management Plan in 1993 (*** ref ***) through the use of piece-wise generalized linear models. These models are constructed by included the additional parameters y_i^* in the vector $\boldsymbol{x}_i'$ (eq. 4) and β_y^* in the vector $\boldsymbol{\beta}$ (eq. 5), where $y_i^* = 0$ if $y_i <$ 1993 and $y_i^* = y_i - 1993$ otherwise, and β_y^* is the difference in the instantaneous rate of change in abundance before and after 1993.

Change in length/weight

Lengths of captured dusky sharks were available from both NMFS trawl surveys, the NC IMS longline survey and the Crooke commercial data. In general, the NMFS trawl surveys capture juvenile dusky sharks (offshore: mean=115.4, se=5.1, max=186; inshore: mean=96.8, se=2.3, max=211), while the longline surveys capture larger, older individuals (NC IMS: mean=99.6, se=0.88, max=290; Crooke: mean=240.4, se=4.1, max=302.3). We estimated changes in length from each survey using generalized linear models with log links and gamma error distributions. Estimates were as follows: NMFS offshore 0.011, SE = 0.008; NMFS inshore 0.006, SE = 0.005; NC IMS -0.0105, SE = 0.001; Crooke -0.0182, SE = 0.0057). Meta-analytic means were estimated separately for trawl surveys (0.009, SE = 0.002) and longline surveys (-0.017, SE = -0.003). From the longline surveys, the absolute decline in mean length, since 1972 is then 44%. We then assume weight is proportional to the cube of length. The corresponding decline in mean weight is then 82%.

Ancillary information

Between 1955 and 1963, Clark and von Schmidt (1965) set bottom longlines in the coastal waters of southwest coast of Florida to collect sharks using gear similar to what is presently being used in the commercially fishery, i.e. close to bottom sets using J hooks and wire leaders. In the winter months (December to February) they set approximately 1518 hooks and captured 37 dusky sharks. More recently, a commercial observer program has operated in the same area. In the winter of 2001, 10831 hooks were set to catch large coastal sharks and 7 duskys were captured and in the winter of 2002, 6284 hooks were used to catch 2 dusky sharks in the commerical longline fishery (Burgess and Morgan 2002). This would imply that the between 1.3 and 2.6 percent of the duskys are left in the area. These estimates likely greatly underestimate the change in dusky sharks because the early data was a scientific collection, as opposed to the recent commercial operations, which would be expected to maximize efficiency. The lack of dusky sharks in the region is also demonstrated their absence in present coastal surveys in the region. Since 1989, the extensive collections and longline surveys by the Mote Marine laboratory (Bob Hueter, Director of Shark Research, Mote Marine Lab., Sarasota Florida) have failed to find any dusky sharks in the region sampled by Clark and von Schmidt (1965). Furthermore, there have been no dusky sharks observed in the strike and gillnet fishery that occurs in south Florida, or along eastern Floria (Calrson and Bruser 1999).

During the early years of the Crooke data collection, dusky sharks were one of the most common species in the summer and fall in the longline collected from the Northeastern Gulf of Mexico. Early than this, they were caught in relatively commonly along the Texas coast (Braughman 1950). However, no dusky sharks were caught in the longline and gillnet surveys in the same region conducted by Calrson and Bruser (1999) between 1996-1999. Similarly, no dusky sharks were caught in the surveys conducted in more offshore areas between 1995 and 2001 (Grace 2001, see http://www.mslabs.noaa.gov/mslabs/docs/pubs.html).

Trawl vs. longline analysis

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References

Bonfil, R. Fish. Res. 29, 101-117 (1997)

Braughman 1950

Calrson and Bruser (1999) Mar Fish Rev 61(3)

Clark and von Schmidt (1965)

Hueter 1991

Table 1. Results of the analysis of various parameterization options for the generalized linear models used for the NMFS and southeast U.S. trawl surveys. The final models used in the analysis are models A.

