2017 EYKT Distance Analysis

by

Jennifer Stahl

# methods

## summary

A total of 35 line transects were performed in EYKT management area from May 8–19, 2017 using the ROV “Buttercup”. For yelloweye rockfish the following information was collected: 3D point measurement (includes perpendicular distance), fish length measurements, fish stage based upon morphological appearance, and behavior. ROV video was reviewed to determine the official start and end times of each line transect and to determine valid portions of the dive, i.e. where the ROV was moving forward and the seafloor was visible. Adult and subadult yelloweye rockfish observed during valid segments of line transect dives were considered for *Distance* analysis; juveniles were excluded from analysis.

The left and right sides of each line transect were sampled and the data pooled for the *Distance* analysis. In Distance, a sampling fraction is defined as 1 if both sides of the line are sampled and as 0.5 if only one side of the transect is sampled as occurred for the submersible surveys. A correction factor was applied for surveys with a sampling fraction of 0.5 in order to obtain the density estimate using data from only one side of the transect line.

## Data Exploration

Histograms of binned fish distance from the line transect were created in Excel. Binned data were examined for patterns that may indicate avoidance (i.e. an increase in the pattern of observations from the origin to a particular distance) or attraction (i.e. a spike of observations at the origin) behavior by yelloweye rockfish and to determine appropriate data structure for input into 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 1–3).

## Distance Analysis

***Data***

Fish density was estimated for three different data sets using *Distance* software:

1. Analysis 1 for age-structured model- All valid adults and subadults
2. Analysis 2 for SAFE – All valid adults and only subadults ≥ 340 mm; subadults with no length data were excluded.

Analyses were performed with different data sets, because 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 2 was performed. Only fish ≥340 mm, the minimum size of (>99.9%) fish captured across management areas in the directed fishery (2001–2015) were included, because the current assessment is not modeled using selectivity 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 will include selectivity as well as weight at age for the biomass calculation. Currently, mean weight is used to estimate biomass from the density estimates. Examinations to include weight at age or weight at length to more accurately calculate biomass are ongoing. Subadults with no length data were excluded in 2017 because the average length of subadults was <340 mm.

For the age-structured model in development, no adults or subadults were excluded based on size (Analysis 1). 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***

Models using the half normal cosine and the hazard rate cosine were explored in the 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***

Analyses were examined 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. Data binning was used for previous submersible surveys because observers tend to round visually estimated distances; therefore, creating measurement error. The ROV provides nearly exact distance measurements to yelloweye rockfish; however, there may still be some error in distances due to the clarity of the video and an inability to always identify the same point in both the left and right stereo cameras. The following data bins were explored in the *Distance* software to determine which bin would produce the best fit of the data: 0.5-ft, 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 (pers. com.) 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. Data truncation for distances greater than 11 ft were explored for unbinned data and 1 ft, 1.5 ft , and 2 ft bins, data binned at 2.5 ft were truncated at 12.5 ft.

***Choosing a model***

*Distance* analysis results were examined to determine if a viable density estimate could be arrived at using the 2017 EYKT ROV data. Adequate model fit was determined visually and by examining diagnostic tests, including Q-Q plots, Chi-square and Kolmogorov-Smirnov (K-S) goodness of fit tests. In addition, the coefficient of variation (CV) was examined to determine 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, the CV values and model fits were compared. However, the AIC cannot be used to compare between models with differing binning or truncation schemes.

Visual examination was used to identify a model 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 data are not binned. 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 is also used to evaluate model fit for models with no binning. Models where the detection function is fit to the raw data rather than to binned data, may still be evaluated with the *X*2 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 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.

# Results/Discussion

Of the 35 valid line transects a total of 146 yelloweye rockfish were observed (in the good segments within the transect), 129 adults and 17 subadults. On average 5 yelloweye adults or subadults were observed per transect (Table 1). No yelloweye rockfish were observed on six of the 2017 EYKT transects. A maximum of 25 yelloweye were observed on a single transect (Table 1).

