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 many surveys for sharks there has been a change from wire to monofilement leaders, which makes it more 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 the fishermen, 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.

Comment [TDS1]: Which ones? Vims?

Specifically, data on dusky shark abundance was obtained from four fishery-independent bottom trawl surveys (National Marine Fishery Service (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

Comment [TDS2]: Need 2004 data

longline survey [North Carolina Institute of 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 X – map showing area of all surveys). 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.

Estimating trends in abundance

General modeling strategy

Trends in relative abundance of dusky sharks from each survey 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 shark is known to undertake large north-south migrations throughout the year (Bonfil, R. Fish. Res. 29, 101-117 (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,

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

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,

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

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.

North Carolina Institute of Marine Sciences longline survey

For the NC IMS survey, ancillary data was limited to the year 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.

Crooke data series

The Crooke data set is from one commercial shark fisherman who was trained to identify sharks. Although this fisherman kept excellent records, there are two limitations with the data set. First, during the first years of the survey, Mr. Crooke 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 XX). 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. However, the differences are small and any of the models are consistent with our results. *** We went with 1976? Why? ***.

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 (give numbers). 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 in 3 different ways. First, a truncated negative binomial model was fit to the data, and the zeros were inputted, using the fit to the data. Then a regular negative binomial model was fit to the data. The difficulty with this approach is that it is difficult to include the uncertainty about the number of zeros in the model. Second, we fit a trend in the total number of sharks present using a truncated negative binomial model, and then fit a logistic to the proportion of dusky sharks present. This approach has the advantage that it is relatively easy to estimate the standard errors of

Comment [TDS3]: Need to calculate this

Comment [TDS4]: unclear

the overall slope estimates, because the two estimates are independent because the parameterisation is orthogonal (Welch et al. 1996). Third, for robustness, we examined the consequence of assuming that there were no missing zeros. [*** Ram, did you do all this?]. *** Refer to table for results of this analysis *** *** say what final model was ***

Model Robustness

We assessed model robustness in two ways. For data sources that included significant ancillary data (trawl surveys), we constructed a 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. In all but one case, the models we used (equation 4 & 5) had the lowest AIC (Table XXX). In the other case, our model AIC was only slightly higher than an alternate model. Regardless of the models used, estimates of instantaneous rate of change in abundance were similar.

We also verified the robustness of our models to assumptions of error structure and model form. [We fit delta log-normal, delta log-gamma, and zero-truncated negative binomial models(?). Results were similar for all models (Table XXX).]

Comment [TDS5]: To what scope do I include these results?

Comment [TDS6]: Do we do this for all surveys or just Crooke?

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. [more about log-likelihoods]

Comment [TDS7]: Need more info on this

Effectiveness of management measures

We examined trends in abundance for change since the implementation of the NMFS Atlantic Sharks Management Plan in 1993 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.

Trawl vs. longline analysis

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Comment [TDS8]: Was anything done here?

Change in length/weight

Lengths of captured dusky sharks were available from the NMFS trawl surveys (offshore mean=115.4, se=5.1, min=19, max=186) (inshore mean=96.8, se=2.3, min=37, max=211), the NC IMS longline survey (mean=99.6, se=0.88, min=30.5, max=290) and the Crooke commercial data (mean=240.4, se=4.1, min=185.4, max=302.3). We did not further consider dusky length from the trawl surveys. They appear to primarily to catch juveniles, and there is no *a priori* reason we expect a change in length of juvenile (*** what are the means ***). Changes in length from each of the longline surveys were

Comment [TDS9]: Too small

Comment [TDS10]: Too small?

Comment [TDS11]: Too small

estimated using generalized linear models with log links and gamma error distributions. Estimates were: NMFS offshore (0.0110, 95% CI:-0.0043 to 0.0262, SE= 0.0078), NMFS inshore (0.0057, 95% CI:-0.0045 to 0.0159, SE= 0.0052), NC IMS (-0.0105, 95% CI: -0.0132 to -0.0077, SE= 0.0014). Meta-analytic mean (-.0088, SE=.0037)

References

Table XX

	negative binomial		delta-gamma		delta-lognormal	
	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

Table XX.

Start year	Zeros included	Estimate	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 XX.

Survey	Model[1]	Parameters	AIC	Year	Year SE	K	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

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

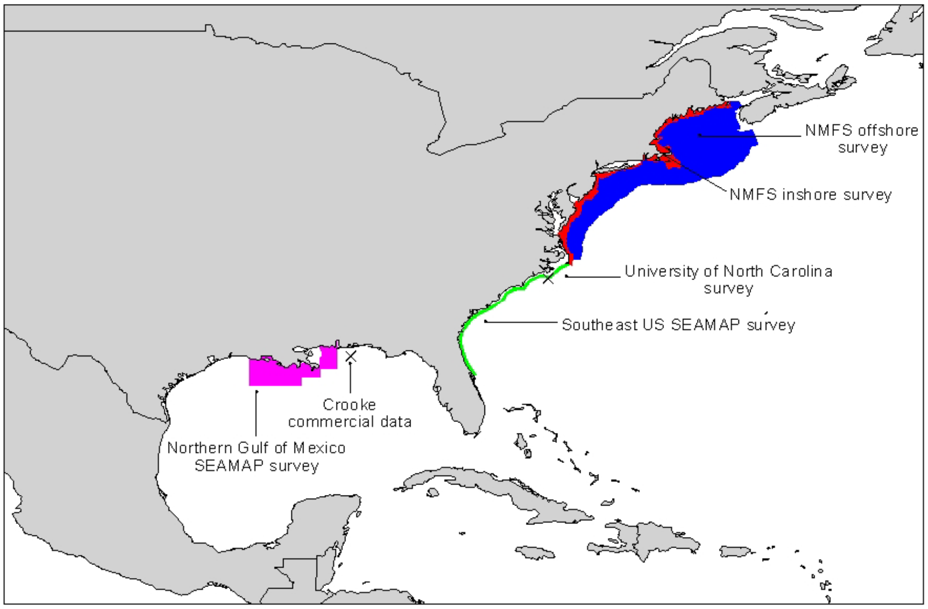
NMFS offshore survey
NMFS inshore survey
University of North Carolina survey
Southeast US SEAMAP survey
Crooke commercial data
Northern Gulf of Mexico SEAMAP survey

Figure X.