# Appendix 1a. Evaluation of random effect models for mean body weight estimation for EBS pollock

Kuriyama et al. (2016) highlight that estimating growth within stock assessments can lead to biases…

This document summarizes the approach presented to the NPFMC in Sept/Oct of 2016 and based on a review conducted in May 2016. The terms of reference and presentations and subsequent reports from this review can be found at: [www.tinyurl.com/pollockCIE2016](http://www.tinyurl.com/pollockCIE2016). This section addresses the approach to selecting body weight estimation for the fishery.

Advice on sustainable fishing practices typically revolves around ensuring that fishing mortality rates are at or below values used as reference points. In most management settings, conservation measures are set based on catch biomass limits with some assumption about expected body mass-at-age (hereafter referred to as weight-at-age) to convert from modeled catch numbers (as specified based on the fishing mortality rates). Typically stock assessment uncertainty presentations focus on absolute values of the population numbers-at-age estimates. Together with uncertainty in stock productivity estimates, risk assessments can be performed on structural models (e.g., Stewart and Martell 2015) but rarely consider uncertainty in expected body weights. While uncertainty in abundance (and productivity) is critical to evaluate risks in management settings, the additional uncertainty due to unknown weight-at-age is typically ignored (Jaworski 2011) and this can result in underestimates of uncertainty. This is exacerbated when stocks depend on one or two year classes?

For many fisheries settings empirical estimates of mean body mass-at-age are quite precise due to sampling design and effort. For example, the uncertainty of estimated mean body mass for the eastern Bering Sea (EBS) walleye pollock (*Gadus chalcogrammus*) for the main fished ages typically has coefficients of variation below 5%.

The model for predicting mean body weight-at-age in the fishery is used only to make predictions of the current year and future year values and their relative uncertainty.

### Data

Fishery sampling for EBS pollock is extensive with large numbers of age, weight, and length measures sampled from the catch each year (see Tables 1.11 and 1.12 above). NMFS observer sampling data on catch-at-length and age composition was estimated using the methods described by Kimura (1989) and modified by Dorn (1992). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: *i*) January–June (all areas, but mainly east of 170°W); *ii*) INPFC area 51 (east of 170°W) from July–December; and *iii*) INPFC area 52 (west of 170°W) from July–December. This method was used to derive the age compositions from 1991-2015 (the period for which all the necessary information is readily available).

The catch-at-age estimation method uses a two-stage bootstrap re-sampling of the data. Observed tows were first selected with replacement, followed by re-sampling actual lengths and age specimens given those sets of tows. This method allows an objective way to specify the effective sample size for fitting fishery age composition data within the assessment model. In addition, estimates of stratum-specific fishery mean weights-at-age (and variances) are provided which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli *et al.* (2007) showed that seasonal aspects of pollock condition factor that could affect estimates of mean weight-at-age vary substantially within years. In 2016, the routine for estimating weights-at-age was updated to be adaptable to other stocks and converted into an R package. The values were re-computed for the period 1991-2014 (and include 2015) and estimated mean body weights-at-age were nearly identical to those previously used. A detailed summary of the relative mean weight-at-age estimates is shown in a series of figures presented as [Supplemental material](https://drive.google.com/a/noaa.gov/file/d/0B6kRaipuhdjdMEltLUgwalJmUXc/view?usp=sharing).

### Models

The growth model followed the parameterization of Schnute and Fournier (1980), with the addition of cohort effects and annual year effects (Table 1a.1). The years and ages for model application can be specified independently of the data extent. As with Jaworski (2011) a series of prediction methods were evaluated against a measure of predictive performance. These alternative estimators for mean weight-at-age were developed based on evaluating a variety of potentially useful independent variables. Potential explanatory variables were evaluated provided that they would be available at the time of the assessment in each year (e.g., since the bottom trawl survey is used to collect temperature information, this may be useful to predict mean weights in the fishery). The objective function used to evaluate estimator performance was simply examining how well “out-of-sample” data were predicted. For example, for a particular estimator, the first iteration data from 1991-2000 were used to estimate the mean weights in 2001 and 2002. These estimated were then compared to the actual mean weights observed for 2001 and 2002. The second iteration repeated this process but used data from 1991-2001 to estimate 2002 and 2003 data for comparison with actual observations. This sequence was continued through to using data from 1991-2014 to estimate 2015 means (and compared with actual 2015 mean values). Since some age-groups are relatively more important than others to the fishery (in terms of prediction errors), comparisons of estimates with “observed” were weighted by the relative importance of different age-groups. The relative importance of different age-groups was computed by using the mean numbers-at-age estimated in the population from Ianelli *et al.* (2015) and accounting for the fishery selectivity and mean weight over that period. This weighting scheme is intended to favor estimators for age-groups that are most important to the fishery and is computed as:

.

