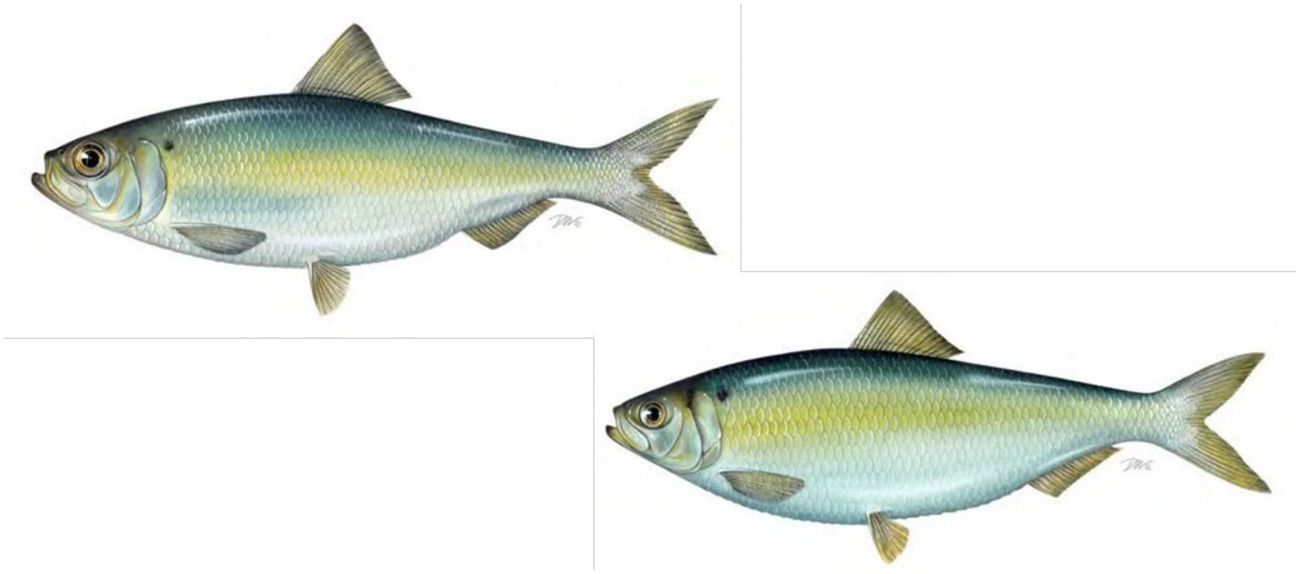
Atlantic States Marine Fisheries Commission

Appendices to the River Herring Benchmark Stock Assessment



August 7, 2024

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Appendix 1: Example GLM Standardizations

MA Trawl Survey Standardization

Survey Description

The Massachusetts Division of Marine Fisheries runs a synoptic coastal trawl survey performed in the spring and autumn. The bottom trawl surveys of Massachusetts territorial waters have been conducted by the Resource Assessment Project of the Massachusetts Division of Marine Fisheries since 1978. The study utilizes a stratified random sampling design and six depth zones. Trawl sites are allocated in proportion to stratum area and randomly chosen in advance within each sampling stratum.

Blueback herring are rarely encountered, so the index was developed for alewife. The majority of alewife in the catches are age-1 herring encountered in the spring and in the survey strata north of Cape Cod, so the survey was subset to May tows in regions 4 and 5. Environmental variables taken at each station include depth and bottom temperature.

Model Selection

The final dataset had `29.3`% positive tows. Strata were defined in part by depth, so a comparison was made between a model with stratum as a covariate and a model with depth and region (STRATUMNAME2) as separate covariates.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STRATUM + TEMP,
               data = dat,
               family = nbinom2)
```

Full model with depth and stratum separated:

```
NB2 <- glmmTMB(FREQ~YEAR + STRATUMNAME2 + DEPTH + TEMP,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STRATUM +TEMP,
                ziformula = ~YEAR+STRATUM+TEMP,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Full model with depth and stratum separated:

```
ZANB.2 <- glmmTMB(FREQ~YEAR + STRATUMNAME2 + DEPTH +TEMP,
                ziformula = ~YEAR + STRATUMNAME2 + DEPTH +TEMP,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial model did not converge and was not pursued further.

GAM

```
GAM.NB <- gam(FREQ~YEAR + STRATUM + s(TEMP),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-altered negative binomial with stratum as the covariate, and favored the full ZANB model over the reduced model with only year as a factor, as well as over intermediate models with different combinations of stratum and temperature.

```
##        dAIC  df
## ZANB     0.0 111
## ZANB.2 306.9 93
## GAM.NB 429.3 62.2
## NB1    462.2 56
## NB2    711.3 47
```

The final model selected was the full zero-altered negative binomial model.

```
##  Family: truncated_nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STRATUM + TEMP
## Zero inflation:        ~YEAR + STRATUM + TEMP
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##  21032.3  21796.3 -10405.2  20810.3     7094
##
##
## Dispersion parameter for truncated_nbinom2 family (): 0.251
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  1.542823   0.714493   2.159 0.030825 *
## YEAR1979     0.117521   0.533855   0.220 0.825765
## YEAR1980     0.043487   0.482743   0.090 0.928222
## YEAR1981     0.520026   0.511281   1.017 0.309104
## YEAR1982     0.611323   0.562474   1.087 0.277105
## YEAR1983     1.237724   0.468226   2.643 0.008207 **
## YEAR1984     1.197174   0.481154   2.488 0.012842 *
## YEAR1985     0.352303   0.533778   0.660 0.509242
## YEAR1986     0.237093   0.512695   0.462 0.643763
```

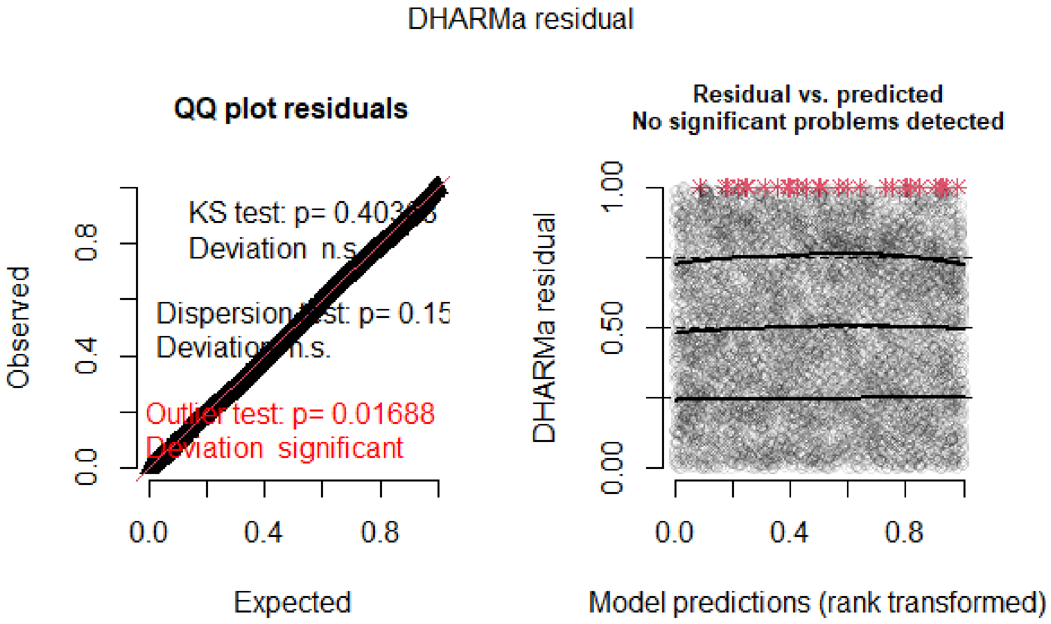
```
## YEAR1987      0.925866   0.517847   1.788 0.073790 .
## YEAR1988      1.127012   0.494214   2.280 0.022583 *
## YEAR1989      1.317781   0.488726   2.696 0.007010 **
## YEAR1990      0.787301   0.496319   1.586 0.112676
## YEAR1991      1.222873   0.580155   2.108 0.035045 *
## YEAR1992      2.277775   0.478437   4.761 1.93e-06 ***
## YEAR1993      0.554878   0.534705   1.038 0.299397
## YEAR1994      0.895797   0.530410   1.689 0.091243 .
## YEAR1995      1.553735   0.499233   3.112 0.001857 **
## YEAR1996      0.289982   0.532157   0.545 0.585810
## YEAR1997     -0.178384   0.499471  -0.357 0.720982
## YEAR1998      0.728753   0.523605   1.392 0.163983
## YEAR1999      2.011004   0.507340   3.964 7.38e-05 ***
## YEAR2000      0.224375   0.466599   0.481 0.630606
## YEAR2001     -1.710578   0.852725  -2.006 0.044855 *
## YEAR2002      0.502600   0.599351   0.839 0.401708
## YEAR2003      1.897081   0.525396   3.611 0.000305 ***
## YEAR2004      0.544855   0.486440   1.120 0.262677
## YEAR2005      1.421923   0.487986   2.914 0.003570 **
## YEAR2006      1.318406   0.465250   2.834 0.004600 **
## YEAR2007      1.629355   0.533119   3.056 0.002241 **
## YEAR2008      1.651270   0.548148   3.012 0.002591 **
## YEAR2009      1.118812   0.492352   2.272 0.023063 *
## YEAR2010     -0.190868   0.542023  -0.352 0.724733
## YEAR2011      2.622515   0.472605   5.549 2.87e-08 ***
## YEAR2012      0.749806   0.475827   1.576 0.115073
## YEAR2013      0.162380   0.486085   0.334 0.738337
## YEAR2014      1.054093   0.473566   2.226 0.026023 *
## YEAR2015      0.811779   0.477551   1.700 0.089154 .
## YEAR2016     -0.045879   0.541179  -0.085 0.932440
## YEAR2017      1.069658   0.495279   2.160 0.030795 *
## YEAR2018      2.078538   0.476007   4.367 1.26e-05 ***
## YEAR2019      0.303325   0.468316   0.648 0.517183
## YEAR2021      0.820997   0.476912   1.721 0.085163 .
## STRATUM26    -0.008016   0.411061  -0.020 0.984442
## STRATUM27     0.248711   0.376471   0.661 0.508845
## STRATUM28    -0.239029   0.370631  -0.645 0.518976
## STRATUM29    -0.615138   0.394136  -1.561 0.118589
## STRATUM30    -1.646721   0.436379  -3.774 0.000161 ***
## STRATUM31    -0.008034   0.458788  -0.018 0.986028
## STRATUM32     0.875026   0.428151   2.044 0.040980 *
## STRATUM33     1.106316   0.408439   2.709 0.006756 **
## STRATUM34     0.627570   0.424967   1.477 0.139742
## STRATUM35    -0.750682   0.406169  -1.848 0.064574 .
## STRATUM36    -0.810534   0.410995  -1.972 0.048595 *
## TEMP         -0.133741   0.045800  -2.920 0.003499 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
```

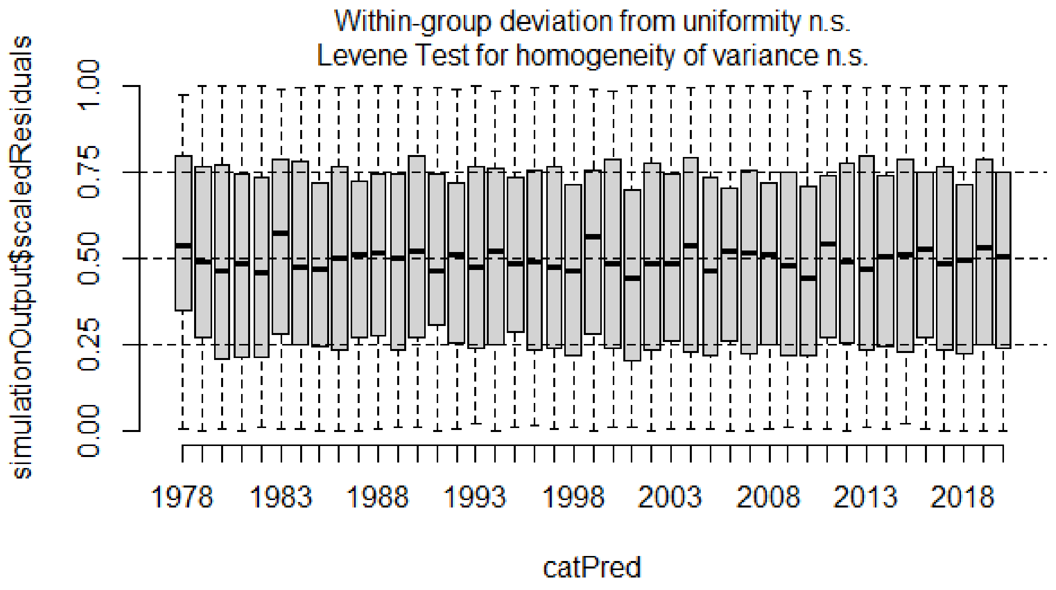
```
##              Estimate Std. Error z value Pr(>|z|)    
## (Intercept)  2.18451    0.45061   4.848 1.25e-06 ***
## YEAR1979     0.43080    0.36130   1.192 0.233112    
## YEAR1980    -0.13209    0.34510  -0.383 0.701898    
## YEAR1981     0.19619    0.35856   0.547 0.584273    
## YEAR1982     0.77442    0.38038   2.036 0.041759 *  
## YEAR1983    -0.64419    0.33645  -1.915 0.055534 .  
## YEAR1984    -0.30116    0.34048  -0.885 0.376419    
## YEAR1985     0.34580    0.36726   0.942 0.346414    
## YEAR1986     0.08136    0.36162   0.225 0.821980    
## YEAR1987     0.42553    0.36284   1.173 0.240894    
## YEAR1988    -0.32245    0.34346  -0.939 0.347830    
## YEAR1989    -0.60929    0.34326  -1.775 0.075895 .  
## YEAR1990    -0.25147    0.35056  -0.717 0.473177    
## YEAR1991     0.26981    0.41002   0.658 0.510509    
## YEAR1992    -0.31269    0.34213  -0.914 0.360740    
## YEAR1993     0.22794    0.37594   0.606 0.544291    
## YEAR1994     0.12217    0.37395   0.327 0.743892    
## YEAR1995    -0.44090    0.35030  -1.259 0.208167    
## YEAR1996     0.58366    0.37147   1.571 0.116130    
## YEAR1997    -0.07738    0.35061  -0.221 0.825315    
## YEAR1998     0.34460    0.37305   0.924 0.355631    
## YEAR1999     0.33187    0.35757   0.928 0.353348    
## YEAR2000    -0.52644    0.33962  -1.550 0.121123    
## YEAR2001     1.82841    0.49463   3.697 0.000219 ***
## YEAR2002     0.96630    0.39689   2.435 0.014905 *  
## YEAR2003    -0.12128    0.35151  -0.345 0.730085    
## YEAR2004    -0.62441    0.34145  -1.829 0.067448 .  
## YEAR2005    -0.77873    0.34071  -2.286 0.022277 *  
## YEAR2006    -0.85994    0.33440  -2.572 0.010123 *  
## YEAR2007     0.45753    0.36111   1.267 0.205156    
## YEAR2008     0.18188    0.35819   0.508 0.611599    
## YEAR2009    -0.30701    0.34380  -0.893 0.371867    
## YEAR2010     0.70105    0.37678   1.861 0.062792 .  
## YEAR2011    -0.73136    0.33210  -2.202 0.027649 *  
## YEAR2012    -0.27012    0.34421  -0.785 0.432596    
## YEAR2013    -0.24448    0.34386  -0.711 0.477086    
## YEAR2014    -0.48504    0.33633  -1.442 0.149260    
## YEAR2015    -0.32434    0.34200  -0.948 0.342942    
## YEAR2016     0.15360    0.37678   0.408 0.683516    
## YEAR2017    -0.39206    0.34278  -1.144 0.252727    
## YEAR2018    -0.54731    0.33557  -1.631 0.102893    
## YEAR2019    -0.39927    0.33720  -1.184 0.236387    
## YEAR2021    -0.33114    0.34440  -0.961 0.336305    
## STRATUM26   -0.72060    0.23442  -3.074 0.002112 ** 
## STRATUM27   -2.09204    0.21947  -9.532  < 2e-16 ***
## STRATUM28   -2.30134    0.22414 -10.268  < 2e-16 ***
## STRATUM29   -1.91976    0.23563  -8.147 3.72e-16 ***
## STRATUM30   -1.41484    0.26504  -5.338 9.39e-08 ***
## STRATUM31   -0.49111    0.26373  -1.862 0.062585 .  
```

