# Preliminary assessment of Pacific cod in the Eastern Bering Sea

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# Comments

# History of current review process

- This is the 11th year of the nearly year-round review process!
  - Although spring “vetting” meetings held only since 2010
    - Models vetted by full Joint Teams 2010-2013
    - Models vetted by Joint Team Subcommittee 2014-2016
    - Models now vetted by BSAI Team Subcommittee
- Accomplishments during the first 10 years of the process:
  - 174 EBS models fully vetted from 2007-2016 (17 per year)
  - 238 Team and SSC comments addressed (24 per year)

# Subcommittee comments (1 of 6)

- Subcommittee considered 26 comments at its 6/17 meeting
  - Plus results from 10 new models (per SSC request)
- At its 6/16 meeting, the SSC opted to discontinue reviewing Subcommittee comments, so Subcommittee has final say
- Some Subcommittee comments pertain to the final assessment only
- Subcommittee recommended that the following models be included in this year's preliminary EBS Pacific cod assessment (continued on following slides):
  - Model 16.6:  Last year's final model, after translating from SS V3.24u to V3.30

# Subcommittee comments (2 of 6)

- Recommended models, continued:
  - Model 17.1:  Same as Model 16.6, except:
    - Adjust timing of the fishery and survey in SS
    - Do not use currently available fishery agecomp data, but do add new fishery agecomps (2015 and 2016)
    - Switch to haul-based input N, catch-weighted sizecomps
    - Develop a prior distribution for natural mortality based on previous estimates
    - Switch to age-based, flat-topped, double normal select.
    - Allow random time variability in selectivity, with $\sigma$s fixed at the restricted MLEs

# Subcommittee comments (3 of 6)

- Recommended models, continued:
  - Model 17.2: Same as Model 17.1, except:
    - Use harmonic mean weighting of composition data
    - Allow time-varying selectivity for fishery but not survey
  - Model 17.3: Same as Model 17.1, except:
    - Use harmonic mean weighting of composition data
    - Estimate survey index standard error internally
  - Model 17.4: Same as Model 17.1, except:
    - Use Francis weighting
  - Model 17.5: Same as Model 17.1, except:
    - Give less weight to fishery comps than survey comps, less to sizecomps than agecomps

# Subcommittee comments (4 of 6)

- Subcommittee recommended these non-model analyses:
  - Compare $\sigma_R$ to the RMSE of estimated recruitment *devs*
  - Report Francis weights from the terminal run if harmonic mean is used and vice-versa

Subcommittee implementing recommendations:

- For switching to haul-based input sample size and catch-weighted sizecomp data, the Subcommittee understands that the author will likely set initial input sample sizes equal to the number of hauls (or sets), rather than a more complicated haul-based approach such as that described by Stewart and Hamel (2014)

# Subcommittee comments (5 of 6)

- Subcommittee implementing recommendations, continued:
  - For giving less weight to fishery comps than survey comps and less to sizecomps than agecomps, if the Francis weightings obtained in Model 17.4 accomplish the same thing, then Model 17.5 does not need to be included
  - Also, the Subcommittee's preferred method for implementing this feature is to begin with the weightings obtained in Model 17.4 and then adjust them as little as possible subject to the constraints described

# Subcommittee comments (6 of 6)

- Subcommittee implementing recommendations, continued:
  - For reporting Francis weights if harmonic mean is used and vice-versa, the confidence intervals surrounding the Francis weights should also be reported
  - For developing a prior distribution for natural mortality based on previous estimates, if faced with a choice between the lognormal and normal..., the Subcommittee prefers the lognormal
- Other Subcommittee conclusions:
  - Subcommittee concluded that the EBS Pcod assessment is not a good candidate for model averaging at this time

# Data

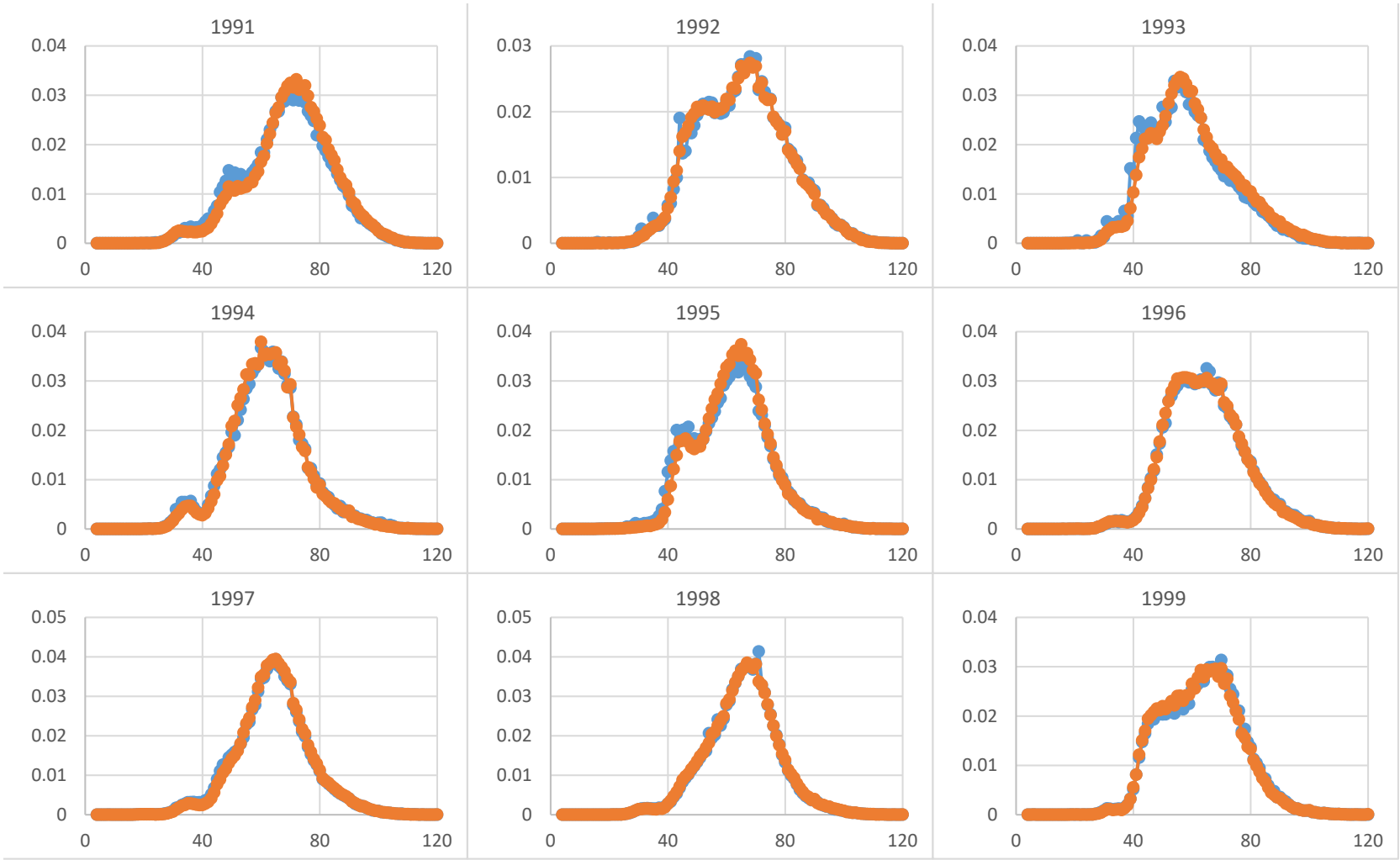
# Data changes (1 of 2)

- For Model 16.6, the data file was identical to the one used in last year's assessment
- For Models 17.x, these changes were made:
  - Sizecomp N measured as number of hauls
    - For 1991-2016, the numbers of hauls sampled for fishery lengths were taken from the domestic observer database
    - For years prior to 1990, the numbers of sampled hauls in the fishery sizecomp data were approximated by using a regression from the 2015 assessment

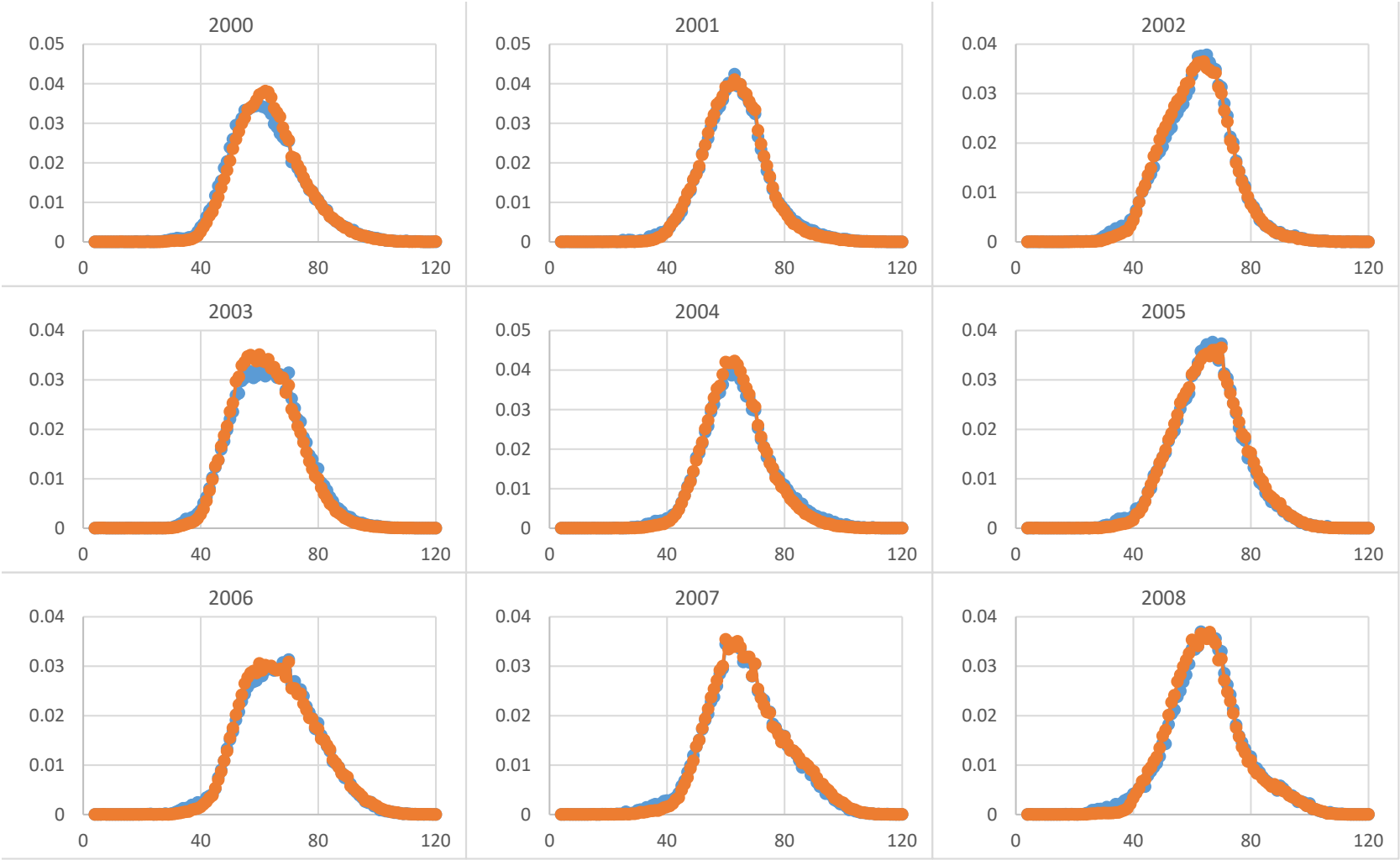
# Data changes (2 of 2)

- Changes in data for Models 17.x, continued:
  - Sizecomp N measured as number of hauls, continued
    - 1991-2016 fishery sizecomp data from each week/gear/area cell were weighted proportionally to the official estimate of catch in that cell
  - Inclusion of fishery agecomps for 2015 and 2016
    - Given a desired annual sample size of 1000 otoliths, the objectives of the otolith sampling design were:
      1. to distribute the sample so as to reflect the proportion of catch in each week/gear/area cell
      2. conditional on achieving the first objective, to maximize the number of hauls sampled