Then the estimator that performed best minimizes:

 where **is the “assessment” year, is the kth estimator for mean weight-at-age , in year **, and  are the actual observations in year . The vector for the weighting was based approach defined above results in:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|  | 0.031 | 0.132 | 0.227 | 0.222 | 0.155 | 0.089 | 0.055 | 0.033 | 0.022 | 0.014 | 0.009 | 0.005 | 0.006 |

### Parameter estimation

The estimation configurations tested included simple means to more complex year- and cohort- specific random effects approaches (Table 1a.2) and was coded in both TMB (Kristensen *et al.,* 2016) and ADMB (Fournier *et al.*,2012). The code used is available at <http://goo.gl/h8So5Z> .

### Results

Seven alternative estimation models were configured for contrast and testing predictability (as depicted by the scoring statistic developed above; Table 1a.3). The projection model for the mean weights-at-age in model testing shows the high level of variability and relatively poor skill in model predictions (Fig. 1a.1). Nonetheless, the performance was substantially improved with the inclusion of current year survey data and modeling the cohort and year effects (Fig. 1a.2).

### Summary and conclusion

The addition of survey data to predict mean weights seems to be a significant improvement over methods that just use running means or incorporate cohort effects, at least for the EBS pollock case. The out-of-sample scores where best for the case where survey and cohort effects are included. For situations where uncertainty in mean weight at age is propagated for ABC determinations, having the year-effect process errors seems useful in addition to the cohort-specific terms.

##### Table 1a.1. Equations and model parameters for growth estimation

|  |  |
| --- | --- |
| Symbol | Description |
|  | Growth model |
|  | Expected mean weight-at-age  in year |
| , | Index for year and age |
|  | Mean length age |
|  | Mean growth increment |
|  | Constant to scale lengths |
|  | Cohort and year effects |
| , , and | Parameters of the von Bertalanffy growth |

##### Table 1a.2. Alternative methods evaluated for computing mean weight-at-age for EBS pollock.

|  |  |
| --- | --- |
| Method | Description |
| Means | Mean fishery weights-at-age of most recent *n* years of data (*n =*1, 3, 5, and 10) |
| Year and Cohort | Year and cohort effect model |
| Year and Cohort with scaled survey data | Include scaled survey weights-at-age () |
| Year effect only  (with scaled survey data) | Year effect model (a random effect parameter for each annual growth increment) |
|  |  |
|  |  |
|  |  |





###### Figure 1a.1. Summary of how summer survey mean weight-at-age data for EBS pollock can be scaled to match reasonably the resulting fishery mean weight-at-age data. The top panel represents the scalars-at-age (here computed but in the model, estimated as free parameters) used to apply the survey data as covariates to the fishery mean-weight estimates.



###### Figure 1a.2. Example projection results compared to data for fishery weights-at-ages 4-7. The lines represent estimates set equal to the most recent value for the current assessment year and next year whereas the solid bullets and triangles represent the modeled estimates for the current assessment year and next year, respectively. The stars represent the final realized estimates based on the observer data.



###### Figure 1a.3. “Out-of-sample” sv cores of performance for different methods for projecting average body weight where projection year of 0 means current (assessment) year and 1 means the coming year used for ABC estimation. Models labeled 1, 3, 5, and 10 represent the means over that many most recent years. The right-most “Models” are random effects approaches with and without survey data included.

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Estimating fishery body weight at age

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# Abstract

For many fisheries settings empirical estimates of mean body mass at age are quite precise due to sampling design and effort. For example, the uncertainty of estimated mean body mass for the eastern Bering Sea (EBS) walleye pollock (*Gadus chalcogrammus*) for the main fished ages typically has coefficients of variation below 5%.