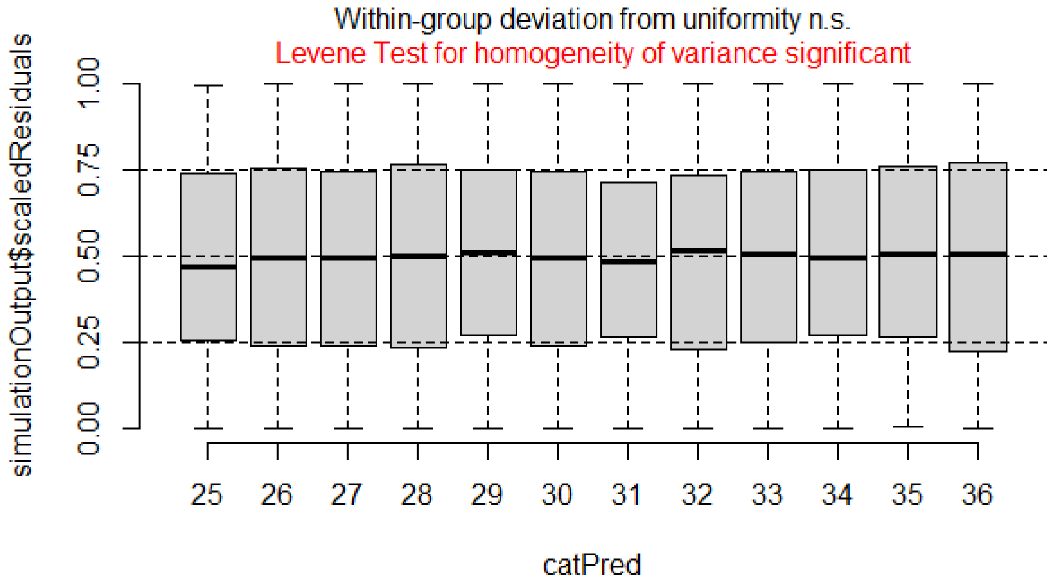
```
## STRATUM32    -1.26628    0.24084  -5.258 1.46e-07 ***
## STRATUM33    -1.39644    0.24050  -5.806 6.38e-09 ***
## STRATUM34    -1.00214    0.25464  -3.935 8.30e-05 ***
## STRATUM35    -1.55978    0.24340  -6.408 1.47e-10 ***
## STRATUM36    -2.28619    0.25214  -9.067  < 2e-16 ***
## TEMP          0.07964    0.02803   2.841 0.004502 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

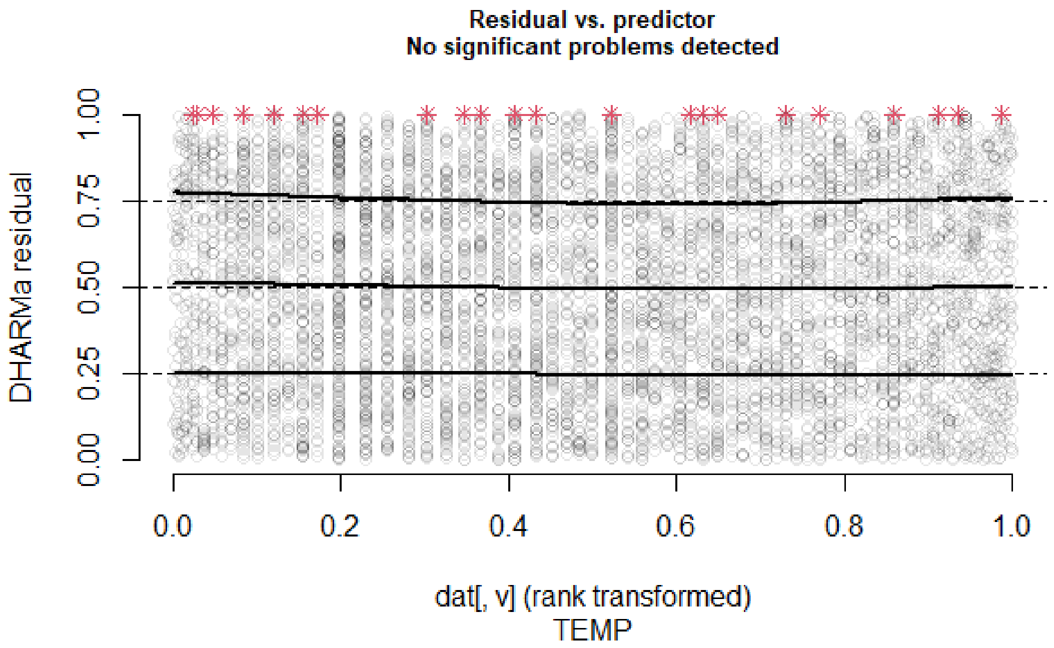
Model Diagnostics

The diagnostics for the zero-altered negative binomial were acceptable, although the outlier test was significant.



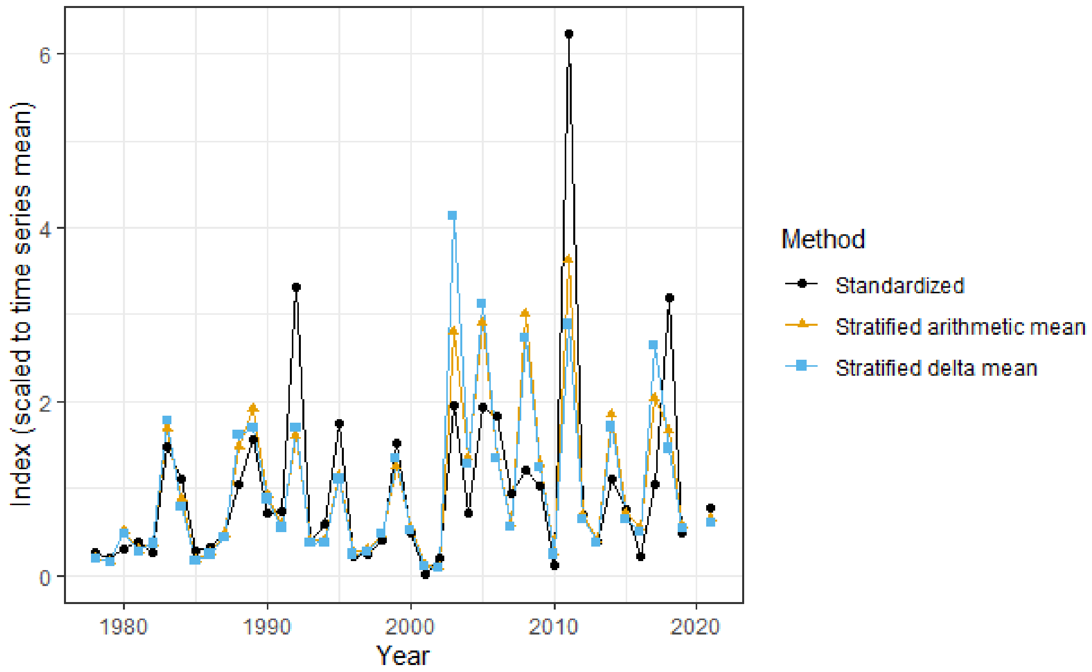

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1978
1983
1988
1993
1998
2003
2008
2013
2018
catPred

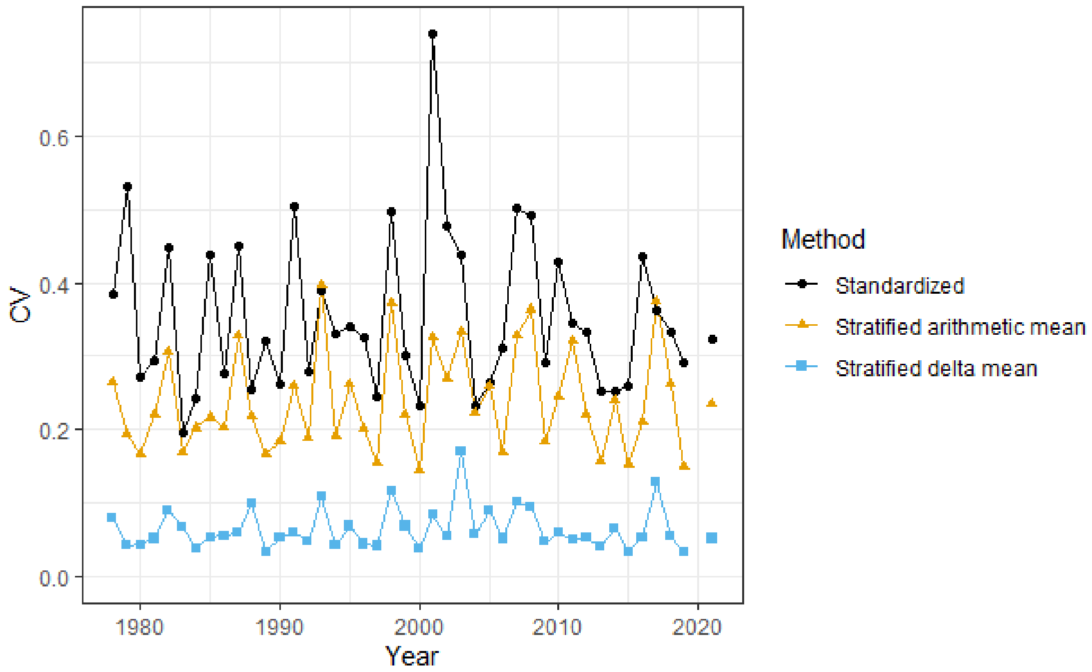

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance significant
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
25
26
27
28
29
30
31
32
33
34
35
36
catPred



Index Comparisons

The standardized index was compared to the stratified mean index calculated using the arithmetic mean and the delta distribution. The standardized index showed a similar trend to the stratified mean indices but had a higher CV.


Index (scaled to time series mean)
0
2
4
6
1980
1990
2000
2010
2020
Year
Method
Standardized
Stratified arithmetic mean
Stratified delta mean


CV
0.0
0.2
0.4
0.6
1980
1990
2000
2010
2020
Year
Method
Standardized
Stratified arithmetic mean
Stratified delta mean

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Stratified Mean	Stratified CV	Delta Mean	Delta Mean CV
1978	0.391	0.38	0.573	0.26	0.589	0.079
1979	0.309	0.53	0.459	0.19	0.461	0.042
1980	0.452	0.27	1.391	0.17	1.468	0.043
1981	0.561	0.29	0.813	0.22	0.838	0.051
1982	0.375	0.45	1.018	0.31	1.103	0.090
1983	2.152	0.20	4.618	0.17	5.348	0.066
1984	1.627	0.24	2.417	0.20	2.392	0.038
1985	0.419	0.44	0.504	0.22	0.500	0.053
1986	0.464	0.28	0.721	0.20	0.731	0.055
1987	0.696	0.45	1.321	0.33	1.311	0.060
1988	1.540	0.25	4.051	0.22	4.843	0.099
1989	2.278	0.32	5.269	0.17	5.093	0.033
1990	1.041	0.26	2.553	0.18	2.656	0.052
1991	1.067	0.50	1.627	0.26	1.667	0.061
1992	4.834	0.28	4.429	0.19	5.084	0.047
1993	0.566	0.39	1.147	0.40	1.124	0.108
1994	0.868	0.33	1.122	0.19	1.141	0.043
1995	2.569	0.34	3.132	0.26	3.343	0.068
1996	0.322	0.33	0.736	0.20	0.740	0.044
1997	0.347	0.25	0.820	0.15	0.826	0.041
1998	0.612	0.50	1.280	0.37	1.431	0.117
1999	2.229	0.30	3.448	0.22	4.036	0.068
2000	0.722	0.23	1.515	0.14	1.563	0.037
2001	0.014	0.74	0.307	0.33	0.318	0.084
2002	0.283	0.48	0.258	0.27	0.258	0.055

Year	Standardized Index	Standardized CV	Stratified Mean	Stratified CV	Delta Mean	Delta Mean CV
2003	2.863	0.44	7.699	0.33	12.411	0.170
2004	1.062	0.23	3.743	0.22	3.875	0.057
2005	2.822	0.27	7.951	0.26	9.370	0.090
2006	2.676	0.31	3.741	0.17	4.053	0.051
2007	1.368	0.50	1.628	0.33	1.679	0.101
2008	1.761	0.49	8.230	0.36	8.208	0.095
2009	1.511	0.29	3.525	0.18	3.751	0.047
2010	0.179	0.43	0.727	0.25	0.737	0.059
2011	9.097	0.34	9.924	0.32	8.672	0.050
2012	1.017	0.33	1.915	0.22	1.955	0.052
2013	0.554	0.25	1.147	0.16	1.159	0.041
2014	1.608	0.25	5.085	0.24	5.138	0.065
2015	1.125	0.26	1.951	0.15	1.962	0.033
2016	0.330	0.44	1.499	0.21	1.510	0.052
2017	1.529	0.36	5.584	0.38	7.943	0.127
2018	4.675	0.33	4.553	0.26	4.393	0.054
2019	0.714	0.29	1.597	0.15	1.619	0.032
2020						
2021	1.142	0.32	1.825	0.24	1.799	0.051

NJ Delaware River Seine Survey Alewife Standardization

Survey Description

New Jersey has conducted a juvenile abundance survey for striped bass in the Delaware River from Trenton to Artificial Island since 1980. The program utilizes a 100-foot bagless beach seine during the months of August, September, and October at representative stations. Since river herring are not collected at all stations, those farthest downriver stations (below the Delaware Memorial Bridges) have been removed from analysis to give a more accurate picture of juvenile production in the lower Delaware River. Length frequencies of juvenile blueback herring and alewife have been determined from collections since 2002. A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest half centimeter; the remainder was enumerated.

Model Selection

The final dataset had 11.06% positive tows.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered negative binomial doe not converge. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
```

```
                ziformula = ~STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

Since this is a fixed station survey, station was treated as a random effect. Treating station as a random effect did not appreciably improve the fit of the model, so that formulation was not used going forward.

```
ZINB.2.re <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+ (1|STATION),
                     ziformula = ~STATION + STEMP+SSAL+SDO,
                     data = dat,
                     family = nbinom2)
```

GAM

```
GAM.NB <- gam(FREQ~YEAR + s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the generalized additive model negative binomial.

```
##         dAIC df
## GAM.NB  0.0 45.3
## ZINB.2 43.8 42
## NB1    50.3 38
## ZINB     NA 75
## ZANB     NA 75
```

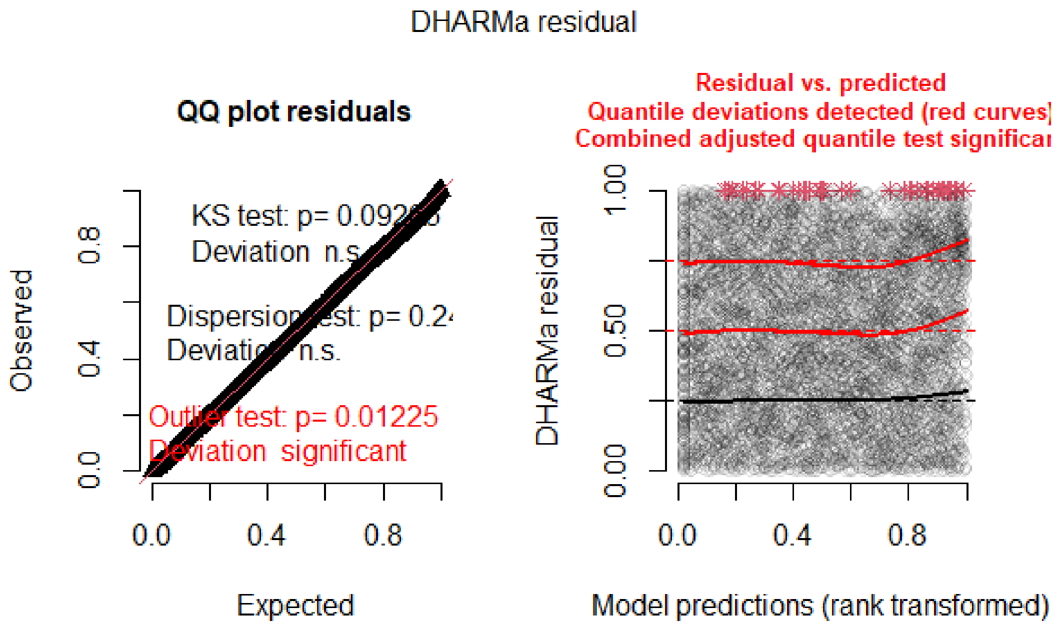
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the generalized additive model negative binomial was selected as the final model. In order to select factors for inclusion in the model, we checked various combinations of covariates for significance and selected the full model.

```
##
## Family: Negative Binomial(0.065)
## Link function: log
##
## Formula:
## FREQ ~ YEAR + s(STEMP) + s(SSAL)
##
## Parametric coefficients:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -1.953e+00  6.231e-01  -3.134 0.001726 **
## YEAR1988     4.031e+00  7.204e-01   5.595 2.21e-08 ***
## YEAR1989     1.413e+00  7.353e-01   1.921 0.054727 .
## YEAR1990     2.095e+00  7.264e-01   2.883 0.003935 **
## YEAR1991     1.762e+00  6.783e-01   2.598 0.009369 **
## YEAR1992    -1.646e+00  7.663e-01  -2.148 0.031752 *
## YEAR1993     2.292e+00  6.897e-01   3.323 0.000892 ***
## YEAR1994     2.199e+00  6.866e-01   3.202 0.001365 **
## YEAR1995     8.680e-01  6.972e-01   1.245 0.213140
```

```
## YEAR1996     4.269e+00  6.827e-01   6.253 4.04e-10 ***
## YEAR1997     1.321e+00  6.976e-01   1.894 0.058280 .
## YEAR1998    -8.907e-01  7.315e-01  -1.218 0.223372
## YEAR1999     1.901e+00  6.926e-01   2.745 0.006053 **
## YEAR2000     5.778e-01  6.910e-01   0.836 0.403060
## YEAR2001     2.344e+00  6.806e-01   3.443 0.000575 ***
## YEAR2002    -3.588e+00  1.001e+00  -3.584 0.000338 ***
## YEAR2003     1.666e+00  6.687e-01   2.491 0.012727 *
## YEAR2004     5.945e-01  6.791e-01   0.875 0.381354
## YEAR2005     2.494e+00  6.636e-01   3.758 0.000171 ***
## YEAR2006    -2.622e+00  8.167e-01  -3.210 0.001327 **
## YEAR2007     2.515e+00  6.667e-01   3.773 0.000162 ***
## YEAR2008    -4.290e-01  6.965e-01  -0.616 0.537929
## YEAR2009     7.239e-01  6.855e-01   1.056 0.290993
## YEAR2010    -1.309e+00  7.355e-01  -1.779 0.075164 .
## YEAR2011     1.274e+00  6.734e-01   1.892 0.058534 .
## YEAR2012    -3.285e+00  8.941e-01  -3.674 0.000239 ***
## YEAR2013    -1.620e+00  7.203e-01  -2.250 0.024475 *
## YEAR2014     2.686e-01  6.845e-01   0.392 0.694700
## YEAR2015     1.433e+00  6.717e-01   2.133 0.032895 *
## YEAR2016    -3.846e+01  3.975e+06   0.000 0.999992
## YEAR2017    -5.108e-01  6.876e-01  -0.743 0.457539
## YEAR2018     1.260e+00  6.743e-01   1.869 0.061630 .
## YEAR2019    -2.079e+00  7.541e-01  -2.757 0.005829 **
## YEAR2021     3.297e-01  7.124e-01   0.463 0.643549
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##            edf Ref.df Chi.sq p-value
## s(STEMP) 4.457  5.453  201.2  <2e-16 ***
## s(SSAL)  3.193  3.945  167.3  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.0306   Deviance explained = 43.9%
## -REML = 4840.4  Scale est. = 1         n = 8083
```

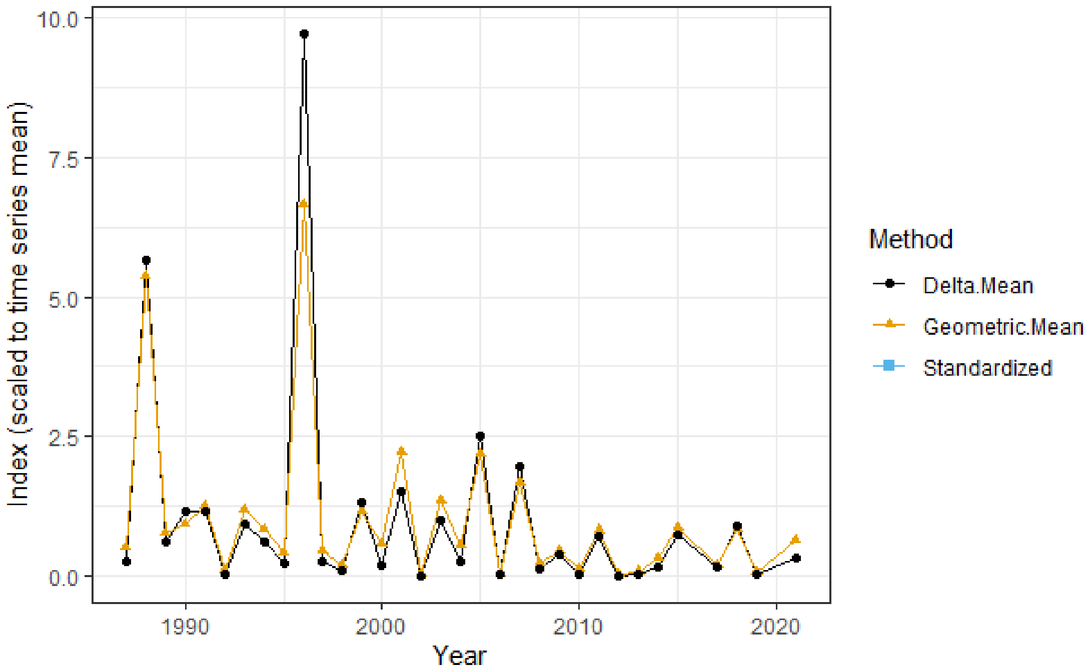
Model Diagnostics

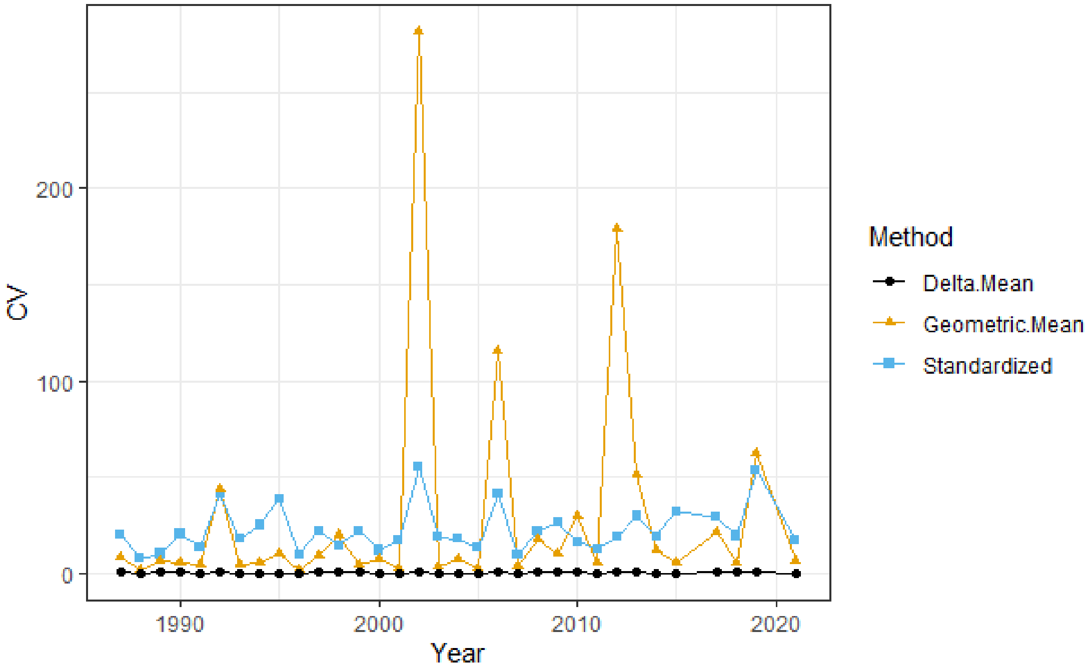
The diagnostics for the zero-altered negative binomial had some significant problems detected and quantile deviations detected.