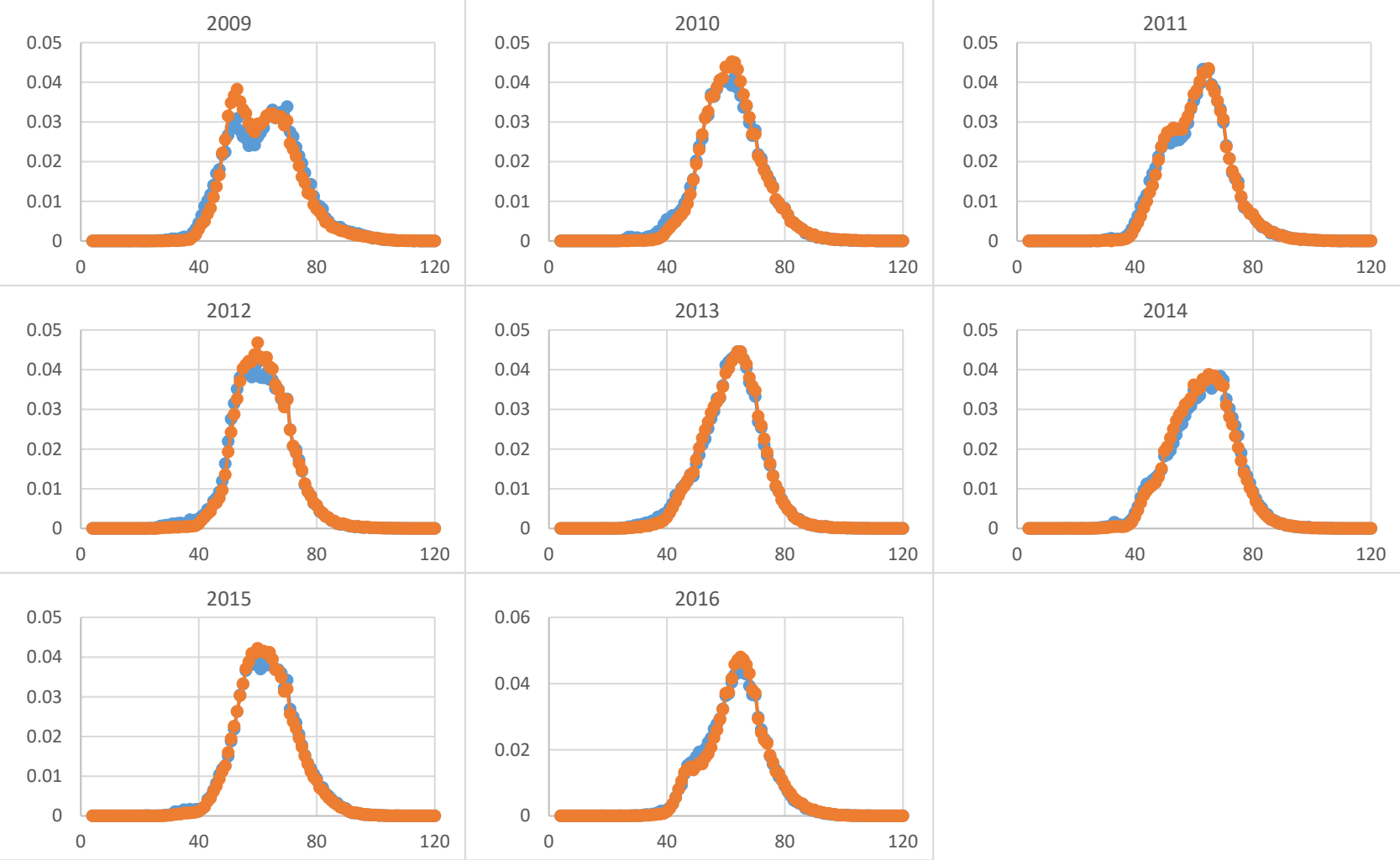
# Comparison of old and new sizecomps (1 of 3)



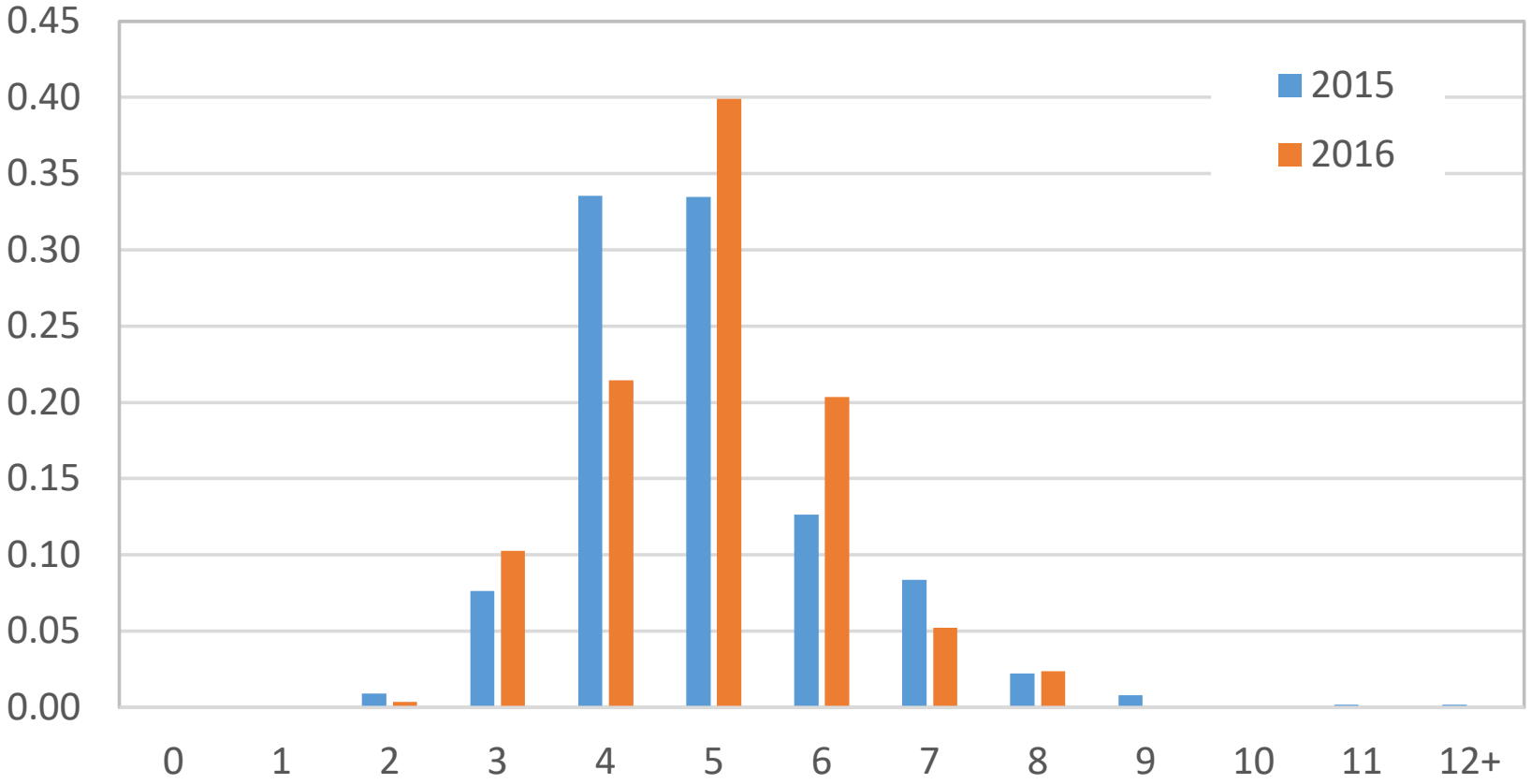
# Comparison of old and new sizecomps (2 of 3)



# Comparison of old and new sizecomps (3 of 3)



# Fishery agecomps for 2015 and 2016



# Model structures

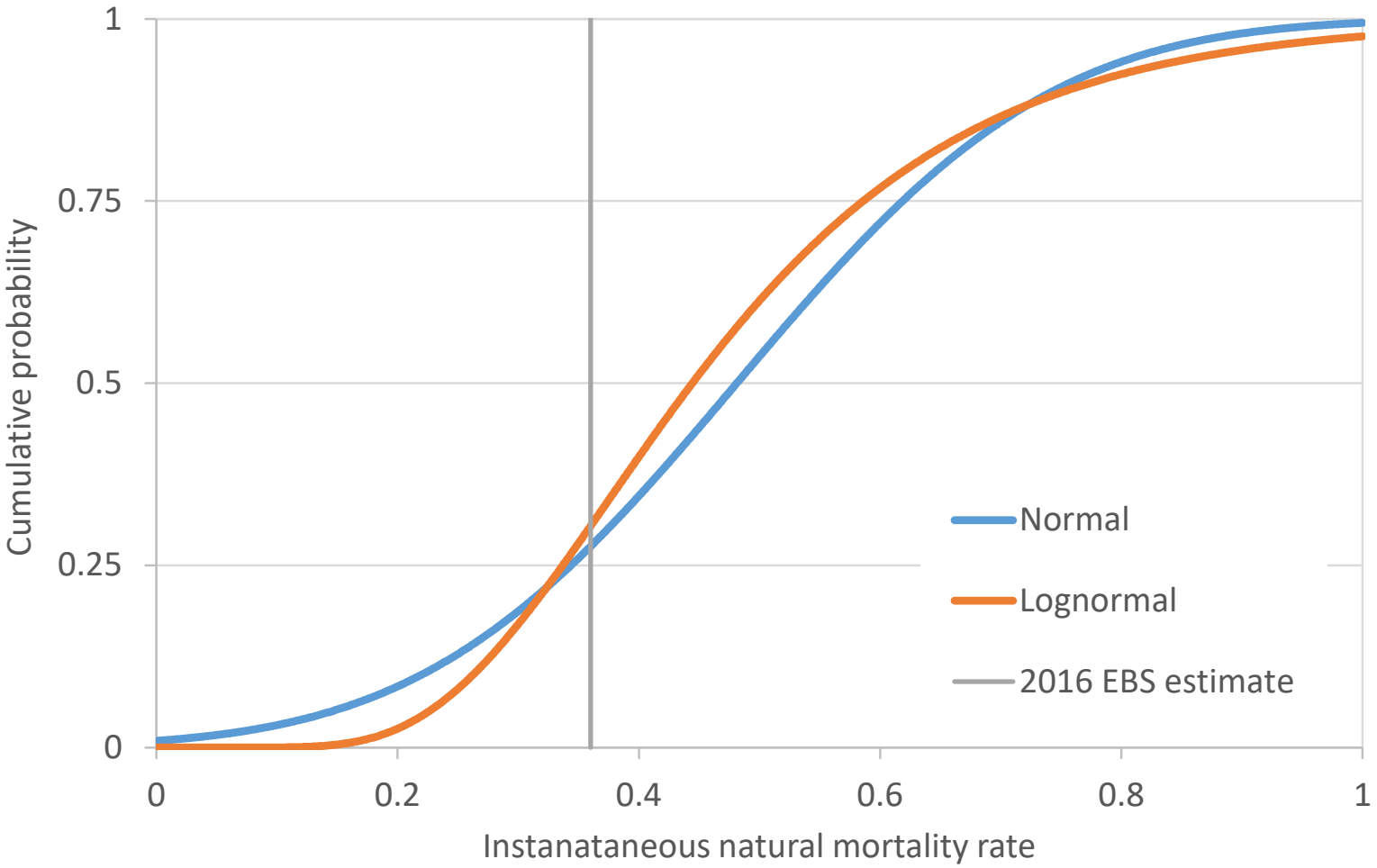
# List of models

- Model 16.6:  Base model
- Models 17.1-17.5:  Requested by Subcommittee
- Model 17.6:  Added by author
  - Same as Model 17.1, except:
    - Use harmonic mean weighting of composition data
    - Allow time-varying length at age 1.5
    - Allow time-varying survey catchability