# Introduction

Modern stock assessment methods that lead to scientific advice on sustainable fishing practices typically revolves around ensuring that fishing mortality rates are at or below values used as reference points. In most management settings, conservation measures are set based on catch biomass limits with some assumption about expected body mass-at-age (hereafter referred to as weight-at-age) to convert from modeled catch numbers (as specified based on the fishing mortality rates). Uncertainty estimates are typically concerned with the absolute values of the population numbers at age estimates and the stock productivity estimates leading to acceptable fishing mortality reference points. While uncertainty from these sources is obviously important for evaluating risks in management settings, the additional uncertainty due to unknown weight at age is typically ignored (Warshneski 2008)

# Methods

The model for predicting mean body weight at age in the fishery is modeled for two purposes, prediction of the current and future year values and their relative uncertainty.

### Data

Fishery sampling for EBS pollock is extensive with large numbers of age, weight, and length measures sampled from the catch each year (Tables 1 and 2). NMFS observer sampling data on catch at length and age composition was estimated using the methods described by Kimura (1989) and modified by Dorn (1992). Length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: *i*) January–June (all areas, but mainly east of 170°W); *ii*) INPFC area 51 (east of 170°W) from July–December; and *iii*) INPFC area 52 (west of 170°W) from July–December. This method was used to derive the age compositions from 1991-2015 (the period for which all the necessary information is readily available).

The catch-at-age estimation method uses a two-stage bootstrap re-sampling of the data. Observed tows were first selected with replacement, followed by re-sampling actual lengths and age specimens given those set of tows. This method allows an objective way to specify the effective sample size for fitting fishery age composition data within the assessment model. In addition, estimates of stratum-specific fishery mean weights-at-age (and variances) are provided which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli et al. (2007) showed that seasonal aspects of pollock condition factor could affect estimates of mean weight-at-age varies substantially within years. In 2016 the routine for estimating weights at age was updated to be adaptable to other stocks and converted into an R package. The values were re-computed for the period 1991-2014 (and includes 2015) and estimated mean body weights at age were nearly identical to those previously used (Figure 1).

As part of the response to the CIE review completed in May 2016, these calculation updates also included some new estimation methods including Francis (2011) method for estimating input effective sample sizes. This was done by the simple method as: , where is the mean age of the *jth* bootstrap in year *y, *is the variance over the bootstrap samples, , the variance of the observed composition in year *y* is calculated as and  is the proportion at age *a* in year *y.* Results applying this method suggest that the effective input sample sizes range about 2 thousand to over 12 thousand fish (Table 3)

### Models

As with Jaworski a series of prediction methods were evaluated against the

Following the parameterization of Schnute and Fournier, with the addition of cohort effects and annual “year” effects we have:

 1

with symbols defined in Table 4. The years and ages for model application can be specified independently of the data extent.

### Eastern Bering Sea pollock case

[for discussion] As an example of the importance of the impact of mean weights, Figure 2 shows the distribution of *Fmsy* and *F35%* values by year and given the estimated inter-annual variability.

Observations

Alternative estimators for mean weight at age were developed based on evaluating a variety of potentially useful independent variables. Potential explanatory variables were evaluated provided that they would be available at the time of the assessment in each year (e.g., since the bottom-trawl survey is used to collect temperature information, this may be useful to predict mean weights in the fishery). The objective function used to evaluate estimator performance was simply examining how well “out-of-sample” data were predicted. For example, for a particular estimator, for the first iteration data from 1991-2000 were used to estimate the mean weights in 2001 and 2002. These estimated were then compared to the actual mean weights observed for 2001 and 2002. The second iteration repeated this process but used data from 1991-2001 to estimate 2002 and 2003 data for comparison with actual observations. This sequence was continued through to using data from 1991-2014 to estimate 2015 means (and compared with actual 2015 mean values). Since some age groups are relatively more important than others to the fishery (in terms of prediction errors), comparisons of estimates with “observed” were weighted by the relative importance of different age groups. The relative importance of estimating different age groups was computed by using the mean numbers at age estimated in the population from Ianelli et al. (2015) and accounting for the fishery selectivity and mean weight over that period. This weighting scheme is intended to favor estimators for age-groups that are most important to the fishery and is computed as

.

