2015 EYKT Distance Analysis

by

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# methods

## summary

A total of 34 line transects were performed in EYKT management area from May 13–18, 2015 using the ROV Buttercup; 33 of these transects were considered valid line transects and were reviewed for fish observations. 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 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, and 2-ft bins (Figure 1; Figure 2).

## Distance Analysis

***Data sets***

Density was estimated in *Distance* software and performed with four different data sets.

1. Analysis 1- All valid adults and subadults included
2. Analysis 2- All valid adults and subadults with dive 11 minimum estimate
3. Analysis 3 - All valid adults and subadults >340 mm
4. Analysis 4 - All valid adults and subadults >340 with dive 11 minimum estimate

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 and 2) because we wanted to explore the effects on the density estimate and the detection function of schooling behavior.

For the current stock assessment (SAFE document presented to the council), Analyses 3 and 4 are provided as options. Analyses 3 and 4 include 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 since 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 included in the analysis, because the average length of subadults in EYKT with valid length measurements was 384 mm and larger than the minimum length of yelloweye observed in the directed EYKT fishery. In 2012 and 2013 yelloweye, <340 mm were also excluded. However, in 2012 yelloweye with no length information were excluded as well, but these data were included in 2013. Yelloweye with no length data were not included in 2012 as we were still developing our methodology and deciding what was appropriate to include. We are now including yelloweye subadults without lengths in the density estimate.

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.

Schooling behavior that was not observed in previous ROV surveys was observed in dive 10 and 11 in 2015. In dive 10, schooling was limited and the behavior of the yelloweye in these schools and the spacing of the schools did not indicate that the fish were following the ROV or were at risk of being double-counted. However, in dive 11 there were several incidences of large schools of yelloweye rockfish, as well as some concern that yelloweye might be following the ROV. As a consequence, no yelloweye were included in any analyses that were observed after video time stamp “23:09:21”; after this time yelloweye were coming from behind the ROV and may have been following it. A couple of yelloweye with unique markings were observed prior to 23:09:21 and reappear after this time, which indicates that some yelloweye were following the ROV and that yelloweye after 23:09:21 should be removed from the analyses. No yelloweye with unique marks were identified more than once prior to 23:09:21.

Two different methods were performed for comparison for yelloweye in dive 11 (where schooling behavior was substantial). In the first method, all adult and subadult yelloweye observed prior to 23:09:21 were included in the density model (60 fish; Analyses 1 and 3). In the second, and more conservative method, all adult and subadult yelloweye that did not exhibit schooling behavior (14 fish) observed prior to 23:09:21 AND a minimum estimate of yelloweye exhibiting schooling behavior (16 fish) were included in the density estimate (total of 30 fish; Analysis 2 and 4). The minimum estimate of schooling yelloweye (16 fish) was obtained by counting the maximum number of yelloweye that could be uniquely identified over a few video frames; all other schooling yelloweye were excluded. This method would eliminate any possibility of double-counting.

***Key functions and adjustment terms***

I explored the models of the half-normal hermite polynomial, 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, and 2-ft. For analyses that were performed without data binning I was able to specify bins 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.

***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 259 yelloweye were observed during valid segments of the line transect dives with 244 adults and 15 subadults. On average 8 yelloweye were observed per transect (Table 1). No adult or subadult yelloweye were observed on two of the 2015 transects and a maximum of 60 yelloweye were observed on dive 11 (only yelloweye observed before 23:09:21 were included in this count to prevent double-counting; Table 1).

Length measurements were examined by maturity to determine which yelloweye to include in density estimates. Lengths were collected from 135 adults, 13 subadults, and 38 juveniles. These data were edited to exclude measurements with large errors (precision >100 mm and root mean square (RMS) error >10 mm) from average, minimum, and maximum length calculations. The horizontal angle of length measurements was also examined to determine if this caused unreasonable length measurements for each maturity stage. However, high horizontal angle alone did not appear to cause unreasonable length measurements, i.e. no lengths with high horizontal angle were outside the range of length measurements for a particular maturity stage, so data were not excluded based on horizontal angle. The 2015 EYKT adult average length is 575 mm with lengths ranging from 426–711 mm; the subadult average length is 384 mm with lengths ranging from 287–525 mm. Juvenile average length is 246 mm with lengths ranging from 140–376. Some overlap occurred between the length range of subadults and juveniles and subadults and adults, but no overlap occurred between juveniles and adults. There were three juveniles ≥340 mm, the criteria we used in some analyses for including subadult rockfish; however, no juveniles were included in any of the density analyses. 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. In addition, juveniles have never been included in past density estimates. There is some subjectivity in maturity staging; consequently, some of these juveniles may be subadults and vice versa; excluding juveniles from all analyses is the more conservative approach. Four subadults were ≤340 mm (Dive 10, specimen 28; Dive 24, specimen 4; Dive 32, specimen 35; and Dive 16, specimen 18) and were excluded from the analyses (analysis 3 and 4) for 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 2015 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 2015, 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 analyses with all four 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 3–10). The hazard rate models also generally had lower AIC values, larger K-S and Chi-square p values, and a tighter fit for the q-q plots; all indicating good model fits to the data. In addition, K-S and Chi-square p-values were much greater than >0.05 indicating little deviation from the model (Appendices 1–4).