Length measurements were examined by fish stage based upon morphological appearance to determine which yelloweye to include in the density estimates. Lengths were collected from 58 adults, 9 subadults, and 22 juveniles. These data were edited to exclude measurements with large errors (horizontal angle>30°, precision >40 mm, and root mean square error (RMSE) >10 mm from the average, minimum, and maximum length calculations. However, each of these errors alone may not cause invalid length measurements. The 2017 EYKT adult average length was 509 mm with lengths ranging from 352–643 mm; the subadult average length was 295 mm with lengths ranging from 270–346 mm. Juvenile average length was 180 mm with lengths ranging from 131–246. With the edited lengths there was no overlap between length ranges for juvenile, subadults, or adults. However, some overlap occurred between the length range of subadults and juveniles as well as between subadults and adults when length data were not edited using precision <40 mm and/or horizontal direction <30; no overlap occurred between juveniles and adults. There is subjectivity in morphological classification, e.g., some subadults may be adults and vice versa. All juveniles were <340 mm and excluded from the distance analysis. Juveniles have not been included in the density analyses in previous years. It may be difficult to obtain valid density estimates for juvenile yelloweye rockfish, because they are more difficult to identify among other small rockfish, and they may exhibit different behaviors such as avoidance of the survey vehicle or be more likely to seek cover. Four 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 2017 EYKT 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 indicate reasonable precision in the density estimate (Table 2). In 2017 EYKT 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 well. However, the variability due to the detection probability was lower in previous surveys.

During the 2017 survey, there was a failure of one of the video sensors after dive 1; consequently, cameras were reconfigured. Standard definition stereo cameras were used instead of the high definition cameras. The belly camera was removed and an auxillary camera was added on the ROV arm above the stereo cameras in a downward facing position. This auxillary camera was reviewed to ensure that we would not miss fish that were under the ROV at close range as was performed with the belly camera review in the past. The auxillary camera had a wider field of view than the belly camera. It is possible that the analysis was affected by using the auxillary camera instead of the belly camera. Because the standard definition cameras were used instead of the high definition cameras, the precision of estimates were likely larger as well as the root mean square errors. It is possible the distance estimates were affected with some unknown effect on the overall density estimate.

Models with good fits to the data were obtained for both analyses. The best models had hazard rate key functions with a cosine series expansion term; these models had a probability detection function with a small shoulder. It is preferred to have a model with a shoulder extending from the transect origin before declining (Figure 3–4). Models created with half normal key functions did not have shoulders, so were excluded from further consideration (Appendix 1–2).

Models without binning were preferred for the 2017 EYKT data. Unbinned data retains data variability, however, binning data can improve the robustness in the density estimator if errors in measurement occur, and/or heaping or avoidance behaviors are present. With the submersible survey, data were grouped because distances were estimated by observers, introducing 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 1–4) or in the behavior of yelloweye rockfish.

In EYKT in 2017, models without data truncation were chosen and fit the data better (Appendix 1–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 rockfish sometimes identifiable at distances as great as 30 ft. Fish observations at greater distances occur less frequently using the ROV as compared to using the submersible, where there was possibility of observations at greater distances. Fish were observed to about 15 ft in EYKT in 2017. In 2012 CSEO, 2013 SSEO, 2016 NSEO, and 2016 CSEO surveys, data models were preferred with no truncation. In 2015, the model was improved with truncation after 11 feet with four fish observed at distances greater and out to 16ft. In 2017 EYKT, only one yelloweye adult or subadult was observed past 12 ft.

Reasonable CV estimates were obtained for EYKT in 2017 with 22% for Analysis 1 and 21% for Analysis 2. An encounter rate of 0.004 yelloweye/m was observed for both analyses. The 2017 EYKT encounter rates are the lowest of any survey in EYKT and are about half of the last ROV survey in the area in 2015. In the past the encounter rates have typically been higher in EYKT compared to the other management area, indicating that the Fairweather grounds can support higher densities of yelloweye. However, the 2017 EYKT encounter rate is similar to those observed in CSEO and NSEO (Table 2).