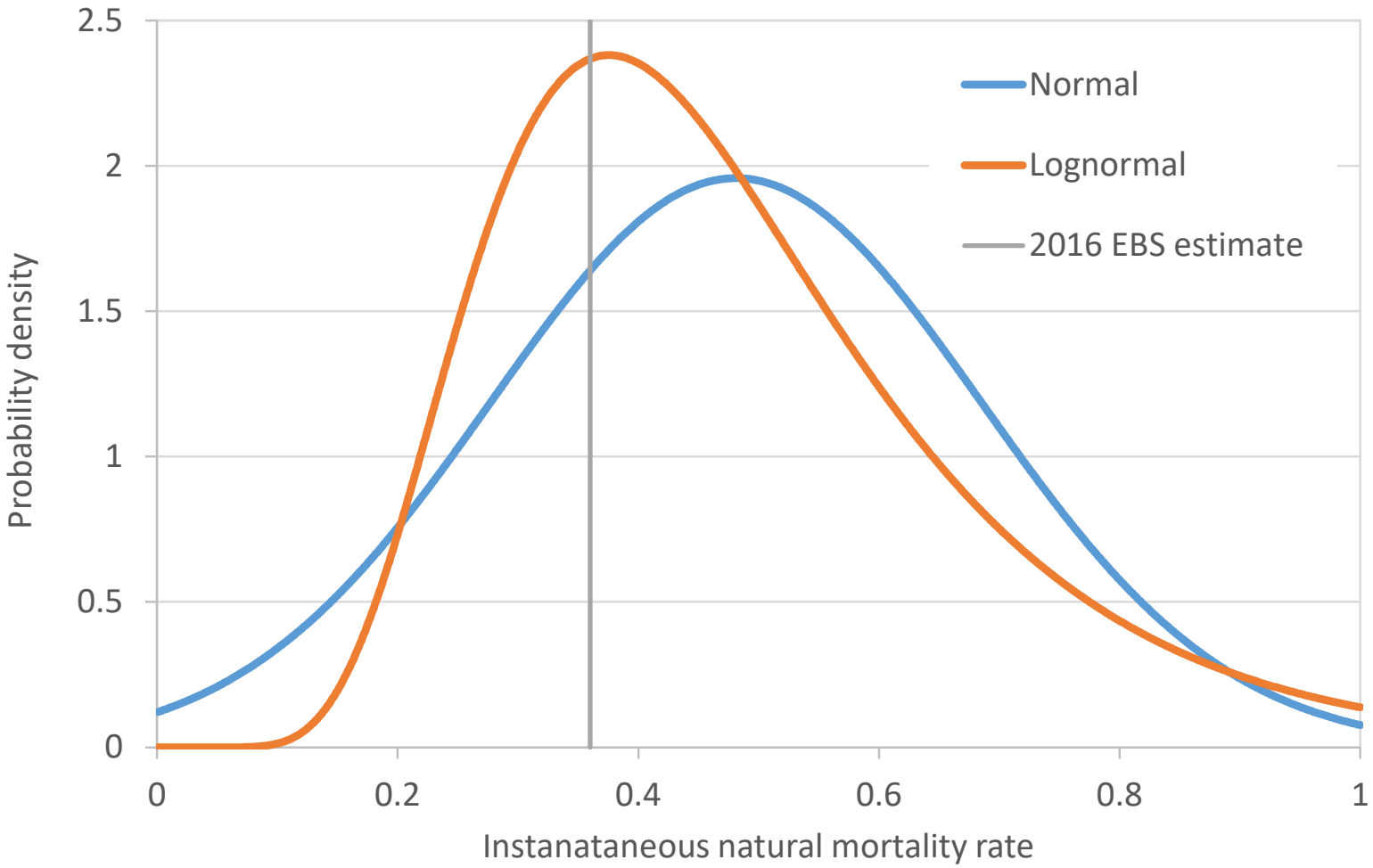
# Model 16.6 (base model)

- One fishery, one gear type, one season per year
- Logistic, age-based selectivity for fishery and survey
- External estimation of time-varying weight-at-length parameters and the standard deviations of ageing error at ages 1 and 20
- All parameters constant over time except for recruitment and fishing mortality
- Internal estimation of all natural mortality, fishing mortality, length-at-age (including ageing bias), recruitment (conditional on Beverton-Holt “steepness” fixed at 1.0), catchability, and selectivity parameters

# Alternative models: prior dist. for *M* (1 of 2)



# Alternative models: prior dist. for *M* (2 of 2)



# Alternative models: selectivity (1 of 4)

- All of the alternative models feature “age-based, flat-topped, double normal selectivity”
- The parameter governing the point at which the flat-topped portion of the function begins and the “ascending width” parameter are the only two parameters estimated
- All of the alternative models also feature random annual time variability in selectivity
- In all cases, development of the model began with both free parameters of the relevant selectivity curve(s) being allowed to vary over time

# Alternative models: selectivity (2 of 4)

- In the case of Model 17.4, however, the tuning process began converging on a configuration that did not result in a positive definite Hessian matrix
- The estimated *devs* for survey selectivity "ascending width" in this configuration were all very small
- When the this parameter was forced to remain constant, the tuning process converged on a model with a positive definite Hessian
- This was accepted as the final version of Model 17.4
  - Two time-varying fishery selectivity parameters, but only one time-varying survey selectivity parameter

# Alternative models: selectivity (3 of 4)

- Because Model 17.5 was requested to be based on Model 17.4 (comment Sub6), Model 17.5 also features time-invariant “ascending width” for the survey selectivity
- The configurations of the models with respect to time-varying selectivity is therefore as follows:

| Fleet | Parameter | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|
| Fishery | Beginning of flat top | x | x | x | x | x | x |
| Fishery | Ascending width | x | x | x | x | x | x |
| Survey | Beginning of flat top | x | | x | x | x | x |
| Survey | Ascending width | x | | x | | | x |

# Alternative models: selectivity (4 of 4)

- *Dev* types:
  - Multiplicative *dev*s for the beginning of the flat top were of the multiplicative type
  - Additive *dev*s for the “ascending width”
- Year ranges for *dev*s:
  - 1977-2016 for the fishery
  - 1982-2016 for the survey

# Alternative models: Model 17.5 weighting

- Model 17.5 is supposed to "give less weight to fishery comps than survey comps, less to sizecomps than agecomps," but this begs two questions:
  1. How should "weight" be measured?
  - Weight = sum (across years) of the nominal sample sizes specified in the data file and the multiplier ("Francis weight") derived during the process of tuning Model 17.4
  2. How much less is "less?"
  - Model 17.5 gives half as much weight to fishery comps as to survey comps and half as much weight to sizecomps as to agecomps

# Alternative models: tuning the *dev* σs

- Method provides restricted MLE for a linear-normal model
- Avoids the downward bias associated with maximizing the penalized likelihood
- Assumed to approximate the restricted MLE for the alternative models
- See document for details

# Alternative models: Model 17.6 (1 of 2)

- Model 17.6 also includes random annual variability in two other parameters:
  - Mean length at age 1.5
    - For the mean length at age 1.5, multiplicative *dev*s were estimated for the years 1981-2015
    - Each *dev* becomes "active" at age 0 in the year for which it is estimated, but its impact on the mean length of age 1.5 fish does not occur until the *following* year
    - Thus, the impacts of the *dev*s estimated for the years 1981-2015 are manifested at age 1.5 in the years 1982-2016

# Alternative models: Model 17.6 (2 of 2)

- Additional random variability in Model 17.6, continued:
  - Log survey catchability (*Q*)
    - Additive *dev*s were estimated for the years 1982-2016
    - Unlike the σs for other time-varying parameters, tuning the σ for the *Q dev*s consisted of equating the RMSE with the mean standard error
    - Rationale:
      - This maintains consistency with historical precedents for dealing with survey index data
      - *Q* has a proportional relationship to the survey index data, for which estimates of the amount of observation error are available

# Results

# Big picture

- Female spawning biomass, FSB relative to $B_{100\%}$, $M$, and $Q$:

| Model: | 16.6 | 17.1 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 |
|---|---|---|---|---|---|---|---|
| *FSB* (2017): | 359,766 | 187,677 | 298,746 | 161,672 | 430,949 | 131,546 | 174,282 |
| *Bratio* (2017): | 0.546 | 0.279 | 0.465 | 0.267 | 0.510 | 0.187 | 0.268 |
| $M$: | 0.363 | 0.333 | 0.369 | 0.372 | 0.320 | 0.313 | 0.345 |
| $Q$: | 0.876 | 1.113 | 0.948 | 0.982 | 1.153 | 1.106 | 1.012 |

# Objective function values, parameter counts

| Component | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|
| Equilibrium catch | 0.00 | 0.14 | 0.01 | 0.01 | 0.01 | 0.05 | 0.02 |
| Survey index | -25.21 | -14.65 | -15.76 | -36.31 | 6.20 | -1.69 | -62.35 |
| Size composition | 1372.94 | 2947.78 | 1454.99 | 1393.99 | 3729.21 | 7437.48 | 1453.89 |
| Age composition | 241.40 | 456.28 | 120.43 | 94.29 | 3434.03 | 3505.39 | 125.06 |
| Recruitment | 4.25 | 14.29 | 1.13 | -5.09 | 32.25 | 12.76 | 5.07 |
| Priors | | 0.25 | 0.11 | 0.09 | 0.33 | 0.37 | 0.19 |
| "Softbounds" | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Non-recruit devs | | -245.56 | -115.84 | -286.45 | -72.94 | -178.40 | -417.90 |
| Total | 1593.39 | 3158.53 | 1445.07 | 1160.54 | 7129.10 | 10776.00 | 1103.97 |

| Sub-component | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|
| Sizecomp (fishery) | 364.60 | 1819.35 | 470.08 | 437.71 | 3531.12 | 767.73 | 469.32 |
| Sizecomp (survey) | 1008.34 | 1128.43 | 984.91 | 956.28 | 198.10 | 6669.75 | 984.57 |
| Sizecomp (total) | 1372.94 | 2947.78 | 1454.99 | 1393.99 | 3729.21 | 7437.48 | 1453.89 |
| Agecomp (fishery) | | 205.72 | 68.86 | 38.75 | 2923.14 | 855.24 | 69.67 |
| Agecomp (survey) | 241.40 | 250.57 | 51.57 | 55.54 | 510.89 | 2650.15 | 55.38 |
| Agecomp (total) | 241.40 | 456.28 | 120.43 | 94.29 | 3434.03 | 3505.39 | 125.06 |

| Parameter type | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|
| Devs | 39 | 189 | 119 | 189 | 154 | 154 | 259 |
| Scalars | 38 | 37 | 37 | 38 | 36 | 36 | 38 |
| Total | 77 | 226 | 156 | 227 | 190 | 190 | 297 |

# Making the fit to index data comparable

- The familiar equation for standard error:

$$\text{mean\_logscale\_std\_err} = \frac{\text{mean\_logscale\_std\_dev}}{\sqrt{\text{mean no hauls}}}$$

- An analogy:

$$\text{model\_RMSE} = \frac{\text{mean\_logscale\_std\_dev}}{\sqrt{\text{effective\_mean\_no\_hauls}}}$$

- After some algebra:

$$\text{effective\_mean\_no\_hauls} = \text{mean\_no\_hauls} \cdot \left( \frac{\text{mean\_logscale\_std\_err}}{\text{model\_RMSE}} \right)^2$$

# Input and output total effective sample sizes

- Input total effective sample size *for a component*:
  - No. years × arithmetic mean (across yrs) × raw N × mult.
- Output total effective sample size *for a component*:
  - For composition data:
    - No. years × harmonic mean (across yrs) × effective N
  - For index data:
    - No. years × arithmetic mean (across yrs) × raw N × ((mean log-scale SE + "extra" SE)/(log-scale RMSE))$^2$

# Input and output effective sample sizes (1 of 2)

| | | | | Model 16.6 | | | | |
|---|---|---|---|---|---|---|---|---|
| Type | Fleet | Yrs | N | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 |
| Size | Fish. | 40 | 300 | 1.0000 | 300 | 569 | 11999 | 22747 |
| Size | Surv. | 35 | 300 | 1.0000 | 300 | 302 | 10498 | 10587 |
| Age | Fish. | _ | _ | _ | _ | _ | _ | _ |
| Age | Surv. | 22 | 300 | 1.0000 | 300 | 59 | 6598 | 1298 |
| | | | | SEave | SEextra | RMSE | | |
| Index | Surv. | 35 | 353 | 0.1079 | 0 | 0.1865 | 12355 | 4137 |
| | | | | | | Ave: | 10363 | 9692 |
| | | | | | | | | 0.94 |