Models without binning were preferred for the 2015 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) or in the behavior of yelloweye rockfish (Figures 3–10).

In 2015, models with data truncation were preferred. 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. In 2012 and 2013, the selected models for the ROV survey did not include any data truncation; however, no fish were 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 (Figure 3–10; Appendices 1–4).

CV estimates of 17-18% were obtained in 2015 for the models that had a minimum estimate of schooling fish for dive 11 (Analyses 2 and 4) whereas models that included all schooling yelloweye prior to 23:09:21(Analyses 1 and 3) had CV estimates of 25% (Table 2). The model which included the minimum estimate of schooling yelloweye had reduced variability (30 compared to 60 fish) with lower a CV. On average, 8 yelloweye (adults and subadults) were observed per transect with dive 10 having the second largest number of sightings with 21 yelloweye (Analysis 1). Our goal of a CV <15% was not met in 2015 or 2013, but was met in 2012 when a larger number of transects were performed in CSEO (Table 2). In EYKT, we performed a comparable number of transects for the area of rockfish habitat as were performed in CSEO in 2012; consequently, more transects per kilometer of habitat may be needed in EYKT to obtain a lower estimate of CV. It is possible, that there is a higher degree of variability in yelloweye density in EYKT management area compared to CSEO. The encounter rate was about double in EYKT compared to CSEO and SSEO management areas (Table 2) with a similar encounter rate observed in EYKT during the 1999 and 2009 submersible surveys (Table 3). In 2015, high definition video was used for the stereo cameras compared to just a few high definition videos in 2013 and none in 2012; this high definition video may have allowed for more yelloweye to be observed from the ROV than in 2012 and 2013.

Valid density estimates were obtained with no violations of distance sampling assumptions, even though,some yelloweye rockfish exhibited schooling behavior. In dive 11, yelloweye rockfish schooling after 23:09:21 were not included in the density estimate because they appeared to be following the ROV and there was concern these fish might be double-counted. Schools of yelloweye observed prior to this time on dive 11, may have been exhibiting some attraction behavior, such as opportunistically feeding using the ROV lights. Still a majority (62%) of yelloweye rockfish on the survey 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; 34% were observed moving into the frame slowly or quickly with 2% moving out of the frame. The remaining yelloweye rockfish were performing behaviors such as chasing other fish. When we only include the minimum estimate for schooling fish, the proportion of yelloweye moving into the frame declines to 27%. The sighting frequency histograms and the probability detection functions for all analyses do not indicate attraction is occurring to the ROV (Figures 1–10). 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 3–10).

The 2015 yelloweye rockfish density estimates ranged from 1,533 yelloweye/km2 for analysis 4, which included only subadults>340 mm and the minimum estimate for dive 11 schooling fish, to 1,796 yelloweye/km2 for analysis 1, which included all subadults and all schooling yelloweye from dive 11. The lowest density estimates occurred when only the minimum estimate for schooling fish on dive 11 was used, which excluded 30 yelloweye. Density estimates with only subadults>340 were only slightly lower than estimates that included all subadults, because only four fish were excluded using this criteria. The 2015 density estimates for all analyses are slightly lower than the 2009 estimate of 1,930 yelloweye/km2 (Figure 11; Table 3). It is likely that this difference in the density estimate represents a decline in the population. During the 6 years between the 2009 submersible and 2015 ROV surveys, fishing pressure occurred on the yelloweye rockfish population in EYKT management area with yelloweye rockfish captured as bycatch in the commercial halibut fishery and in the directed DSR fishery which was open annually from 2012–2015 with approximately 307,149 pounds of yelloweye harvested. Yelloweye rockfish are late maturing and slow growing; consequently, replacement of recruits to the fisheries, and those assessed in our Distance analysis, would be slow. In addition, because yelloweye rockfish have high site fidelity, we would not expect replacement of yelloweye rockfish from other management areas. The decline in yelloweye density in EYKT is consistent with the trend observed in the other management areas in recent years, CSEO in 2012 and SSEO in 2013.

# 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*** | ***2013*** | ***2015*** | ***2015*** | ***2015*** | ***2015*** |
| **Management Area** | ***CSEO*** | ***SSEO*** | ***EYKT*** | ***EYKT*** | ***EYKT*** | ***EYKT*** |
| **Model Name** |  |  | ***Analysis 1*** | ***Analysis 2*** | ***Analysis 3*** | ***Analysis 4*** |
| **Model Data** | ***AD & SUB>340 mm*** | ***AD & SUB>340 mm*** | ***AD & SUB*** | ***AD & SUB***  ***Dive 11 min.*** | ***AD & SUB>340 mm*** | ***AD & SUB>340 mm***  ***Dive 11 min.*** |
| **Number line transects** | 46 | 31 | 33 | 33 | 33 | 33 |
| **Meters surveyed** | 38,590 | 30,439 | 22,896 | 22,896 | 22,896 | 22,896 |
| **Number transects with no AD/SUB ye observations** | 7 | 8 | 2 | 2 | 2 | 2 |
| **Average SUB & AD per transect** | 2.6 | 3.4 | 8.4 | 7.4 | 7.7 | 7.3 |
| **Maximum SUB & AD per transect** | 9 | 15 | 60 | 30 | 60 | 30 |
| **Number AD & SUB included in model1** | 1183 | 118 | 255 | 225 | 2512 | 2212 |
| **Number of AD included in model1** | 112 | 93 | 240 | 210 | 240 | 210 |
| **Number of SUB included in model1** | 63 | 25 | 15 | 15 | 112 | 112 |
| **Max. distance (ft) AD & SUB in model1** | 10.39 | 10.86 | 11 | 11 | 11 | 11 |

1 These counts do not include fish that were removed from the models due to truncation.

2 Four subadults were excluded from these analyses because they were ≤340 mm. Subadults with no length information were included.