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
10.0
7.5
5.0
2.5
0.0
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
200
100
0
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1987	0	20.20	0.138	7.90	0.313	0.49
1988	0	7.48	1.414	1.68	7.417	0.29
1989	0	10.18	0.200	6.02	0.794	0.45
1990	0	20.43	0.243	5.49	1.497	0.52
1991	0	13.75	0.329	4.11	1.497	0.30
1992	0	41.09	0.023	43.23	0.035	0.36
1993	0	17.84	0.315	4.16	1.239	0.30
1994	0	24.96	0.217	5.57	0.807	0.32
1995	0	38.71	0.109	10.00	0.270	0.34
1996	0	9.83	1.754	1.72	12.767	0.26
1997	0	22.04	0.116	9.51	0.352	0.37
1998	0	14.39	0.052	19.87	0.110	0.42
1999	0	21.81	0.306	4.47	1.739	0.38
2000	0	12.05	0.150	7.13	0.251	0.19
2001	0	17.24	0.581	2.55	1.974	0.22
2002	0	55.29	0.004	281.31	0.006	1.00
2003	0	18.66	0.357	3.73	1.322	0.23
2004	0	17.76	0.146	7.53	0.333	0.23
2005	0	13.03	0.580	2.87	3.276	0.25
2006	0	41.01	0.009	115.25	0.019	0.82
2007	0	9.60	0.438	3.48	2.585	0.29
2008	0	22.04	0.059	17.80	0.179	0.42
2009	0	26.13	0.114	9.82	0.502	0.41
2010	0	16.22	0.034	30.06	0.056	0.35
2011	0	12.73	0.215	5.70	0.937	0.31

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2012	0	18.75	0.006	178.56	0.009	0.74
2013	0	29.68	0.020	51.32	0.055	0.60
2014	0	19.25	0.086	12.34	0.223	0.33
2015	0	32.03	0.227	5.44	0.947	0.29
2017	0	28.86	0.049	21.50	0.209	0.53
2018	0	19.46	0.223	5.64	1.159	0.35
2019	0	53.65	0.016	62.31	0.028	0.51
2021	0	16.82	0.171	6.55	0.408	0.30

NJ Delaware River Seine Survey Blueback Herring Standardization

Survey Description

New Jersey has conducted a juvenile abundance survey for striped bass in the Delaware River from Trenton to Artificial Island since 1980. The program utilizes a 100-foot bagless beach seine during the months of August, September, and October at representative stations. Since river herring are not collected at all stations, those farthest downriver stations (below the Delaware Memorial Bridges) have been removed from analysis to give a more accurate picture of juvenile production in the lower Delaware River. Length frequencies of juvenile blueback herring and alewife have been determined from collections since 2002. A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest half centimeter; the remainder was enumerated.

Model Selection

The final dataset had 44.32% positive tows.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

```
ZINB.2 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

Since this is a fixed station survey, station was treated as a random effect. Treating station as a random effect did not appreciably improve the fit of the model, so that formulation was not used going forward.

```
ZINB.2.re <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+ (1|STATION),
                     ziformula = ~STATION + STEMP+SSAL+SDO,
                     data = dat,
                     family = nbinom2)
```

GAM

```
GAM.NB <- gam(FREQ~YEAR + s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC heavily favored the zero-altered negative binomial.

```
##        dAIC  df
## ZANB     0.0 75
## GAM.NB 460.1 54.4
## ZINB.2 656.8 42
## NB1    697.5 38
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, we checked various combinations of covariates for significance and selected the full model.

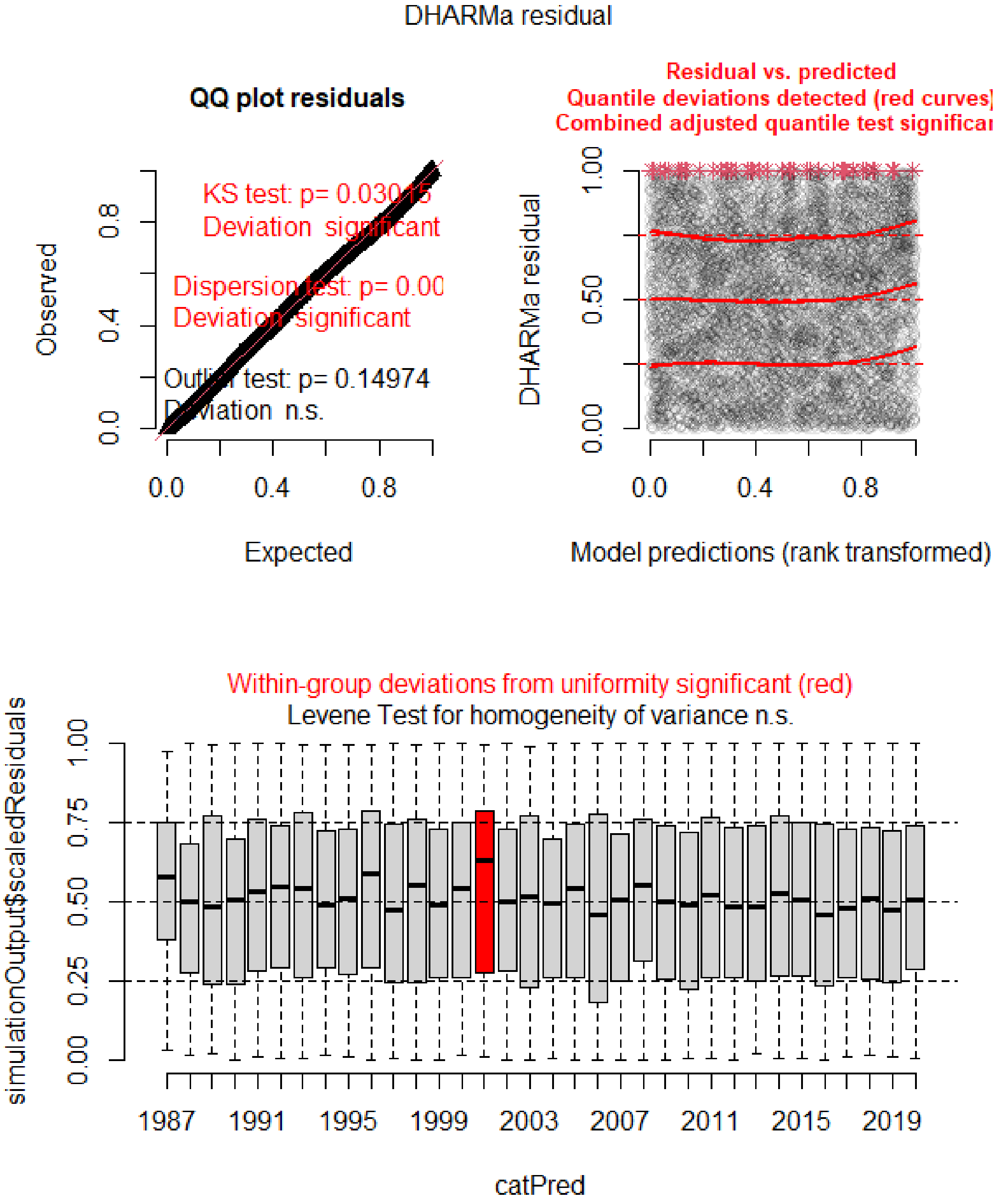
```
##  Family: truncated_nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + SSAL + SDO
## Zero inflation:        ~YEAR + STEMP + SSAL + SDO
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##  41138.0  41662.8 -20494.0  40988.0     8008
##
##
## Dispersion parameter for truncated_nbinom2 family (): 0.0351
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  2.42025    0.76291   3.172 0.001512 **
## YEAR1988     0.93209    0.57833   1.612 0.107026
## YEAR1989    -0.05950    0.56113  -0.106 0.915548
## YEAR1990    -0.97050    0.55774  -1.740 0.081848 .
## YEAR1991    -0.27086    0.50475  -0.537 0.591527
```

```
## YEAR1992    -0.77087    0.50227  -1.535 0.124837    
## YEAR1993     0.25705    0.50854   0.505 0.613231    
## YEAR1994    -1.79155    0.52015  -3.444 0.000573 ***
## YEAR1995    -1.19093    0.54754  -2.175 0.029626 *  
## YEAR1996    -0.13619    0.50234  -0.271 0.786306    
## YEAR1997    -1.55507    0.50832  -3.059 0.002219 ** 
## YEAR1998    -1.43844    0.50864  -2.828 0.004684 ** 
## YEAR1999    -0.49500    0.52442  -0.944 0.345221    
## YEAR2000    -0.19461    0.50357  -0.386 0.699148    
## YEAR2001     0.04809    0.50287   0.096 0.923806    
## YEAR2002    -1.44492    0.56814  -2.543 0.010983 *  
## YEAR2003    -1.02207    0.49674  -2.058 0.039635 *  
## YEAR2004    -0.79405    0.49768  -1.595 0.110601    
## YEAR2005    -0.48541    0.50169  -0.968 0.333270    
## YEAR2006    -4.81770    0.57739  -8.344  < 2e-16 ***
## YEAR2007    -0.45713    0.51757  -0.883 0.377114    
## YEAR2008    -1.83061    0.54343  -3.369 0.000755 ***
## YEAR2009    -1.20281    0.51360  -2.342 0.019185 *  
## YEAR2010    -1.54366    0.52531  -2.939 0.003297 ** 
## YEAR2011    -0.78418    0.49679  -1.579 0.114451    
## YEAR2012    -3.38872    0.57156  -5.929 3.05e-09 ***
## YEAR2013    -1.91658    0.52256  -3.668 0.000245 ***
## YEAR2014    -1.13425    0.50536  -2.244 0.024803 *  
## YEAR2015    -1.30598    0.51463  -2.538 0.011159 *  
## YEAR2016    -2.72488    0.54410  -5.008 5.50e-07 ***
## YEAR2017    -1.88265    0.52362  -3.595 0.000324 ***
## YEAR2018    -1.69487    0.50815  -3.335 0.000852 ***
## YEAR2019    -2.20118    0.53698  -4.099 4.15e-05 ***
## YEAR2021    -1.48081    0.53663  -2.759 0.005790 ** 
## STEMP        0.02127    0.01094   1.944 0.051889 .  
## SSAL        -0.33331    0.03284 -10.148  < 2e-16 ***
## SDO          0.06538    0.04665   1.401 0.161094    
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 
## 
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)    
## (Intercept) -2.354605   0.399962  -5.887 3.93e-09 ***
## YEAR1988     0.077129   0.329296   0.234 0.814811    
## YEAR1989     0.357573   0.326140   1.096 0.272913    
## YEAR1990     0.469691   0.324385   1.448 0.147633    
## YEAR1991    -0.210208   0.302221  -0.696 0.486715    
## YEAR1992     0.066758   0.300541   0.222 0.824216    
## YEAR1993    -0.646202   0.317099  -2.038 0.041565 *  
## YEAR1994     0.560694   0.306193   1.831 0.067074 .  
## YEAR1995     0.872238   0.312395   2.792 0.005237 ** 
## YEAR1996    -0.856196   0.319244  -2.682 0.007319 ** 
## YEAR1997    -0.300746   0.309239  -0.973 0.330784    
## YEAR1998    -0.252123   0.310604  -0.812 0.416953    
## YEAR1999    -0.121867   0.312729  -0.390 0.696767
```

```
## YEAR2000    -0.444761   0.308619  -1.441 0.149546    
## YEAR2001    -1.020529   0.315824  -3.231 0.001232 ** 
## YEAR2002     1.860923   0.310574   5.992 2.07e-09 ***
## YEAR2003     0.334770   0.293406   1.141 0.253879    
## YEAR2004     0.207633   0.296067   0.701 0.483113    
## YEAR2005     0.113995   0.294651   0.387 0.698845    
## YEAR2006     2.576135   0.330802   7.788 6.83e-15 ***
## YEAR2007     0.332330   0.296496   1.121 0.262348    
## YEAR2008     1.487376   0.306344   4.855 1.20e-06 ***
## YEAR2009     0.844819   0.297675   2.838 0.004539 ** 
## YEAR2010     1.053817   0.302740   3.481 0.000500 ***
## YEAR2011    -0.060831   0.297997  -0.204 0.838249    
## YEAR2012     2.365216   0.320659   7.376 1.63e-13 ***
## YEAR2013     1.359774   0.298827   4.550 5.36e-06 ***
## YEAR2014     0.090221   0.297874   0.303 0.761978    
## YEAR2015     0.653538   0.295907   2.209 0.027203 *  
## YEAR2016     1.509961   0.308139   4.900 9.57e-07 ***
## YEAR2017     1.098084   0.299523   3.666 0.000246 ***
## YEAR2018     0.695246   0.296251   2.347 0.018935 *  
## YEAR2019     1.277608   0.302744   4.220 2.44e-05 ***
## YEAR2021     0.619759   0.313139   1.979 0.047796 *  
## STEMP        0.044878   0.006019   7.456 8.95e-14 ***
## SSAL         0.358791   0.019266  18.623  < 2e-16 ***
## SDO          0.108288   0.025475   4.251 2.13e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model Diagnostics

The diagnostics for the zero-altered negative binomial had some significant problems detected and quantile deviations detected.

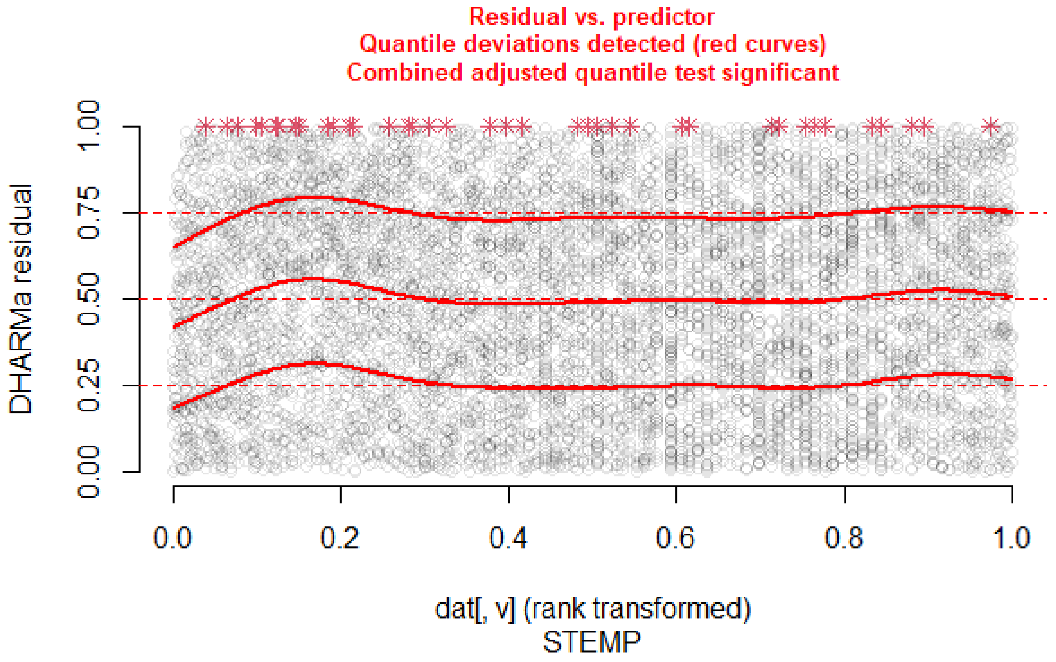


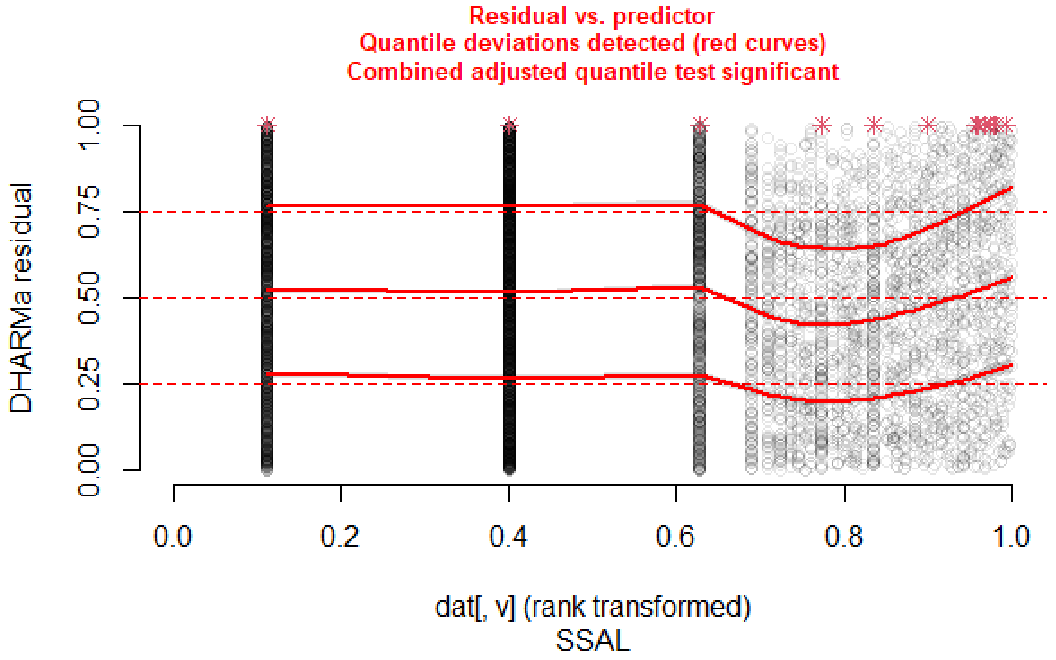
DHARMa residual

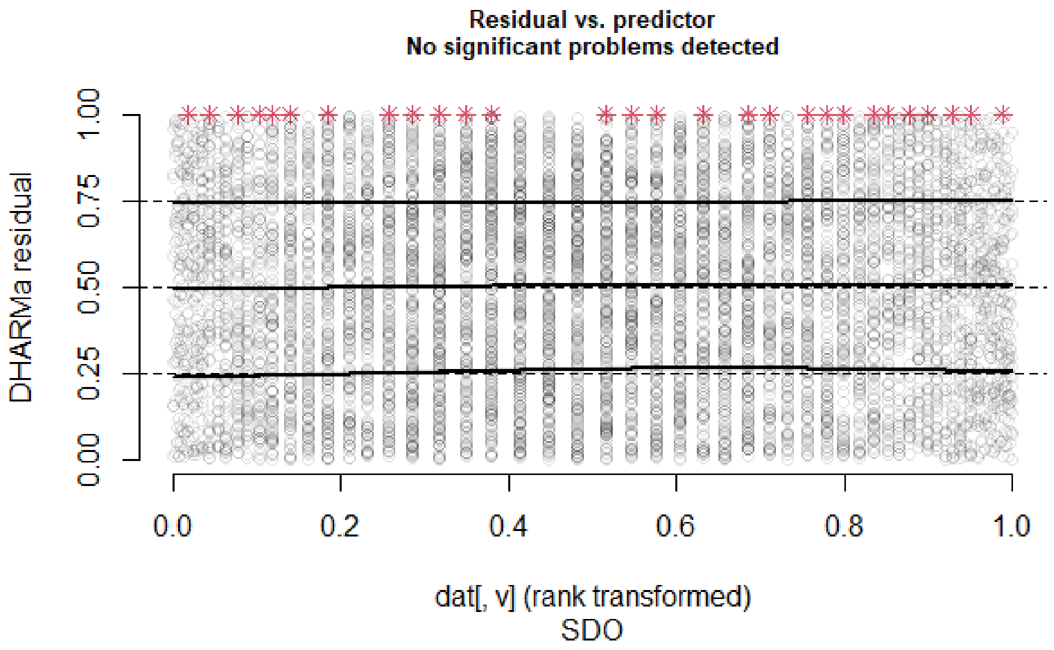
QQ plot residuals

Residual vs. predicted
Quantile deviations detected (red curves
Combined adjusted quantile test significa

Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.