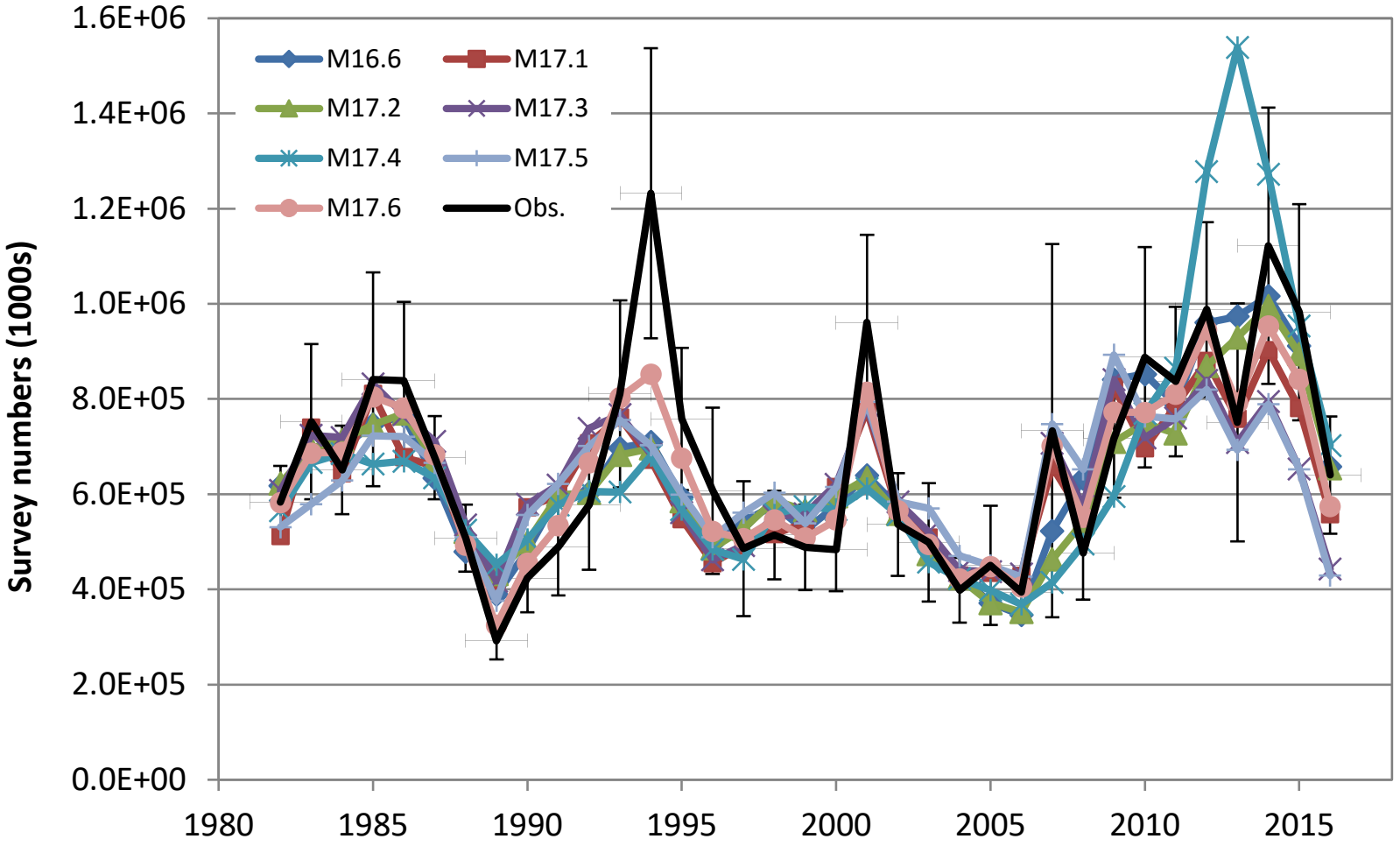
| | | | | Model 17.1 | | | | | Model 17.2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Fleet | Yrs | N | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 |
| Size | Fish. | 38 | 5849 | 1.0000 | 5849 | 1771 | 222271 | 67315 | 0.1910 | 1117 | 1120 | 42454 | 42558 |
| Size | Surv. | 35 | 345 | 1.0000 | 345 | 286 | 12083 | 10014 | 0.8303 | 287 | 287 | 10033 | 10033 |
| Age | Fish. | 2 | 10410 | 1.0000 | 10410 | 1730 | 20820 | 3459 | 0.3718 | 3870 | 3876 | 7741 | 7752 |
| Age | Surv. | 22 | 358 | 1.0000 | 358 | 75 | 7873 | 1654 | 0.1135 | 41 | 41 | 894 | 893 |
| | | | | SEave | SEextra | RMSE | | | SEave | SEextra | RMSE | | |
| Index | Surv. | 35 | 353 | 0.1079 | 0 | 0.1928 | 12355 | 3870 | 0.1079 | 0 | 0.2013 | 12355 | 3549 |
| | | | | | | Ave: | 55080 | 17263 | | | Ave: | 14695 | 12957 |

# Input and output effective sample sizes (2 of 2)

| | | | | Model 17.3 | | | | | Model 17.4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Fleet | Yrs | N | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 |
| Size | Fish. | 38 | 5849 | 0.1910 | 1117 | 1113 | 42454 | 42295 | 2.3684 | 13853 | 2241 | 526425 | 85151 |
| Size | Surv. | 35 | 345 | 0.9716 | 335 | 335 | 11740 | 11737 | 0.0448 | 15 | 104 | 541 | 3646 |
| Age | Fish. | 2 | 10410 | 0.1660 | 1728 | 1736 | 3456 | 3472 | 30.5489 | 318014 | 6776 | 636027 | 13552 |
| Age | Surv. | 22 | 358 | 0.2474 | 89 | 89 | 1948 | 1955 | 0.0406 | 15 | 6 | 320 | 141 |
| | | | | SEave | SEextra | RMSE | | | SEave | SEextra | RMSE | | |
| Index | Surv. | 35 | 353 | 0.1079 | 0.1105 | 0.2140 | 12355 | 12868 | 0.1079 | 0 | 0.2530 | 12355 | 2248 |
| | | | | | | Ave: | 14390 | 14465 | | | Ave: | 235134 | 20948 |

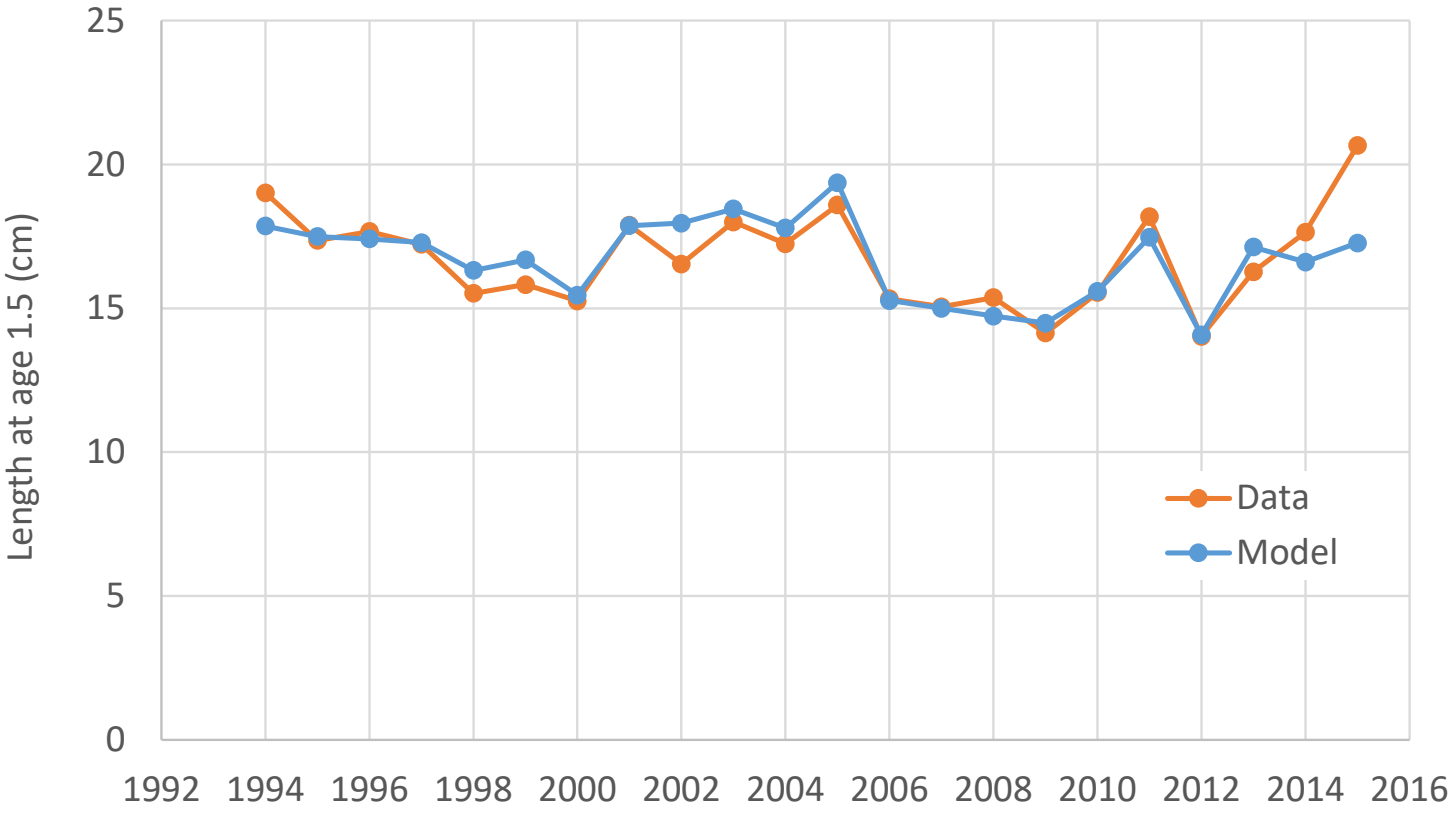
| | | | | Model 17.5 | | | | | Model 17.6 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Fleet | Yrs | N | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 | Mult | N×Mult | Har | ΣNeff1 | ΣNeff2 |
| Size | Fish. | 38 | 5849 | 0.1919 | 1122 | 783 | 42654 | 29746 | 0.1881 | 1100 | 1103 | 41809 | 41911 |
| Size | Surv. | 35 | 345 | 7.0648 | 2439 | 354 | 85364 | 12377 | 1.5068 | 520 | 520 | 18207 | 18213 |
| Age | Fish. | 2 | 10410 | 4.0977 | 42657 | 2388 | 85314 | 4775 | 0.3425 | 3565 | 3568 | 7131 | 7136 |
| Age | Surv. | 22 | 358 | 21.6483 | 7747 | 164 | 170437 | 3617 | 0.2225 | 80 | 80 | 1752 | 1753 |
| | | | | SEave | SEextra | RMSE | | | SEave | SEextra | RMSE | | |
| Index | Surv. | 35 | 353 | 0.1079 | 0 | 0.2169 | 12355 | 3057 | 0.1079 | 0 | 0.1081 | 12355 | 12312 |
| | | | | | | Ave: | 79225 | 10715 | | | Ave: | 16251 | 16265 |

# Fit to trawl survey index

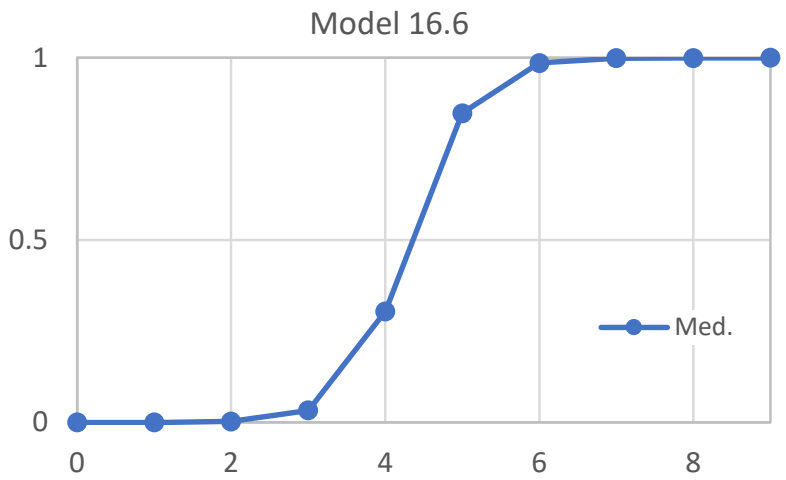


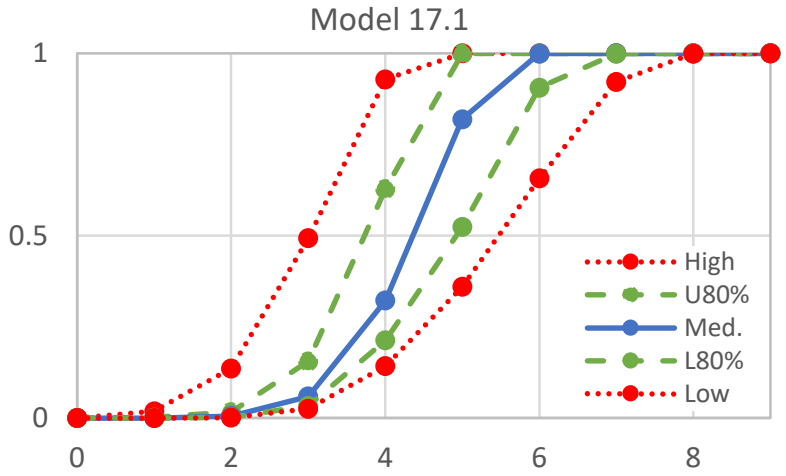
# Fit to length at age 1.5 (Model 17.6)