3 Twenty subadults were excluded from this analysis because they were ≤340 mm or had no length information.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | ***2012*** | ***2013*** | ***2015*** | ***2015*** | ***2015*** | ***2015*** |
| **Management Area** | **CSEO** | **SSEO** | **EYKT** | **EYKT** | **EYKT** | **EYKT** |
| **Model Name** |  |  | ***Analysis 1*** | ***Analysis 2*** | ***Analysis 3*** | ***Analysis 4*** |
| **Model Data** | ***AD & SUB>340 mm*** | ***AD & SUB>340 mm*** | ***AD & SUB*** | ***AD & SUB***  ***Dive 11 min.*** | ***AD & SUB>340*** | ***AD & SUB>340***  ***Dive 11 min.*** |
| **Density (ye/** **km2)** | 752 | 986 | 1796 | 1641 | 1755 | 1533 |
| **Lower CI (95%) Density** |  |  | 1097 | 1153 | 1065 | 1080 |
| **Upper CI (95%) Density** |  |  | 2941 | 2334 | 2891 | 2176 |
| **CV of Density** | 0.13 | 0.22 | 0.25 | 0.18 | 0.25 | 0.17 |
| **Variance components** |  |  |  |  |  |  |
| **- Detection probability** | 18% | 8% | 3% | 11% | 3% | 8% |
| **-Encounter rate** | 82% | 92% | 97% | 89% | 97% | 92% |
| **Encounter rate (yelloweye/L)** | 0.003 | 0.004 | 0.008 | 0.007 | 0.008 | 0.007 |
| **Effective strip width (ft)** | 6.7 | 6.5 | 7.3 | 7.0 | 7.3 | 7.4 |

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

**Table 3. EYKT distance analysis results and model inputs. For 2015, we included the results for models which are being considered for the current stock assessment methods.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Year | # transects | # yelloweye in model | Meters surveyed | Encounter rate (yelloweye/L) | Density  (ye/ km2) | CV |
| 1995 | 17 | 330 | 22,896 | 0.014 | 2,711 | 0.20 |
| 1997 | 20 | 350 | 19,240 | 0.018 | 2,576 | 0.28 |
| 1999 | 20 | 236 | 25,198 | 0.009 | 1,584 | 0.18 |
| 2003 | 20 | 335 | 17,878 | 0.019 | 3,825 | 0.17 |
| 2009 | 37 | 215 | 29,890 | 0.007 | 1,930 | 0.17 |
| 20151 | 33 | 251 | 31,981 | 0.008 | 1,755 | 0.25 |
| 20152 | 33 | 221 | 31,981 | 0.007 | 1,533 | 0.17 |

1 Analysis 3, model with adults and subadults>340 mm

2 Analysis 4, model with adults and subadults>340 mm and with dive 11 minimum estimate

**Figure 1. Frequency histograms for all adult and subadult yelloweye rockfish.**

**Figure 2. Frequency histograms for all adult and subadult yelloweye rockfish with the minimum estimate of schooling fish for dive 11.**



**Figure 3. All adults and subadults hazard rate with no binning and no truncation, 1.58 ft intervals shown.**



**Figure 4. All adults and subadults, hazard rate with no binning and truncation after 11 ft, 0.73 ft intervals shown.**



**Figure 5. All adults and subadults with dive 11 minimum estimate, hazard rate with no binning or truncation, 1.58 ft intervals shown.**



**Figure 6. All adults and subadults with dive 11 minimum estimate, hazard rate with no binning and truncation after 11 ft, 0.73 ft intervals shown.**



**Figure 7. All adults and subadults >340 mm, hazard rate with no binning or truncation, 1.58 ft intervals shown.**



**Figure 8. All adults and subadults >340 mm, hazard rate with no binning and truncation after 11 ft, 0.73ft intervals shown.**



**Figure 9. All adults and subadults >340 mm with dive 11 minimum, hazard rate with no binning or truncation, 1.58 ft intervals shown.**



**Figure 10. All adults and subadults >340 mm with dive 11 minimum, hazard rate with no binning and truncation after 11 ft, 0.73ft intervals shown.**

**Figure 11. Density estimates for EYKT management area. For 2015, the two estimates being considered for current stock assessment methods are shown: in blue is the estimate which includes all schooling yelloweye for dive 11 and subadults >340 and the estimate in orange shows a minimum estimate for schooling yelloweye in dive 11 and subadults >340.**

**Appendices**

**Model Results for all Models Explored by Analysis**

**Appendix 1. Analysis 1 - All adults and all subadults. The preferred model for the age-structured assessment is marked with an asterisk (Appendix 1E).**

