2016 NSEO Distance Analysis

by

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# methods

## summary

A total of 36 line transects were performed in NSEO management area from June 9–15, 2016 using the ROV “Buttercup”. For yelloweye rockfish the following information was collected: 3D point measurement (includes perpendicular distance), length measurements, maturity, and behavior. ROV video was also reviewed to determine the official start and end times of each line transect and to determine which portions of the dive were considered valid, i.e. where the ROV was going forward and the seafloor was visible. Adult and subadult yelloweye rockfish observed during “good” segments of line transect dives were considered for distance analysis; no juveniles were included in any distance analysis.

Both the left and right sides of each transect were sampled and the data were pooled for the distance analysis. The sampling fraction for the ROV survey was equal to 1; for the submersible surveys the sampling fraction was 0.5 and a correction factor was applied in order to obtain the density estimate using data from only one side of the transect line.

## Data Exploration

Frequency histograms of the binned distance data were created in excel. Binned data were examined for any patterns that may indicate avoidance or attraction behavior by yelloweye rockfish and to determine which bins would produce the best models in the Distance program, i.e. a model with a shoulder and a decreasing frequency of observations with distance from the ROV. The following bins were examined: 0.5-ft, 1-ft, 1.5-ft, 2-ft, 2.5-ft bins (Figure 1; Figure 2).

## Distance Analysis

***Data***

Density was estimated in *Distance* software and performed using two different data sets:

1. Analysis 1 for age-structured model- All valid adults and subadults
2. Analysis 2 for SAFE- All valid adults and subadults ≥ 340 mm

Analysis was performed with different data sets, because 1) the current stock assessment needs differ from the age-structured model that is being explored for future stock assessments.

For the current stock assessment (SAFE document presented to the council), analysis 1 was performed using all adults and subadults ≥340 mm. Only fish ≥340 mm, the minimum size of fish captured across management areas in the directed fishery were included, because the current assessment does not have a selectivity factor to account for catchability of the longline gear. If all subadult and adult fish were included in the density estimate as available biomass for exploitation, there would be a risk of overharvest because the commercial fishing gear does not catch smaller subadults. An age-structured assessment model is in development that would include selectivity as well as age and size stratified weights for the biomass calculation. Currently, we are using an average weight to extrapolate out density to biomass and are exploring using age or size stratified weights to more accurately calculate biomass. Subadults with no length measurements were not included in the 2016 analysis, because the average length of subadults in NSEO with valid length measurements was 309 mm and smaller than the minimum length of yelloweye observed in the directed fishery. Yelloweye juveniles and subadults <340 mm were also excluded for analyses of 2012, 2013, and 2015 data. In 2012, we also excluded fish with no length information, because the average length was <340 mm (339 mm); however, in 2013 and 2015, yelloweye subadults with no length data were included, because the average length was ≥ 340 mm with 467 mm in 2013 and 383 mm in 2015.

For the age-structured model in development, no adults or subadults were excluded based on size (Analysis 1 and 2). This age-structured model accounts for selectivity, i.e. small fish contribute proportionately less to the spawning stock biomass than larger fish.

***Key functions and adjustment terms***

I explored the models of the half normal cosine and the hazard rate cosine in my distance analyses. The uniform and negative exponential models were not considered, because the negative exponential is generally used for salvaging poorly collected data and the uniform assumes that there is no decrease in probability to the effective width of the key function (T. Quinn pers. com.).

***Data binning***

I performed analyses with and without data binning. If no binning was used then the analyses were performed with the exact distance data. Data binning was explored to determine if it would improve the results for the analyses. Data binning may increase the robustness of the results. We used data binning for previous submersible surveys because observers tend to naturally round visually estimated distances; therefore, creating measurement error. For the ROV data we have close to exact measurements for distances to yelloweye rockfish; however, there may still be some error in distances due to the clarity of the video and our inability to always identify the same exact point in both the left and right stereo cameras. We explored the following data bins in the Distance software to determine which bin would produce the best fit of the data: 1-ft, 1.5-ft, 2-ft, 2.5-ft. For analyses that were performed without data binning, bins were selected by the Distance program for the chi-square test diagnostics; these bins only affect the results of the chi-square tests and do not affect the density estimate.