Valid density estimates were obtained with no violations of distance sampling assumptions. A majority of adult and subadult (81%) yelloweye rockfish exhibited neutral behaviors, such as milling, hovering, resting on the bottom, swimming actively in the frame, or seeking cover when first observed by the ROV; 14% were observed moving into the frame slowly or quickly. However, none were observed moving out of the frame slowly or quickly. The remaining 5% of yelloweye rockfish exhibited behaviors such as feeding, being chased, or chasing other fish. Even though more yelloweye were observed moving into the frame rather than out, I do not believe attraction behavior biased the density estimate. There was actually less fish observed at each of the distance intervals of 0 ft, 1 ft, or 2 ft compared to 3 ft. You might expect a spike at the origin of the probability detection function if attraction behavior occurred and might cause a bias in the density estimate. (Buckland et al. 2001).

In EYKT in 2017, yelloweye rockfish density was 1,209 yelloweye/km2 for the analysis that included all subadults and 1,072 yelloweye/km2 for the analysis that included only subadults ≥340 mm. Twelve subadults were excluded from Analysis 2, four subadults that were <340 mm and eight subadults with no length information. The 2017 EYKT density estimate was much lower than the last two survey estimates in the area in 2015 (1,533 yelloweye/km2) and 2003 (1,930 yelloweye/km2); however the confidence intervals of the 2017 density estimate did still overlap with those from the 2015 and 2009 surveys (Table 5). Since the last survey of EYKT in 2015, the management area was open to directed fishing of demersal shelf rockfish in in all years. In addition, yelloweye rockfish were caught as incidental catch in the halibut and lingcod commercial fishing.

# 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)*** | ***2016*** | ***2016[[5]](#footnote-5)*** | ***2017*** | ***2017[[6]](#footnote-6)*** |
| **Management Area** | ***CSEO*** | ***SSEO*** | ***EYKT*** | ***EYKT*** | ***NSEO*** | ***NSEO*** | ***CSEO*** | ***CSEO*** | ***EYKT*** | ***EYKT*** |
| **Model Data** | ***AD & SUB≥340 mm*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** | ***AD & All Subadults*** | ***AD & SUB≥340 mm*** |
| **Assessment method** | ***SAFE*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** |
| **# line transects** | 46 | 31 | 33 | 33 | 36 | 36 | 32 | 32 | 35 | 35 |
| **Meters surveyed** | 38,590 | 30,439 | 22,896 | 22,896 | 34,435 | 34,435 | 30,726 | 30,726 | 33,960 | 33,960 |
| **# transects w/o ye** | 7 | 8 | 2 | 2 | 7 | 8 | 1 | 1 | 6 | 6 |
| **Avg ye per transect** | 2.6 | 3.4 | 8.4 | 7.7 | 4.7 | 3.5 | 5.3 | 5.1 | 5.1 | 4.7 |
| **Max. ye per transect** | 9 | 15 | 60 | 60 | 20 | 16 | 13 | 13 | 25 | 21 |
| **# AD & SUB in model**[[7]](#footnote-7) | 118 | 118 | 255 | 251 | 170 | 125 | 164 | 157 | 146 | 134 |
| **# AD in model7** | 112 | 93 | 240 | 240 | 119 | 119 | 151 | 151 | 129 | 129 |
| **# SUB in model7** | 6 | 25 | 15 | 11 | 51 | 6 | 13 | 6 | 17 | 5 |
| **Max. distance (ft) ye** | 10.39 | 10.86 | 11 | 11 | 11.5 | 11.5 | 14.7 | 14.7 | 14.7 | 14.7 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | ***2012*** | ***2013*** | ***2015*** | ***2015*** | ***2016*** | ***2016*** | ***2016*** | ***2016*** | ***2017*** | ***2017*** |
| **Management Area** | **CSEO** | **SSEO** | **EYKT** | **EYKT** | **NSEO** | **NSEO** | **CSEO** | **CSEO** | **EYKT** | **EYKT** |
| **Model Data** | ***AD & SUB>340 mm*** | ***AD & SUB>340 mm*** | ***AD & All SUB*** | ***AD & SUB>340*** | ***AD & All SUB*** | ***AD & SUB>340*** | ***AD & All SUB*** | ***AD & SUB>340*** | ***AD & All SUB*** | ***AD & SUB>340*** |
| **Assessment method** | ***SAFE*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** | ***Age*** | ***SAFE*** |
| **Density (ye/** **km2)** | 752 | 986 | 1796 | 1755 | 960 | 701 | 1142 | 1073 | 1209 | 1072 |
| **Lower CI (95%) Density** | 586 | 641 | 1097 | 1065 | 675 | 476 | 870 | 813 | 788 | 703 |
| **Upper CI (95%) Density** | 966 | 1517 | 2941 | 2891 | 1366 | 1033 | 1499 | 1416 | 1857 | 1635 |
| **CV of Density** | 0.13 | 0.22 | 0.25 | 0.25 | 0.18 | 0.20 | 0.14 | 0.14 | 0.22 | 0.21 |
| **Variance components** |  |  |  |  |  |  |  |  |  |  |
| **- Detection probability** | 18% | 8% | 3% | 3% | 6% | 9% | 22% | 23% | 8% | 9% |
| **-Encounter rate** | 82% | 92% | 97% | 97% | 94% | 91% | 78% | 77% | 92% | 91% |
| **Encounter rate (yelloweye/m)** | 0.003 | 0.004 | 0.008 | 0.008 | 0.005 | 0.004 | 0.005 | 0.005 | 0.004 | 0.004 |
| **Effective strip width (ft)** | 6.7 | 6.5 | 7.3 | 7.3 | 8.4 | 8.5 | 7.8 | 7.8 | 5.8 | 6.0 |