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.A. No binning or truncation, 259 observations, width 15.77*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1190 | 1196 | 1198 |
| Density (ye/km2) | 1791 | 1968 | 1878 |
| D LCL (ye/km2) | 1102 | 1177 | 1127 |
| D UCL (ye/km2) | 2909 | 3290 | 3129 |
| CV of D | 0.242 | 0.259 | 0.257 |
| Judgement | Pretty good fit with shoulder for 1.58 ft bins; For 0.986 ft bins, pretty good fit with some deviation around 3ft; For 0.657 ft bins, OK fit with shoulder but has a couple large deviations. | 1.58 ft bin has good fit but not great shoulder; 0.986 ft bins is OK fit with not much shoulder; 0.657 ft bins is not great fit. | Pretty good fit with good shoulder for 1.58 ft bins; OK fit with good shoulder and some deviation; not very good fit but good shoulder for 0.657 ft bins |
| X2 P-value | 0.53 (1.58 ft bins); 0.28 (0.986 ft bins); 0.099 (0.657 ft bins) | 0.17 (1.58 ft bins); 0.06 (0.986 ft bins); 0.01 (0.657 ft bins) | 0.53 (1.58 ft bins); 0.28 (0.986 ft bins); 0.099 (0.657 ft bins) |
| # parameters | 2 | 3 | 2 |
| Q-q plot | Good tight fit | Lots of deviation in middle | Ok fit with some deviation |
| K-S P-value | 0.99 | 0.555 | 0.9185 |
| warnings | No warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.B. 1-ft bins, no truncation, 259 observations, width 15.77*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1194 | 1199 | 1200 |
| Density (ye/km2) | 1788 | 1963 | 2158 |
| D LCL (ye/km2) | 1100 | 1173 | 1327 |
| D UCL (ye/km2) | 2906 | 3283 | 3508 |
| CV of D | 0.242 | 0.260 | 0.243 |
| Judgement | Good fit with shoulder | OK fit, but not great, slight shoulder | Not good fit at origin and no shoulder |
| X2 P-value | 0.44 | 0.100 | 0.043 |
| # parameters | 2 | 3 | 1 |
| warnings | No warnings | Parameters being constrained to obtain monotonicity | No warnings |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.C. 1.5-ft bins, no truncation, 259 observations, width 15.77*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 985 | 990 | 992 |
| Density (ye/km2) | 1777 | 1962 | 1892 |
| D LCL (ye/km2) | 1093 | 1173 | 1136 |
| D UCL (ye/km2) | 2887 | 3281 | 3153 |
| CV of D | 0.242 | 0.259 | 0.257 |
| Judgement | Looks like good fit with nice shoulder | Bad fit at shoulder, OK shoulder and fit. | Bad fit at origin. Otherwise OK. |
| X2 P-value | 0.08 | 0.01 | <0.01 |
| # parameters | 2 | 3 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; convergence failure; some parameters are highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.D. 2-ft bins, no truncation, 259 observations, width 15.77 ft*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 840 | 844 | 845 |
| Density (ye/km2) | 1776 | 1962 | 2153 |
| D LCL (ye/km2) | 1092 | 1170 | 1324 |
| D UCL (ye/km2) | 2887 | 3290 | 3501 |
| CV of D | 0.243 | 0.261 | 0.243 |
| Judgement | good fit with nice shoulder | Good fit with OK shoulder | OK fit but no shoulder |
| X2 P-value | 0.80 | 0.34 | 0.16 |
| # parameters | 2 | 3 | 1 |
| warnings | No warnings | Parameters being constrained to obtain monotonicity | No warnings |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.E. No binning, truncation after 11ft, 255 observations, width 11 ft*** | | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1133 | 1135 | 1135 |
| Density (ye/km2) | 1796 | 1953 | 1924 |
| D LCL (ye/km2) | 1097 | 1159 | 1142 |
| D UCL (ye/km2) | 2941 | 3290 | 3241 |
| CV of D | 0.246 | 0.263 | 0.263 |
| Judgement | 1.1 ft bins-Good shoulder, good fit); 0.73 ft bins-Good shoulder, good fit in most bins; Good shoulder, some bins bad fit | 1.1 ft bins-good fit but no shoulder; 0.73 ft bins-OK fit, OK shoulder; 0.48 ft bins- not great fit at many bins | 1.1 ft bins-good fit but no shoulder; 0.73 ft bins-OK fit, OK shoulder; 0.48 ft bins- not great fit at many bins |
| X2 P-value | 0.45(1.1 ft bins), 0.67 (0.73 ft bins), 0.61 (0.48 ft bins) | 0.32 (1.1 ft bins), 0.46 (0.73 ft bins), 0.50 (0.48 ft bins) | 0.34 (1.1 ft), 0.47 (0.73 ft), 0.48 (0.48 ft) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Very good fit | Not great fit | Not great fit |
| K-S P-value | 0.99 | 0.61 | 0.74 |
| warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity |  |