***Data Truncation***

Distance data are often truncated in order to prevent the tail of the model from overly influencing the model fit, because it is most important for the model to fit near the origin of the transect line. Terry Quinn (personal communication) suggests truncating 5-10% for distance data; Buckland et al. (2001) says this method is a simple way to truncate data but may produce unsatisfactory results. I explored excluding observations that occurred at distances greater than 11 ft for unbinned data and data in 1 ft bins, and discarding observations greater than 10.5 ft for data in 1.5 ft bins, and observations greater than 10 ft for data in 2 ft and 2.5 ft bins.

***Choosing a model***

I examined the results of the Distance analyses to determine if the 2015 ROV data were able to produce a valid density estimate. It was determined if the data fit a model well by examining the fit visually and by examining diagnostic tests, including Q-q plots and Chi-square and Kolmogorov-Smirnov (K-S) goodness of fit tests. In addition, the coefficient of variation (CV) was examined to determine if we were able to produce data with good precision.

The preferred model key function and adjustment term was chosen against other models with the same binning and truncation scheme by comparing the AIC values, model fits, and CV values between models. To determine if binning or truncation improved the model results and determine what would be the best binning scheme for the data, we compared the CV values and model fit. However, the AIC cannot be used to compare between models without the same binning or truncation schemes.

For visual examination, a model is preferred with a good fit at the origin, a shoulder, and a shape that is biologically realistic, e.g. a model with a decreasing probability of detection with distance rather than a uniform probability of detection throughout the observed distances. The K-S and *X*2 goodness of fit tests are used to determine if the data fit the model well. The K-S test is considered to be a better goodness of fit test; however, it only provides diagnostics if no binning is performed. If the K-S or chi-square p-values are not significant (p > 0.05) it suggests the model has a reasonable fit with no significant deviations in the model. The Q-q plot can also be used to evaluate model fit for models with no binning. For models where the detection function is fitted to the raw data rather than to the binned data, the *X*2 test may still be used as a diagnostic of the goodness of fit by assessing how well selected binned data fits the detection model.

The AIC value was used to determine the model with the best key function and adjustment term for models with the same binning and truncation schemes. A lower AIC score is preferred and the AIC score incorporates the number of parameters, giving a penalty for more parameters. The ∆AIC indicates the degree to which the model with the lowest AIC is preferred over other models. A ∆AIC<2 indicates no credible evidence of superiority of the lower AIC model over the higher, ∆AIC 2–4 weak evidence, 4–7 definite evidence, 7–10 strong evidence, and >10 very strong evidence.

The precision of the density estimates was determined by examining the CV of the density estimate and the variance components of the density estimate. The CV was used to determine if a model had good precision. If a density estimate has a CV<20% then the model is considered to have sufficiently high precision. The variance of the density estimate is composed of the variance due to the detection function and the variance due to the encounter rate. As the model fit to the data improves, the component of variance due to the detection function decreases. The variance in the encounter rate is due to the variability in the number of observations among transects. If the data fits the model well, then the variance of the density estimate due to the detection function should be low.

# Results/Discussion

A total of 170 yelloweye rockfish were observed during valid segments of line transect dives with 119 adults and 51 subadults; 6 of the subadults were ≥ 340 mm out of the 36 subadults with length measurements . On average 5 yelloweye adults or subadults were observed per transect; however, only 4 yelloweye ≥ 340 mm, on average, were observed (Table 1). No adult or subadult yelloweye were observed on seven of the 2016 transects with eight transects with no yelloweye ≥ 340 mm. A maximum of 20 yelloweye were observed on dive 11 with a maximum of 16 yelloweye ≥ 340 mm observed on each of dive 11 and 23 (Table 1).

Length measurements were examined by maturity to determine which yelloweye to include in density estimates. Lengths were collected from 63 adults, 15 subadults, and 37 juveniles. These data were edited to exclude measurements with large errors (horizontal angle>30, precision >40 mm, and root mean square (RMS) error >10 mm) from the average, minimum, and maximum length calculations. However, each of these errors alone may not cause invalid length measurements. The 2016 NSEO adult average length is 506 mm with lengths ranging from 366–698 mm; the subadult average length is 309 mm with lengths ranging from 233–433 mm. Juvenile average length is 196 mm with lengths ranging from 115–317. Some overlap occurred between the length range of subadults and juveniles and subadults and adults, but no overlap occurred between juveniles and adults. There is some subjectivity in maturity staging; consequently, some juveniles may be subadults and vice versa or some subadults may be adults and vice versa. All juveniles were <340 mm and excluded from the distance analysis. Juveniles have never been included in the density analyses for the ROV or submersible. It may be difficult to obtain valid density estimates for juvenile yelloweye, because they are more difficult to identify among other small rockfish, especially in the past with standard definition cameras, and juvenile rockfish may exhibit different behaviors such as avoidance to the survey vehicle or be more likely to seek cover than other stages. Juvenile behavior in response to the ROV or submersible has not been fully explored. Thirty subadults were <340 mm and were excluded from the distance analysis using current stock assessment methods. Prior to 2012, all subadults and adults were included in the density analysis because no length data were available for the submersible survey; however, size and morphology would have been easier to judge in-situ from the submersible than from the ROV video.