Then the estimator that performed best minimizes:

 where **is the “assessment” year, is the kth estimator for mean weight at age , in year **, and  are the actual observations in year . The vector for the weighting was based on estimates from 2000-2015:

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 0.031 | 0.132 | 0.227 | 0.222 | 0.155 | 0.089 | 0.055 | 0.033 | 0.022 | 0.014 | 0.009 | 0.005 | 0.006 |

Table 1.

|  |  |
| --- | --- |
| Method | Description[[1]](#footnote-2) |
| 1.*n* | Mean fishery weights at age of most recent *n* years of data (*n =*1, 3, 5, and 10) |
| 2 | Scaled survey weights at age () |
| 3 | Year effect model (a random effect parameter for each annual growth increment) |
| 4 | Cohort effect model (a random effect parameter for each cohort) |
| 5 | Year and cohort effect model |
| 6 | Supplemental survey data |
|  |  |
|  |  |
|  |  |
|  |  |

Table 2. Parameters used in methods 3-5.

|  |  |
| --- | --- |
| Symbol |  |
|  |  |
|  | Expected mean weight at age  in year |
| , | Index for year and age |
|  | Mean length age |
|  | Mean growth increment |
|  | Constant to scale lengths |
|  | Cohort and year effects |
| , , and | Parameters of the von Bertalanffy growth |
|  |  |
|  |  |

### Parameter estimation

##### Table 3. Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2015, as sampled by the NMFS observer program.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Length Frequency samples** | | | | | | | |
|  | A Season | | B Season SE | | B Season NW | |  |
| Year | Males | Females | Males | Females | Males | Females | Total |
| 1977 | 26,411 | 25,923 | 4,301 | 4,511 | 29,075 | 31,219 | 121,440 |
| 1978 | 25,110 | 31,653 | 9,829 | 9,524 | 46,349 | 46,072 | 168,537 |
| 1979 | 59,782 | 62,512 | 3,461 | 3,113 | 62,298 | 61,402 | 252,568 |
| 1980 | 42,726 | 42,577 | 3,380 | 3,464 | 47,030 | 49,037 | 188,214 |
| 1981 | 64,718 | 57,936 | 2,401 | 2,147 | 53,161 | 53,570 | 233,933 |
| 1982 | 74,172 | 70,073 | 16,265 | 14,885 | 181,606 | 163,272 | 520,273 |
| 1983 | 94,118 | 90,778 | 16,604 | 16,826 | 193,031 | 174,589 | 585,946 |
| 1984 | 158,329 | 161,876 | 106,654 | 105,234 | 243,877 | 217,362 | 993,332 |
| 1985 | 119,384 | 109,230 | 96,684 | 97,841 | 284,850 | 256,091 | 964,080 |
| 1986 | 186,505 | 189,497 | 135,444 | 123,413 | 164,546 | 131,322 | 930,727 |
| 1987 | 373,163 | 399,072 | 14,170 | 21,162 | 24,038 | 22,117 | 853,722 |
| 1991 | 160,491 | 148,236 | 166,117 | 150,261 | 141,085 | 139,852 | 906,042 |
| 1992 | 158,405 | 153,866 | 163,045 | 164,227 | 101,036 | 102,667 | 843,244 |
| 1993 | 143,296 | 133,711 | 148,299 | 140,402 | 27,262 | 28,522 | 621,490 |
| 1994 | 139,332 | 147,204 | 159,341 | 153,526 | 28,015 | 27,953 | 655,370 |
| 1995 | 131,287 | 128,389 | 179,312 | 154,520 | 16,170 | 16,356 | 626,032 |
| 1996 | 149,111 | 140,981 | 200,482 | 156,804 | 18,165 | 18,348 | 683,890 |
| 1997 | 124,953 | 104,115 | 116,448 | 107,630 | 60,192 | 53,191 | 566,527 |
| 1998 | 136,605 | 110,620 | 208,659 | 178,012 | 32,819 | 40,307 | 707,019 |
| 1999 | 36,258 | 32,630 | 38,840 | 35,695 | 16,282 | 18,339 | 178,044 |
| 2000 | 64,575 | 58,162 | 63,832 | 41,120 | 40,868 | 39,134 | 307,689 |
| 2001 | 79,333 | 75,633 | 54,119 | 51,268 | 44,295 | 45,836 | 350,483 |
| 2002 | 71,776 | 69,743 | 65,432 | 64,373 | 37,701 | 39,322 | 348,347 |
| 2003 | 74,995 | 77,612 | 49,469 | 53,053 | 51,799 | 53,463 | 360,390 |
| 2004 | 75,426 | 76,018 | 63,204 | 62,005 | 47,289 | 44,246 | 368,188 |
| 2005 | 76,627 | 69,543 | 43,205 | 33,886 | 68,878 | 63,088 | 355,225 |
| 2006 | 72,353 | 63,108 | 28,799 | 22,363 | 75,180 | 65,209 | 327,010 |
| 2007 | 62,827 | 60,522 | 32,945 | 25,518 | 75,128 | 69,116 | 326,054 |
| 2008 | 46,125 | 51,027 | 20,493 | 23,503 | 61,149 | 64,598 | 266,894 |
| 2009 | 46,051 | 44,080 | 19,877 | 18,579 | 50,451 | 53,344 | 232,379 |
| 2010 | 39,495 | 41,054 | 19,194 | 20,591 | 40,449 | 41,323 | 202,106 |
| 2011 | 58,822 | 62,617 | 60,254 | 65,057 | 51,137 | 48,084 | 345,971 |
| 2012 | 53,641 | 57,966 | 45,044 | 46,940 | 50,167 | 53,224 | 306,982 |
| 2013 | 52,303 | 62,336 | 37,434 | 44,709 | 49,484 | 49,903 | 296,168 |
| 2014 | 55,954 | 58,097 | 46,568 | 51,950 | 46,643 | 46,202 | 305,414 |
| 2015 | 55,646 | 56,507 | 45,074 | 41,218 | 46,237 | 43,084 | 287,766 |