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| --- | --- | --- | --- |
| ***Appendix 1.F. 1 ft bins, truncation after 11ft, 255 observations, width 11 ft*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1137 | 1138 | 1138 |
| Density (ye/km2) | 1800 | 1943 | 1914 |
| D LCL (ye/km2) | 1098 | 1153 | 1137 |
| D UCL (ye/km2) | 2949 | 3274 | 3224 |
| CV of D | 0.247 | 0.263 | 0.263 |
| Judgement | Good shoulder and good fit | OK fit, but not 1.0 at origin | OK fit, but not 1.0 at origin |
| X2 P-value | 0.84 | 0.70 | 0.71 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 1.G. 2 ft bins, truncation after 10 ft bin, 250 observations, width 10 ft*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 751 | 752 | 751 |
| Density (ye/km2) | 1769 | 1955 | 1926 |
| D LCL (ye/km2) | 1071 | 1145 | 1131 |
| D UCL (ye/km2) | 2920 | 3337 | 3281 |
| CV of D | 0.251 | 0.270 | 0.269 |
| Judgement | Good fit and good shoulder | OK fit, but not much shoulder | OK fit, but not much shoulder |
| X2 P-value | 0.50 | 0.27 | 0.44 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

**Appendix 2. All adults and all subadults, dive 11 minimum estimate. The preferred model for the age-structured assessment is marked with an asterisk (Appendix 2E).**

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 2.A. No binning or truncation, 229 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1063 | 1068 | 1069 |
| Density (ye/km2) | 1564 | 1673 | 1872 |
| D LCL (ye/km2) | 1112 | 1147 | 1330 |
| D UCL (ye/km2) | 2200 | 2439 | 2634 |
| CV of D | 0.17 | 0.19 | 0.17 |
| Judgement | 1.58 ft bins-Very good, fit with nice shoulder  1.05 ft bins-pretty good fit with nice shoulder  0.72 ft bins-not a very good fit at some bins, nice shoulder | 1.58 ft bins-good fit but no shoulder  1.05 ft bins-OK fit but no shoulder  0.72 ft bins-not very good fit & no shoulder | 1.58 ft bin-OK fit but no shoulder  1.05 ft bin-OK fit but no shoulder  0.72 ft-bad fit |
| X2 P-value | 0.64 (1.58ft), 0.38 (1.05ft), 0.37 (0.72 ft bins) | 0.079 (1.58 ft), 0.012 (1.05 ft bins), <0.01 (0.72ft bins) | 0.19 (1.58 ft bin), 0.12 (1.05 ft), 0.06 (0.72 ft) |
| # parameters | 2 | 2 | 1 |
| Q-q plot | Pretty good fit, a little deviation in middle | Ok fit, some deviation | Lots of deviation. Not a good fit |
| K-S P-value | 0.97 | 0.95 | 0.35 |
| warnings | No warnings | Parameters being constrained to obtain monotonicity | No warnings |

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| --- | --- | --- | --- |
| ***Appendix 2.B. 1 ft bins no truncation, 229 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1066 | 1070 | 1070 |
| Density (ye/km2) | 1565 | 1871 | 1871 |
| D LCL (ye/km2) | 1112 | 1329 | 1329 |
| D UCL (ye/km2) | 2202 | 2633 | 2633 |
| CV of D | 0.170 | 0.170 | 0.170 |
| Judgement | Good fit with nice shoulder | OK fit but no shoulder | OK fit but no shoulder |
| X2 P-value | 0.58 | 0.13 | 0.13 |
| # parameters | 2 | 1 | 1 |
| warnings | None | None | none |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 2.C. 1.5 ft bin, no truncation, 229 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite- was same as half normal cosine** |
| AIC | 880 | 885 |  |
| Density (ye/km2) | 1565 | 1874 |  |
| D LCL (ye/km2) | 1112 | 1332 |  |
| D UCL (ye/km2) | 2203 | 2638 |  |
| CV of D | 0.170 | 0.170 |  |
| Judgement | Good fit and nice shoulder | OK fit but no shoulder |  |
| X2 P-value | 0.14 | 0.02 |  |
| # parameters | 2 | 1 |  |
| warnings | None | none |  |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 2.D. 2 ft bin, no truncation, 229 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite-was same as half normal cosine** |
| AIC | 751 | 753 |  |
| Density (ye/km2) | 1569 | 1875 |  |
| D LCL (ye/km2) | 1113 | 1332 |  |
| D UCL (ye/km2) | 2211 | 2639 |  |
| CV of D | 0.171 | 0.171 |  |
| Judgement | Good fit with nice shoulder | Good fit but no shoulder |  |
| X2 P-value | 0.94 | 0.43 |  |
| # parameters | 2 | 1 |  |
| warnings | None | none |  |