The 2016 NSEO ROV survey results suggest that using an ROV to conduct line transect sampling continues to be a valid method to estimate yelloweye rockfish density. Models were produced that fit the data well, the assumptions of distance sampling were met, and CV estimates were obtained that indicate reasonable precision in the density estimate (Table 2). In 2016 NSEO management area, the majority of the variance of the density estimates was due to the variability of the encounter rate with the remaining variance due to the detection probability (Table 2). The variance due to the detection probability decreases as the fit of the model to the data improves; the low variance due to the detection probability indicates that the data fits the model very well.

Models with good fits to the data were obtained for both analyses with the two different data sets. The best models had hazard rate key functions with a cosine series expansion term; these models had a probability detection function with a wide shoulder extending from the transect origin before declining at larger distances (Figure 3; Figure 4). The half normal key function generally fit the data well with some models with larger K-S and Chi-square p values and a tighter fit to the q-q plots than the hazard rate models (Appendix 1; Appendix 2); however, the half normal key function produced models with biologically unrealistic shapes. The haza≥rd rate models generally had lower AIC values than half normal models; however, the difference wasn’t large enough for that model to be preferred using only the AIC as criteria (Appendix 1; Appendix 2).

Models without binning were preferred for the 2016 NSEO data. Ungrouped data retains the variability in the data by fitting the model to the raw data rather than the binned data that has distance observations averaged for each bin. However, binning data can improve the robustness in the density estimator if errors in measurement occur, heaping, or avoidance behavior. With the submersible survey, data were grouped because distances were estimated by observers, so there was both error in distance measurements and heaping of data due to rounding by the observer (i.e. 2ft, 10 ft, 15, etc.). With the ROV survey, stereo cameras allow measurements to be taken with minimal error. In addition, there was no indication of avoidance behavior in the detection function (i.e. increase in frequency histograms from origin to some distance; Figure 1 and 2) or in the behavior of yelloweye rockfish.

In NSEO in 2016, models without data truncation were chosen and fit the data better (Appendix 1 and Appendix 2). Truncation is employed to prevent the tail of the model from overly influencing the overall model fit. Data were generally truncated for the submersible surveys with yelloweye sometimes identifiable at distances as great as 30 ft. Fish observations are not as variable at the right tail for the ROV survey as they were for the submersible survey where there was possibility of observations at larger distances. Fish were observed only to 10.5 ft in NSEO in 2016. In 2012 and 2013, the selected models for the ROV survey also did not include any data truncation with no fish observed past 11 ft in those years. In 2015, four fish were observed at distances greater than 11 ft with the greatest observed at approximately 16 ft. In 2015, model fits were improved with truncation of data after 11 ft with larger chi-square p-values.

Good CV estimates were obtained for NSEO in 2016 with 20% for the model with all subadults and 18% for the model with subadults ≥ 340 mm (Table 2). The encounter rate was 0.005 yelloweye/m for the model with all subadults and 0.004 yelloweye/m for the model with only subadults ≥ 340 mm. The 2016 NSEO encounter rates are similar to what has been observed with the ROV in CSEO (0.003 yelloweye/m) and SSEO (0.004 yelloweye/m) however are about half of the observed encounter rate in EYKT (0.008 yelloweye/m), which may support higher densities of yelloweye rockfish than other areas (Table 2).

Valid density estimates were obtained with no violations of distance sampling assumptions. A majority (86%) of adult and subadult (98%) yelloweye rockfish were performing neutral behaviors, such as milling, hovering, resting on the bottom, swimming actively in the frame, or seeking cover when first observed by the ROV; 9% of adults and no subadults were observed moving into the frame slowly or quickly with 2% adults and 2% subadults moving out of the frame. The remaining yelloweye rockfish were performing behaviors such as feeding. The sighting frequency histograms and the probability detection functions for all analyses do not indicate attraction is occurring to the ROV (Figures 1–2). If attraction was occurring then a spike at the origin of the probability detection function would occur (Buckland et al. 2001). In addition, no avoidance behavior was indicated by the pattern of yelloweye observations with distance; if avoidance behavior occurred, there would tend to be lower detections closer to the transect line and then an increase in detection with increasing distance from the line (Buckland et al. 2001). Instead the probability detection functions of the preferred models have a broad shoulder before declining (Figures 1–2).

