2013 ROV Distance Analysis

# Methods

*Distance Data*- A total of 118 yelloweye were included in the density analysis in 2013, 93 adults and 25 subadults. All subadults and adults were included in the density analysis. In 2012 subadults were only included in the analysis if their length was >350 mm and no subadults were included if there was no length for the fish. In 2013, we revised our criteria on which subadults to include in the density analysis; subadults were included if they were ≥340 mm and we included subadults even if no length data were available. These criteria were changed, because in 2013 an adult and a subadult fish were recorded at 340 mm, which is less than the previous cut-off of >350 mm. Adults have never been excluded from the density analysis, so I decided to include both the adult and subadult at 340 mm. Subadults with no length data were included in the analysis, because these subadults would likely be ≥340 mm since the average length of the 17 subadults with length data was 465 mm. Eight out of 25 subadult yelloweye did not have length data. I expect the subadult length data to be reasonable since only one length had a horizontal orientation >30 and RMS values for length endpoints were ≤10 mm. The average length for the last ten years of the directed SSEO commercial fishery was 553 mm; however, the minimum length of fish sampled from this fishery was 310 mm. Consequently it is possible that the subadults observed from the ROV could be caught in the commercial fishery. Prior to 2012 both 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 from inside the submersible than from the ROV stereo cameras. In 2013, no juveniles were included in the analysis; however, one juvenile was recorded as ≥340 mm. We decided not to include this larger juvenile for consistency; no juveniles have been included in analyses in the past.

Both the left and right sides of the 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 survey 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.

*Histograms*- 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 model in the Distance program, such as a model with a shoulder and a decreasing frequency of observations with distance from the ROV. The following bins were examined: 0.5-ft, 0.75-ft, 1-ft, 1.25-ft, 1.5-ft, 1.75-ft, 2-ft, and 2.5-ft bins (Figure 1).

*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 would often unknowingly round their distances, distances were often visually estimated and had 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, 1.75-ft, 2-ft, 2.5-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 (pers. comm.) 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 was often truncated for the submersible surveys; with yelloweye sometimes identifiable at distances as great as 30 ft. However, the field of view for the ROV survey is smaller due to differences in camera type and position; during the 2013 ROV survey fish were observed to 11 ft. It may not be necessary to truncate the ROV data, because fish observations may not be as variable at the right tail as they were for the submersible survey where there was possibility of observations at larger distances.

*Choosing a model*

I examined the results of the Distance analyses to determine if the 2013 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

*Choosing a model*

The preferred model for our 2013 ROV data had the hazard rate key function with a cosine adjustment term and no binning or truncation. This model has a good fit to the data; visually the probability detection function has a wide shoulder and declining probability of detection at larger distances (Figure 2). In addition, the K-S and chi-square test P-values were not significant suggesting a good model fit (Table 1). Also, the Q-q plot had generally a good fit with only minor deviation. The CV for then density estimate was 0.22 indicating OK precision.

*Key function*-The hazard rate cosine models were preferred over the half normal cosine or half normal hermite models. The hazard rate cosine models had the lowest CV values, lowest AICs, highest p-values, and best model fits as determined by the K-S and *X*2 values, q-q plots, and visual examination of the model (Tables 1–8; Figures 2–3).

The hazard rate model had the lowest AIC score when compared to the half normal cosine or the half normal hermite models for models with no binning and models explored with binning with the exception of the models with 2.5 bins, which had the same AIC score for all model key functions (Tables 1–8). The ∆AIC was between 2-4, indicating weak evidence that the model with the lowest AIC is preferred, for the hazard rate cosine compared to the next best model for the following models with no binning and models with the binning schemes of 1-ft, 1.5-ft, 1.75-ft, and 2-ft. The models examined had the same number of parameters of 2 with the exception of the model with no binning and truncation at 5% at the right tail; this model had one more parameter for the hazard rate model compared to the half normal cosine and half normal hermite.

Compared to the half normal hermite or half normal cosine models the hazard rate cosine models fit the data the best based on visual examination of detection functions and goodness of fit tests. The hazard rate model also has a larger shoulder at the origin, which is preferred for the probability detection function. For the model using exact data, q-q plots and the K-S test were produced for comparison between the models (Table 1; 7–8). The q-q plots had more deviation for the half normal cosine and half normal hermite models with only minor deviation for the hazard rate cosine models. The K-S P-value was also highest for the hazard rate models.