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| --- | --- | --- | --- |
| ***Appendix 2.E. No binning, truncation after 11ft, 225 observations with 11 width*** | | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1009 | 1008 | 1008 |
| Density (ye/km2) | 1641 | 1692 | 1666 |
| D LCL (ye/km2) | 1153 | 1141 | 1125 |
| D UCL (ye/km2) | 2334 | 2508 | 2467 |
| CV of D | 0.176 | 0.199 | 0.198 |
| Judgement | 1.22 ft bins-really good fit with nice shoulder; 0.73 ft bins-OK fit with some deviation; 0.89 ft bins- OK fit but not good at some intervals | 1.22 ft bins-good fit but not real shoulder; 0.73 ft-good fit with a little bit of a shoulder; 0.5 ft bins-good fit at most intervals | 1.22 ft bins-good fit but not real shoulder; 0.73 ft-good fit with a little bit of a shoulder; 0.5 ft bins-good fit at most intervals; |
| X2 P-value | 0.77 (1.22 ft bins), 0.85 (0.73 ft bins), 0.89 (0.5 ft bins) | 0.80 (1.22 ft bins); 0.84 (0.73 ft bins); 0.88 (0.5 ft bins) | 0.81 (1.22 ft bins); 0.82 (0.73 ft bins); 0.87 (0.5 ft bins) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Pretty good fit with small deviations | OK fit with some deviation | Pretty good fit with little deviation |
| K-S P-value | 0.99 | 0.90 | 0.97 |
| warnings | No warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are very highly correlated |

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| --- | --- | --- | --- |
| ***Appendix 2.F. 1 ft bin, truncation after 11ft, 225 observations with 11 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1010 | 1010 | 1011 |
| Density (ye/km2) | 1636 | 1685 | 1659 |
| D LCL (ye/km2) | 1148 | 1136 | 1120 |
| D UCL (ye/km2) | 2330 | 2500 | 2457 |
| CV of D | 0.177 | 0.199 | 0.199 |
| Judgement | Very good fit and good shoulder | Very good fit and a little bit of a shoulder | Very good fit and a little bit of a shoulder |
| X2 P-value | 0.87 | 0.89 | 0.88 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity |

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| --- | --- | --- | --- |
| ***Appendix 2.G. 1.5 ft bin, truncation after 11ft, 225 observations with 10.5 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 823 | 824 | 824 |
| Density (ye/km2) | 1599 | 1674 | 1817 |
| D LCL (ye/km2) | 1125 | 1123 | 1278 |
| D UCL (ye/km2) | 2273 | 2494 | 2585 |
| CV of D | 0.175 | 0.202 | 0.176 |
| Judgement | Good fit with nice shoulder | Good fit with a little bit of a shoulder | OK fit but no shoulder |
| X2 P-value | 0.52 | 0.40 | 0.29 |
| # parameters | 2 | 2 | 1 |
| warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 2.H. 2 ft bin, truncation after 11ft, 221 observations with 10 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 664 | 665 | 664 |
| Density (ye/km2) | 1576 | 1708 | 1682 |
| D LCL (ye/km2) | 1105 | 1136 | 1123 |
| D UCL (ye/km2) | 2249 | 2568 | 2520 |
| CV of D | 0.177 | 0.207 | 0.204 |
| Judgement | Good fit with nice shoulder | Good fit with a little bit of a shoulder | Good fit with a little bit of a shoulder |
| X2 P-value | 0.77 | 0.61 | 0.82 |
| # parameters | 2 | 2 | 2 |
| warnings | The number of adjustment parameters allowed has been reduced to 2 because of limited number of intervls | The number of adjustment parameters allowed has been reduced to 3 because of limited number of intervals; Parameters being constrained to obtain monotonicity | The number of adjustment parameters allowed has been reduced to 3 because of limited number of intervals; Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

**Appendix 3. - All adults and subadults >340 mm (subadults with no lengths or lengths with bad length information are included). The preferred model for the stock assessment is marked with an asterisk (Appendix 3E).**

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| --- | --- | --- | --- |
| ***Appendix 3.A. No binning or truncation, 255 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1174 | 1180 | 1182 |
| Density (ye/km2) | 1751 | 1833 | 1830 |
| D LCL (ye/km2) | 1071 | 1095 | 1091 |
| D UCL (ye/km2) | 2861 | 3071 | 3069 |
| CV of D | 0.245 | 0.260 | 0.261 |
| Judgement | 1.58 ft bins-Good fit with nice shoulder; 1.05 ft bins- good fit with nice shoulder; 0.69 ft bins-Ok fit but not great at some bins. | All are OK fit but not great shoulder and <1.0 at origin. | Fit for all bins is OK with a little bit of a shoulder, but <1.0 at origin and fit to 0.69 bins has some deviation. |
| X2 P-value | 0.55 (1.58 ft bins); 0.33 (1.05 ft bins); 0.43 (0.69 ft bins) | All bins<0.05 | All bins <0.05 |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Really tight fit | Ok fit with some deviation | Ok fit with some deviation |
| K-S P-value | 0.99 | 0.91 | 0.92 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

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| --- | --- | --- | --- |
| ***Appendix 3.B. 1 ft bin no truncation, 255 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1178 | 1183 | 1184 |
| Density (ye/km2) | 1747 | 1919 | 1852 |
| D LCL (ye/km2) | 1069 | 1140 | 1105 |
| D UCL (ye/km2) | 2856 | 3231 | 3102 |
| CV of D | 0.245 | 0.263 | 0.260 |
| Judgement | Good fit with good shoulder | OK fit with slight shoulder but <1.0 at origin | OK fit with slight shoulder but <1.0 at origin |
| X2 P-value | 0.42 | 0.09 | <0.05 |
| # parameters | 2 | 3 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity |  |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 3.C. 1.5 ft bin no truncation, 255 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 972 | 977 | 978 |
| Density (ye/km2) | 1740 | 1921 | 1840 |
| D LCL (ye/km2) | 1064 | 1142 | 1097 |
| D UCL (ye/km2) | 2744 | 3233 | 3087 |
| CV of D | 0.245 | 0.263 | 0.261 |
| Judgement | Good fit and good shoulder | OK fit with slight shoulder but <1.0 at origin | OK fit with slight shoulder but <1.0 at origin |
| X2 P-value | 0.08 | <0.05 | <0.05 |
| # parameters | 2 | 3 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity |  |