In NSEO in 2016, yelloweye rockfish density was 960 yelloweye/km2 for the analysis that included all subadults and 701 yelloweye/km2 for the analysis which included only subadults ≥340 mm. A large number of subadults <340 mm (30 yelloweye) and subadults with no length data (15 yelloweye) were excluded from the analysis with only subadults ≥340; consequently, there was a large difference in the density estimate between these analyses. The 2016 NSEO density estimate which included all subadults was much larger than the density estimate of 765 yelloweye/km2 from the 1994 submersible survey; however, the 2016 estimate of 701 yelloweye/km2 which excluded subadults <340 mm was very similar to the 1994 estimate (Table 5). In 1994, less than half the number of transects and meters of transect were surveyed compared to 2016. As a result the CV was also much higher in 1994 and the confidence interval wider for the density estimate. During the 24 years between the 1994 submersible survey and the 2016 ROV survey, both recruitment and fishing mortality would have occurred in the area. The commercial halibut fishery was open to fishing in NSEO during these years and would have caught yelloweye rockfish as bycatch and some sport fishing may have occurred in the area; however, NSEO was closed to directed commercial fishing of yelloweye rockfish. Yelloweye rockfish are late maturing and slow growing; consequently, replacement of recruits to the fisheries, and those assessed in our Distance analysis, is slow. However, it is probable recruitment to the fisheries occurred with 24 years between surveys and the directed fishery closures. In addition, a large number of juvenile and subadult yelloweye <340 mm (86 juveniles and 44 subadults<340 mm) (Table 3)that are not yet large enough to be captured in commercial fisheries were observed in 2016 compared to only a few, 4 juveniles and 1 subadult, observed in 1994 (Table 4). However, it is likely that some juveniles and subadults would have missed in 1994 that were close to the submersible because no forward facing camera was used that year to improve observations of yelloweye on the transect line. In other areas, CSEO, SSEO, and EYKT declines have been observed in yelloweye rockfish in recent years; however in contrast, these areas have been open to directed commercial fishing in many of the recent years and sport fishery harvest would have occurred in some areas as well.

# References

Buckland, S. T., D. R. Anderson, K. P Burnham, and J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling. Oxford University Press.

**TABLES AND FIGURES**

**Table 1. ROV survey summaries and distance inputs.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | ***2012[[1]](#footnote-1)*** | ***2013[[2]](#footnote-2)*** | ***2015*** | ***2015[[3]](#footnote-3)*** | ***2016*** | ***2016[[4]](#footnote-4)*** |
| **Management Area** | ***CSEO*** | ***SSEO*** | ***EYKT*** | ***EYKT*** | ***NSEO*** | ***NSEO*** |
| **Model Data** | ***AD & SUB≥340 mm*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** |
| **Model Use** | ***SAFE*** | ***SAFE*** | ***Age Model*** | ***SAFE*** | ***Age Model*** | ***SAFE*** |
| **Number line transects** | 46 | 31 | 33 | 33 | 36 | 36 |
| **Meters surveyed** | 38,590 | 30,439 | 22,896 | 22,896 | 34,435 | 34,435 |
| **Number transects with no ye observations included in model** | 7 | 8 | 2 | 2 | 7 | 8 |
| **Average number ye observations (included in model) per transect** | 2.6 | 3.4 | 8.4 | 7.7 | 4.7 | 3.5 |
| **Maximum ye observations (included in model) per transect** | 9 | 15 | 60 | 60 | 20 | 16 |
| **Number AD & SUB included in model****[[5]](#footnote-5)** | 1183 | 118 | 255 | 2512 | 170 | 125 |
| **Number of AD included in model5** | 112 | 93 | 240 | 240 | 119 | 119 |
| **Number of SUB included in model5** | 63 | 25 | 15 | 112 | 51 | 6 |
| **Max. distance (ft) of ye observations (included in model)5** | 10.39 | 10.86 | 11 | 11 | 11.5 | 11.5 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | ***2012*** | ***2013*** | ***2015*** | ***2015*** | ***2016*** | ***2016*** |
| **Management Area** | **CSEO** | **SSEO** | **EYKT** | **EYKT** | **NSEO** | **NSEO** |
| **Model Data** | ***AD & SUB>340 mm*** | ***AD & SUB>340 mm*** | ***AD & All SUB*** | ***AD & SUB>340*** | ***AD & All SUB*** | ***AD & SUB>340*** |
| **Model Use** | ***SAFE*** | ***SAFE*** | ***Age Model*** | ***SAFE*** | ***Age Model*** | ***SAFE*** |
| **Density (ye/** **km2)** | 752 | 986 | 1796 | 1755 | 960 | 701 |
| **Lower CI (95%) Density** | 586 | 641 | 1097 | 1065 | 675 | 476 |
| **Upper CI (95%) Density** | 966 | 1517 | 2941 | 2891 | 1366 | 1033 |
| **CV of Density** | 0.13 | 0.22 | 0.25 | 0.25 | 0.18 | 0.20 |
| **Variance components** |  |  |  |  |  |  |
| **- Detection probability** | 18% | 8% | 3% | 3% | 6% | 9% |
| **-Encounter rate** | 82% | 92% | 97% | 97% | 94% | 91% |
| **Encounter rate (yelloweye/m)** | 0.003 | 0.004 | 0.008 | 0.008 | 0.005 | 0.004 |
| **Effective strip width (ft)** | 6.7 | 6.5 | 7.3 | 7.3 | 8.4 | 8.5 |