*Binning*- Our results from the 2012 and 2013 ROV survey indicate that it may not be necessary to bin our ROV data because we are obtaining distance measurements with little observer or measurement error by using a stereo camera system. For the preferred hazard rate models, the CV values were similar for models with binned and unbinned data. The *X*2 values were high for models with the bins of 1.75 ft, 2 ft, and 2.5 ft bins (≥0.78) and for the model with no binning but with truncation at 10.5 ft at the right tail (0.93; Table 1–8). The model without binning or truncation had *X*2 values from 0.46–0.57 dependent on bins used for the goodness of fit tests (Table 1). In addition, the density estimates did not vary greatly between the preferred hazard rate models whether data was binned or not binned (33 ye/km2 between the lowest and highest density for hazard rate models withhigh *X*2 values). These results indicate that not binning the data is preferred for the 2013 ROV data. Choosing a model with no bins 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.

*Truncation-* For the ROV surveys, truncation may not be necessary because fish are not observed to as great of a distance as they were during the submersible surveys. During the 2013 ROV survey we only observed yelloweye out to around 11 ft compared to approximately 30 ft for submersible surveys. Truncation is employed to prevent the tail of the model from overly influencing the overall model fit. For the 2013 ROV survey it doesn’t appear that the tail of the model is overly influencing the model. Models were explored with truncation at 5% of the right tail; these models did not fit the data well and dropped off abruptly at the right tail. Models with no binning but truncation at 10.5 ft were explored; one fish observation was removed at 10.9 ft for these models. The hazard rate model with no binning and truncation at 10.5 ft had a very high *X*2 value of 0.92 compared to the hazard rate model with no binning and no truncation with *X*2 values 0.46–0.57. Although, the *X*2 value was much higher for the model with truncation there seemed to be little other differences in the model diagnostics, i.e. both models had similar CV and K-S values. In addition, the difference in the density estimate between these models was only 13 yelloweye/km2. These results indicate that the model with no truncation may be preferred in order to retain all of the data in the model.

*Model assessment*

The 2013 ROV survey results suggest that using an ROV to conduct line transect sampling continues to be a valid method to estimate yelloweye rockfish density. A model was produced that fit the data well, the assumptions of distance sampling were met, and a CV estimate (22%) was obtained that indicates reasonable precision in the density estimate. However, our goal of a CV <15% was not met. A total of 60 transects were planned for 2013 in order to obtain this desired CV; however, technical issues with the stereo cameras resulted in only 31 completed transects. A better precision was obtained for the 2005 SSEO sub survey (17%) and for the 2012 CSEO ROV survey (13%). Fifteen more transects were performed on the 2012 ROV survey, which likely contributed to the better CV estimate. However, the same numbers of yelloweye were included in the 2013 density estimate as in 2012. Even though the 2013 survey had a higher encounter rate than in 2012, a higher variability in the number of yelloweye observed per transect probably contributed to a lower CV in 2013 (Table 9). Consequently, a larger number of transects may be needed in the SSEO management area compared to the CSEO management area in order to obtain a CV<15%. Only one more transect was completed during the 2005 SSEO survey than in the 2013 ROV survey; however, the number of adult and subadult yelloweye observed, the encounter rate (n/L), and the average number of yelloweye per transect were all over double for the 2005 survey. The larger field of view for the submersible survey may have contributed to the higher number of yelloweye observed per transect and the larger encounter rate for the 2005 survey. In addition, less yelloweye rockfish may be identifiable from the ROV video due to poor video quality compared to identification by an observer inside the submersible. This decline in yelloweye encounter rate and yelloweye observed per transect may also be due to a decline in the yelloweye population in this management area.

In 2013 the majority of the variance of the density estimate was due to the variability of the encounter rate (92%) with the remaining variance due to the detection probability. The variance components of the 2005 density estimate are unknown; for the 2012 CSEO ROV survey the majority of the variance was also due to the encounter rate (82%) with the remaining due to the detection probability. The variance due to the detection probability decreases as the fit of the model to the data improves; only 8% of the variance was composed of the detection probability variance compared to 18% in 2012; this indicates that the data fits the model very well for the 2013 ROV survey.