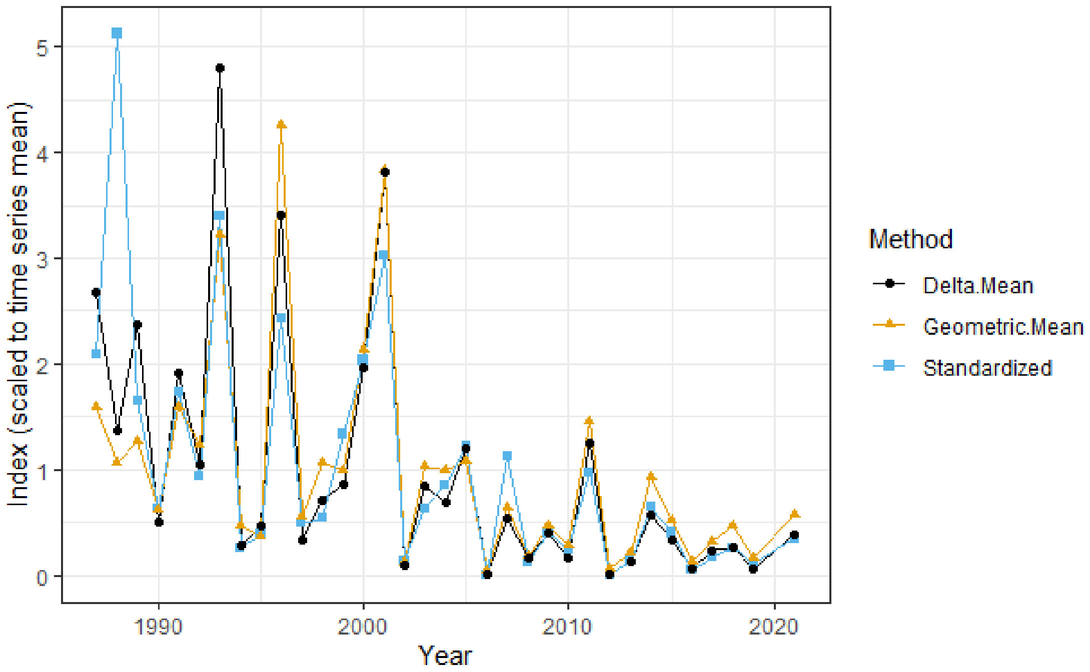

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant

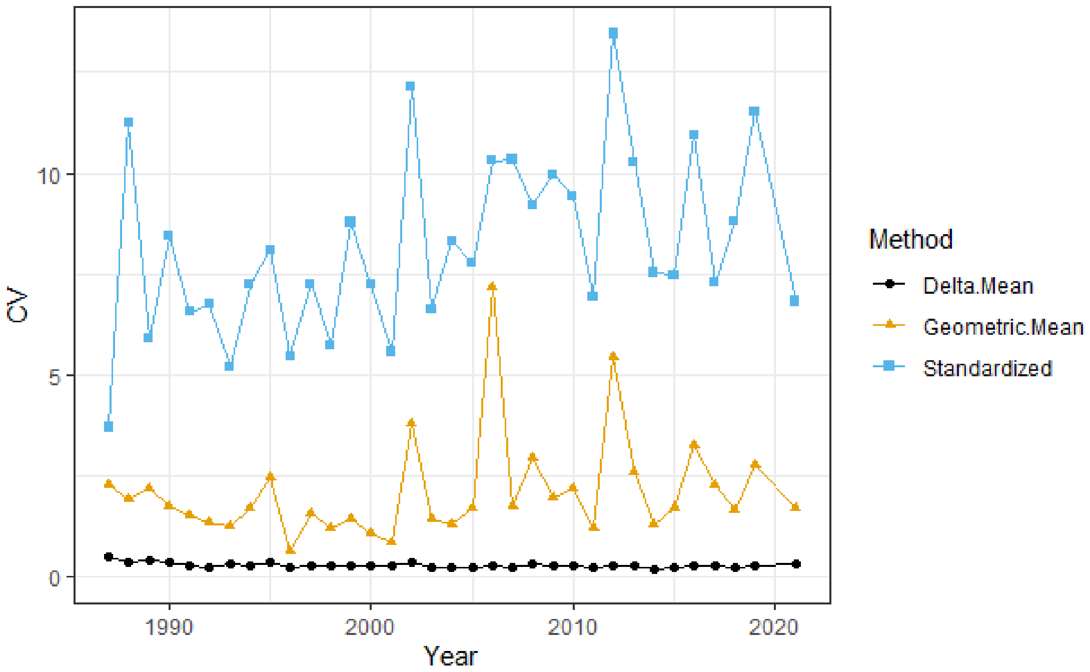

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
0
1
2
3
4
5
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
5
10
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1987	11.756	3.69	5.630	2.25	106.176	0.48
1988	28.854	11.24	3.753	1.89	54.073	0.37
1989	9.335	5.91	4.494	2.16	94.009	0.41
1990	3.534	8.43	2.216	1.73	20.059	0.34
1991	9.771	6.56	5.633	1.51	75.936	0.25
1992	5.280	6.74	4.360	1.33	41.391	0.23
1993	19.162	5.20	11.402	1.24	189.942	0.29
1994	1.477	7.22	1.692	1.69	11.531	0.26
1995	2.227	8.09	1.337	2.45	18.743	0.36
1996	13.675	5.46	15.098	0.63	134.978	0.23
1997	2.798	7.25	1.992	1.54	13.115	0.25
1998	3.089	5.73	3.756	1.19	28.304	0.25
1999	7.542	8.78	3.521	1.44	34.477	0.28
2000	11.464	7.23	7.555	1.05	77.806	0.25
2001	17.078	5.57	13.561	0.82	150.958	0.25
2002	0.826	12.14	0.440	3.77	4.254	0.34
2003	3.608	6.62	3.668	1.40	33.271	0.21
2004	4.830	8.32	3.538	1.27	27.415	0.21
2005	6.875	7.77	3.857	1.67	47.380	0.23
2006	0.015	10.30	0.155	7.16	0.366	0.24
2007	6.355	10.34	2.293	1.72	21.501	0.23
2008	0.758	9.20	0.669	2.94	6.357	0.32
2009	2.240	9.97	1.658	1.97	15.992	0.26
2010	1.386	9.41	1.027	2.17	6.866	0.25
2011	5.508	6.94	5.180	1.19	49.455	0.22

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2012	0.076	13.46	0.224	5.43	0.840	0.26
2013	0.766	10.27	0.747	2.57	4.981	0.25
2014	3.633	7.53	3.283	1.29	22.899	0.19
2015	2.274	7.47	1.866	1.71	13.285	0.20
2016	0.304	10.95	0.470	3.25	2.526	0.26
2017	0.958	7.28	1.108	2.25	9.580	0.26
2018	1.503	8.81	1.673	1.65	10.356	0.21
2019	0.613	11.53	0.592	2.74	2.875	0.24
2021	1.948	6.81	2.007	1.67	15.473	0.29

NJ Ocean Trawl Alewife Survey Standardization

Survey Description

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay five times a year (January, April, June, August and October). There are 15 strata with five strata assigned to three different depth regimes; inshore (3 to 5 fathoms), mid-shore (5 to 10 fathoms), and off-shore (10 to 15 fathoms). Station allocation and location is random and stratified by strata size.

The survey net is a two-seam trawl with forward netting of 4.7 inch stretch mesh and rear netting of 3.1 inches stretch mesh. The codend is 3.0 inches stretch mesh and is lined with a 0.25 inch bar mesh liner. Each trawl is 20 minutes long and at the end of each tow, the total weight of each species is measured in kg and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm. A series of water quality parameters, such as surface and bottom salinity, temperature and dissolved oxygen, are also recorded at the start of each tow. New Jersey began collecting otoliths and other biological data in 2009 to develop age at length keys for both species. Processing and aging of these samples will be completed as funding becomes available.

Subsetting

Months were subset to January and April since those are the months where the most River Herring are encountered.

Model Selection

The final dataset had 62.91% positive tows.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STRATUM+STEMP+SSAL+SDO,
```

```
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial encountered convergence problems. Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STRATUM+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~STRATUM+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

GAM

Full model:

```
GAM.NB <- gam(FREQ~YEAR + STRATUM + s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-altered negative binomial.

```
##         dAIC  df
## ZANB      0.0 99
## GAM.NB 188.8 60.6
## NB1    239.4 50
## ZINB      NA 99
## ZINB.2    NA 68
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

```
##  Family: truncated_nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STRATUM + SDO
## Zero inflation:        ~YEAR + STRATUM + SSAL + SDO
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##  12702.7  13242.9  -6255.4  12510.7     1956
##
##
## Dispersion parameter for truncated_nbinom2 family (): 0.0645
##
## Conditional model:
```

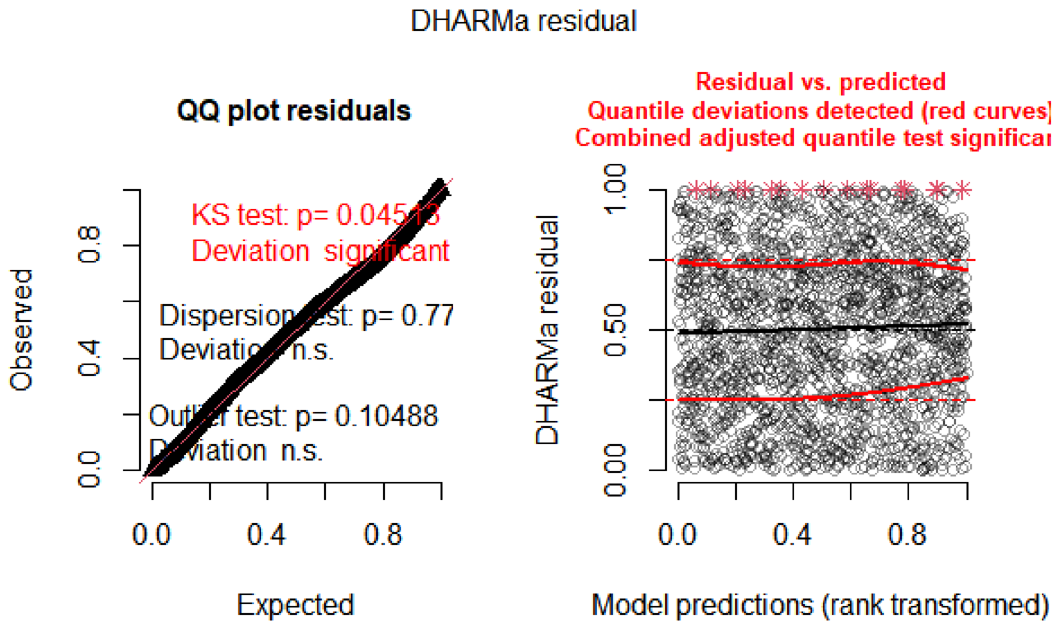
```
##             Estimate Std. Error z value Pr(>|z|)    
## (Intercept)  8.54256    1.40824   6.066 1.31e-09 ***
## YEAR1990    -1.01409    0.72388  -1.401 0.161241    
## YEAR1991    -0.62641    0.69720  -0.898 0.368937    
## YEAR1992    -1.62309    0.65248  -2.488 0.012862 *  
## YEAR1993    -0.51200    0.65762  -0.779 0.436236    
## YEAR1994    -1.39056    0.67198  -2.069 0.038513 *  
## YEAR1995    -1.03359    0.71192  -1.452 0.146549    
## YEAR1996     0.01883    0.70490   0.027 0.978694    
## YEAR1997     0.63116    0.70424   0.896 0.370134    
## YEAR1998     1.37092    0.68143   2.012 0.044238 *  
## YEAR1999     0.25982    0.66740   0.389 0.697053    
## YEAR2000     0.75210    0.77011   0.977 0.328762    
## YEAR2001    -1.26696    0.70462  -1.798 0.072166 .  
## YEAR2002     0.68829    0.79716   0.863 0.387904    
## YEAR2003    -0.79081    0.66856  -1.183 0.236866    
## YEAR2004     0.63983    0.70785   0.904 0.366045    
## YEAR2005    -0.19408    0.69390  -0.280 0.779708    
## YEAR2006    -1.78613    0.67428  -2.649 0.008074 ** 
## YEAR2007     0.09435    0.70905   0.133 0.894137    
## YEAR2008     0.36417    0.67953   0.536 0.592020    
## YEAR2009    -0.90734    0.67767  -1.339 0.180602    
## YEAR2010    -2.17404    0.79744  -2.726 0.006405 ** 
## YEAR2011    -1.19406    0.68571  -1.741 0.081623 .  
## YEAR2012    -0.24556    0.69087  -0.355 0.722265    
## YEAR2013    -1.26450    0.69365  -1.823 0.068310 .  
## YEAR2014    -1.78232    0.68200  -2.613 0.008965 ** 
## YEAR2015    -0.33355    0.71171  -0.469 0.639315    
## YEAR2016     0.07217    0.71729   0.101 0.919860    
## YEAR2017    -1.49039    0.80825  -1.844 0.065188 .  
## YEAR2018    -1.51676    0.70511  -2.151 0.031470 *  
## YEAR2019    -0.18851    0.86722  -0.217 0.827917    
## YEAR2020    -0.79804    0.80000  -0.998 0.318494    
## STRATUM13    1.51840    0.39527   3.841 0.000122 ***
## STRATUM14    0.17392    0.37820   0.460 0.645618    
## STRATUM15   -0.94414    0.35526  -2.658 0.007869 ** 
## STRATUM16   -0.33768    0.35765  -0.944 0.345083    
## STRATUM17   -1.40853    0.38353  -3.673 0.000240 ***
## STRATUM18   -1.83110    0.36061  -5.078 3.82e-07 ***
## STRATUM19   -1.26674    0.36034  -3.515 0.000439 ***
## STRATUM20   -2.10680    0.37189  -5.665 1.47e-08 ***
## STRATUM21   -1.03952    0.43526  -2.388 0.016927 *  
## STRATUM22   -0.76537    0.39781  -1.924 0.054361 .  
## STRATUM23   -2.55015    0.39899  -6.392 1.64e-10 ***
## STRATUM24   -1.55675    0.37333  -4.170 3.05e-05 ***
## STRATUM25   -1.52927    0.38698  -3.952 7.76e-05 ***
## STRATUM26   -0.49847    0.40668  -1.226 0.220312    
## SDO         -0.52023    0.10049  -5.177 2.25e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

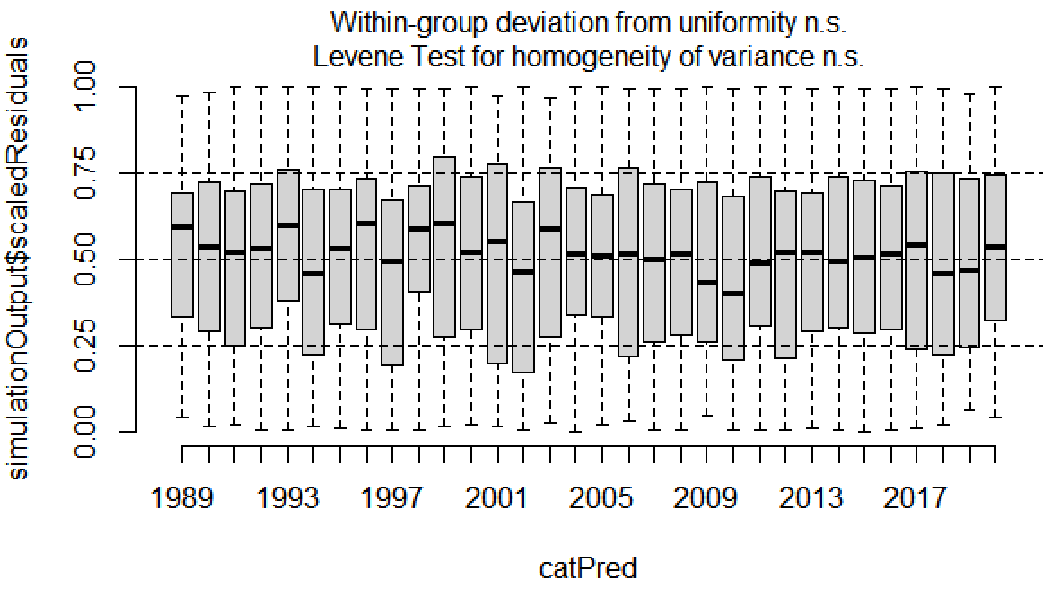
```
##
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)    
## (Intercept) -8.792625   1.540277  -5.708 1.14e-08 ***
## YEAR1990     0.631118   0.496054   1.272 0.203275    
## YEAR1991    -0.931280   0.513983  -1.812 0.070003 .  
## YEAR1992    -0.925147   0.500355  -1.849 0.064461 .  
## YEAR1993    -0.900358   0.518805  -1.735 0.082662 .  
## YEAR1994    -0.904141   0.506049  -1.787 0.073991 .  
## YEAR1995    -0.516772   0.513773  -1.006 0.314495    
## YEAR1996    -0.786573   0.506729  -1.552 0.120601    
## YEAR1997     0.037383   0.479504   0.078 0.937859    
## YEAR1998    -2.313705   0.663057  -3.489 0.000484 ***
## YEAR1999    -1.600729   0.558546  -2.866 0.004158 ** 
## YEAR2000     0.803923   0.491851   1.634 0.102157    
## YEAR2001     0.815224   0.481117   1.694 0.090181 .  
## YEAR2002     0.558316   0.491477   1.136 0.255958    
## YEAR2003    -0.780226   0.497621  -1.568 0.116902    
## YEAR2004    -0.086411   0.482870  -0.179 0.857975    
## YEAR2005     0.307484   0.487867   0.630 0.528524    
## YEAR2006     0.213635   0.496115   0.431 0.666748    
## YEAR2007     0.257653   0.491601   0.524 0.600202    
## YEAR2008    -0.104702   0.490473  -0.213 0.830959    
## YEAR2009    -1.018589   0.528013  -1.929 0.053719 .  
## YEAR2010     1.921169   0.507480   3.786 0.000153 ***
## YEAR2011     0.245293   0.480644   0.510 0.609812    
## YEAR2012     0.005404   0.483134   0.011 0.991076    
## YEAR2013     0.016612   0.485190   0.034 0.972687    
## YEAR2014    -0.156519   0.480614  -0.326 0.744679    
## YEAR2015     0.536758   0.488798   1.098 0.272153    
## YEAR2016     0.104010   0.491763   0.212 0.832493    
## YEAR2017     0.964031   0.541683   1.780 0.075126 .  
## YEAR2018     0.564860   0.478520   1.180 0.237829    
## YEAR2019     0.689189   0.561043   1.228 0.219294    
## YEAR2020     0.076512   0.565368   0.135 0.892350    
## STRATUM13   -0.573426   0.326109  -1.758 0.078681 .  
## STRATUM14   -0.645377   0.323340  -1.996 0.045937 *  
## STRATUM15   -0.364765   0.298365  -1.223 0.221501    
## STRATUM16   -0.215513   0.297666  -0.724 0.469060    
## STRATUM17    0.286059   0.299664   0.955 0.339781    
## STRATUM18   -0.350582   0.306627  -1.143 0.252893    
## STRATUM19   -0.004235   0.300145  -0.014 0.988742    
## STRATUM20    0.542294   0.303491   1.787 0.073962 .  
## STRATUM21   -0.066390   0.316328  -0.210 0.833764    
## STRATUM22    0.654295   0.302600   2.162 0.030600 *  
## STRATUM23    1.145933   0.310993   3.685 0.000229 ***
## STRATUM24   -0.559559   0.327328  -1.709 0.087363 .  
## STRATUM25    0.670988   0.297968   2.252 0.024330 *  
## STRATUM26    0.432329   0.313117   1.381 0.167364    
## SSAL         0.162554   0.034022   4.778 1.77e-06 ***
```

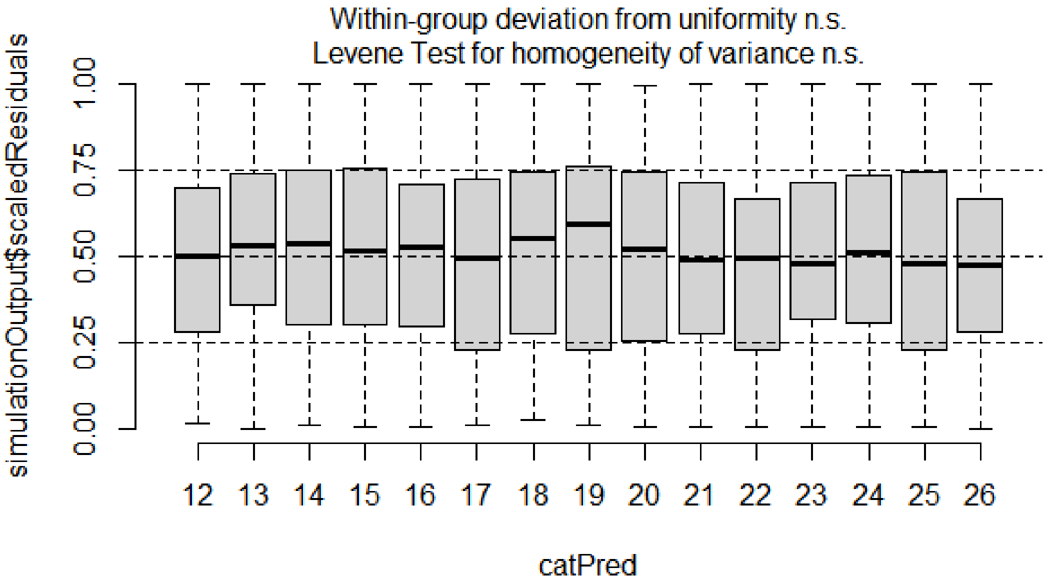
```
## SDO          0.316833   0.076070   4.165 3.11e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