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| --- | --- | --- | --- |
| ***Appendix 3.D. 2 ft bin no truncation, 255 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 829 | 833 | 834 |
| Density (ye/km2) | 1737 | 1855 | 1852 |
| D LCL (ye/km2) | 1062 | 1108 | 1104 |
| D UCL (ye/km2) | 2840 | 3107 | 3107 |
| CV of D | 0.246 | 0.260 | 0.261 |
| Judgement | Good fit and nice shoulder | Good fit, with little bit of a shoulder | Good fit, with little bit of a shoulder |
| X2 P-value | 0.79 | 0.10 | 0.04 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; parameters are highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 3.E. No binning, truncation after 11ft, 251 observations with 11 width*** | | | |
|  | **Hazard rate cosine\*** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1117 | 1119 | 1119 |
| Density (ye/km2) | 1755 | 1912 | 1884 |
| D LCL (ye/km2) | 1065 | 1128 | 1111 |
| D UCL (ye/km2) | 2891 | 3243 | 3193 |
| CV of D | 0.249 | 0.267 | 0.266 |
| Judgement | Good fit at most bins; nice shoulder | OK fit at most bins; slight shoulder; origin<1.0 | OK fit at most bins; slight shoulder; origin<1.0 |
| X2 P-value | 0.44 (1.1 ft bins); 0.66 (0.74 ft bins); 0.58 (0.48 ft bins) | 0.29 (1.1 ft bins); 0.44 (0.73 ft bins); 0.46 (0.48 ft bins) | 0.32 (1.1 ft bins); 0.46 (0.73 ft bins); 0.45 (0.48 ft bins) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Very tight fit | Some considerable deviation | Some deviation |
| K-S P-value | 0.996 | 0.57 | 0.71 |
| warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

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| --- | --- | --- | --- |
| ***Appendix 3.F. 1 ft bin, truncation after 11ft, 251 observations with 11 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1121 | 1122 | 1122 |
| Density (ye/km2) | 1757 | 1902 | 1874 |
| D LCL (ye/km2) | 1066 | 1121 | 1106 |
| D UCL (ye/km2) | 296 | 3226 | 3175 |
| CV of D | 0.250 | 0.267 | 0.266 |
| Judgement | Very good fit and good shoulder | Good fit, not much of a shoulder; <1.0 at origin | Good fit and slight shoulder |
| X2 P-value | 0.83 | 0.66 | 0.68 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 3.G. 2 ft bins, truncation after 10ft, 247 observations, 10ft width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 740 | 742 | 741 |
| Density (ye/km2) | 1727 | 1785 | 1886 |
| D LCL (ye/km2) | 1040 | 1008 | 1100 |
| D UCL (ye/km2) | 2868 | 3161 | 3232 |
| CV of D | 0.254 | 0.292 | 0.273 |
| Judgement | Good fit and good shoulder but few bins | Good fit and good shoulder but few bins | OK fit, but not much shoulder and <1.0 at origin |
| X2 P-value | 0.48 | 0.36 | 0.40 |
| # parameters | 2 | 3 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are highly correlated |

**Appendix 4- Analysis 4- All adults and subadults>340 mm (subadults with no lengths or lengths with bad information are included), dive 11 minimum estimates. The preferred model for the stock assessment is marked with an asterisk (Appendix 4E).**