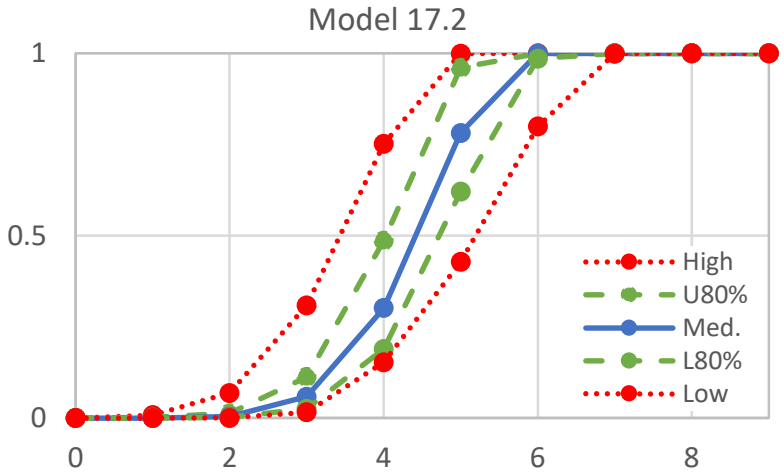
- Correlation = 0.81



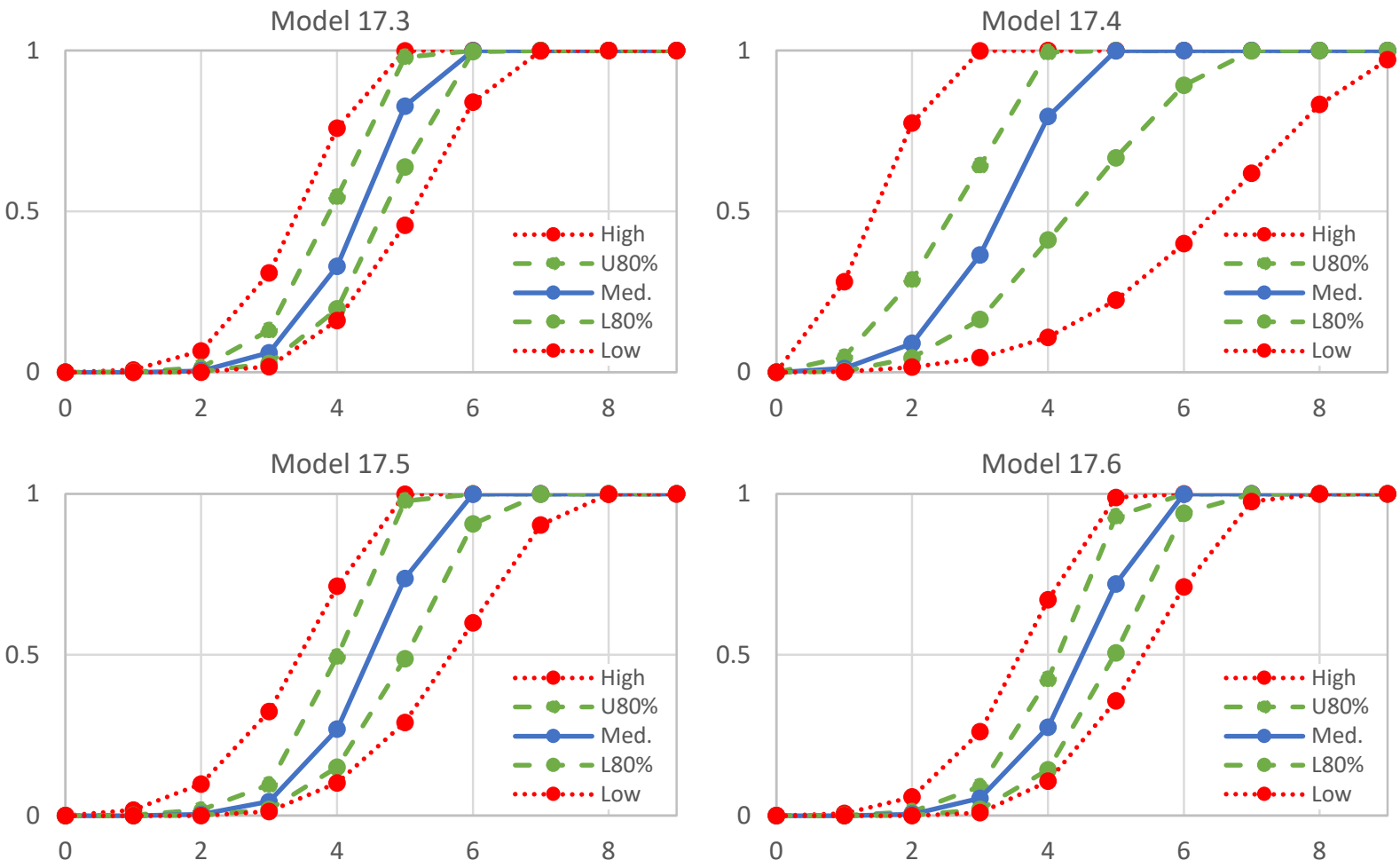
# Fishery selectivity (Models 16.6 and 17.1-17.2)



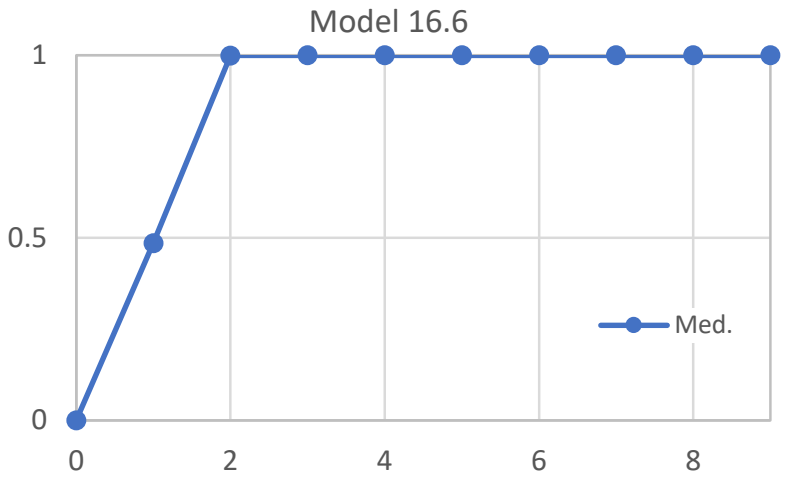



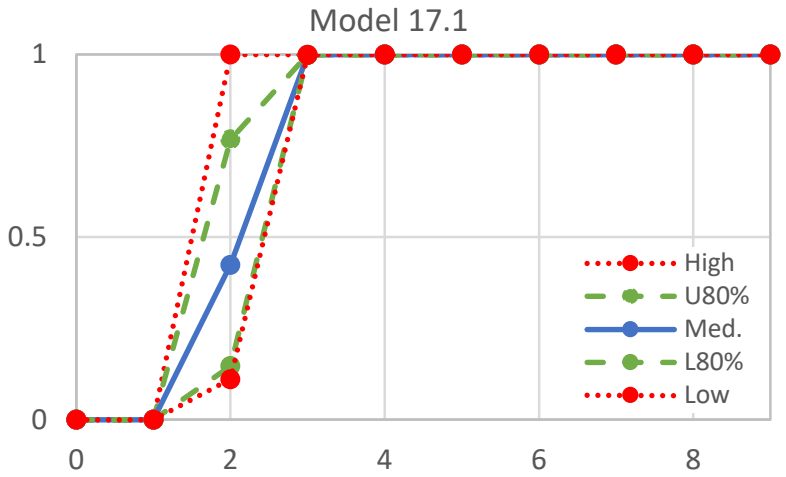



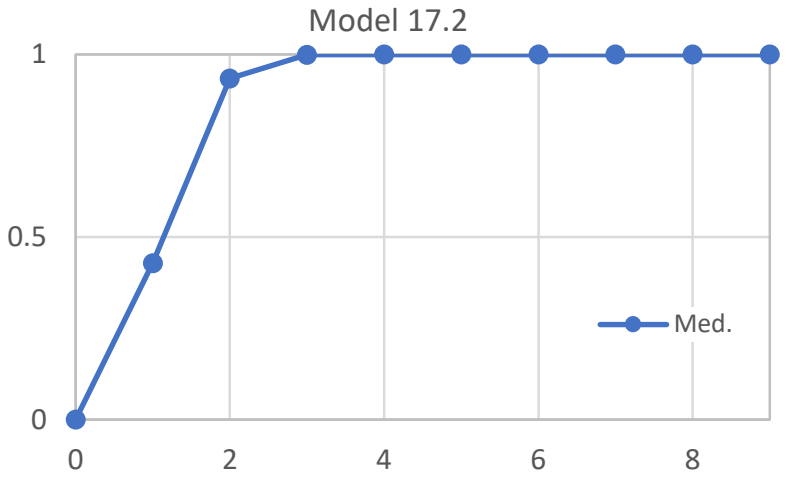
# Fishery selectivity (Models 17.3-17.6)



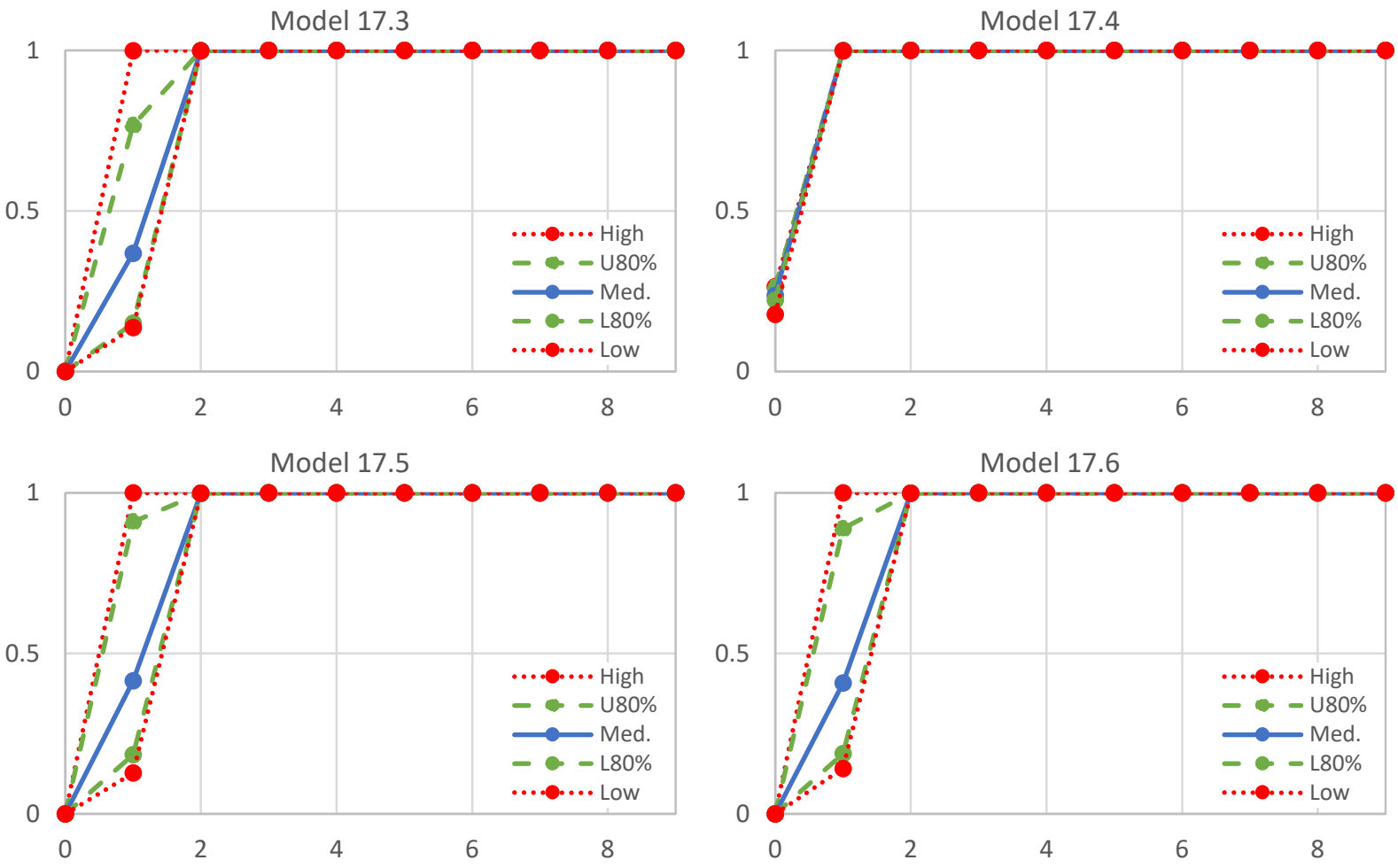
# Survey selectivity (Models 16.6 and 17.1-17.2)