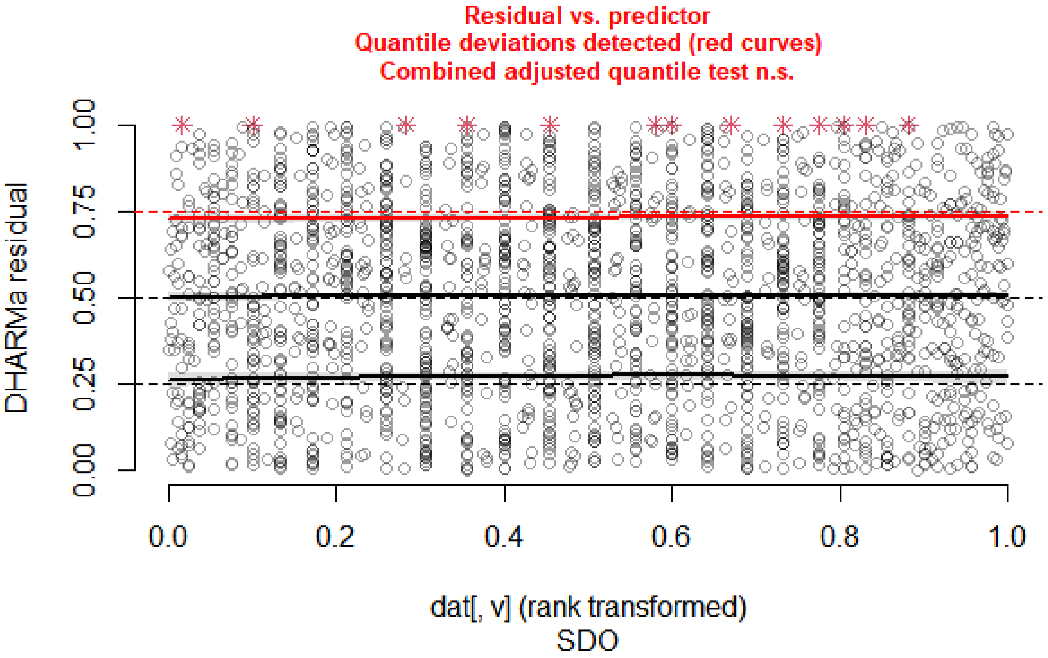
Model Diagnostics

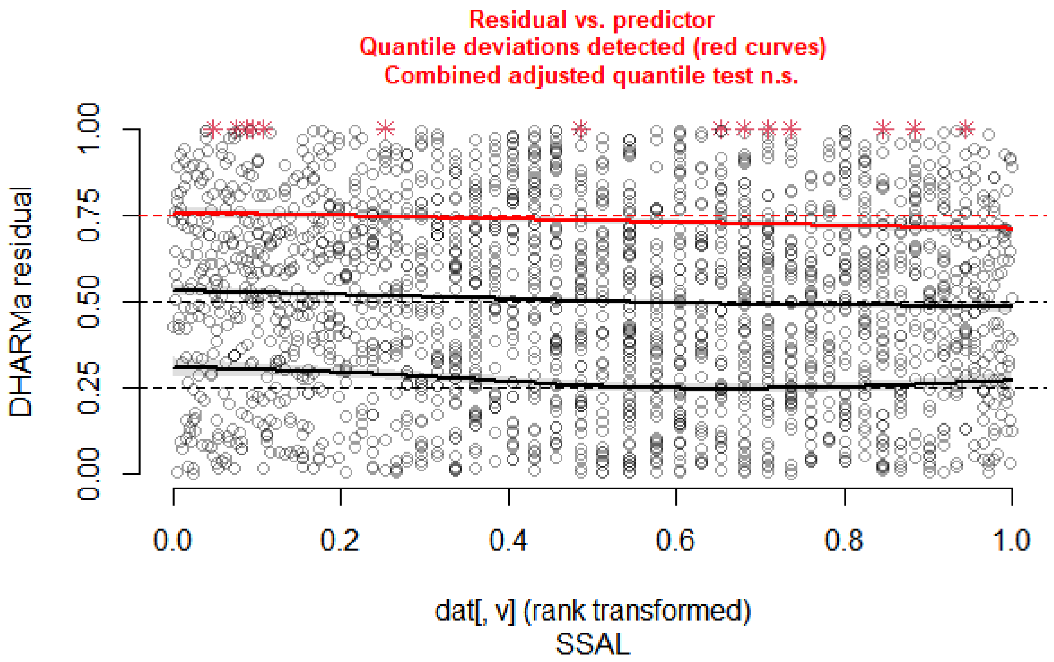
The diagnostics for the zero-altered negative binomial had some quantile deviations detected.





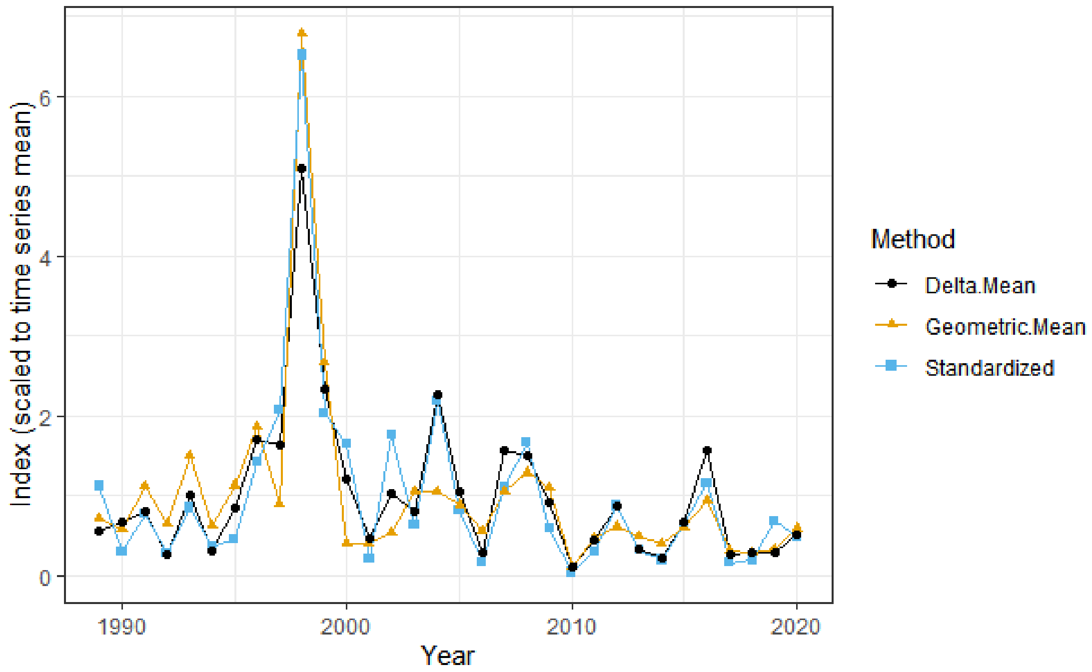

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
catPred

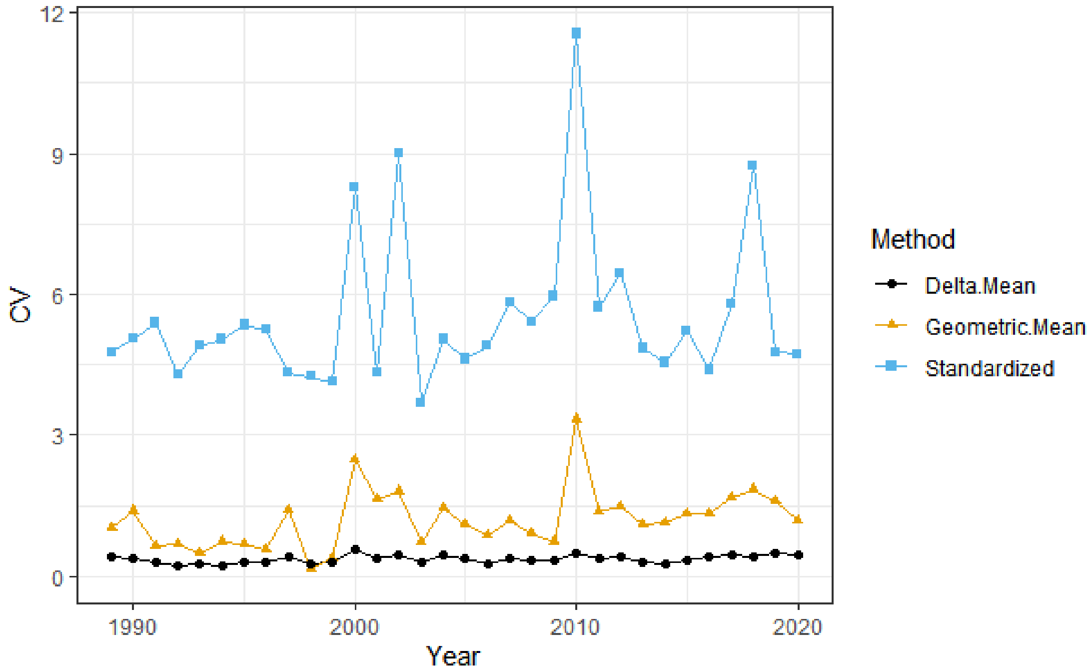

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test n.s.
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
SDO



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
0
2
4
6
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
3
6
9
12
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1989	7.175	4.76	3.140	1.03	13.424	0.42
1990	1.979	5.05	2.568	1.39	16.173	0.39
1991	4.899	5.39	5.006	0.64	19.444	0.30
1992	1.806	4.29	2.852	0.67	6.595	0.21
1993	5.462	4.91	6.633	0.50	24.250	0.27
1994	2.271	5.04	2.820	0.74	7.345	0.24
1995	2.984	5.35	5.012	0.68	20.340	0.29
1996	9.085	5.25	8.227	0.57	40.981	0.30
1997	13.305	4.33	3.974	1.42	38.957	0.43
1998	41.751	4.25	30.075	0.14	121.798	0.28
1999	13.034	4.13	11.852	0.37	55.964	0.32
2000	10.551	8.28	1.760	2.47	28.793	0.55
2001	1.392	4.33	1.791	1.63	11.237	0.39
2002	11.261	9.00	2.390	1.81	24.387	0.45
2003	4.038	3.70	4.689	0.71	19.304	0.30
2004	14.021	5.04	4.671	1.45	54.328	0.45
2005	5.234	4.62	3.923	1.11	25.319	0.36
2006	1.108	4.91	2.443	0.87	6.966	0.25
2007	7.133	5.83	4.628	1.18	37.569	0.39
2008	10.709	5.42	5.715	0.90	35.755	0.34
2009	3.756	5.96	4.890	0.74	22.073	0.33
2010	0.264	11.55	0.479	3.34	2.590	0.50
2011	1.977	5.73	2.056	1.38	10.922	0.38
2012	5.602	6.44	2.728	1.49	21.090	0.42
2013	2.014	4.85	2.202	1.12	8.217	0.29

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2014	1.273	4.55	1.802	1.15	5.564	0.28
2015	4.096	5.23	2.696	1.32	16.045	0.35
2016	7.420	4.39	4.141	1.35	37.374	0.41
2017	1.022	5.80	1.386	1.69	6.614	0.45
2018	1.237	8.75	1.275	1.85	6.876	0.40
2019	4.383	4.76	1.525	1.60	7.137	0.49
2020	3.141	4.72	2.627	1.17	12.123	0.45

NJ Ocean Trawl Blueback Herring Survey Standardization

Survey Description

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay five times a year (January, April, June, August and October). There are 15 strata with five strata assigned to three different depth regimes; inshore (3 to 5 fathoms), mid-shore (5 to 10 fathoms), and off-shore (10 to 15 fathoms). Station allocation and location is random and stratified by strata size.

The survey net is a two-seam trawl with forward netting of 4.7 inch stretch mesh and rear netting of 3.1 inches stretch mesh. The codend is 3.0 inches stretch mesh and is lined with a 0.25 inch bar mesh liner. Each trawl is 20 minutes long and at the end of each tow, the total weight of each species is measured in kg and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm. A series of water quality parameters, such as surface and bottom salinity, temperature and dissolved oxygen, are also recorded at the start of each tow. New Jersey began collecting otoliths and other biological data in 2009 to develop age at length keys for both species. Processing and aging of these samples will be completed as funding becomes available.

Subsetting

Months were subset to January and April since those are the months where the most River Herring are encountered.

Model Selection

The final dataset had 62.91% positive tows.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STRATUM+STEMP+SSAL+SDO,
```

```
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial encountered convergence problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STRATUM+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STRATUM + STEMP + SSAL + SDO,
                ziformula = ~STRATUM+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

GAM

CPUE is not linear with regard to some environmental predictors such as temperature, so a general additive model was run.

Full model:

```
GAM.NB <- gam(FREQ~YEAR + STRATUM + s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-altered negative binomial.

```
##         dAIC  df
## ZANB      0.0 99
## GAM.NB   86.5 64.1
## NB1     151.8 50
## ZINB       NA 99
## ZINB.2     NA 68
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

```
##  Family: truncated_nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STRATUM + STEMP + SDO
## Zero inflation:        ~YEAR + STRATUM + STEMP
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##  13414.6  13954.7  -6611.3  13222.6     1956
##
```

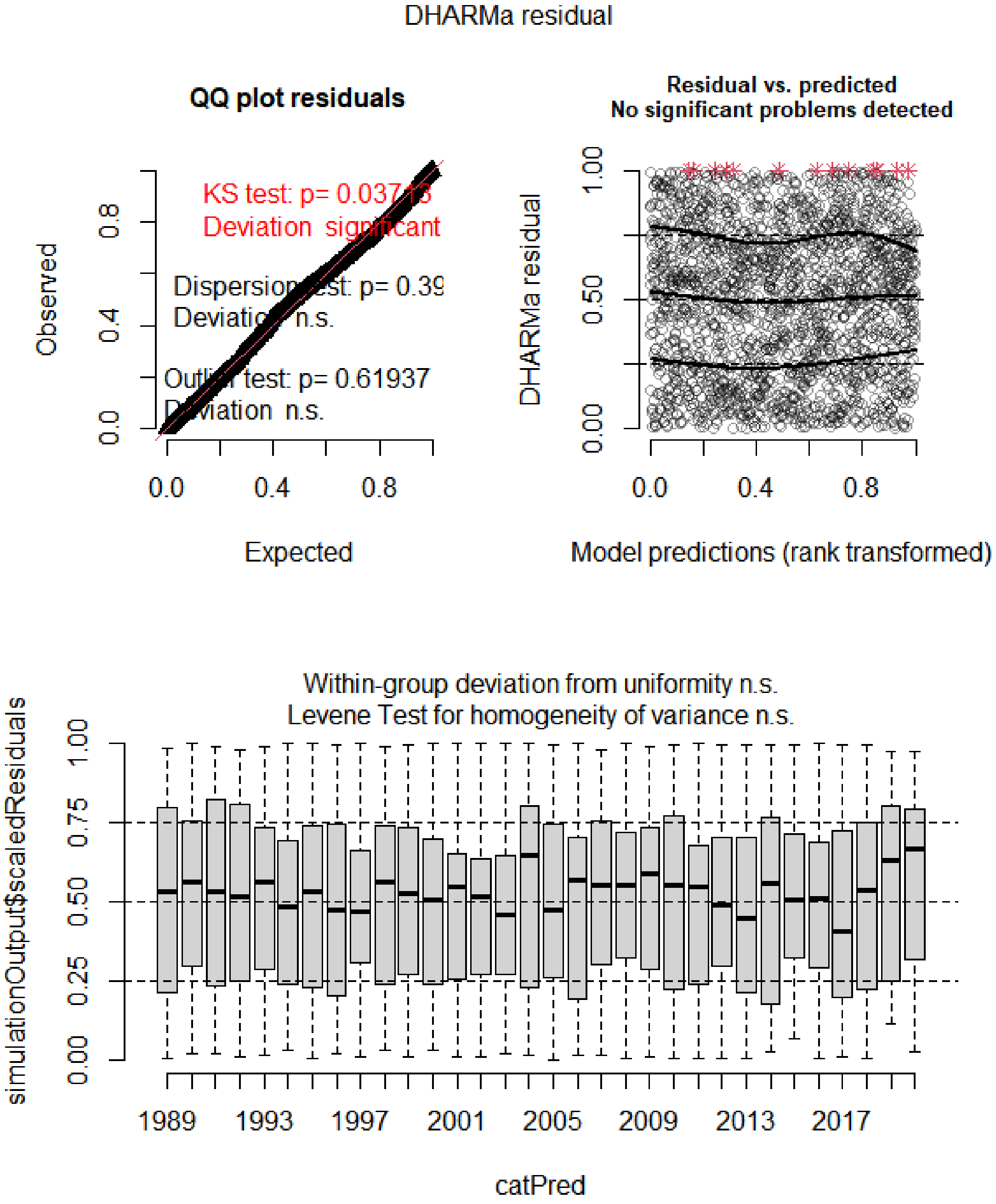
```
##
## Dispersion parameter for truncated_nbinom2 family (): 0.00592
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  3.698456   3.767620   0.982  0.32628
## YEAR1990    -0.115799   0.836943  -0.138  0.88996
## YEAR1991    -0.056558   0.777730  -0.073  0.94203
## YEAR1992     0.343780   0.777815   0.442  0.65850
## YEAR1993    -0.705852   0.758976  -0.930  0.35237
## YEAR1994     0.288096   0.804279   0.358  0.72019
## YEAR1995    -0.009788   0.843944  -0.012  0.99075
## YEAR1996    -0.760118   0.827375  -0.919  0.35825
## YEAR1997     2.376860   0.835133   2.846  0.00443 **
## YEAR1998     0.172747   0.767995   0.225  0.82203
## YEAR1999    -0.176137   0.770612  -0.229  0.81921
## YEAR2000    -0.718994   0.816117  -0.881  0.37832
## YEAR2001    -0.778970   0.792160  -0.983  0.32544
## YEAR2002     2.283054   0.895650   2.549  0.01080 *
## YEAR2003     0.447523   0.795652   0.562  0.57380
## YEAR2004     0.410673   0.842409   0.488  0.62591
## YEAR2005     0.140102   0.781893   0.179  0.85779
## YEAR2006     0.690659   0.816686   0.846  0.39773
## YEAR2007     0.797151   0.806538   0.988  0.32298
## YEAR2008     1.363920   0.748575   1.822  0.06845 .
## YEAR2009     0.473136   0.820340   0.577  0.56410
## YEAR2010    -0.664118   0.833350  -0.797  0.42549
## YEAR2011    -0.066473   0.792728  -0.084  0.93317
## YEAR2012     0.554704   0.759729   0.730  0.46531
## YEAR2013     1.054376   0.778562   1.354  0.17565
## YEAR2014    -0.350075   0.769111  -0.455  0.64899
## YEAR2015     1.088183   0.818951   1.329  0.18393
## YEAR2016     1.146582   0.849621   1.349  0.17717
## YEAR2017     1.481417   1.018741   1.454  0.14590
## YEAR2018     0.419993   0.786814   0.534  0.59349
## YEAR2019    -0.103618   0.869150  -0.119  0.90510
## YEAR2020     0.953553   0.891535   1.070  0.28482
## STRATUM13    0.516613   0.466738   1.107  0.26835
## STRATUM14   -0.107909   0.459015  -0.235  0.81414
## STRATUM15   -0.958912   0.410347  -2.337  0.01945 *
## STRATUM16   -0.265256   0.442940  -0.599  0.54927
## STRATUM17   -0.272555   0.451165  -0.604  0.54577
## STRATUM18   -0.642292   0.458737  -1.400  0.16147
## STRATUM19   -0.277660   0.440366  -0.630  0.52835
## STRATUM20   -0.595322   0.430653  -1.382  0.16686
## STRATUM21   -1.202218   0.461218  -2.607  0.00914 **
## STRATUM22    0.227695   0.443065   0.514  0.60732
## STRATUM23   -0.998906   0.433901  -2.302  0.02133 *
## STRATUM24   -1.113203   0.455327  -2.445  0.01449 *
## STRATUM25    0.110079   0.437081   0.252  0.80116
```