**Table 2. Distance outputs for ROV surveys.**

**Table 3. Juveniles and subadults observed during ROV surveys.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Management area** | **Juveniles** | **Subadults** | **Subadults <340 mm** | **Subadults >340 mm** | **Subadults no length data** | **Juvenile average length (mm)** | **Subadult average length (mm)** |
| 2012[[6]](#footnote-6) | CSEO | 30 | 13 | 7 | 5 | 1 | 249 | 339 |
| 20136 | SSEO | 10 | 25 | 0 | 8 | 17 | 225 | 467 |
| 2015 | EYKT | 61 | 15 | 4 | 9 | 2 | 242 | 383 |
| 2016 | NSEO | 86 | 51 | 30 | 6 | 15 | 197 | 309 |

**Table 4. Juveniles and subadults observed during submersible surveys.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Management area** | **Juveniles** | **Subadults** |
| 1994[[7]](#footnote-7) | CSEO | 53 | 3 |
| 19947 | SSEO | 25 | 8 |
| 19947 | NSEO | 4 | 1 |
| 1995 | EYKT | 80 | 9 |
| 1995 | CSEO | 48 | 18 |
| 1997 | CSEO | 28 | 9 |
| 1997 | EYKT | 47 | 18 |
| 1999 | EYKT | 64 | 7 |
| 1999 | SSEO | 36 | 0 |
| 2003 | CSEO | 74 | 13 |
| 2003 | EYKT | 80 | 33 |
| 2005 | SSEO | 78 | 11 |
| 2007 | CSEO | 88 | 15 |
| 2009 | EYKT | 48 | 10 |

**Table 5. NSEO distance analysis results and model inputs for the SAFE.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | # transects | # yelloweye in model | Meters surveyed | Encounter rate (yelloweye/L) | Density  (ye/ km2) | Lower CI (95%;  ye/ km2) | Upper CI(95%;  ye/ km2) | CV |
| 1994 | 13 | 62 | 17,622 | 0.004 | 765 | 383 | 1527 | 0.33 |
| 2016 | 36 | 125 | 34,435 | 0.004 | 701 | 476 | 1033 | 0.20 |

**Figure 1. Frequency histograms for analysis for age structured model which includes all adult and subadult yelloweye rockfish.**

**Figure 2. Frequency histograms for all adult and subadult yelloweye rockfish ≥340 mm.**



**Figure 3. All adults and subadults model for age structured assessment with hazard rate key function and no binning and no truncation of data, 1.44 ft intervals shown.**



**Figure 4. All adults and subadults ≥340 mm model for SAFE with hazard rate key function with no binning and no truncation, 1.64 ft intervals shown.**

**Appendices**

**Results for all Models Explored by Analysis**

**Appendix 1. Analysis 1 for age structured model, includes all adults and all subadults. The preferred model for the age structured assessment has no binning or truncation (Appendix 1.A.).**