**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[[8]](#footnote-8) | 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 |
| 2016 | CSEO | 22 | 13 | 4 | 6 | 3 | 226 | 347 |
| 2017 | EYKT | 47 | 17 | 4 | 5 | 8 | 180 | 295 |

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Management area** | **Juveniles** | **Subadults** |
| 1994[[9]](#footnote-9) | 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. EYKT distance analysis results and model inputs for the SAFE. The 2017 model below includes all adults and subadults ≥340 and with no length information.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 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 |
| 1995 | 17 | 330 | 22,896 | 0.014 | 2,711 | 1,776 | 4,141 | 0.20 |
| 1997 | 20 | 350 | 19,240 | 0.018 | 2,576 | 1,459 | 4,549 | 0.28 |
| 1999 | 20 | 236 | 25,198 | 0.009 | 1,461 | 992 | 2,150 | 0.19 |
| 2003 | 20 | 335 | 17,878 | 0.019 | 3,825 | 2,702 | 5,415 | 0.17 |
| 2009 | 37 | 215 | 29,890 | 0.007 | 1,930 | 1,389 | 2,682 | 0.17 |
| 2015 | 33 | 251 | 22,896 | 0.008 | 1,533 | 1,080 | 2,176 | 0.17 |
| 2017 | 35 | 134 | 33,960 | 0.004 | 1,072 | 703 | 1,635 | 0.21 |