##### Table 3. (continued) Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2015, as sampled by the NMFS observer program.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Length – weight samples** | | | | | | | |
|  | A Season | | B Season SE | | B Season NW | |  |
| Males | Females | Males | Females | Males | Females | Total |
| 1977 | 1,222 | 1,338 | 137 | 166 | 1,461 | 1,664 | 5,988 |
| 1978 | 1,991 | 2,686 | 409 | 516 | 2,200 | 2,623 | 10,425 |
| 1979 | 2,709 | 3,151 | 152 | 209 | 1,469 | 1,566 | 9,256 |
| 1980 | 1,849 | 2,156 | 99 | 144 | 612 | 681 | 5,541 |
| 1981 | 1,821 | 2,045 | 51 | 52 | 1,623 | 1,810 | 7,402 |
| 1982 | 2,030 | 2,208 | 181 | 176 | 2,852 | 3,043 | 10,490 |
| 1983 | 1,199 | 1,200 | 144 | 122 | 3,268 | 3,447 | 9,380 |
| 1984 | 980 | 1,046 | 117 | 136 | 1,273 | 1,378 | 4,930 |
| 1985 | 520 | 499 | 46 | 55 | 426 | 488 | 2,034 |
| 1986 | 689 | 794 | 518 | 501 | 286 | 286 | 3,074 |
| 1987 | 1,351 | 1,466 | 25 | 33 | 72 | 63 | 3,010 |
| 1991 | 2,712 | 2,781 | 2,339 | 2,496 | 1,065 | 1,169 | 12,562 |
| 1992 | 1,517 | 1,582 | 1,911 | 1,970 | 588 | 566 | 8,134 |
| 1993 | 1,201 | 1,270 | 1,448 | 1,406 | 435 | 450 | 6,210 |
| 1994 | 1,552 | 1,630 | 1,569 | 1,577 | 162 | 171 | 6,661 |
| 1995 | 1,215 | 1,259 | 1,320 | 1,343 | 223 | 232 | 5,592 |
| 1996 | 2,094 | 2,135 | 1,409 | 1,384 | 1 | 1 | 7,024 |
| 1997 | 628 | 627 | 616 | 665 | 511 | 523 | 3,570 |
| 1998 | 1,852 | 1,946 | 959 | 923 | 327 | 350 | 6,357 |
| 1999 | 5,318 | 4,798 | 7,797 | 7,054 | 3,532 | 3,768 | 32,267 |
| 2000 | 12,421 | 11,318 | 12,374 | 7,809 | 7,977 | 7,738 | 59,637 |
| 2001 | 14,882 | 14,369 | 10,778 | 10,378 | 8,777 | 9,079 | 68,263 |
| 2002 | 14,004 | 13,541 | 12,883 | 12,942 | 7,202 | 7,648 | 68,220 |
| 2003 | 14,780 | 15,495 | 9,401 | 10,092 | 9,994 | 10,261 | 70,023 |
| 2004 | 7,690 | 7,890 | 6,819 | 6,847 | 4,603 | 4,321 | 38,170 |
| 2005 | 7,390 | 7,033 | 5,109 | 4,115 | 6,927 | 6,424 | 36,998 |
| 2006 | 7,324 | 6,989 | 5,085 | 4,068 | 6,842 | 6,356 | 36,664 |
| 2007 | 6,681 | 6,635 | 4,278 | 3,203 | 7,745 | 7,094 | 35,636 |
| 2008 | 4,256 | 4,787 | 2,056 | 2,563 | 5,950 | 6,316 | 25,928 |
| 2009 | 4,470 | 4,199 | 2,273 | 2,034 | 5,004 | 5,187 | 23,167 |
| 2010 | 4,536 | 5,272 | 2,261 | 2,749 | 4,125 | 4,618 | 23,561 |
| 2011 | 6,772 | 6,388 | 6,906 | 6,455 | 5,809 | 4,634 | 36,964 |
| 2012 | 5,500 | 5,981 | 4,508 | 4,774 | 4,928 | 5,348 | 31,039 |
| 2013 | 6,525 | 5,690 | 4,313 | 3,613 | 4,920 | 4,849 | 29,910 |
| 2014 | 5,675 | 5,871 | 4,753 | 5,180 | 4,785 | 4,652 | 30,916 |
| 2015 | 5,310 | 5,323 | 4,645 | 4,188 | 4,337 | 4,011 | 27,766 |