The behavior of yelloweye rockfish appears to be suitable for line transect sampling with the ROV. The majority of yelloweye rockfish appeared to be milling, hovering, or resting on the bottom when encountered by the ROV. There appears to be little or no overt attraction or avoidance behavior that would adversely influence the distance estimate. The sighting frequency histograms and probability detection functions did not indicate any attraction or avoidance behavior. There was no spike at the origin of the probability detection function indicating that there probably wasn’t any attraction behavior (Figure 2). 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. Instead the probability detection function has a broad shoulder until around 4 ft when the probability of detection appears to decline (Figure 2); this same general pattern is observed in the frequency histograms of distance with some variation between binning schemes on the distance that the decline in probability occurs.

The assumption of distance sampling that all yelloweye rockfish on the transect line were observed appeared to be met. The stereo camera field of view was similar to that of the forward-facing camera and indicated that fish close to the ROV and along the transect line were easily observed.

The ROV is appropriate for performing line transect sampling even though there is a more limited field of view compared to the submersible. In 2013 in SSEO management area, yelloweye rockfish were only observed to about 11 ft with the ROV compared to 30 ft with the submersible in 2005; this variation in the field of view between the sub and ROV are due to differences in the type and orientation of the cameras and the lack of the in-situ observer in the submersible. The differences in field of view are accounted for because the probability detection function is scaled to the effective width in order to estimate density (Figure 4). The effective width is the distance at which the probability of being detected is the same before or after that particular distance and is calculated from the probability of detection within the width of the line transect multiplied by the total width of the line transect (Figure 4); the width of the line transect is the distance at which the largest observation occurred. In addition, if the probability of detection at the origin is assumed to be 100%, then line transect estimation is equivalent to estimating the probability of detection at the origin. Consequently, it is most important to have a good model fit near the transect line and a smaller field of view should not affect the density estimation as long as an appropriate sample size is obtained.

The 2013 yelloweye rockfish density estimate of 986 yelloweye/km2 was a decline from the 2005 estimate of 2,196 yelloweye/km2. It is likely that this difference in the density estimate represents a real decline in the population. During the 8 years between the 2005 submersible and 2013 ROV surveys, fishing pressure occurred on the yelloweye rockfish population in SSEO management area with yelloweye rockfish captured in the sport fisheries, as bycatch in the commercial halibut fishery, and in the directed DSR fishery which was open from 2008–2013 with approximately 404,700 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 2013 SSEO density estimate is less than half the 2005 density estimate for this area and is the lowest estimate out of the four years that a survey has been conducted for this area. The survey density estimates had an increasing trend in this management area for the first three survey years of 1994, 1995, and 2005; the 2013 estimate broke the trend with a drop in the estimate (Figure 5). The 2013 density estimate is similar to the 1994 estimate; however in 1994 only 13 transects were performed, which may be a low sample size for obtaining a precise density estimate.

# 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.

Table 1. Results from models with exact data with no binning and no truncation.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 498 | 501 | 501 |
| Density (ye/km2) | 986 | 1081 | 1070 |
| D LCL (ye/km2) | 641 | 663 | 655 |
| D UCL (ye/km2) | 1517 | 1765 | 1749 |
| CV of D | 0.22 | 0.25 | 0.25 |
| Judgement | Good fit for 1.55 ft bins; Good fit with some deviation for 1.09 ft and 0.68 ft bins | Good fit but not much of a shoulder for 1.55 ft bins; OK fit with some deviation and not much of a shoulder for 1.09 ft bins; more deviation and not much of a shoulder for 0.68 ft bins. | Good fit but not much of a shoulder for 1.55 ft bins; OK fit with some deviation and not much of a shoulder for 1.09 ft bins; more deviation and not much of a shoulder for 0.68 ft bins. |
| X2 P-value | 0.52 (1.55 ft bins); 0.57 (1.09 ft bins); 0.46 (0.68 ft bins) | 0.20 (1.55 ft bins); 0.37 (1.09 ft bins); 0.26 (0.68 ft bins) | 0.23 (1.55 ft bins); 0.38 (1.09 ft bins); 0.25 (0.68 ft bins) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Good fit with minor deviation | Deviation throughout plot | Deviation throughout plot |
| K-S P-value | 0.93 | 0.73 | 0.81 |
| warnings | None | Parameters constrained to obtain monotonicity (2) | Parameters constrained to obtain monotonicity;  some parameters are very highly correlated |