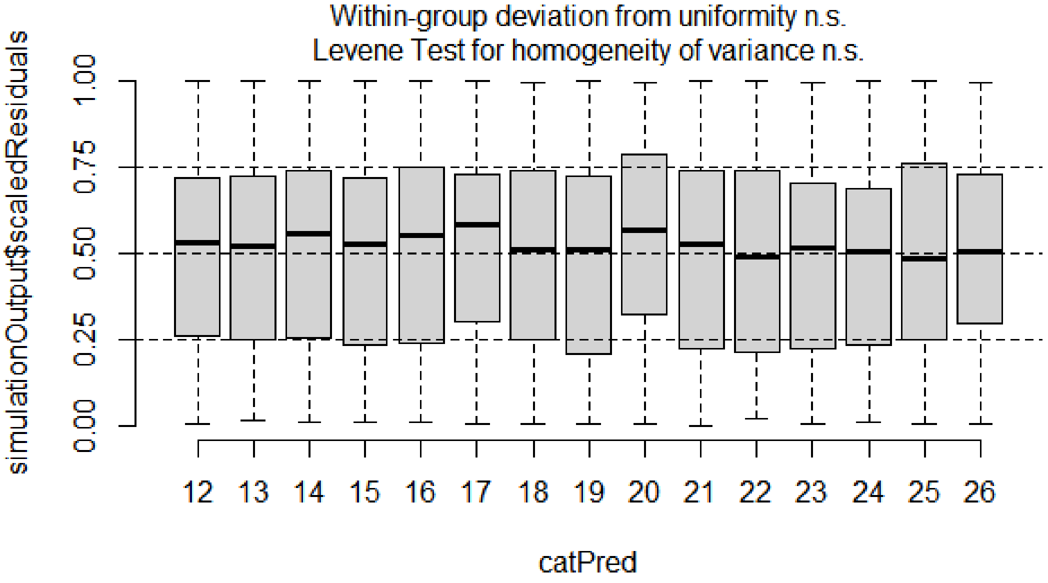
```
## STRATUM26    0.153075   0.497521   0.308  0.75833  
## STEMP       -0.109202   0.042399  -2.575  0.01001 *
## SDO         -0.278980   0.140535  -1.985  0.04713 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)   
## (Intercept) -1.501170   0.460157  -3.262  0.00111 **
## YEAR1990     0.382069   0.463424   0.824  0.40969   
## YEAR1991     0.134586   0.462119   0.291  0.77087   
## YEAR1992    -0.067188   0.461265  -0.146  0.88419   
## YEAR1993    -0.383061   0.475919  -0.805  0.42089   
## YEAR1994    -0.623563   0.494202  -1.262  0.20704   
## YEAR1995    -0.079056   0.458169  -0.173  0.86301   
## YEAR1996     0.118168   0.461964   0.256  0.79811   
## YEAR1997     0.163672   0.457220   0.358  0.72036   
## YEAR1998    -0.018190   0.456511  -0.040  0.96822   
## YEAR1999    -0.308701   0.469784  -0.657  0.51111   
## YEAR2000    -0.117978   0.467130  -0.253  0.80061   
## YEAR2001     0.169171   0.462584   0.366  0.71458   
## YEAR2002     0.207873   0.453449   0.458  0.64665   
## YEAR2003    -0.577974   0.481550  -1.200  0.23005   
## YEAR2004     0.441765   0.462954   0.954  0.33997   
## YEAR2005    -0.479994   0.474900  -1.011  0.31215   
## YEAR2006    -0.612152   0.470630  -1.301  0.19336   
## YEAR2007    -0.234434   0.459710  -0.510  0.61008   
## YEAR2008    -0.823033   0.479880  -1.715  0.08633 . 
## YEAR2009    -0.335564   0.468984  -0.716  0.47429   
## YEAR2010     0.869651   0.459157   1.894  0.05822 . 
## YEAR2011     0.525898   0.461341   1.140  0.25431   
## YEAR2012    -0.526480   0.470239  -1.120  0.26288   
## YEAR2013    -0.099551   0.462016  -0.215  0.82940   
## YEAR2014    -0.145713   0.470416  -0.310  0.75675   
## YEAR2015     0.086482   0.461623   0.187  0.85139   
## YEAR2016     0.369060   0.453813   0.813  0.41608   
## YEAR2017     1.025061   0.510976   2.006  0.04485 * 
## YEAR2018     0.424219   0.460629   0.921  0.35707   
## YEAR2019     0.006457   0.551038   0.012  0.99065   
## YEAR2020    -0.481685   0.567174  -0.849  0.39573   
## STRATUM13   -0.323120   0.292641  -1.104  0.26953   
## STRATUM14   -0.252582   0.289143  -0.874  0.38236   
## STRATUM15   -0.242729   0.272901  -0.889  0.37377   
## STRATUM16    0.103055   0.266577   0.387  0.69906   
## STRATUM17    0.468223   0.261746   1.789  0.07364 . 
## STRATUM18    0.314236   0.265368   1.184  0.23635   
## STRATUM19    0.097880   0.266800   0.367  0.71372   
## STRATUM20    0.299839   0.264368   1.134  0.25672   
## STRATUM21    0.014617   0.283108   0.052  0.95882   
## STRATUM22    0.334008   0.264340   1.264  0.20639   
```

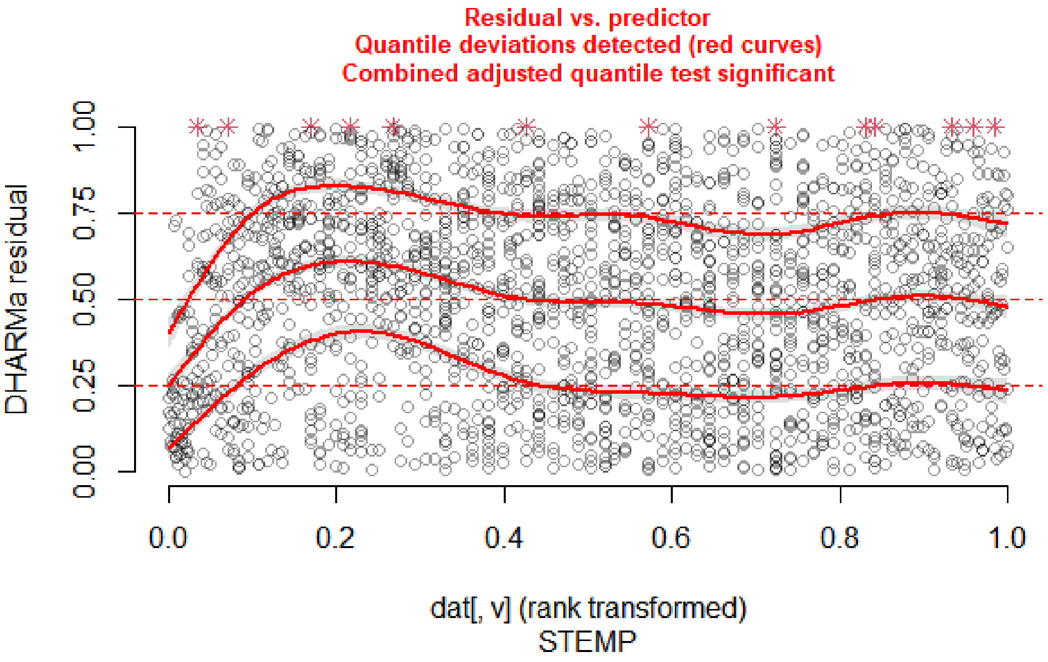
```
## STRATUM23    0.618923   0.261206   2.369  0.01781 *
## STRATUM24   -0.012503   0.285790  -0.044  0.96510
## STRATUM25    0.298240   0.263856   1.130  0.25834
## STRATUM26    0.690909   0.272897   2.532  0.01135 *
## STEMP        0.105603   0.019661   5.371 7.82e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

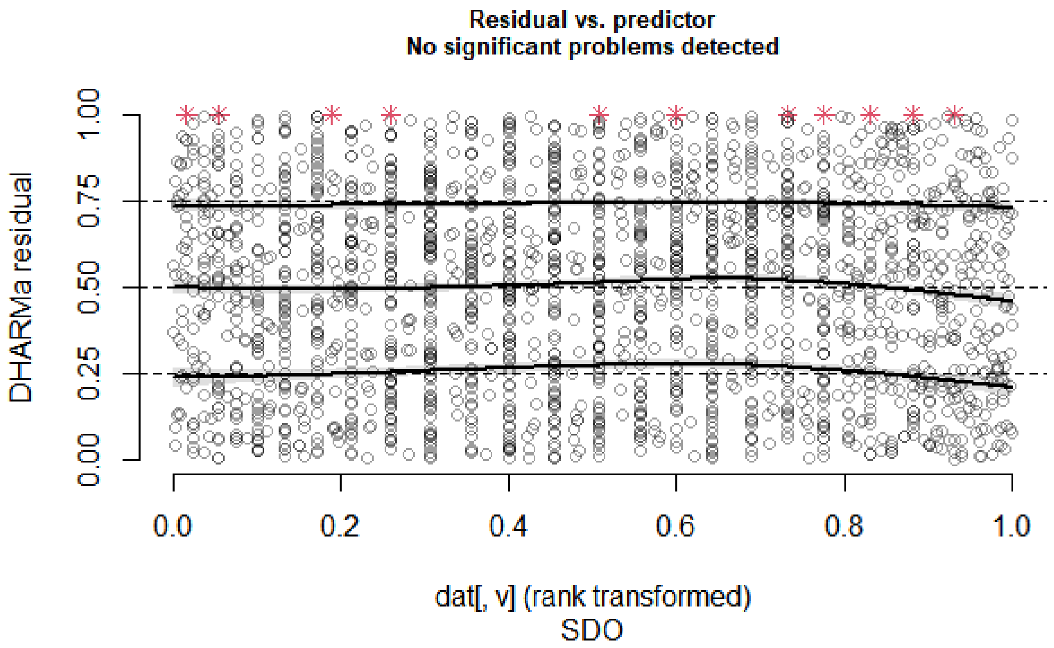
Model Diagnostics

The diagnostics for the zero-altered negative binomial were acceptable, although the KS test was significant and quantile deviations were detected for STEMP.


DHARMa residual
QQ plot residuals
KS test: p= 0.03713
Deviation significant
Dispersion test: p= 0.39
Deviation n.s.
Outlier test: p= 0.61937
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1989
1993
1997
2001
2005
2009
2013
2017
catPred

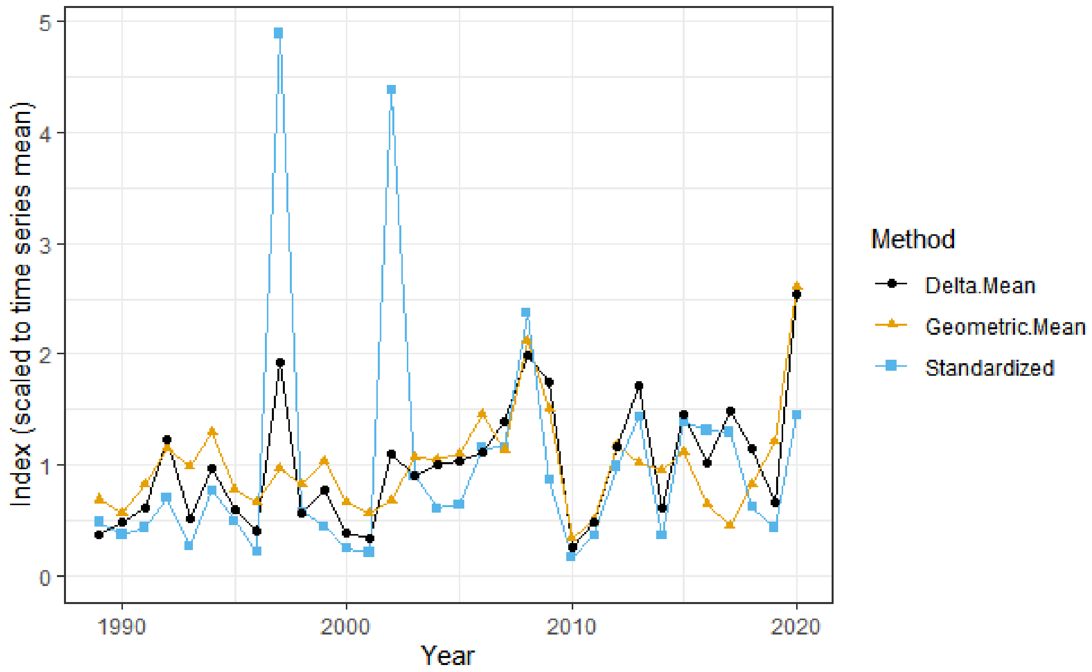

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
catPred

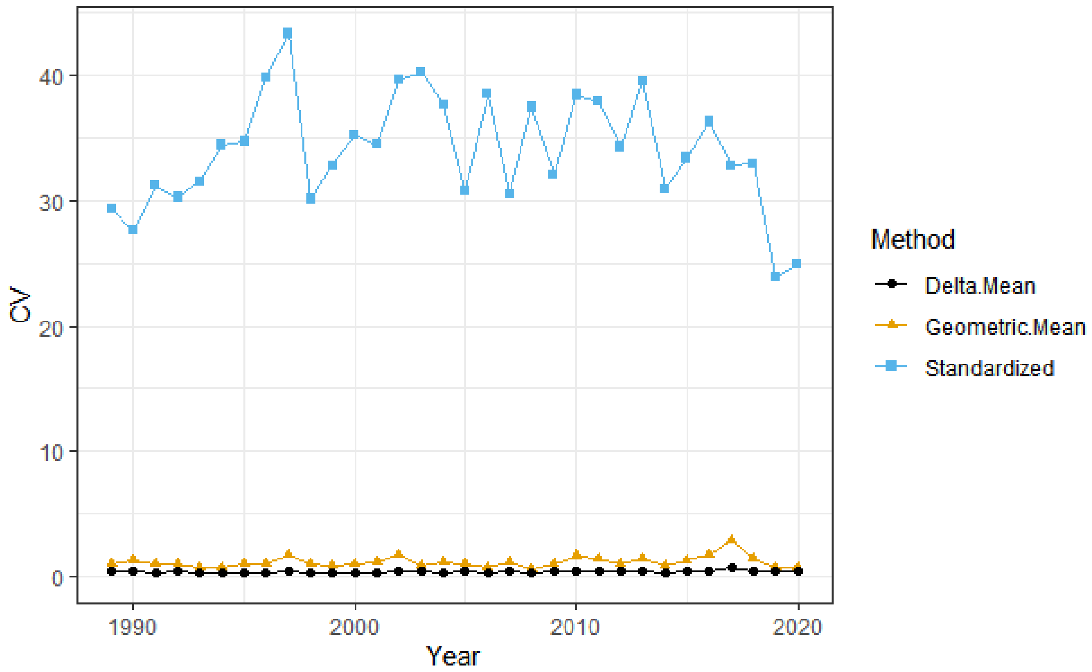

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
0
1
2
3
4
5
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
10
20
30
40
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1989	0.509	29.35	2.834	0.92	9.255	0.36
1990	0.389	27.58	2.359	1.30	12.260	0.36
1991	0.458	31.15	3.422	0.95	15.580	0.31
1992	0.736	30.27	4.729	1.00	31.235	0.36
1993	0.284	31.52	4.091	0.67	13.247	0.26
1994	0.815	34.45	5.318	0.69	24.563	0.32
1995	0.519	34.72	3.205	1.01	15.090	0.32
1996	0.228	39.84	2.751	0.95	10.186	0.28
1997	5.157	43.35	4.010	1.66	48.898	0.46
1998	0.609	30.12	3.426	0.92	14.514	0.29
1999	0.472	32.83	4.265	0.83	19.936	0.32
2000	0.259	35.24	2.756	0.93	9.911	0.29
2001	0.219	34.49	2.303	1.10	8.785	0.31
2002	4.613	39.66	2.825	1.67	28.018	0.44
2003	0.946	40.25	4.421	0.88	22.911	0.34
2004	0.640	37.67	4.341	1.09	25.374	0.31
2005	0.679	30.77	4.511	0.92	26.506	0.36
2006	1.216	38.48	6.025	0.68	28.313	0.30
2007	1.222	30.54	4.702	1.10	35.431	0.38
2008	2.495	37.46	8.774	0.61	50.770	0.33
2009	0.911	32.10	6.207	0.92	44.658	0.37
2010	0.175	38.47	1.393	1.63	6.445	0.35
2011	0.382	37.92	2.091	1.47	12.224	0.38
2012	1.040	34.29	4.857	0.93	29.798	0.36
2013	1.513	39.54	4.219	1.44	43.712	0.44

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2014	0.377	30.93	3.905	0.80	15.709	0.29
2015	1.465	33.42	4.602	1.21	36.883	0.39
2016	1.382	36.31	2.658	1.75	25.895	0.43
2017	1.365	32.82	1.850	2.84	37.887	0.67
2018	0.652	32.94	3.395	1.38	29.068	0.41
2019	0.458	23.89	4.988	0.66	16.730	0.34
2020	1.532	24.88	10.770	0.64	64.843	0.45

DE 16 ft Alewife Survey Standardization

Survey Description

The Delaware Estuary is monitored annually by Delaware Department of Natural Resources and Environmental Control (DNREC) Division of Fish & Wildlife (DFW) to document the relative abundance and distribution of a number of important juvenile finfish species encountered in the estuary from April through October at 38 fixed stations using a 16’ trawl seine. Tow duration was 10 minutes for the 16-foot trawl survey. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). JAIs were determined for yoy and age 1 blueback herring and alewife resulting from collections during juvenile finfish surveys. Length frequencies have been determined for blueback herring and alewife resulting from collections during juvenile finfish surveys conducted on the Delaware River and Delaware Bay. A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest millimeter; the remainder were enumerated.

Subsetting Data

The years were limited to 1990 and subsequent. Months were limited to April for the Age 1 index and June through October for the YOY index.

Model Selection

The YOY data in the final dataset had 6.98% positive tows while the Age 1 data had 11.72% positive tows. Because of the very low positive tows, the YOY data was not standardized. The Age 1 data is considered zero-inflated.

The following refers to the Age 1 index.

Zero-Altered Negative Binomial

The full zero-altered negative binomial had some convergence problems. Full model:

```r
ZANB <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SAL,
                ziformula = ~YEAR+DEPTH+STEMP+SAL,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SAL,
                ziformula = ~YEAR+DEPTH+STEMP+SAL,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SAL,
                ziformula = ~DEPTH+STEMP+SAL,
                data = dat,
                family = nbinom2)
```

GAM

```
GAM.NB <- gam(FREQ~YEAR + s(DEPTH) + s(STEMP) + s(SAL),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-inflated negative binomial with depth, surface temperature, and salinity as covariates.

```
##        dAIC df
## ZINB.2  0.0 38
## GAM.NB  5.7 37.2
## ZANB   26.6 67
```

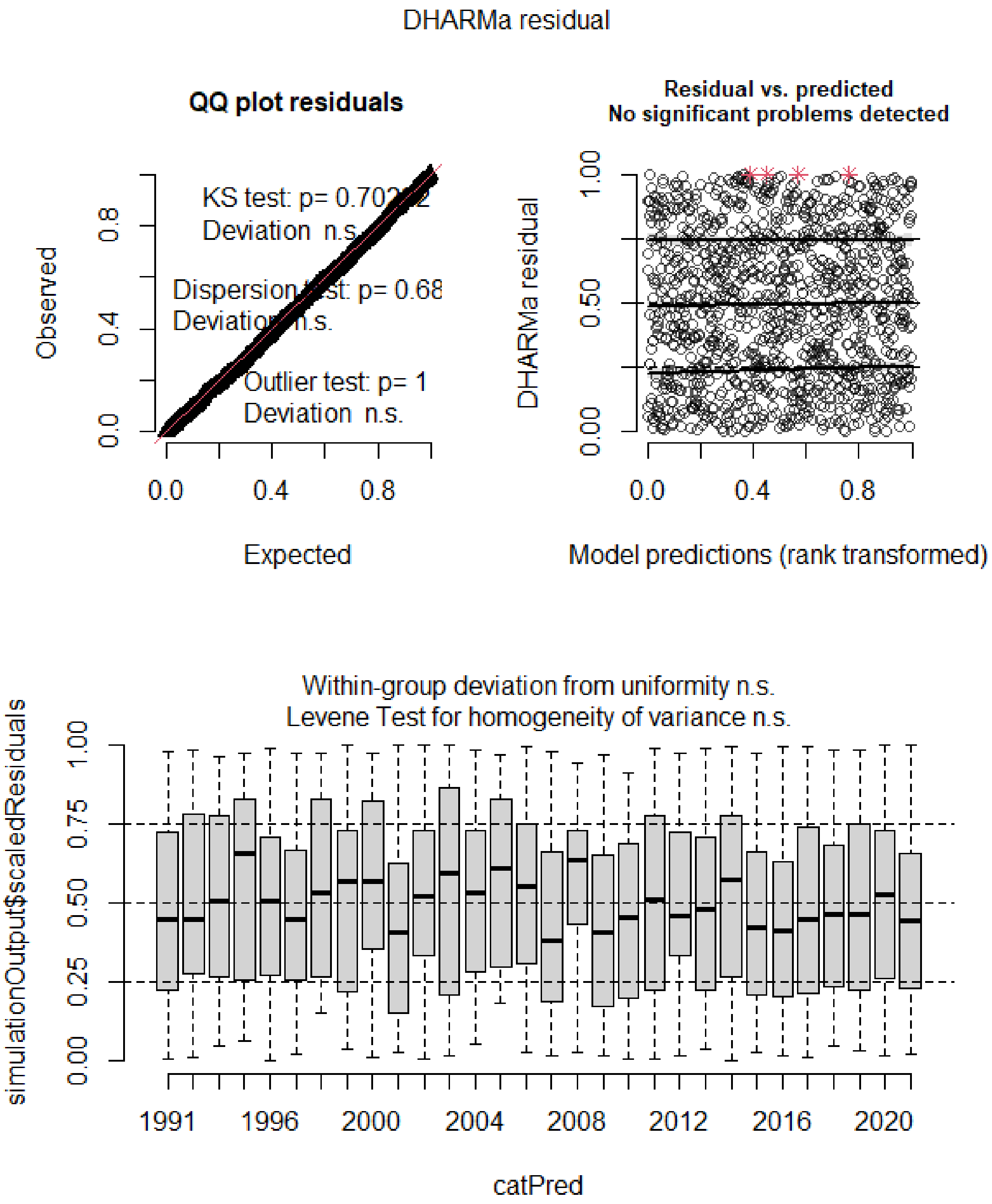
After checking residuals and using fixed stations as a random effect which did not improve the model, we selected a zero-inflated negative binomial. In order to select factors for inclusion in the model, we checked various combinations of covariates for significance. The final model is the full model.