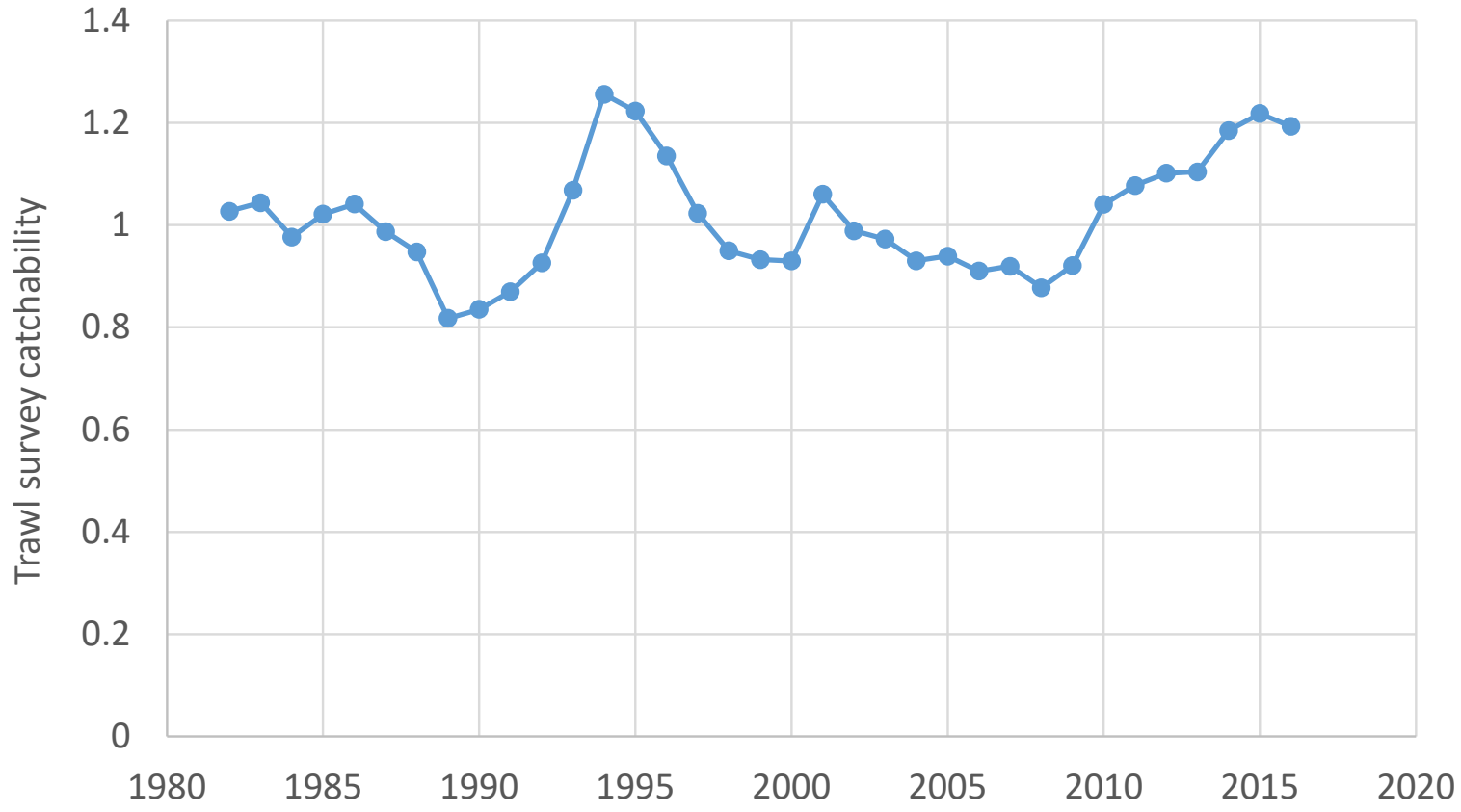



# Survey selectivity (Models 17.3-17.6)



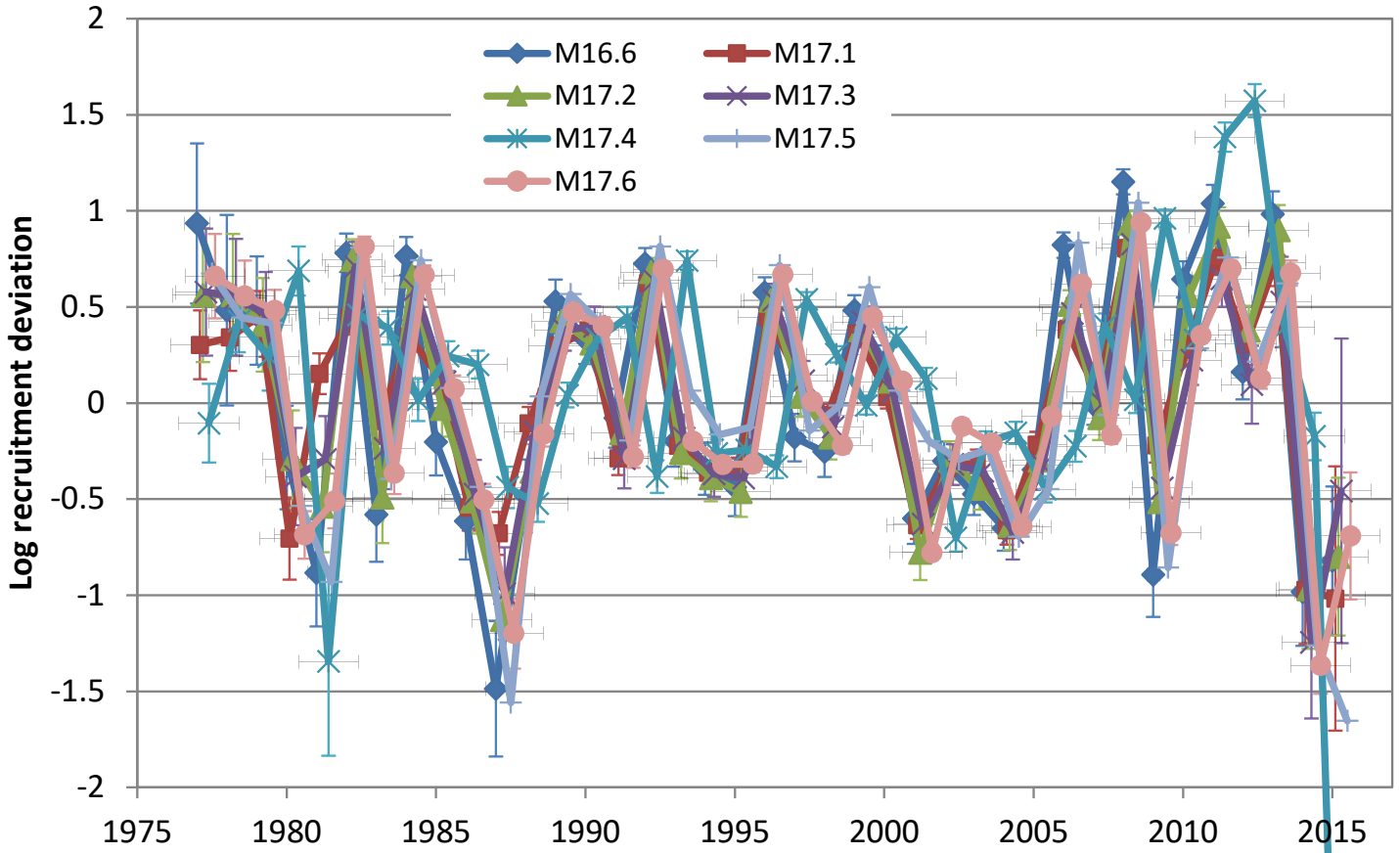
# Trawl survey catchability (Model 17.6)