**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, 1.84 ft intervals shown.**



**Figure 4. Model with all adults and subadults ≥340 mm with hazard rate key function and no binning or truncation, 2.1 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, 146 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 618 | 620 |
| Density (ye/km2) | 1209 | 1400 |
| D LCL (ye/km2) | 788 | 915 |
| D UCL (ye/km2) | 1857 | 2142 |
| CV of D | 0.215 | 0.213 |
| Judgement | Good fit with nice shoulder | OK fit but not very good at small lengths |
| X2 P-value | 0.78 (1.84 ft bins), 0.15 (1.23 ft bins), 0.24 (0.82 ft bins) | 0.09 (1.84 ft), 0.012 (1.23 ft), 0.003 (0.82 ft) |
| # parameters | 2 | 1 |
| Q-q plot | OK fit with some deviation | Lots of deviation at smaller lengths |
| K-S P-value | 0.91 | 0.32 |
| warnings | Parameters being constrained to obtain montonicity | none |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.B. 1-ft bins, no truncation, 146 observations, width*** 15 | | |
| AIC | 623 | 624 |
| Density (ye/km2) | 1209 | 1383 |
| D LCL (ye/km2) | 786 | 902 |
| D UCL (ye/km2) | 1860 | 2122 |
| CV of D | 0.216 | 0.214 |
| Judgement | Bad fit | Bad fit |
| X2 P-value | 0.12 | 0.001 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.C. 1.5-ft bins, no truncation, 146 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 501 | 500 |
| Density (ye/km2) | 1265 | 1410 |
| D LCL (ye/km2) | 820 | 920 |
| D UCL (ye/km2) | 1952 | 2163 |
| CV of D | 0.217 | 0.214 |
| Judgement | OK fit and good shoulder | OK fit |
| X2 P-value | 0.25 | 0.02 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.D. 2-ft bins, no truncation, 146 observations, width 16*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 429 | 432 |
| Density (ye/km2) | 1158 | 1346 |
| D LCL (ye/km2) | 754 | 878 |
| D UCL (ye/km2) | 1780 | 2065 |
| CV of D | 0.215 | 0.214 |
| Judgement | Good fit with nice shoulder and good shape | OK fit but no shoulder |
| X2 P-value | 0.64 | 0.04 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.E. 2.5 ft bins, no truncation, 146 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 352 | 352 |
| Density (ye/km2) | 1261 | 1423 |
| D LCL (ye/km2) | 814 | 927 |
| D UCL (ye/km2) | 1953 | 2184 |
| CV of D | 0.22 | 0.21 |
| Judgement | Good fit and nice shoulder | Good fit but no shoulder |
| X2 P-value | 0.85 | 0.38 |
| # parameters | 2 | 1 |
| warnings | none | none |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.F. No binning, truncation after 11ft, 145observations, width 11*** | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** |
| AIC | 602 | 601 |
| Density (ye/km2) | 1273 | 1256 |
| D LCL (ye/km2) | 830 | 778 |
| D UCL (ye/km2) | 1952 | 2028 |
| CV of D | 0.21 | 0.24 |
| Judgement | Good fit with nice shoulder | Nice shape and OK fit |
| X2 P-value | 0.3 (1.38 ft), 0.37 (0.92 ft), 0.25 (0.6 ft) | 0.5 (1.38 ft), 0.4 (0.92 ft), 0.67 (0.61 ft) |
| # parameters | 2 | 2 |
| Q-q plot | Some deviation, especially near the small distances | Some deviation especially near the small distances |
| K-S P-value | 0.7 | 0.76 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.G. 1 ft bins, truncation after 11ft, 145 observations, width 11ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 607 | 606 |
| Density (ye/km2) | 1260 | 1407 |
| D LCL (ye/km2) | 820 | 922 |
| D UCL (ye/km2) | 1937 | 2148 |
| CV of D | 0.22 | 0.21 |
| Judgement | Not very good fit | Not very good fit |
| X2 P-value | 0.09 | 0.07 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

|  |  |  |
| --- | --- | --- |
| ***Appendix 1.H. 1.5 ft bins, truncation after 12 ft bin, 145 observations, width 12 ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 488 | 485 |
| Density (ye/km2) | 1277 | 1451 |
| D LCL (ye/km2) | 832 | 951 |
| D UCL (ye/km2) | 1960 | 2213 |
| CV of D | 0.22 | 0.21 |
| Judgement | OK fit with nice shoulder | OK fit |
| X2 P-value | 0.19 | 0.32 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

|  |  |  |
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| ***Appendix 1.I. 2 ft bins, truncation after 12 ft, 145 observations, width 12 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 415 | 415 |
| Density (ye/km2) | 1159 | 1206 |
| D LCL (ye/km2) | 759 | 749 |
| D UCL (ye/km2) | 1771 | 1944 |
| CV of D | 0.21 | 0.24 |
| Judgement | Good fit and nice shoulder | Good fit |
| X2 P-value | 0.62 | 0.67 |
| # parameters | 2 | 2 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