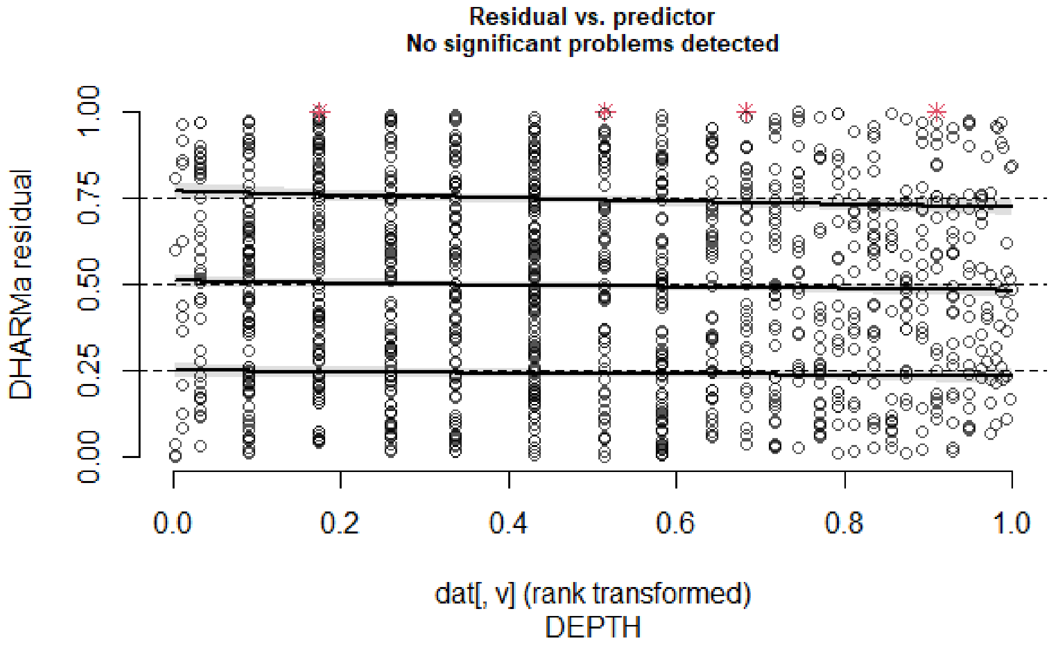
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + DEPTH + STEMP + SAL
## Zero inflation:        ~DEPTH + STEMP + SAL
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   1109.5   1299.7   -516.8   1033.5     1063
##
##
## Dispersion parameter for nbinom2 family (): 1.16
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -3.616e+00  1.321e+00  -2.737 0.006201 **
## YEAR1992    -1.419e+00  5.946e-01  -2.386 0.017040 *
## YEAR1994    -9.948e-02  5.705e-01  -0.174 0.861563
## YEAR1995     5.780e-01  5.051e-01   1.144 0.252458
## YEAR1996    -7.572e-01  5.747e-01  -1.318 0.187642
## YEAR1997     1.578e+00  5.473e-01   2.883 0.003935 **
## YEAR1998    -1.735e+00  6.161e-01  -2.817 0.004851 **
## YEAR1999    -3.585e-01  6.017e-01  -0.596 0.551289
## YEAR2000    -3.276e+00  1.157e+00  -2.832 0.004624 **
```

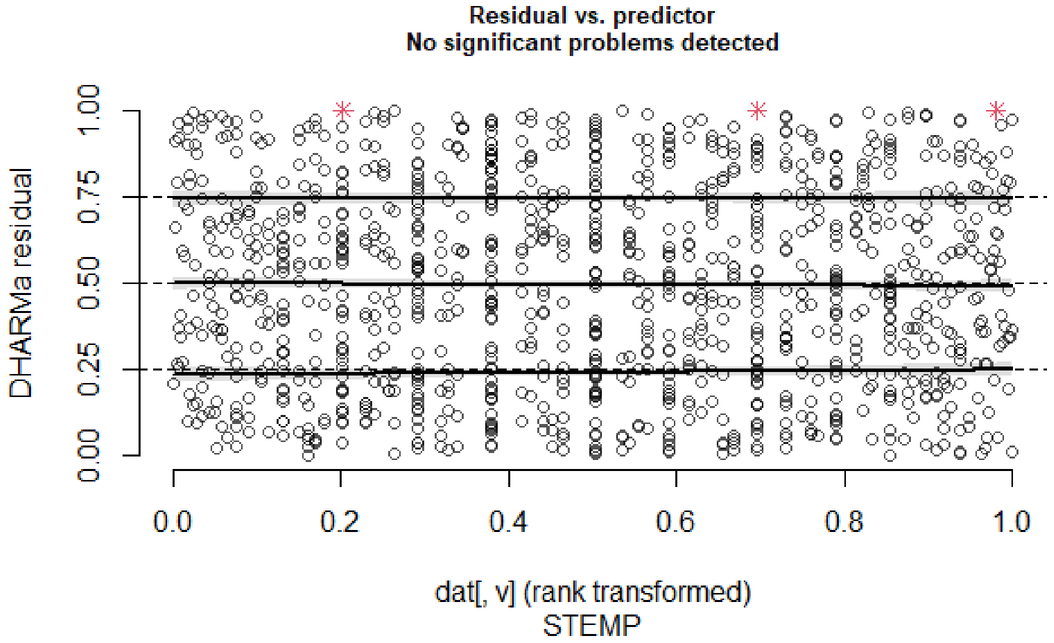
```
## YEAR2001    -1.006e+00  7.347e-01  -1.369 0.170974
## YEAR2002    -2.666e+00  8.491e-01  -3.140 0.001692 **
## YEAR2003    -2.137e+01  6.804e+03  -0.003 0.997494
## YEAR2004    -7.723e-01  7.295e-01  -1.059 0.289751
## YEAR2005    -1.354e+00  1.351e+00  -1.002 0.316381
## YEAR2006    -1.358e+00  7.046e-01  -1.928 0.053894 .
## YEAR2007    -2.853e+00  1.148e+00  -2.486 0.012919 *
## YEAR2008    -1.503e+00  6.893e-01  -2.181 0.029161 *
## YEAR2009    -2.043e+01  6.157e+03  -0.003 0.997352
## YEAR2010    -2.185e+01  7.555e+03  -0.003 0.997692
## YEAR2011    -1.054e+00  7.172e-01  -1.469 0.141847
## YEAR2012    -3.351e+00  1.147e+00  -2.922 0.003475 **
## YEAR2013    -2.113e+00  8.155e-01  -2.591 0.009579 **
## YEAR2014    -2.557e+00  1.164e+00  -2.196 0.028080 *
## YEAR2015     1.329e+00  8.251e-01   1.611 0.107262
## YEAR2016    -1.241e+00  7.298e-01  -1.701 0.088984 .
## YEAR2017    -3.319e+00  1.132e+00  -2.932 0.003372 **
## YEAR2018    -2.293e+00  1.184e+00  -1.936 0.052839 .
## YEAR2019    -1.484e+00  6.288e-01  -2.359 0.018303 *
## YEAR2020    -1.884e+00  8.425e-01  -2.237 0.025318 *
## YEAR2021    -2.297e+00  8.153e-01  -2.817 0.004842 **
## DEPTH        6.569e-03  2.378e-02   0.276 0.782388
## STEMP        3.740e-01  9.919e-02   3.771 0.000163 ***
## SAL         -1.273e-02  2.302e-02  -0.553 0.580281
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -2.61949    1.15351  -2.271  0.02315 *
## DEPTH        0.08109    0.02711   2.991  0.00278 **
## STEMP        0.14942    0.06962   2.146  0.03186 *
## SAL          0.04560    0.02591   1.760  0.07847 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

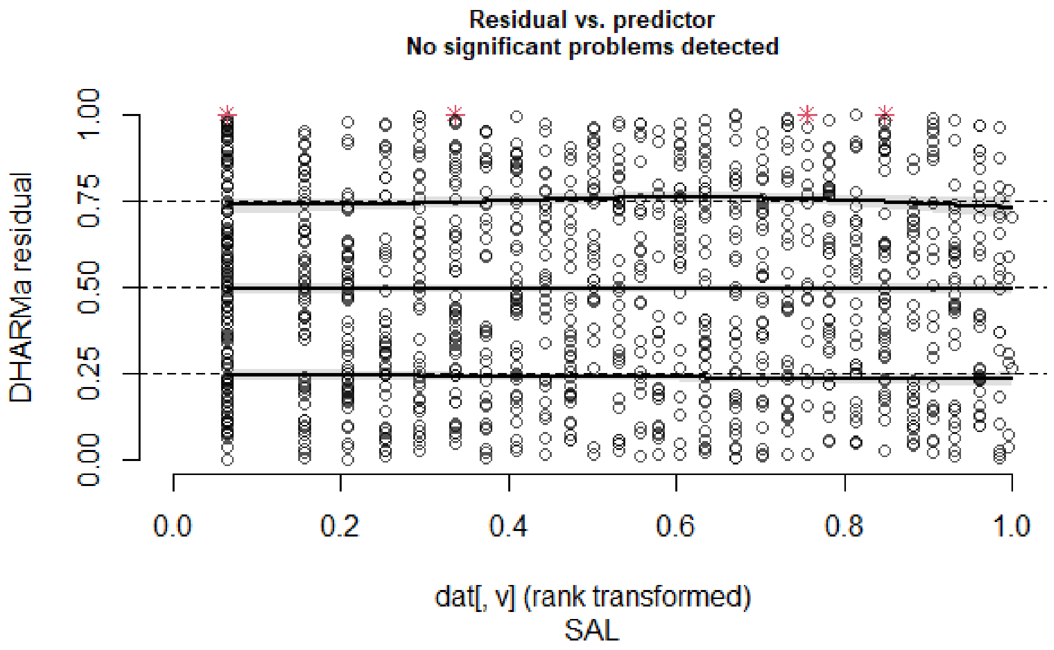
Model Diagnostics

The diagnostics for the zero-inflated negative binomial were acceptable with no significant problems detected.


DHARMa residual
QQ plot residuals
KS test: p= 0.702
Deviation n.s.
Dispersion test: p= 0.68
Deviation n.s.
Outlier test: p= 1
Deviation n.s.
Observed
0.0
0.4
0.8
0.0
0.4
0.8
Expected
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
0.0
0.4
0.8
Model predictions (rank transformed)
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1991
1996
2000
2004
2008
2012
2016
2020
catPred

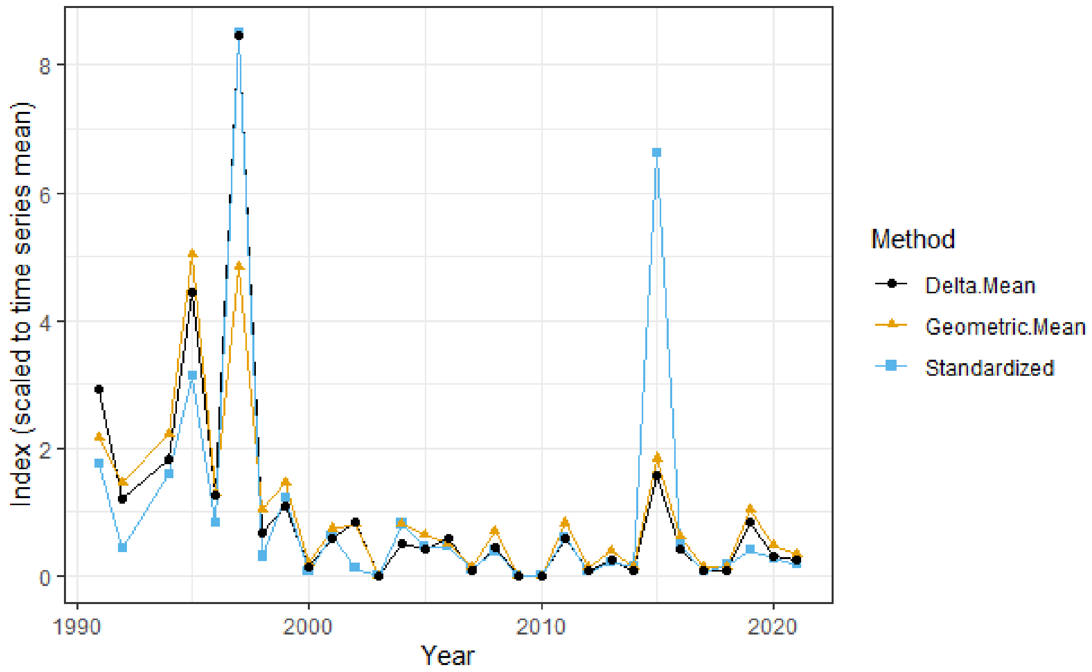

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
DEPTH

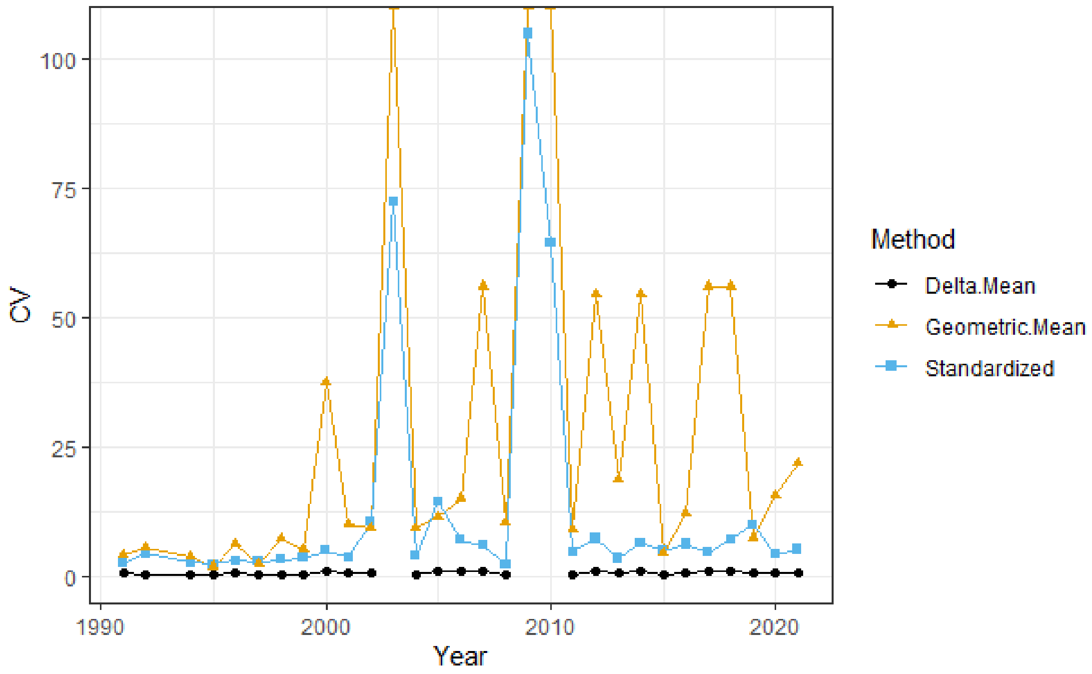

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution.The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
0
2
4
6
8
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
25
50
75
100
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1991	0.592	2.46	0.302	4.14	0.884	0.54
1992	0.143	4.36	0.205	5.36	0.363	0.42
1994	0.536	2.77	0.310	3.68	0.550	0.34
1995	1.055	2.28	0.707	1.85	1.344	0.28
1996	0.277	2.97	0.182	6.14	0.381	0.51
1997	2.866	2.87	0.680	2.37	2.563	0.46
1998	0.104	3.18	0.144	7.24	0.204	0.36
1999	0.413	3.49	0.205	5.28	0.327	0.37
2000	0.022	4.89	0.027	37.36	0.038	1.00
2001	0.216	3.69	0.104	10.08	0.176	0.63
2002	0.041	10.47	0.114	9.49	0.255	0.67
2003	0.000	72.53	0.000	Inf	0.000	
2004	0.273	3.86	0.113	9.18	0.154	0.38
2005	0.153	14.44	0.091	11.39	0.125	1.00
2006	0.152	6.99	0.070	15.07	0.179	0.87
2007	0.034	5.92	0.018	56.11	0.026	1.00
2008	0.132	2.35	0.098	10.48	0.135	0.42
2009	0.000	105.02	0.000	Inf	0.000	
2010	0.000	64.35	0.000	Inf	0.000	
2011	0.206	4.76	0.116	9.02	0.179	0.45
2012	0.021	7.27	0.018	54.67	0.026	1.00
2013	0.072	3.43	0.055	18.58	0.077	0.56
2014	0.046	6.47	0.018	54.67	0.026	1.00
2015	2.235	4.90	0.258	4.37	0.473	0.39
2016	0.171	6.18	0.085	12.15	0.128	0.50

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2017	0.021	4.63	0.018	56.11	0.026	1.00
2018	0.060	7.11	0.018	56.11	0.026	1.00
2019	0.134	9.94	0.144	7.43	0.258	0.48
2020	0.090	4.19	0.065	15.69	0.091	0.56
2021	0.059	5.18	0.047	21.72	0.077	0.74

DE 16 ft Blueback Herring Survey Standardization

Survey Description

The Delaware Estuary is monitored annually by Delaware Department of Natural Resources and Environmental Control (DNREC) Division of Fish & Wildlife (DFW) to document the relative abundance and distribution of a number of important juvenile finfish species encountered in the estuary from April through October at 38 fixed stations using a 16' trawl seine. Tow duration was 10 minutes for the 16-foot trawl survey. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). JAIs were determined for yoy and age 1 blueback herring and alewife resulting from collections during juvenile finfish surveys. Length frequencies have been determined for blueback herring and alewife resulting from collections during juvenile finfish surveys conducted on the Delaware River and Delaware Bay. A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest millimeter; the remainder were enumerated.

Subsetting Data

The years were limited to 1990 and subsequent. Months were limited to April and May for the Age 1 index and June through October for the YOY index.There were quite a few years with zero catch (13 years for YOY and 10 years for Age 1). The proportion positive for YOY was only 1.08% and there were convergence problems with almost all methods. The YOY index was not standardized. The proportaion positive for Age 1 was 3.09% and there were convergence problems with almost all methods. The Age 1 index was not standardized.

DE 30 ft Alewife Survey Standardization

Survey Description

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of a number of important finfish species. A 30-foot bottom trawl was used to sample nine fixed stations in the Delaware Bay from March through December. Tow duration was 20 minutes with a minimum tow time of 10 minutes required for the data to be considered valid. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). Adult densities were calculated for blueback herring and alewife by dividing the number of individuals for a species by the distance towed (N/NM) at each station sampled. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated for each tow.

Subsetting Data

The years were limited to 1990 and subsequent since there was a vessel change before the 1990 year. Months were limited to April and May for the Age 1 index and June through October for the YOY index.

Model Selection

The YOY data in the final dataset had 2% positive tows while the Age 1 data had 37.6% positive tows. Because of the very low positive tows, the YOY data was not standardized. The Age 1 data is considered zero-inflated.

The following refers to the Age 1 index.