Survey	Model[1]	Parameters	AIC[2]	Year	Year SE	K[3]	K SE
NMFS offshore	A	16	266.2	-0.076	0.035	3.515	1.667
	B	14	304.1	-0.071	0.032	7.197	3.387
	C	9	279.4	-0.094	0.025	9.593	4.575
	D	7	346.7	-0.088	0.023	23.654	11.049
	E	83	438.8	-0.090	0.023	8.562	3.934
NMFS inshore	A	16	344.1	-0.105	0.033	13.536	3.871
	B	14	431.8	-0.109	0.031	19.598	4.840
	C	10	336.6	-0.136	0.027	14.266	4.090
	D	8	433.5	-0.125	0.026	24.564	5.819
	E	96	550.2	-0.121	0.025	10.940	2.848
SEAMAP	A	16	236.5	-0.205	0.077	6.975	2.521
	B	14	234.9	-0.196	0.080	9.439	3.233
	C	10	278.8	-0.242	0.087	43.657	13.670
	D	8	281.7	-0.179	0.074	46.948	15.414
	E	42	293.3	-0.221	0.072	11.450	4.110

Comment [TDS6]: We never refer to K from this table in the text of the supplement

1. A – Year, Depth, $Depth^2$, Temperature, $Temperature^2$, Latitude, Seasonal Cycle, Seasonal Cycle * Latitide; B - Year, Depth, $Depth^2$, Latitude, Seasonal Cycle, Seasonal Cycle * Latitide; C - Year, Depth, $Depth^2$, Temperature, $Temperature^2$,

Season; D - Year, Depth, Depth^2, Season; E – Year, Season, Stratum, Season*Stratum

2. Akaike's information criterion
3. Negative binomial dispersion parameter

Table 2. The effect of start date and the inclusion of zeros, estimated from a negative binomial distribution, on relative trends in abundance for the Crooke commercial data.

Start year	Zeros included	Year	StdErr	*p*
1975	Y	-0.1596	0.0532	0.0027
1975	N	-0.1493	0.0502	0.0029
1976	Y	-0.1905	0.0619	0.0021
1976	N	-0.1521	0.0666	0.0224
1977	Y	-0.2350	0.0664	0.0004
1977	N	-0.1886	0.0716	0.0085

Table 3. Results of models assuming various error distributions.

	negative binomial		delta-log gamma		delta-log normal	
	Year	SE	Year	SE	Year	SE
NMFS offshore	-0.076	0.035	-0.087	0.045	-0.070	0.051
NMFS inshore	-0.105	0.033	-0.091	0.032	-0.147	0.061
SEAMAP	-0.205	0.077	-0.256	0.064	-0.257	0.064
NC IMS	-0.162	0.017	-0.219	0.021	-0.231	0.024
Crooke	-0.191	0.062	-0.250	0.069	-0.267	0.073

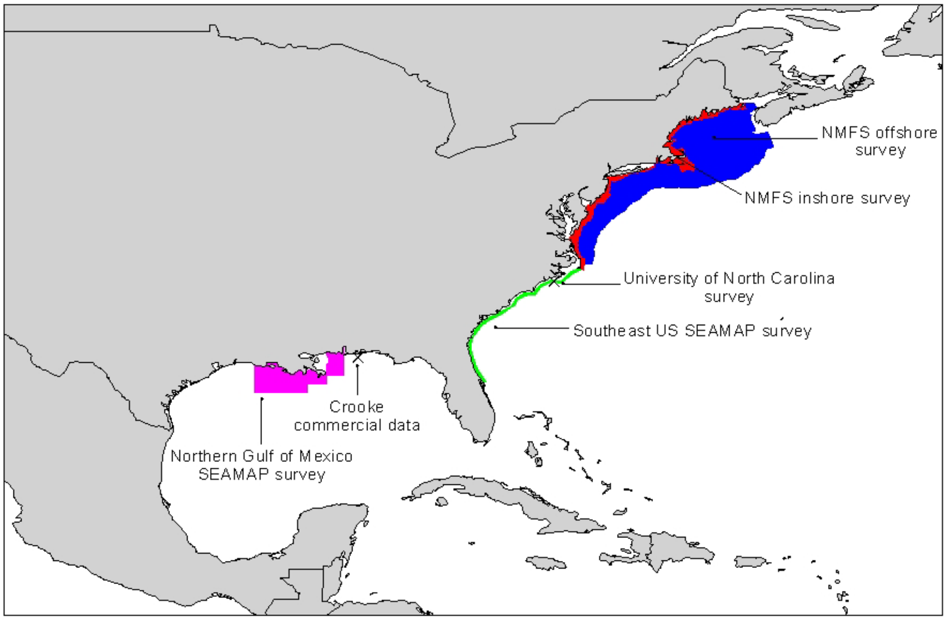

Figure 1. Map showing locations of data used in dusky shark analysis.