Table 2. Results from models with 1-ft bins.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 498 | 500 | 500 |
| Density (ye/km2) | 989 | 1089 | 1079 |
| D LCL (ye/km2) | 643 | 663 | 655 |
| D UCL (ye/km2) | 1521 | 1789 | 1778 |
| CV of D | 0.22 | 0.25 | 0.25 |
| Judgement | Good fit with wide shoulder; 1-2 ft bin below detection probability | Good fit but not much of a shoulder; 1-2 ft bin below detection probability | Good fit but not much of a shoulder; 1-2 ft bin below detection probability |
| X2 P-value | 0.48 | 0.30 | 0.30 |
| # parameters | 2 | 2 | 2 |
| warnings | None | Parameters constrained to obtain monotonicity (2) | Parameters constrained to obtain monotonicity (2) |

Table 3. Results from models with 1.5-ft bins.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 405 | 407 | 407 |
| Density (ye/km2) | 976 | 1083 | 1077 |
| D LCL (ye/km2) | 634 | 660 | 653 |
| D UCL (ye/km2) | 1500 | 1780 | 1777 |
| CV of D | 0.21 | 0.25 | 0.26 |
| Judgement | Good fit with wide shoulder | Good fit but minimal shoulder | Good fit but minimal shoulder |
| X2 P-value | 0.41 | 0.15 | 0.16 |
| # parameters | 2 | 2 | 2 |
| warnings | None | Parameters constrained to obtain monotonicity | Parameters constrained to obtain monotonicity; parameter 2 is at upper bound |

Table 4. Results from models with 1.75-ft bins.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 370 | 372 | 372 |
| Density (ye/km2) | 981 | 1081 | 1076 |
| D LCL (ye/km2) | 637 | 658 | 651 |
| D UCL (ye/km2) | 1509 | 1778 | 1778 |
| CV of D | 0.22 | 0.25 | 0.26 |
| Judgement | Good fit with wide shoulder | Good fit but minimal shoulder | Good fit but minimal shoulder |
| X2 P-value | 0.96 | 0.67 | 0.68 |
| # parameters | 2 | 2 | 2 |
| warnings | None | Parameters constrained to obtain monotonicity (2) | Parameters constrained to obtain monotonicity |

Table 5. Results from models with 2-ft bins.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 339 | 341 | 341 |
| Density (ye/km2) | 1014 | 1080 | 1074 |
| D LCL (ye/km2) | 656 | 655 | 649 |
| D UCL(ye/km2) | 1566 | 1780 | 1779 |
| CV of D | 0.22 | 0.25 | 0.26 |
| Judgement | Good fit with good shoulder | Good fit with minimal shoulder | Good fit with minimal shoulder |
| X2 P-value | 0.78 | 0.19 | 0.19 |
| # parameters | 2 | 2 | 2 |
| warnings | Parameters constrained to obtain monotonicity | Parameters constrained to obtain monotonicity (2) | Parameters constrained to obtain monotonicity (2);  Warning convergence failure;  Some parameters are very highly correlated |

Table 6. Results from models with 2.5-ft bins.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 293 | 293 | 293 |
| Density (ye/km2) | 986 | 1067 | 1062 |
| D LCL (ye/km2) | 639 | 645 | 639 |
| D UCL (ye/km2) | 1521 | 1764 | 1767 |
| CV of D | 0.22 | 0.26 | 0.26 |
| Judgement | Good fit with good shoulder; bin seems large though for data set. | Good fit with minimal shoulder | Good fit with minimal shoulder |
| X2 P-value | 0.94 | 0.47 | 0.49 |
| # parameters | 2 | 2 | 2 |
| warnings |  | Parameters constrained to obtain monotonicity (2); | Parameters constrained to obtain monotonicity (2);  Convergence failure;  Some parameters are highly correlated |

Table 7. Results from models with no binning and truncation after 10.5 ft.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 486 | 490 | 490 |
| Density (ye/km2) | 983 | 1104 | 1093 |
| D LCL (ye/km2) | 637 | 674 | 666 |
| D UCL (ye/km2) | 1517 | 1809 | 1796 |
| CV of D | 0.22 | 0.25 | 0.25 |
| Judgement | Really good fit with wide shoulder (1.75 ft bins) | OK fit, but first bin lower than 1. Not much of shoulder (1.75 ft bins) | OK fit, but first bin lower than 1. Not much of shoulder(1.75 ft bins) |
| X2 P-value | 0.93 (1.75 ft bins) | 0.52 (1.75 ft bins) | 0.63(1.75 ft bins) |
| # parameters | 2 | 2 | 2 |
| Q-q plot | Good fit with minor deviation at beginning | Deviation throughout plot | Deviation throughout plot |
| K-S P-value | 0.92 | 0.56 | 0.8059 |
| warnings | None | Parameters constrained to obtain monotonicity | Parameters constrained to obtain monotonicity;  some parameters are very highly correlated |