- Autocorrelation of *devs* (estimated parameter) = 0.50

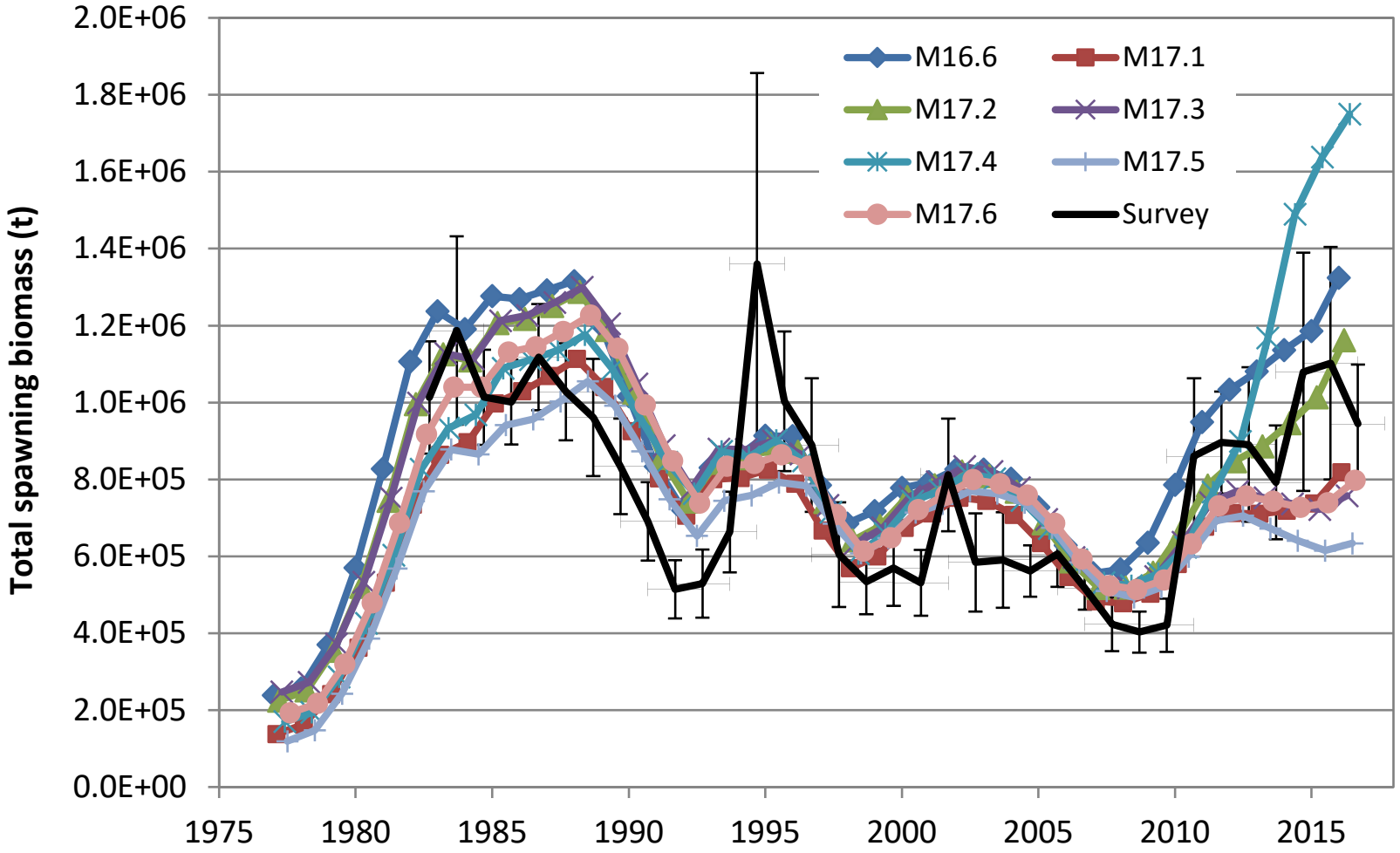


# Age 0 recruitment *devs*

- Model 17.4 correlation with other models = 0.24-0.45



# Total (age 0+) biomass, with survey biomass



# Harmonic mean and Francis weights (1 of 2)

| Model | Type | Fleet | Model Multiplier | Harmonic mean | | Francis (2011, Equation TA1.8) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Multiplier | Adjust | Multiplier | Adjust | Adj.(L95%) | Adj.(U95%) |
| M16.6 | Length | Fishery | 1.0000 | 1.8958 | 1.8958 | 0.2105 | 0.2105 | 0.1429 | 0.3615 |
| M16.6 | Length | Survey | 1.0000 | 1.0084 | 1.0084 | 0.2217 | 0.2217 | 0.1412 | 0.4569 |
| M16.6 | Age | Survey | 1.0000 | 0.1967 | 0.1967 | 0.2040 | 0.2040 | 0.1198 | 0.4664 |
| M17.1 | Length | Fishery | 1.0000 | 0.3029 | 0.3029 | 1.5692 | 1.5692 | 1.0823 | 2.7426 |
| M17.1 | Length | Survey | 1.0000 | 0.8288 | 0.8288 | 0.2311 | 0.2311 | 0.1560 | 0.4466 |
| M17.1 | Age | Fishery | 1.0000 | 0.1661 | 0.1661 | 0.8157 | 0.8157 | 0.8157 | infinity |
| M17.1 | Age | Survey | 1.0000 | 0.2101 | 0.2101 | 0.2522 | 0.2522 | 0.1470 | 0.6707 |
| M17.2 | Length | Fishery | 0.1910 | 0.1915 | 1.0025 | 0.2639 | 1.3815 | 1.0132 | 2.0883 |
| M17.2 | Length | Survey | 0.8303 | 0.8303 | 1.0001 | 0.1190 | 0.1434 | 0.0859 | 0.2897 |
| M17.2 | Age | Fishery | 0.3718 | 0.3724 | 1.0015 | 0.5203 | 1.3994 | 1.3994 | infinity |
| M17.2 | Age | Survey | 0.1135 | 0.1135 | 0.9997 | 0.1079 | 0.9509 | 0.5252 | 2.4545 |
| M17.3 | Length | Fishery | 0.1910 | 0.1903 | 0.9963 | 0.3823 | 2.0017 | 1.5552 | 2.9672 |
| M17.3 | Length | Survey | 0.9716 | 0.9714 | 0.9997 | 0.3761 | 0.3871 | 0.2533 | 0.7052 |
| M17.3 | Age | Fishery | 0.1660 | 0.1667 | 1.0045 | 0.7397 | 4.4560 | 4.4560 | infinity |
| M17.3 | Age | Survey | 0.2474 | 0.2483 | 1.0036 | 0.2992 | 1.2095 | 0.7393 | 2.9756 |

# Harmonic mean and Francis weights (2 of 2)

| Model | Type | Fleet | Model Multiplier | Harmonic mean | | Francis (2011, Equation TA1.8) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Multiplier | Adjust | Multiplier | Adjust | Adj.(L95%) | Adj.(U95%) |
| M17.4 | Length | Fishery | 2.3684 | 0.3831 | 0.1618 | 2.3701 | 1.0007 | 0.6725 | 1.9112 |
| M17.4 | Length | Survey | 0.0448 | 0.3018 | 6.7358 | 0.0448 | 1.0003 | 0.6530 | 2.1189 |
| M17.4 | Age | Fishery | 30.5489 | 0.6509 | 0.0213 | 30.5448 | 0.9999 | 0.9999 | infinity |
| M17.4 | Age | Survey | 0.0406 | 0.0179 | 0.4398 | 0.0406 | 0.9995 | 0.5590 | 3.5087 |
| M17.5 | Length | Fishery | 0.1919 | 0.1338 | 0.6974 | 0.0317 | 0.1654 | 0.1063 | 0.3409 |
| M17.5 | Length | Survey | 7.0648 | 1.0244 | 0.1450 | 0.4062 | 0.0575 | 0.0411 | 0.1013 |
| M17.5 | Age | Fishery | 4.0977 | 0.2294 | 0.0560 | 1.0813 | 0.2639 | 0.2639 | infinity |
| M17.5 | Age | Survey | 21.6483 | 0.4595 | 0.0212 | 0.6903 | 0.0319 | 0.0181 | 0.0850 |
| M17.6 | Length | Fishery | 0.1881 | 0.1886 | 1.0024 | 0.2636 | 1.4016 | 1.0417 | 2.1257 |
| M17.6 | Length | Survey | 1.5068 | 1.5073 | 1.0004 | 0.4446 | 0.2951 | 0.2017 | 0.5300 |
| M17.6 | Age | Fishery | 0.3425 | 0.3427 | 1.0007 | 0.6991 | 2.0413 | 2.0413 | infinity |
| M17.6 | Age | Survey | 0.2225 | 0.2226 | 1.0006 | 0.2857 | 1.2840 | 0.8316 | 2.8291 |

# Key parameters (Table 2.1.5)

| | Model 16.6 | | Model 17.1 | | Model 17.2 | | Model 17.3 | | Model 17.4 | | Model 17.5 | | Model 17.6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter/constant | Est. | SD | Est. | SD | Est. | SD | Est. | SD | Est. | SD | Est. | SD | Est. | SD |
| Natural mortality | 0.3625 | 0.013 | 0.3331 | 0.009 | 0.3686 | 0.016 | 0.3723 | 0.013 | 0.3196 | 0.021 | 0.3128 | 0.004 | 0.3449 | 0.011 |
| Initial fishing mortality | 0.1554 | 0.056 | 0.8505 | 0.310 | 0.1942 | 0.074 | 0.1751 | 0.058 | 0.5725 | 0.183 | 1.3134 | 0.842 | 0.2339 | 0.099 |
| Length at a=1.5 mean | 16.4011 | 0.088 | 16.5445 | 0.082 | 16.3720 | 0.091 | 16.3727 | 0.084 | 35.4975 | 0.156 | 16.3104 | 0.031 | 16.7850 | 0.277 |
| Length at a=1.5 dev SD | | | | | | | | | | | | | 0.0936 | _ |
| Asymptotic length | 99.3869 | 1.901 | 109.9040 | 1.058 | 104.9930 | 1.727 | 106.1030 | 1.742 | 120.5450 | 1.174 | 107.1690 | 1.135 | 104.5350 | 1.636 |
| Brody growth coefficient | 0.1974 | 0.012 | 0.1563 | 0.005 | 0.1761 | 0.009 | 0.1739 | 0.009 | 0.0995 | 0.003 | 0.1576 | 0.005 | 0.1770 | 0.008 |
| Richards growth coef. | 1.0499 | 0.048 | 1.1975 | 0.023 | 1.1075 | 0.040 | 1.1057 | 0.037 | 1.5910 | 0.037 | 1.1600 | 0.019 | 1.0432 | 0.035 |
| Length at a=1 SD | 3.4251 | 0.058 | 3.4983 | 0.050 | 3.4223 | 0.058 | 3.4554 | 0.055 | 4.8030 | 0.078 | 3.3943 | 0.021 | 3.0796 | 0.039 |
| Length at a=20 SD | 9.7171 | 0.282 | 8.3603 | 0.136 | 9.2442 | 0.225 | 8.8043 | 0.236 | 7.4946 | 0.184 | 9.6703 | 0.137 | 9.6923 | 0.205 |
| Ageing bias at a=1 | 0.3210 | 0.013 | 0.3365 | 0.011 | 0.3370 | 0.034 | 0.3419 | 0.019 | 0.7846 | 0.005 | 0.3383 | 0.003 | 0.3520 | 0.020 |
| Ageing bias at a=20 | 0.3513 | 0.154 | -0.3884 | 0.113 | -1.1456 | 0.251 | -0.2301 | 0.190 | 0.9732 | 0.066 | -0.2466 | 0.031 | -0.8161 | 0.187 |
| ln(mean post-76 recruits) | 13.2195 | 0.104 | 12.8790 | 0.067 | 13.1953 | 0.110 | 13.1578 | 0.095 | 12.7959 | 0.132 | 12.8103 | 0.031 | 13.0273 | 0.083 |
| σ(recruitment) | 0.6377 | 0.066 | 0.4693 | _ | 0.5602 | _ | 0.4958 | _ | 0.9708 | _ | 0.6551 | _ | 0.5730 | _ |
| ln(pre-77 recruits offset) | -1.0990 | 0.216 | -1.5149 | 0.030 | -1.2066 | 0.177 | -1.1067 | 0.164 | -1.8085 | 0.046 | -1.2602 | 0.235 | -1.2416 | 0.168 |
| ln(catchability) | -0.1328 | 0.065 | 0.1068 | 0.040 | -0.0537 | 0.055 | -0.0181 | 0.066 | 0.1425 | 0.081 | 0.1006 | 0.025 | 0.0122 | 0.057 |
| ln(catchability) dev SD | | | | | | | | | | | | | 0.0898 | _ |
| ln(catchability) dev corr. | | | | | | | | | | | | | 0.4959 | 0.126 |
| Survey index "extra SE" | | | | | | | 0.1105 | 0.031 | | | | | | |

# Constraints on randomly varying parameters

- σs for *dev* vectors:

| Dev vector | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|
| Recruitment | 0.6377 | 0.4693 | 0.5602 | 0.4958 | 0.9708 | 0.6551 | 0.5730 |
| Selectivity begin peak (fishery) | | 0.1222 | 0.1078 | 0.0993 | 0.2595 | 0.1261 | 0.1037 |
| Selectivity ascend width (fishery) | | 0.3619 | 0.2564 | 0.2287 | 0.9773 | 0.4366 | 0.2573 |
| Selectivity begin peak (survey) | | 0.0524 | | 0.0545 | 0.1703 | 0.0554 | 0.0535 |
| Selectivity ascend width (survey) | | 0.1597 | | 0.1593 | | | 0.1595 |
| Length at age 1.5 | | | | | | | 0.0936 |
| ln(Catchability) | | | | | | | 0.0898 |

- $\sigma_R$ versus standard deviation of *devs*:

| Model: | 16.6 | 17.1 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 |
|---|---|---|---|---|---|---|---|
| $\sigma_R$: | 0.6377 | 0.4693 | 0.5602 | 0.4958 | 0.9708 | 0.6551 | 0.5730 |
| SD(Rdevs): | 0.6631 | 0.4758 | 0.5672 | 0.5036 | 0.9836 | 0.6670 | 0.5807 |

# Retrospective bias

- Mohn's rho, with limits on acceptable values:

| Model: | 16.6 | 17.1 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 |
|---|---|---|---|---|---|---|---|
| Rho: | 0.148 | 0.101 | 0.287 | 0.094 | 0.122 | 0.313 | 0.074 |
| M: | 0.363 | 0.333 | 0.369 | 0.372 | 0.320 | 0.313 | 0.345 |
| Min: | -0.207 | -0.197 | -0.209 | -0.210 | -0.192 | -0.190 | -0.201 |
| Max: | 0.281 | 0.267 | 0.284 | 0.286 | 0.260 | 0.256 | 0.272 |

# Model averaging

# Effective number of parameters

- Method: Find the number of free parameters that gives the same sum of squares as the full set of penalized *devs*
- Shading indicates cases where algorithm failed

| | M16.6 | | M17.1 | | M17.2 | | M17.3 | | M17.4 | | M17.5 | | M17.6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vector | nyrs | npar | nyrs | npar | nyrs | npar | nyrs | npar | nyrs | npar | nyrs | npar | nyrs | npar |
| Recruitment | 39 | 22 | 39 | 11 | 39 | 20 | 39 | 11 | 39 | 1 | 39 | 17 | 39 | 8 |
| Length at a=1.5 | | | | | | | | | | | | | 35 | 35 |
| ln(Catchability) | | | | | | | | | | | | | 35 | 1 |
| Sel_fish_P1 | | | 40 | 3 | 40 | 2 | 40 | 2 | 40 | 3 | 40 | 1 | 40 | 2 |
| Sel_fish_P3 | | | 40 | 3 | 40 | 1 | 40 | 1 | 40 | 1 | 40 | 3 | 40 | 1 |
| Sel_surv_P1 | | | 35 | 1 | | | 35 | 1 | 35 | 1 | 35 | 35 | 35 | 1 |
| Sel_surv_P3 | | | 35 | 1 | | | 35 | 1 | | | | | 35 | 1 |
| Sum | 39 | 22 | 189 | 19 | 119 | 23 | 189 | 16 | 154 | 6 | 154 | 56 | 259 | 49 |
| Nominal parms | | 77 | | 226 | | 156 | | 227 | | 190 | | 190 | | 297 |
| Effective parms | | 60 | | 56 | | 60 | | 54 | | 42 | | 92 | | 87 |

# Input and output effective sample sizes

- Input effective sample sizes

| Type | Fleet | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|---|
| Sizecomp | Fishery | 11,999 | 222,271 | 42,454 | 42,454 | 526,425 | 42,654 | 41,809 |
| Sizecomp | Survey | 10,498 | 12,083 | 10,033 | 11,740 | 541 | 85,364 | 18,207 |
| Agecomp | Fishery | | 20,820 | 7,741 | 3,456 | 636,028 | 85,314 | 7,131 |
| Agecomp | Survey | 6,598 | 7,873 | 894 | 1,948 | 320 | 170,437 | 1,752 |
| Index | Survey | 12,355 | 12,355 | 12,355 | 12,355 | 12,355 | 12,355 | 12,355 |
| | Average: | 10,363 | 55,080 | 14,695 | 14,390 | 235,134 | 79,225 | 16,251 |