##### Table 4. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977-2015, as sampled by the NMFS observer program.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Number of samples aged** | | | | | | |
|  | A Season | | B Season SE | | B Season NW | |  |
|  | Males | Females | Males | Females | Males | Females | Total |
| 1977 | 1,229 | 1,344 | 137 | 166 | 1,415 | 1,613 | 5,904 |
| 1978 | 1,992 | 2,686 | 407 | 514 | 2,188 | 2,611 | 10,398 |
| 1979 | 2,647 | 3,088 | 152 | 209 | 1,464 | 1,561 | 9,121 |
| 1980 | 1,854 | 2,158 | 93 | 138 | 606 | 675 | 5,524 |
| 1981 | 1,819 | 2,042 | 51 | 52 | 1,620 | 1,807 | 7,391 |
| 1982 | 2,030 | 2,210 | 181 | 176 | 2,865 | 3,062 | 10,524 |
| 1983 | 1,200 | 1,200 | 144 | 122 | 3,249 | 3,420 | 9,335 |
| 1984 | 980 | 1,046 | 117 | 136 | 1,272 | 1,379 | 4,930 |
| 1985 | 520 | 499 | 46 | 55 | 426 | 488 | 2,034 |
| 1986 | 689 | 794 | 518 | 501 | 286 | 286 | 3,074 |
| 1987 | 1,351 | 1,466 | 25 | 33 | 72 | 63 | 3,010 |
| 1991 | 420 | 423 | 272 | 265 | 320 | 341 | 2,041 |
| 1992 | 392 | 392 | 371 | 386 | 178 | 177 | 1,896 |
| 1993 | 444 | 473 | 503 | 493 | 124 | 122 | 2,159 |
| 1994 | 201 | 202 | 570 | 573 | 131 | 141 | 1,818 |
| 1995 | 298 | 316 | 436 | 417 | 123 | 131 | 1,721 |
| 1996 | 468 | 449 | 442 | 433 | 1 | 1 | 1,794 |
| 1997 | 433 | 436 | 284 | 311 | 326 | 326 | 2,116 |
| 1998 | 592 | 659 | 307 | 307 | 216 | 232 | 2,313 |
| 1999 | 540 | 500 | 730 | 727 | 306 | 298 | 3,100 |
| 2000 | 666 | 626 | 843 | 584 | 253 | 293 | 3,265 |
| 2001 | 598 | 560 | 724 | 688 | 178 | 205 | 2,951 |
| 2002 | 651 | 670 | 834 | 886 | 201 | 247 | 3,489 |
| 2003 | 583 | 644 | 652 | 680 | 260 | 274 | 3,092 |
| 2004 | 560 | 547 | 599 | 697 | 244 | 221 | 2,867 |
| 2005 | 611 | 597 | 613 | 489 | 419 | 421 | 3,149 |
| 2006 | 608 | 599 | 590 | 457 | 397 | 398 | 3,048 |
| 2007 | 639 | 627 | 586 | 482 | 583 | 570 | 3,485 |
| 2008 | 492 | 491 | 313 | 356 | 541 | 647 | 2,838 |
| 2009 | 488 | 416 | 285 | 325 | 400 | 434 | 2,346 |
| 2010 | 624 | 545 | 504 | 419 | 465 | 414 | 2,971 |
| 2011 | 581 | 808 | 579 | 659 | 404 | 396 | 3,427 |
| 2012 | 517 | 571 | 480 | 533 | 485 | 579 | 3,165 |
| 2013 | 703 | 666 | 517 | 402 | 568 | 526 | 3,381 |
| 2014 | 609 | 629 | 475 | 553 | 413 | 407 | 3,086 |
| 2015 | 653 | 642 | 511 | 491 | 502 | 509 | 3,308 |