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| ***Appendix 1.J. 2.5 ft bins, truncation after 12 ft, 145 observations, width 12.5 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 338 | 338 |
| Density (ye/km2) | 1257 | 1464 |
| D LCL (ye/km2) | 816 | 960 |
| D UCL (ye/km2) | 1935 | 2234 |
| CV of D | 0.22 | 0.21 |
| Judgement | Good fit and good shoulder | Good fit but no shoulder |
| X2 P-value | 0.67 | 0.83 |
| # parameters | 2 | 2 |
| warnings | The number of adjustment parameters allowed has been reduced to 2 because of limited number of intervals | The number of adjustment parameters allowed has been reduced to 3 because of limited number of intervals |

**Appendix 2. Analysis 3 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, 134 observations, width 14.7*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 575 | 577 |
| Density (ye/km2) | 1072 | 1246 |
| D LCL (ye/km2) | 703 | 819 |
| D UCL (ye/km2) | 1635 | 1896 |
| CV of D | 0.211 | 0.210 |
| Judgement | Good fit and nice shoulder | Shape realistic, OK fit, but not great shoulder |
| X2 P-value | 0.49 (2.1 bins), 0.38 (1.34 bins), 0.17 (0.87 bins) | 0.18 (2.1 bins), 0.08 (1.34 bins), 0.009 (0.87 bins) |
| # parameters | 2 | 1 |
| Q-q plot | Some deviation at smaller distances | A lot of deviation at small distances |
| K-S P-value | 0.75 | 0.16 |
| warnings | Parameters being constrained to obtain montonicity | None |

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| ***Appendix 2.B. 1-ft bins, no truncation, 134 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 580 | 581 |
| Density (ye/km2) | 1059 | 1231 |
| D LCL (ye/km2) | 693 | 808 |
| D UCL (ye/km2) | 1616 | 1876 |
| CV of D | 0.21 | 0.21 |
| Judgement | Bad fit | Bad fit |
| X2 P-value | 0.11 | 0.004 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

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| ***Appendix 2.C. 1.5-ft bins, no truncation, 134 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 469 | 469 |
| Density (ye/km2) | 1097 | 1252 |
| D LCL (ye/km2) | 716 | 821 |
| D UCL (ye/km2) | 1680 | 1908 |
| CV of D | 0.21 | 0.21 |
| Judgement | Good shoulder but not very good fit at some bins | No shoulder, OK fit at most bins |
| X2 P-value | 0.14 | 0.028 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

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| ***Appendix 2.D. 2-ft bins, no truncation, 134 observations, width 16*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 401 | 404 |
| Density (ye/km2) | 1028 | 1199 |
| D LCL (ye/km2) | 673 | 786 |
| D UCL (ye/km2) | 1569 | 1827 |
| CV of D | 0.21 | 0.21 |
| Judgement | Good shoulder and OK fit | OK fit but no shoulder |
| X2 P-value | 0.56 | 0.06 |
| # parameters | 2 | 1 |
| warnings | Parameters being constrained to obtain montonicity | none |

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| ***Appendix 2.E. 2.5 ft bins, no truncation, 134 observations, width 15*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 331 | 331 |
| Density (ye/km2) | 1106 | 1268 |
| D LCL (ye/km2) | 719 | 832 |
| D UCL (ye/km2) | 1701 | 1934 |
| CV of D | 0.216 | 0.211 |
| Judgement | Good fit and good shoulder | Good fit but no shoulder |
| X2 P-value | 0.86 | 0.50 |
| # parameters | 2 | 1 |
| warnings | None | none |