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.A. No binning or truncation, 170 observations, width 11.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 782 | 783 |
| Density (ye/km2) | 960 | 1161 |
| D LCL (ye/km2) | 675 | 744 |
| D UCL (ye/km2) | 1366 | 1814 |
| CV of D | 0.175 | 0.227 |
| Judgement | Good shoulder and model shape with pretty good fit. | Unrealistic shape for all but good fit. |
| X2 P-value | 0.70 (1.44 ft bins), 0.75 (0.885 ft bins), 0.91 (0.605 ft bins) | 0.9 (1.44 ft bins), 0.75 (0.885 ft bins), 0.94 (0.605 ft bins) |
| # parameters | 2 | 3 |
| Q-q plot | An OK fit at ends but lots of deviation in the middle | Pretty good fit |
| K-S P-value | 0.36 | 0.98 |
| warnings | None | Parameters are being constrained to monotonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.B. 1-ft bins, no truncation, 170 observations, width 12*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 782 | 784 |
| Density (ye/km2) | 974 | 1110 |
| D LCL (ye/km2) | 685 | 707 |
| D UCL (ye/km2) | 1387 | 1744 |
| CV of D | 0.176 | 0.23 |
| Judgement | Good shoulder and good fit and most bits but a couple with deviation. | No shoulder and unrealistic shape |
| X2 P-value | 0.58 | 0.49 |
| # parameters | 2 | 3 |
| warnings | None | Parameters are being constrained to monotonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.C. 1.5-ft bins, no truncation, 170 observations, width 12*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 644 | 645 |
| Density (ye/km2) | 969 | 1181 |
| D LCL (ye/km2) | 681 | 755 |
| D UCL (ye/km2) | 1380 | 1846 |
| CV of D | 0.176 | 0.228 |
| Judgement | Good shoulder and good shape | Unrealistic shape |
| X2 P-value | 0.82 | 0.92 |
| # parameters | 2 | 3 |
| warnings | None | Parameters are being constrained to monotonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.D. 2-ft bins, no truncation, 170 observations, width 12*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 548 | 550 |
| Density (ye/km2) | 983 | 1031 |
| D LCL (ye/km2) | 641 | 641 |
| D UCL (ye/km2) | 1658 | 1658 |
| CV of D | 0.244 | 0.244 |
| Judgement | Good shoulder and good shape | A little bit of shoulder and pretty good fit but slightly strange shape at origin |
| X2 P-value | 0.67 | 0.53 |
| # parameters | 2 | 3 |
| warnings | None | Parameters are being constrained to monotonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.E. 2.5 ft bins, no truncation, 170 observations, width 12.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 477 | 478 |
| Density (ye/km2) | 960 | 1208 |
| D LCL (ye/km2) | 674 | 769 |
| D UCL (ye/km2) | 1367 | 1898 |
| CV of D | 0.176 | 0.231 |
| Judgement | Good shoulder and good fit but few intervals | Very unrealistic shape |
| X2 P-value | 0.38 | 0.67 |
| # parameters | 2 | 3 |
| warnings | none | *Parameters being constrained to monotonicity* |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.F. No binning, truncation after 11ft, 168 observations, width 11.5*** | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** |
| AIC | 760 | 762 |
| Density (ye/km2) | 949 | 1133 |
| D LCL (ye/km2) | 666 | 704 |
| D UCL (ye/km2) | 1351 | 1822 |
| CV of D | 0.176 | 0.243 |
| Judgement | A good shoulder and an ok fit. However, some bad fitting for some bins | Unrealistic shape and some bad fits for some bins |
| X2 P-value | 0.70 (1.38 ft bins), 0.82 (0.917 ft bins), 0.48 (0.579 ft bins) | 0.71 (1.38 ft bins), 0.85 (0.917 ft bins), 0.45 (0.579 ft bins) |
| # parameters | 2 | 4 |
| Q-q plot | Lots of deviation in the middle | Pretty good fit with some deviation |
| K-S P-value | 0.27 | 0.95 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.G. 1 ft bins, truncation after 11ft, 168 observations, width 11ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 760 | 761 |
| Density (ye/km2) | 973 | 1136 |
| D LCL (ye/km2) | 681 | 718 |
| D UCL (ye/km2) | 1388 | 1796 |
| CV of D | 0.177 | 0.234 |
| Judgement | Good shoulder but some bins have poor fit | Unrealistic shape |
| X2 P-value | 0.58 | 0.48 |
| # parameters | 2 | 3 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.H. 1.5 ft bins, truncation after 10.5 ft bin, 168 observations, width 10.5 ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 623 | 624 |
| Density (ye/km2) | 972 | 1195 |
| D LCL (ye/km2) | 825 | 825 |
| D UCL (ye/km2) | 1731 | 1731 |
| CV of D | 0.186 | 0.186 |
| Judgement | Good shoulder and ok fit | No shoulder and abrupt ending |
| X2 P-value | 0.69 | 0.36 |
| # parameters | 2 | 1 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