Table 8. Results from models with no binning and truncation after 5% at right tail.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Hazard rate cosine** | **Half normal cosine** | **Half normal hermite** |
| AIC | 432 | 433 | 433 |
| Density (ye/km2) | 981 | 1107 | 1107 |
| D LCL (ye/km2) | 1526 | 1770 | 1770 |
| D UCL(ye/km2) | 1526 | 1770 | 1770 |
| CV of D | 0.22 | 0.24 | 0.24 |
| Judgement | Not great fit at origin, drop off at right tail is sudden, and very wide shoulder for 1.01 ft, 0.707 ft, and 0.471 ft bins. | Not great fit at origin or right tail with sudden drop off at tail; not much of a shoulder for 1.01 ft, 0.707 ft, and 0.471 ft bins. | Not great fit at origin or right tail with sudden drop off at tail; not much of a shoulder for 1.01 ft, 0.707 ft, and 0.471 ft bins. |
| X2 P-value | 0.39 (1.01 ft bins); 0.33 (0.707 ft bins); 0.41 (0.471 ft bins) | 0.25(1.01 ft bins); 0.10 (0.707 ft bins); 0.19 (0.471 ft bins) | 0.25(1.01 ft bins); 0.10 (0.707 ft bins); 0.19 (0.471 ft bins) |
| # parameters | 2 | 1 | 1 |
| Q-q plot | Good fit, some deviation at beginning | Some deviation in middle of plot | Some deviation of plot |
| K-S P-value | 0.90 | 0.76 | 0.76 |
| warnings | Parameters constrained to obtain monotonicity | Parameters constrained to obtain monotonicity | Parameters constrained to obtain monotonicity |

Table 9. Comparison between the 2005 SSEO sub survey, 2012 CSEO ROV survey, and the 2013 SSEO ROV survey.

|  |  |  |  |
| --- | --- | --- | --- |
|  | ***2005*** | ***2012*** | ***2013*** |
| ***Density estimate*** | 2196 ye/km2 | 752 ye/km2 | 986 ye/km2 |
| ***Density estimate CV*** | 0.17 | 0.13 | 0.22 |
| ***Variance components*** | ? | 18% DP/82% ER | 8% DP/92% ER |
| ***Encounter rate (n/L)*** | 0.0095 ye/L | 0.003 ye/L | 0.0039 ye/L |
| ***Avg. number ye (adult & subadult) observed per transect*** | 8.6 | 2.6 | 3.4 |
| ***Number of adult & subadult observed*** | 276 | 118 | 118 |
| ***Range of ye (adult & subadult) observed per transect*** | 0-30 | 0-9 | 0-15 |
| ***Number of transects performed*** | 32 | 46 | 31 |
| ***ESW (ft)*** | ? | 6.67 | 6.45 |
| ***Number of adults*** | 264 | 112 | 93 |
| ***Number of subadults*** | 12 | 6 | 25 |
| ***Number transects with no adult or subadult ye observed*** | 1 | 7 | 8 |
| ***Greatest distance ye (adult & subadult) observed (ft)*** | 30 | 10.39 | 10.86 |

Figure 1. Frequency histograms of 2013 ROV distance data for selected bins.

Figure 1. Continued.



Figure 2. Detection function for hazard rate cosine model that was fitted to exact data shown overlaid distance data binned into 1.55 ft intervals.



Figure 3. Detection function for half normal cosine model that was fitted to exact data shown overlaid distance data binned into 1.55 ft intervals (the model for the half normal hermite is similar).

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |

*n* = total number yelloweye rockfish adults and subadults >350 mm observed

= the probability density function evaluated at the origin of the transect line

*L* = total line length

*µ*  = the effective width

*w*  = width of line transect

*Pa* = probability of observing an object in the defined area

Figure 4. The equations used to estimate density using line transect sampling.

Figure 5. Density of yelloweye rockfish in SSEO management area estimated using the submersible (1994, 1999, 2005) and the ROV (2013).