- Output effective sample sizes

| Type | Fleet | M16.6 | M17.1 | M17.2 | M17.3 | M17.4 | M17.5 | M17.6 |
|---|---|---|---|---|---|---|---|---|
| Sizecomp | Fishery | 22,747 | 67,315 | 42,558 | 42,295 | 85,151 | 29,746 | 41,911 |
| Sizecomp | Survey | 10,587 | 10,014 | 10,033 | 11,737 | 3,646 | 12,377 | 18,213 |
| Agecomp | Fishery | | 3,459 | 7,752 | 3,472 | 13,552 | 4,775 | 7,136 |
| Agecomp | Survey | 1,298 | 1,654 | 893 | 1,955 | 141 | 3,617 | 1,753 |
| Index | Survey | 4,137 | 3,870 | 3,549 | 12,868 | 2,248 | 3,057 | 12,312 |
| | Average: | 9,692 | 17,263 | 12,957 | 14,465 | 20,948 | 10,715 | 16,265 |

# Effective sample size per effective parameter

- Means are computed across components

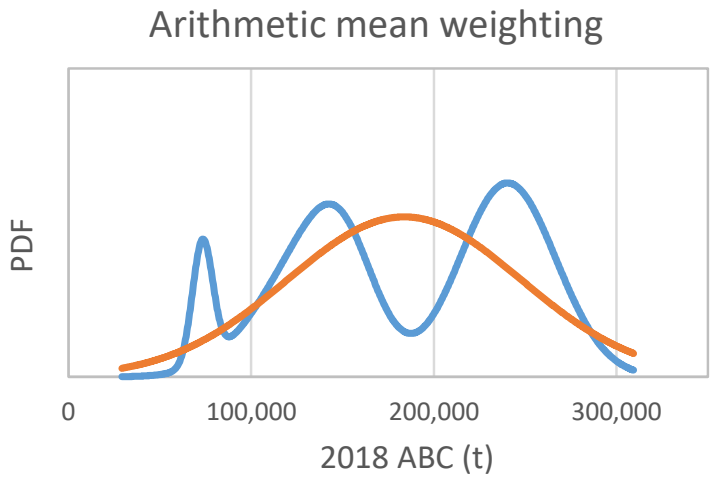
| Model | Arithmetic | | Geometric | | Harmonic | |
|---|---|---|---|---|---|---|
| | Mean | Weight | Mean | Weight | Mean | Weight |
| 16.6 | 162 | 0.0920 | 100 | 0.1278 | 58 | 0.1405 |
| 17.1 | 308 | 0.1756 | 122 | 0.1560 | 70 | 0.1709 |
| 17.2 | 216 | 0.1230 | 106 | 0.1357 | 50 | 0.1222 |
| 17.3 | 268 | 0.1526 | 157 | 0.2003 | 94 | 0.2277 |
| 17.4 | 499 | 0.2841 | 100 | 0.1283 | 15 | 0.0366 |
| 17.5 | 116 | 0.0663 | 78 | 0.1001 | 59 | 0.1421 |
| 17.6 | 187 | 0.1065 | 119 | 0.1518 | 66 | 0.1601 |
| Sum: | 1756 | 1 | 782 | 1 | 412 | 1 |

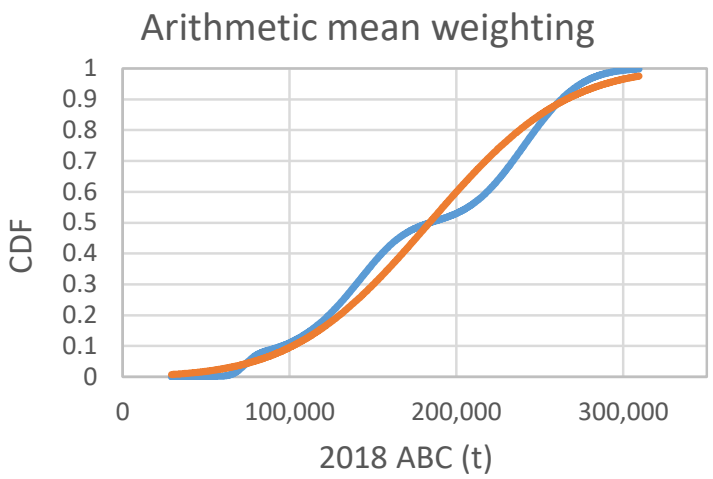
# Model-specific distributions of 2018 ABC

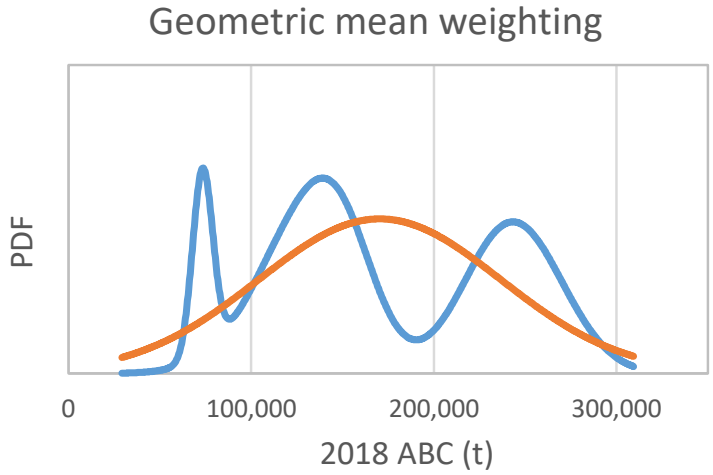
- Based on Hessian approximation

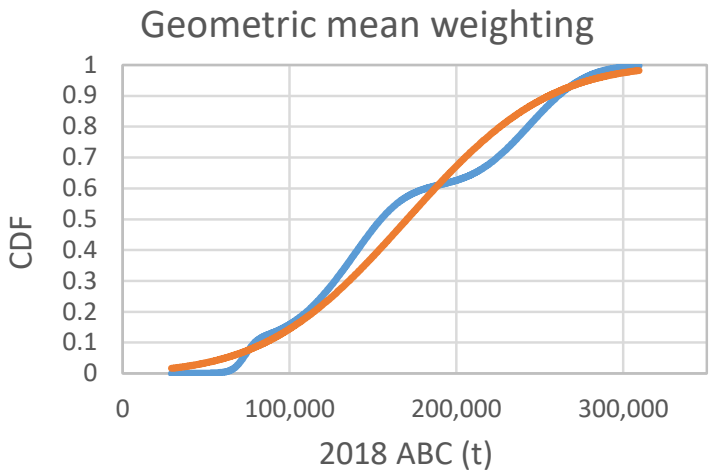
| Model | 2018 ABC | |
|---|---|---|
| | Mean | SD |
| 16.6 | 258031 | 23900 |
| 17.1 | 150324 | 18403 |
| 17.2 | 236527 | 23211 |
| 17.3 | 121543 | 28344 |
| 17.4 | 236901 | 26178 |
| 17.5 | 73343 | 5545 |
| 17.6 | 130064 | 22732 |

# Model averaging (1 of 2)

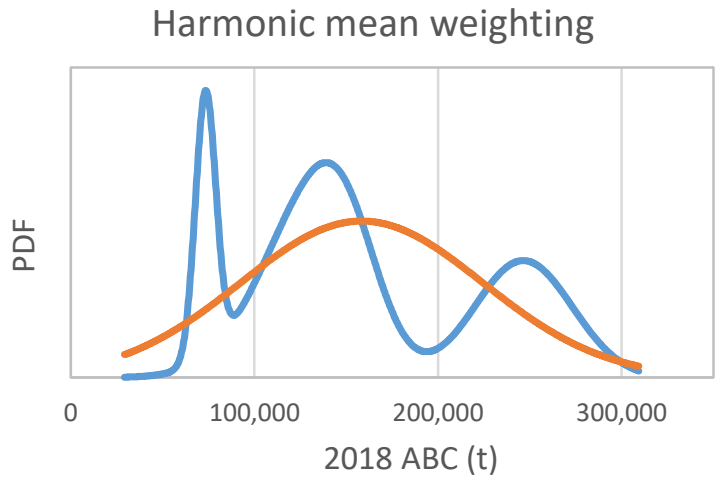


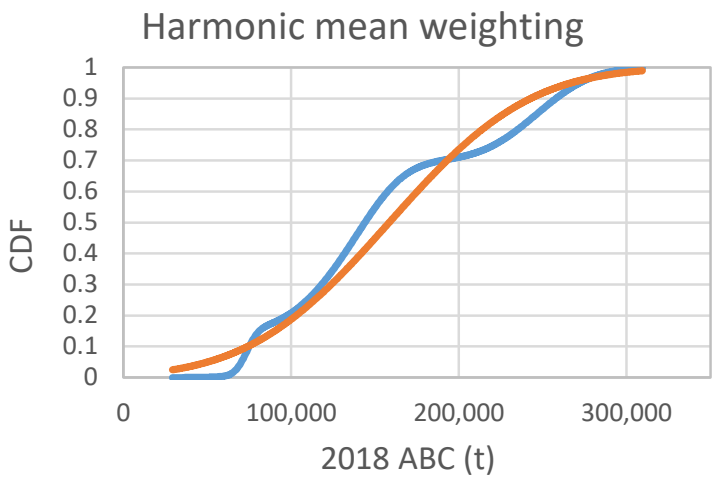



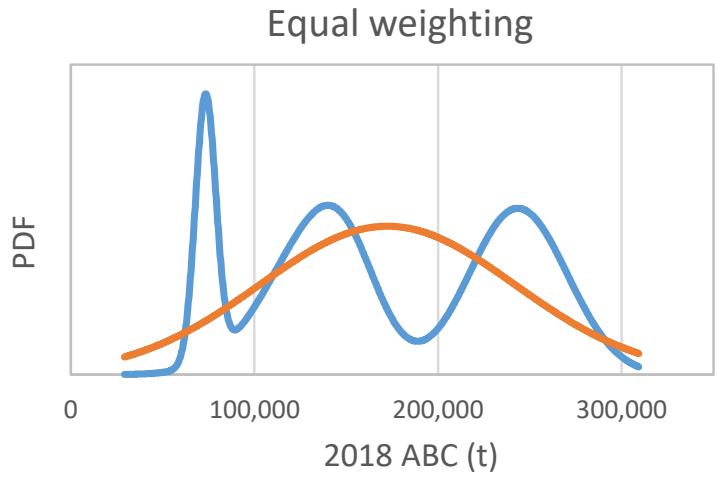



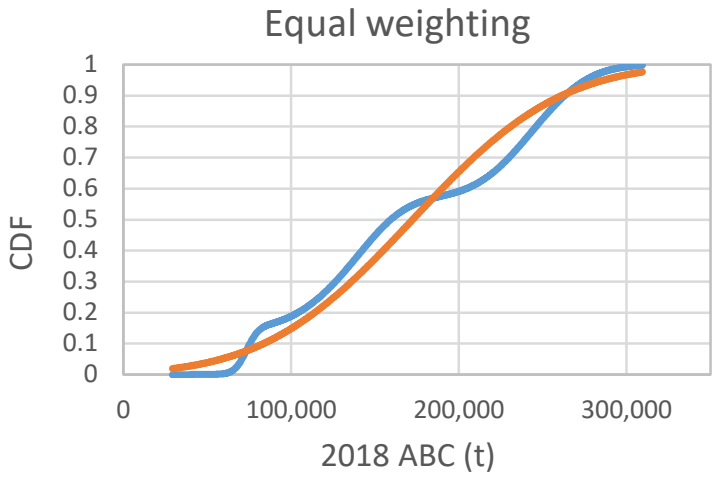



# Model averaging (2 of 2)



# Model averaging statistics

| Weight | Mean | Sdev | L90% | U90% | L95% | U95% | L99% | U99% |
|---|---|---|---|---|---|---|---|---|
| Arithmetic | 183,794 | 64,088 | 78,378 | 289,210 | 58,183 | 309,405 | 18,714 | 348,875 |
| Geometric | 170,348 | 66,351 | 61,212 | 279,485 | 40,304 | 300,393 | -559 | 341,256 |
| Harmonic | 158,439 | 65,896 | 50,050 | 266,827 | 29,286 | 287,591 | -11,297 | 328,174 |
| Equal | 172,390 | 69,456 | 58,146 | 286,635 | 36,260 | 308,521 | -6,515 | 351,296 |