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| ***Appendix 1.I. 2 ft bins, truncation after 10 ft, 167 observations, width 10 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 518 | 518 |
| Density (ye/km2) | 999 | 1161 |
| D LCL (ye/km2) | 695 | 799 |
| D UCL (ye/km2) | 1435 | 1688 |
| CV of D | 0.181 | 0.188 |
| Judgement | Good shoulder and ok fit | No shoulder and abrupt tail |
| X2 P-value | 0.48 | 0.27 |
| # parameters | 2 | 1 |
| warnings | none | Parameters are being constrained to monotonicity |

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| ***Appendix 1.J. 2.5 ft bins, truncation after 10 ft, 167 observations, width 10 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 447 | 446 |
| Density (ye/km2) | 986 | 1142 |
| D LCL (ye/km2) | 683 | 785 |
| D UCL (ye/km2) | 1423 | 1662 |
| CV of D | 0.183 | 0.188 |
| Judgement | Good shoulder and good fit but few bins | No shoulder, few bins, and abrupt end |
| X2 P-value | 0.20 | 0.21 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to monotonicity | Parameters being constrained to monotonicity |

**Appendix 2. Analysis 2 for SAFE, includes all adults and subadults ≥ 340 mm. The preferred model for the SAFE has no binning or truncation (Appendix 2.A.).**

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| ***Appendix 2.A. No binning or truncation, 125 observations, width 11.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 584 | 584 |
| Density (ye/km2) | 701 | 848 |
| D LCL (ye/km2) | 476 | 566 |
| D UCL (ye/km2) | 1033 | 1270 |
| CV of D | 0.194 | 0.203 |
| Judgement | Good shoulder and OK fit and some bins and poor fit at others. | Not much of a shoulder and fit is poor at some bins |
| X2 P-value | 0.42 (1.64 ft bins), 0.30 (1.05 ft bins), 0.37 (0.719 ft bins) | 0.28 (1.64 ft bins), 0.27 (1.05 ft bins), 0.33 (0.719 ft bins) |
| # parameters | 2 | 1 |
| Q-q plot | Some deviation in middle and beginning | Some deviation in the middle |
| K-S P-value | 0.50 | 0.79 |
| warnings | None | Parameters are being constrained to monotonicity |

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| ***Appendix 2.B. 1-ft bins, no truncation, 125 observations, width 11.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 583 | 585 |
| Density (ye/km2) | 700 | 793 |
| D LCL (ye/km2) | 476 | 478 |
| D UCL (ye/km2) | 1029 | 1315 |
| CV of D | 0.193 | 0.26 |
| Judgement | Good shoulder and OK fit and some bits but poor fit at other bins | Unrealistic shape |
| X2 P-value | 0.60 | 0.49 |
| # parameters | 2 | 3 |
| warnings | None | Parameters are being constrained to monotonicity |

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| ***Appendix 2.C. 1.5-ft bins, no truncation, 125 observations, width 11.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 483 | 484 |
| Density (ye/km2) | 694 | 871 |
| D LCL (ye/km2) | 472 | 584 |
| D UCL (ye/km2) | 1020 | 1297 |
| CV of D | 0.193 | 0.2 |
| Judgement | Good shoulder and good fit | No shoulder but ok fit |
| X2 P-value | 0.84 | 0.60 |
| # parameters | 2 | 1 |
| warnings | None | Parameters are being constrained to monotonicity |

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| ***Appendix 2.D. 2-ft bins, no truncation, 125 observations, width 11.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 409 | 411 |
| Density (ye/km2) | 708 | 803 |
| D LCL (ye/km2) | 481 | 502 |
| D UCL (ye/km2) | 1043 | 1285 |
| CV of D | 0.194 | 0.24 |
| Judgement | Good shoulder and good shape | Good fit and good shape with slight shoulder |
| X2 P-value | 0.78 | 0.35 |
| # parameters | 2 | 2 |
| warnings | None | Parameters are being constrained to monotonicity |

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| ***Appendix 2.E. 2.5 ft bins, no truncation, 125 observations, width 12.5*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 360 | 361 |
| Density (ye/km2) | 682 | 816 |
| D LCL (ye/km2) | 464 | 487 |
| D UCL (ye/km2) | 1002 | 1368 |
| CV of D | 0.192 | 0.265 |
| Judgement | Good shoulder and fit but few bins | Unrealistic shape but OK fit |
| X2 P-value | 0.67 | 0.79 |
| # parameters | 2 | 3 |
| warnings | none | *Parameters being constrained to monotonicity* |