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.A. No binning or truncation, 225 observations with 15.77 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1047 | 1052 | 1052 |
| Density (ye/km2) | 1524 | 1618 | 1827 |
| D LCL (ye/km2) | 1081 | 1105 | 1295 |
| D UCL (ye/km2) | 2148 | 2368 | 2578 |
| CV of D | 0.17 | 0.192 | 0.171 |
| Judgement | Good fit with good shoulder |  |  |
| X2 P-value | 0.35 (1.75 ft bins); 0.36 (1.05 ft bins); 0.34 (0.72 ft bins) | 0.09 (1.75 ft bins); 0.01 (1.05 ft bins); <0.05(0.72 ft bins) | Good fit with slight shoulder, for 1.05 ft and 0.72 ft bins <1.0 at origin |
| # parameters | 2 | 2 | 1 |
| Q-q plot | Really good fit | Some deviation |  |
| K-S P-value | 0.98 | 0.95 |  |
| warnings | None | Parameters being constrained to obtain monotonicity | None |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.B. 1 ft bins, no truncation, 225 observations with 16 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 1050 | 1054 | 1054 |
| Density (ye/km2) | 1524 | 1826 | 1826 |
| D LCL (ye/km2) | 1081 | 1294 | 1294 |
| D UCL (ye/km2) | 2150 | 2576 | 2576 |
| CV of D | 0.171 | 0.171 | 0.171 |
| Judgement | Good fit and wide shoulder | OK fit but no shoulder | OK fit but no shoulder |
| X2 P-value | 0.55 | 0.13 | 0.13 |
| # parameters | 2 | 1 | 1 |
| warnings | None | None | none |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.C. 1.5 ft bins, no truncation, 225 observations with 16.5 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 867 | 871 | 872 |
| Density (ye/km2) | 1528 | 1083 | 1831 |
| D LCL (ye/km2) | 1083 | 1023 | 1298 |
| D UCL (ye/km2) | 2156 | 2365 | 2583 |
| CV of D | 0.171 | 0.213 | 0.171 |
| Judgement | Good fit, nice shoulder | Good fit, nice shoulder | OK fit, but no shoulder |
| X2 P-value | 0.14 | 0.05 | 0.02 |
| # parameters | 2 | 4 | 1 |
| warnings | none | Parameters being constrained to obtain monotonicity | none |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.D. 2 ft bins, no truncation, 225 observations with 16.5 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 740 | 743 | 743 |
| Density (ye/km2) | 1529 | 1831 | 1831 |
| D LCL (ye/km2) | 1083 | 1297 | 1297 |
| D UCL (ye/km2) | 2160 | 2584 | 2584 |
| CV of D | 0.172 | 0.171 | 0.171 |
| Judgement | Good shoulder and good fit | OK fit but no shoulder | OK fit but no shoulder |
| X2 P-value | 0.94 | 0.42 | 0.42 |
| # parameters | 2 | 1 | 1 |
| warnings | None | None | none |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.E. No binning truncation at 11ft, 221 observations with 11 width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 991 | 992 | 992 |
| Density (ye/km2) | 1533\* | 1652 | 1626 |
| D LCL (ye/km2) | 1080 | 1110 | 1094 |
| D UCL (ye/km2) | 2176 | 2457 | 2416 |
| CV of D | 0.174 | 0.201 | 0.200 |
| Judgement | Nice shoulder and good fit for 1.22 ft and 0.79 ft bins. Fit not great at some bins for 0.5ft. | Good fit for 0.74 and 0.71 ft bins, but not great fit at some bins for 0.5 ft bins. Not a great shoulder for any of the bins. | Good fit for 0.74 and 0.71 ft bins, but not great fit at some bins for 0.5 ft bins. Not a great shoulder for any of the bins. |
| X2 P-value | 0.88 (1.22 ft bins), 0.83 (0.79 ft bins), 0.88 (0.5 ft bins) | 0.74 (1.22 ft bins), 0.71 (0.79 ft bins), 0.84 (0.5 ft bins) | 0.76 (1.22 ft bins); 0.71 (0.79 ft bins), 0.83 (0.5ft bins) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Very tight fit | Ok fit with some deviation | Ok fit with some deviation |
| K-S P-value | 0.99 | 0.80 | 0.91 |
| warnings | None | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are very highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.F. 1 ft bins, truncation after 11ft, 221 observations with 11ft width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 994 | 994 | 995 |
| Density (ye/km2) | 1559 | 1644 | 1619 |
| D LCL (ye/km2) | 1095 | 1105 | 1089 |
| D UCL (ye/km2) | 2219 | 2448 | 2405 |
| CV of D | 0.176 | 0.201 | 0.200 |
| Judgement | Nice shoulder and good fit | OK fit but not much of a shoulder | Good fit with slight shoulder |
| X2 P-value | 0.92 | 0.86 | 0.86 |
| # parameters | 2 | 2 | 2 |
| warnings | none | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity; some parameters are very highly correlated |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.G. 1.5 ft bins, truncation after 11ft, 221 observations with 10.5ft width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 810 | 811 | 811 |
| Density (ye/km2) | 1562 | 1634 | 1772 |
| D LCL (ye/km2) | 1095 | 1093 | 1242 |
| D UCL (ye/km2) | 2227 | 2443 | 2528 |
| CV of D | 0.177 | 0.204 | 0.177 |
| Judgement | Good fit and good shoulder | OK fit but not much of a shoulder | OK fit bun no shoulder |
| X2 P-value | 0.51 | 0.38 | 0.28 |
| # parameters | 2 | 2 | 1 |
| warnings | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity | Parameters being constrained to obtain monotonicity |

|  |  |  |  |
| --- | --- | --- | --- |
| ***Appendix 4.H. 2 ft bins, truncation after 11ft, 217 observations with 10ft width*** | | | |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 654 | 654 | 654 |
| Density (ye/km2) | 1535 | 1667 | 1642 |
| D LCL (ye/km2) | 1073 | 1104 | 1092 |
| D UCL (ye/km2) | 2197 | 2515 | 2467 |
| CV of D | 0.178 | 0.209 | 0.206 |
| Judgement | Good fit with good shoulder but very few bins. | Good fit, not much of a shoulder, very few bins. | Good fit, not much of a shoulder, very few bins. |
| X2 P-value | 0.78 | 0.58 | 0.80 |
| # parameters | 2 | 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 2 because of limited number of intervals. Parameters being constrained to obtain monotonicity | The number of adjustment parameters allowed has been reduced to 2 because of limited number of intervals. Parameters being constrained to obtain monotonicity; some parameters are highly correlated. |