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| ***Appendix 2.F. No binning, truncation after 11ft, 133 observations, width 11*** | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** |
| AIC | 559 | 558 |
| Density (ye/km2) | 1067 | 1123 |
| D LCL (ye/km2) | 704 | 695 |
| D UCL (ye/km2) | 1619 | 1815 |
| CV of D | 0.21 | 0.245 |
| Judgement | Good shoulder and shape and OK fit. | OK shape and OK fit. |
| X2 P-value | 0.21 (1.57 bins), 0.07 (1 ft bins), 0.23 (0.65 ft bins) | 0.16 (1.57 bins), 0.07 (1 ft bins), 0.26 (0.65 ft bins) |
| # parameters | 2 | 2 |
| Q-q plot | Some deviation near beginning | A lot of deviation near small distances |
| K-S P-value | 0.77 | 0.49 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

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| ***Appendix 2.G. 1 ft bins, truncation after 11ft, 133 observations, width 11 ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 564 | 563 |
| Density (ye/km2) | 1122 | 1104 |
| D LCL (ye/km2) | 733 | 688 |
| D UCL (ye/km2) | 1718 | 1773 |
| CV of D | 0.21 | 0.24 |
| Judgement | Not very good fit but good shape with shoulder | Not very good fit but OK shape |
| X2 P-value | 0.076 | 0.08 |
| # parameters | 2 | 2 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

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| ***Appendix 2.H. 1.5 ft bins, truncation after 12 ft bin, 133 observations, width 12 ft*** | | |
|  | **Hazard rate cosine** | **Half normal cosine** |
| AIC | 456 | 453 |
| Density (ye/km2) | 1129 | 1123 |
| D LCL (ye/km2) | 739 | 699 |
| D UCL (ye/km2) | 1725 | 1802 |
| CV of D | 0.21 | 0.24 |
| Judgement | Good fit mostly and good shape with nice shoulder | OK fit at middle and end but not great at beginning |
| X2 P-value | 0.1 | 0.19 |
| # parameters | 2 | 2 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

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| --- | --- | --- |
| ***Appendix 2.I. 2 ft bins, truncation after 12 ft,133 observations, width 12 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 387 | 387 |
| Density (ye/km2) | 1021 | 1078 |
| D LCL (ye/km2) | 672 | 669 |
| D UCL (ye/km2) | 1549 | 1737 |
| CV of D | 0.209 | 0.243 |
| Judgement | Good fish and shape with nice shoulder | Good fit and OK shape |
| X2 P-value | 0.51 | 0.52 |
| # parameters |  | 2 |
| warnings | Parameters being constrained to obtain montonicity | Parameters being constrained to obtain montonicity |

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| --- | --- | --- |
| ***Appendix 2.J. 2.5 ft bins, truncation after 12.5 ft, 133 observations, width 12.5 ft*** | | |
|  | Hazard rate cosine | Half normal cosine |
| AIC | 319 | 318 |
| Density (ye/km2) | 1101 | 1304 |
| D LCL (ye/km2) | 720 | 859 |
| D UCL (ye/km2) | 1683 | 1978 |
| CV of D | 0.21 | 0.21 |
| Judgement | Very good fit and good shape with nice shoulder | No shoulder but fit OK |
| X2 P-value | 0.69 | 0.8 |
| # parameters | 2 | 1 |
| warnings | The number of adjustment parameters allowed has been reduced to 2 because of limited number of intervals | The number of adjustment parameters allowed has been reduced to 3 because of limited number of intervals |

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 NSEO, 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. In 2016 CSEO, 4 subadults were <340 mm and excluded from this SAFE model. Three subadults with no length were excluded as well. [↑](#footnote-ref-5)
6. In 2017 EYKT, 4 subadults were <340 mm and excluded from this SAFE model. Eight subadults with no length were excluded as well. [↑](#footnote-ref-6)
7. These counts do not include fish that were removed from the models due to truncation. [↑](#footnote-ref-7)
8. 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-8)
9. No forward facing camera was used in 1994, so some juveniles and subadults may have been missed. [↑](#footnote-ref-9)