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| ***Appendix 2.F. No binning, truncation after 11ft, 123 observations, width 11*** | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** |
| AIC | 564 | 565 |
| Density (ye/km2) | 680 | 857 |
| D LCL (ye/km2) | 461 | 567 |
| D UCL (ye/km2) | 1002 | 1296 |
| CV of D | 0.194 | 0.208 |
| Judgement | Good shoulder and good fit at some bins and poor fit at others | No shoulder and an abrupt end. Fit is good and some bins and poor at others. |
| X2 P-value | 0.8 (1.57 ft bins), 0.59 (1 ft bins), 0.63 (0.688 ft bins) | 0.22 (1.57 ft bins), 0.24 (1 ft bins), 0.49 (0.688 ft bins) |
| # parameters | 2 | 1 |
| Q-q plot | Lots of deviation in middle and some at beginning | Lots of deviation in the middle |
| K-S P-value | 0.3 | 0.73 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

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| ***Appendix 2.G. 1 ft bins, truncation after 11ft, 123 observations, width 11ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 561 | 565 |
| Density (ye/km2) | 702 | 862 |
| D LCL (ye/km2) | 475 | 574 |
| D UCL (ye/km2) | 1038 | 1295 |
| CV of D | 0.195 | 0.205 |
| Judgement | Good shoulder and an ok fit with some deviation for some bins | No shoulder and abrupt end |
| X2 P-value | 0.6 | 0.24 |
| # parameters | 2 | 1 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

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| ***Appendix 2.H. 1.5 ft bins, truncation after 10.5 ft bin, 123 observations, width 10.5 ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 463 | 462 |
| Density (ye/km2) | 710 | 839 |
| D LCL (ye/km2) | 477 | 557 |
| D UCL (ye/km2) | 1055 | 1264 |
| CV of D | 0.198 | 0.206 |
| Judgement | Good shoulder and good fit | No shoulder and abrupt end otherwise good fit |
| X2 P-value | 0.80 | 0.70 |
| # parameters | 2 | 1 |
| warnings | *Parameters being constrained to monotonicity* | *Parameters being constrained to monotonicity* |

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| ***Appendix 2.I. 2 ft bins, truncation after 10 ft, 122 observations, width 10 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 381 | 381 |
| Density (ye/km2) | 711 | 829 |
| D LCL (ye/km2) | 478 | 548 |
| D UCL (ye/km2) | 1058 | 1256 |
| CV of D | 0.199 | 0.209 |
| Judgement | Good shoulder and good fit | No shoulder, abrupt end |
| X2 P-value | 0.57 | 0.31 |
| # parameters | 2 | 1 |
| warnings | Parameters are being constrained to monotonicity | Parameters are being constrained to monotonicity |

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| ***Appendix 2.J. 2.5 ft bins, truncation after 10 ft, 122 observations, width 10 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 331 | 330 |
| Density (ye/km2) | 696 | 792 |
| D LCL (ye/km2) | 463 | 522 |
| D UCL (ye/km2) | 1045 | 1202 |
| CV of D | 0.204 | 0.210 |
| Judgement | Good shoulder and fit, few bins | No shoulder, abrupt end, few bins |
| X2 P-value | 0.41 | 0.43 |
| # parameters | 2 | 1 |
| warnings | Parameters are being constrained to monotonicity | Parameters are being constrained to monotonicity |

1. In 2012, 7 subadults less than <340 mm and 1 subadult with no length data were excluded. [↑](#footnote-ref-1)
2. In 2013, no subadults were less than <340 mm. 17 subadults with no length data were included. [↑](#footnote-ref-2)
3. In 2015, 4 subadults were less than <340 mm and excluded from the SAFE model. Two subadults had no length and were included. [↑](#footnote-ref-3)
4. In 2016, 30 subadults were <340 mm and excluded from the SAFE model. Fifteen subadults had no length and were excluded as well. [↑](#footnote-ref-4)
5. These counts do not include fish that were removed from the models due to truncation. [↑](#footnote-ref-5)
6. No belly camera was used in 2012 and 2013, so it is possible that some juveniles and/or subadults were missed during video review. [↑](#footnote-ref-6)
7. No forward facing camera was used in 1994, so some juveniles and subadults may have been missed. [↑](#footnote-ref-7)