Table 5. Sample size estimates derived from bootstrap variability and catch-at-age proportions.

|  |  |  |  |
| --- | --- | --- | --- |
| Year | Mean age | CV Mean age | “Effective N” |
| 1991 | 7.56 | 0.78% | 2,639 |
| 1992 | 6.07 | 0.73% | 5,667 |
| 1993 | 4.86 | 0.42% | 12,546 |
| 1994 | 5.13 | 0.62% | 2,474 |
| 1995 | 5.74 | 0.50% | 3,010 |
| 1996 | 6.48 | 0.58% | 2,085 |
| 1997 | 5.98 | 0.47% | 4,891 |
| 1998 | 6.19 | 0.48% | 3,701 |
| 1999 | 5.74 | 0.49% | 5,310 |
| 2000 | 5.95 | 0.46% | 5,521 |
| 2001 | 6.23 | 0.55% | 3,201 |
| 2002 | 6.12 | 0.57% | 3,475 |
| 2003 | 5.55 | 0.55% | 5,024 |
| 2004 | 5.41 | 0.61% | 3,695 |
| 2005 | 5.52 | 0.43% | 4,257 |
| 2006 | 5.80 | 0.50% | 3,539 |
| 2007 | 6.14 | 0.46% | 4,235 |
| 2008 | 6.57 | 0.54% | 3,733 |
| 2009 | 5.99 | 0.64% | 4,607 |
| 2010 | 5.25 | 0.51% | 6,928 |
| 2011 | 5.41 | 0.41% | 6,883 |
| 2012 | 5.03 | 0.43% | 6,629 |
| 2013 | 5.38 | 0.40% | 5,705 |
| 2014 | 5.82 | 0.40% | 4,284 |
| 2015 | 5.24 | 0.40% | 8,411 |



Figure 1. Comparisons of average fishery weight at age (kg) for EBS pollock, 1991-2015 from the 2015 assessment and the current revised estimates.



Figure 2. Projection results compared to data for fishery weights-at-ages 4-7. The lines represent estimates set equal to the most recent value for the current assessment year and next year whereas the solid bullets and triangles represent the modeled estimates for the current assessment year and next year, respectively.

Kuriyama, Peter T., Kotaro Ono, Felipe Hurtado-Ferro, Allan C. Hicks, Ian G. Taylor, Roberto R. Licandeo, Kelli F. Johnson, et al. 2016. “An Empirical Weight-at-Age Approach Reduces Estimation Bias Compared to Modeling Parametric Growth in Integrated, Statistical Stock Assessment Models When Growth Is Time Varying.” *Fisheries Research* 180: 119–27. https://doi.org/10.1016/j.fishres.2015.09.007.

1. [↑](#footnote-ref-2)