Negative Binomial

The negative binomial converges with a good dispersion. Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO,
                ziformula = ~STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

Since this is a fixed station survey, station (TOW.ID) was treated as a random effect. Treating station as a random effect did not appreciably improve the fit of the model, so that formulation was not used going forward.

```
ZINB.2.re <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+ (1|TOW.ID),
                     ziformula = ~STEMP+SSAL+SDO,
                     data = dat,
                     family = nbinom2)
```

GAM

```
GAM.NB <- gam(FREQ~YEAR +  s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC slightly favored the zero-inflated negative binomial with surface temperature, surface salinity, and surface dissolved oxygen as covariates and treating station as a random effect.

```
##             dAIC df
## ZINB.2.re    0.0 40
## GAM.NB       1.3 40.3
## NB1          6.3 35
## ZINB.2       7.1 39
## ZANB        29.5 69
## ZINB          NA 69
```

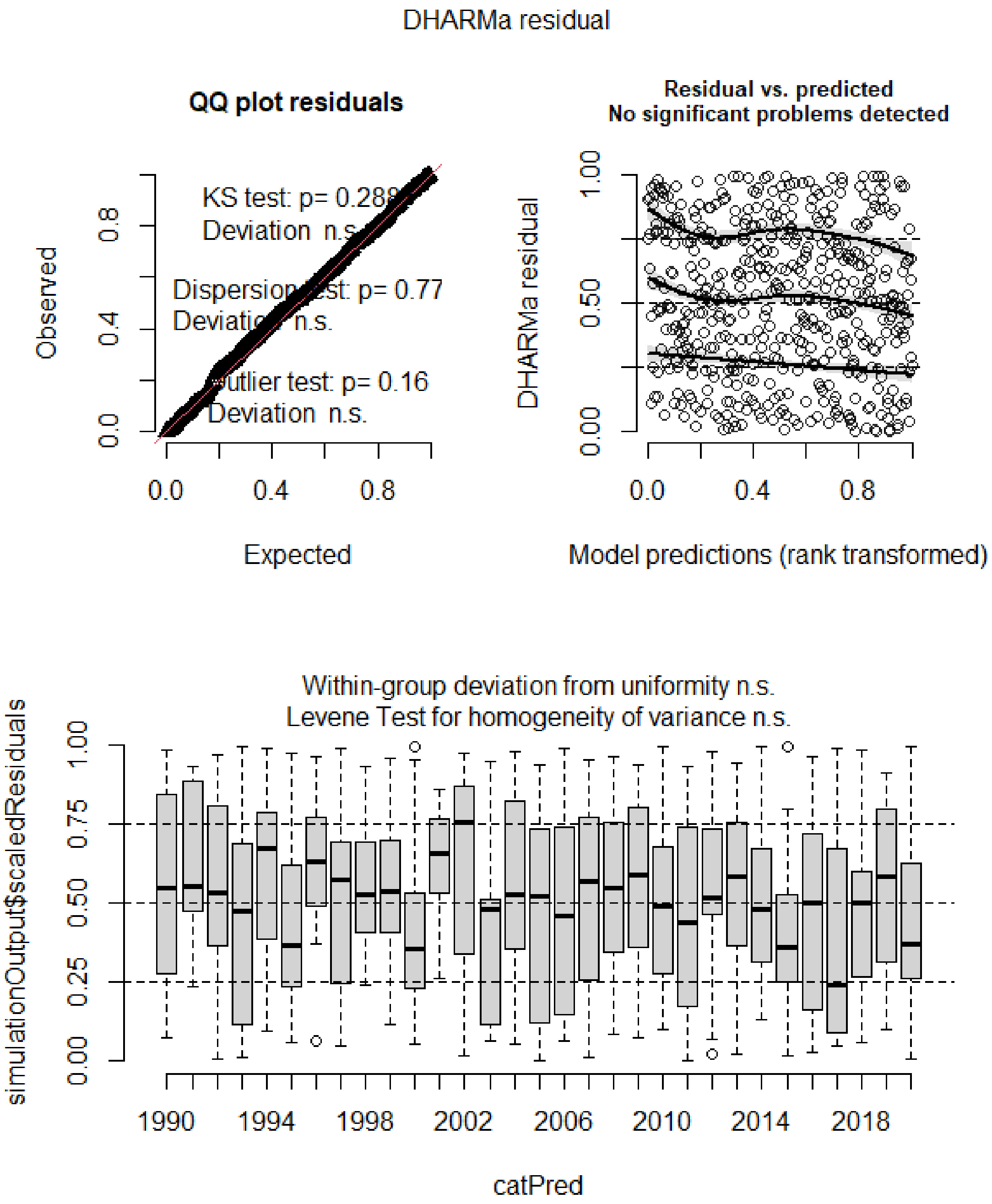
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, we checked various combinations of covariates for significance. The final model had surface temperature and surface salinity as covariates.

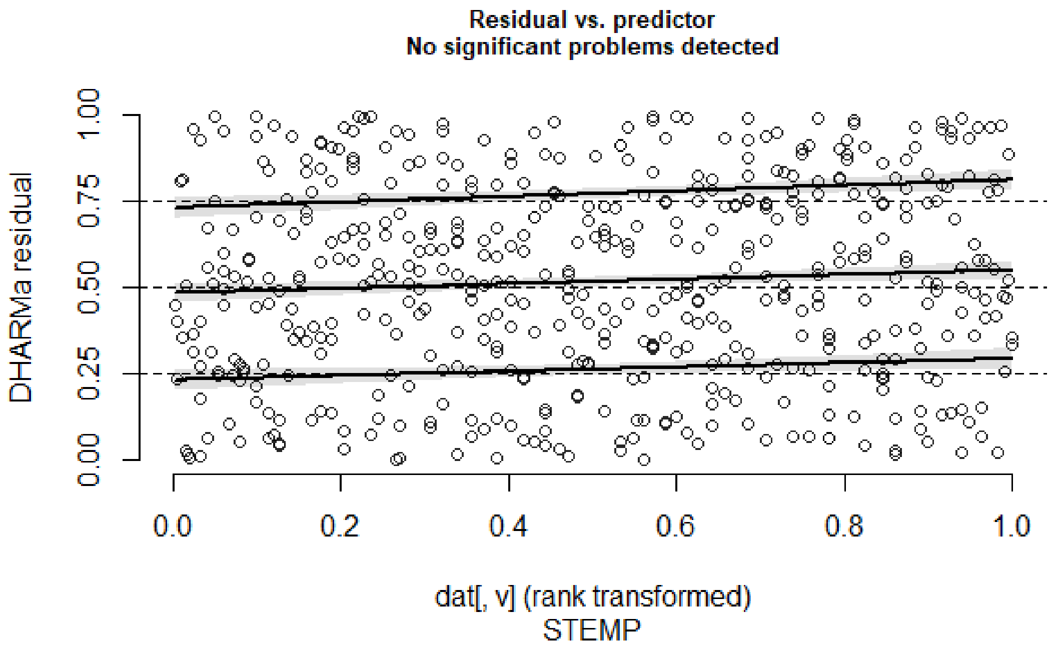
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + SSAL
## Zero inflation:        ~STEMP + SSAL
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   1349.5   1505.1   -637.8   1275.5      458
##
##
## Dispersion parameter for nbinom2 family (): 0.529
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  3.39685    0.91357   3.718 0.000201 ***
## YEAR1991     0.29133    1.32657   0.220 0.826171
## YEAR1992    -0.20976    0.77136  -0.272 0.785668
## YEAR1993     2.20203    0.74006   2.975 0.002925 **
## YEAR1994     2.48284    0.74431   3.336 0.000851 ***
## YEAR1995     0.81986    0.90282   0.908 0.363819
## YEAR1996     1.81808    0.72618   2.504 0.012292 *
## YEAR1997     0.58318    0.81970   0.711 0.476801
## YEAR1998     0.09017    1.00107   0.090 0.928232
## YEAR1999     1.59607    0.77764   2.052 0.040125 *
## YEAR2000     1.80701    0.75035   2.408 0.016031 *
## YEAR2001    -0.18384    1.12699  -0.163 0.870419
## YEAR2002     0.24280    0.95628   0.254 0.799570
## YEAR2003    -0.68785    1.28353  -0.536 0.592025
## YEAR2004     2.23205    0.75818   2.944 0.003240 **
## YEAR2005     1.42468    0.71551   1.991 0.046464 *
## YEAR2006     1.45802    0.80537   1.810 0.070239 .
## YEAR2007    -2.54200    1.27874  -1.988 0.046824 *
## YEAR2008     0.04291    0.78456   0.055 0.956381
## YEAR2009     0.43499    0.78517   0.554 0.579576
## YEAR2010     0.69192    0.76053   0.910 0.362940
## YEAR2011     2.11183    0.71764   2.943 0.003253 **
## YEAR2012     2.70555    0.77444   3.494 0.000477 ***
## YEAR2013     1.33768    0.74709   1.791 0.073368 .
## YEAR2014     0.76270    0.76706   0.994 0.320069
## YEAR2015     0.73084    0.78798   0.927 0.353674
## YEAR2016     2.58231    0.71689   3.602 0.000316 ***
## YEAR2017     0.90098    0.74644   1.207 0.227417
## YEAR2018     1.73676    0.71093   2.443 0.014569 *
## YEAR2019    -0.01271    0.81768  -0.016 0.987598
## YEAR2021     1.98570    0.72923   2.723 0.006469 **
## STEMP       -0.24242    0.04291  -5.650 1.61e-08 ***
## SSAL        -0.06246    0.01639  -3.810 0.000139 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
```

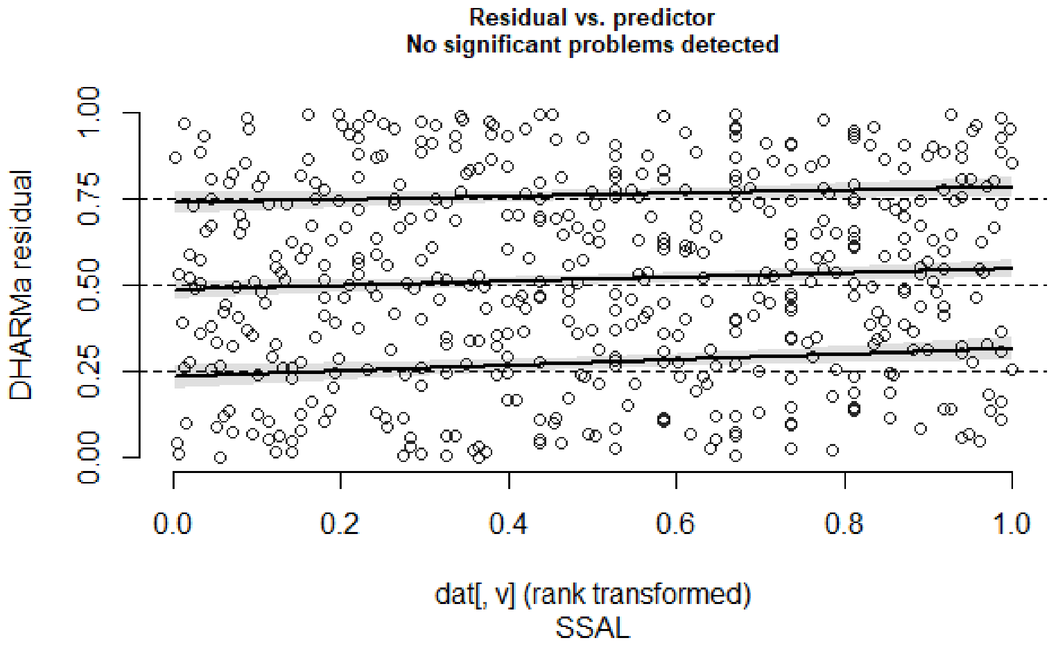
```
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -17.8851     5.5590  -3.217  0.00129 **
## STEMP         0.4127     0.1631   2.531  0.01138 *
## SSAL          0.4261     0.1552   2.746  0.00603 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model Diagnostics

The diagnostics for the negative binomial were acceptable with no significant problems detected.

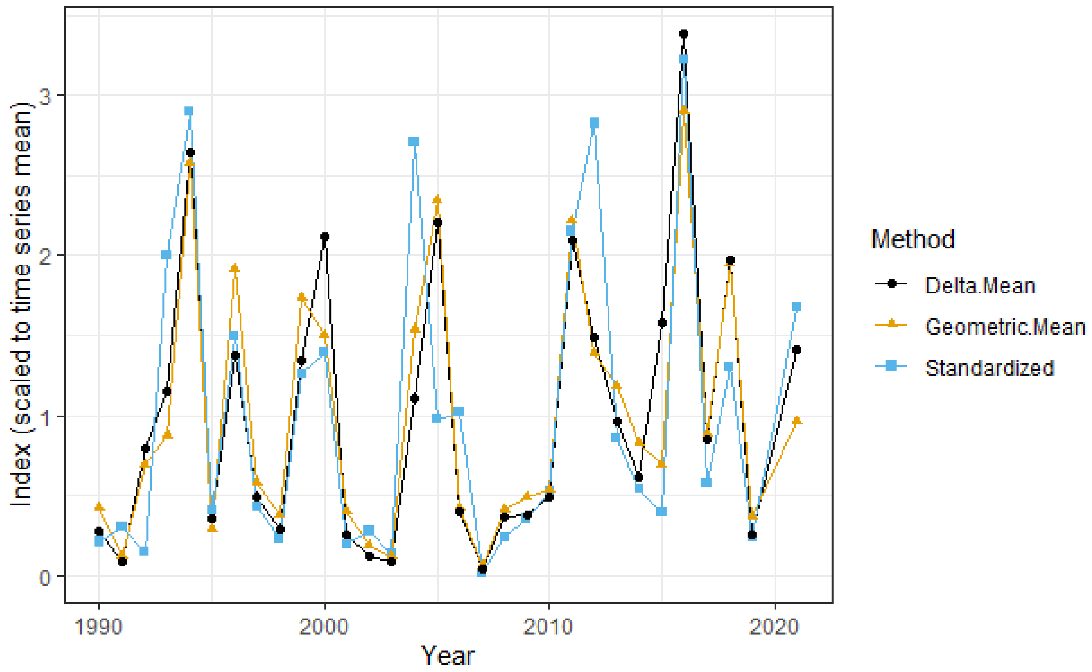

DHARMa residual
QQ plot residuals
KS test: p= 0.288
Deviation n.s.
Dispersion test: p= 0.77
Deviation n.s.
Outlier test: p= 0.16
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
catPred
0.00
0.25
0.50
0.75
1.00
1990
1994
1998
2002
2006
2010
2014
2018

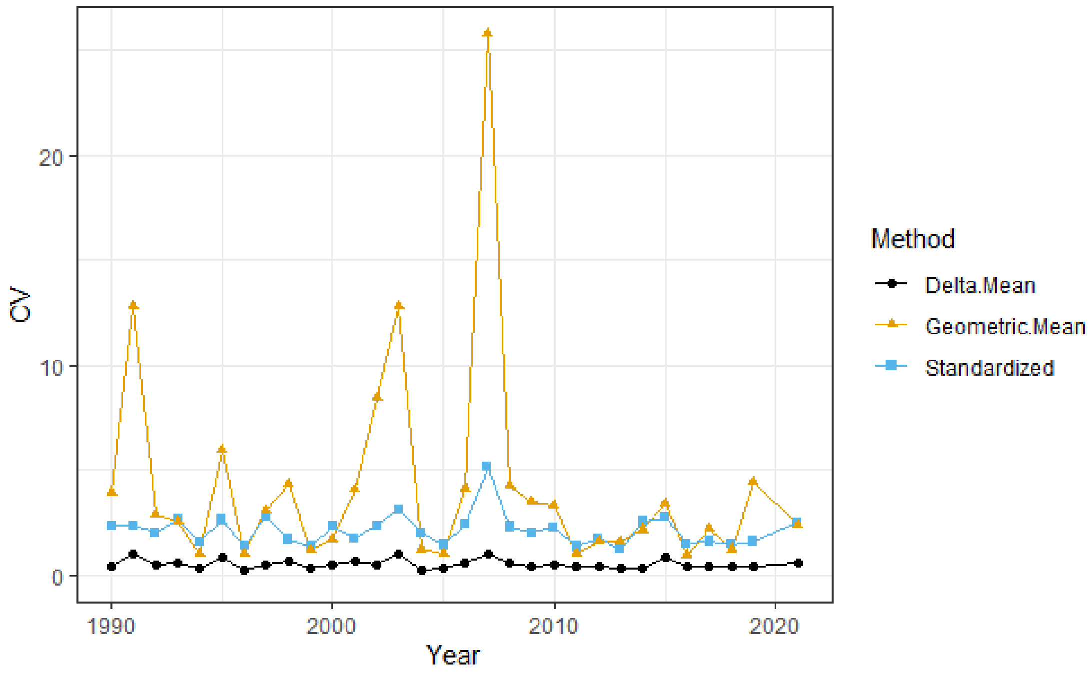




Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
0
1
2
3
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
10
20
1990
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1990	0.229	2.37	0.274	3.93	0.373	0.40
1991	0.331	2.34	0.080	12.83	0.111	1.00
1992	0.159	2.03	0.456	2.89	1.051	0.50
1993	2.156	2.66	0.574	2.55	1.522	0.59
1994	3.125	1.57	1.685	0.99	3.477	0.37
1995	0.437	2.64	0.192	5.95	0.467	0.86
1996	1.612	1.37	1.254	1.02	1.813	0.27
1997	0.468	2.79	0.379	3.08	0.643	0.50
1998	0.254	1.69	0.251	4.37	0.375	0.70
1999	1.363	1.36	1.134	1.17	1.760	0.34
2000	1.505	2.31	0.979	1.72	2.783	0.53
2001	0.214	1.76	0.260	4.10	0.333	0.63
2002	0.302	2.34	0.122	8.46	0.167	0.54
2003	0.145	3.11	0.080	12.83	0.111	1.00
2004	2.921	2.00	1.006	1.23	1.452	0.27
2005	1.055	1.44	1.533	1.03	2.909	0.32
2006	1.105	2.41	0.279	4.13	0.534	0.58
2007	0.018	5.14	0.039	25.81	0.056	1.00
2008	0.262	2.30	0.268	4.24	0.487	0.56
2009	0.387	2.03	0.318	3.53	0.501	0.44
2010	0.567	2.28	0.351	3.35	0.644	0.51
2011	2.323	1.35	1.447	1.05	2.761	0.38
2012	3.052	1.76	0.907	1.65	1.960	0.45
2013	0.923	1.21	0.774	1.64	1.264	0.35
2014	0.584	2.55	0.541	2.17	0.815	0.35

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2015	0.428	2.75	0.456	3.44	2.070	0.84
2016	3.482	1.50	1.899	0.97	4.452	0.40
2017	0.618	1.61	0.580	2.23	1.115	0.45
2018	1.410	1.47	1.274	1.23	2.592	0.38
2019	0.263	1.62	0.240	4.46	0.332	0.41
2021	1.808	2.54	0.632	2.41	1.854	0.59

DE 30 ft Blueback Herring Survey Standardization

Survey Description

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of a number of important finfish species. A 30-foot bottom trawl was used to sample nine fixed stations in the Delaware Bay from March through December. Tow duration was 20 minutes with a minimum tow time of 10 minutes required for the data to be considered valid. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). Adult densities were calculated for blueback herring and alewife by dividing the number of individuals for a species by the distance towed (N/NM) at each station sampled. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated for each tow.

Subsetting Data

The years were limited to 1992 and subsequent since there was a vessel change before the 1990 year and zero catch in 1991. Months were limited to April and May for the Age 1 index and June through October for the YOY index.

Model Selection

The YOY data in the final dataset had 0.74% positive tows while the Age 1 data had 11.1% positive tows. Because of the very low positive tows, the YOY data was not standardized. The Age 1 data is considered zero-inflated.

The following refers to the Age 1 index.

Negative Binomial

The negative binomial did not converge and was not pursued further.

Zero-Altered Negative Binomial

The zero-altered negative binomial did not converge.

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SSAL + SDO,
                ziformula = ~YEAR+DEPTH+STEMP+SSAL+SDO,
```

```
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SSAL + SDO,
                ziformula = ~YEAR+DEPTH+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SSAL + SDO,
                ziformula = ~DEPTH+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

Since this is a fixed station survey, station (TOW.ID) was treated as a random effect. Treating station as a random effect did not appreciably improve the fit of the model, so that formulation was not used going forward.

```
ZINB.2.re <- glmmTMB(FREQ~YEAR + DEPTH + STEMP + SSAL + SDO+ (1|TOW.ID),
                     ziformula = ~DEPTH+STEMP+SSAL+SDO,
                     data = dat,
                     family = nbinom2)
```

GAM

```
GAM.NB <- gam(FREQ~YEAR + s(DEPTH) + s(STEMP) + s(SSAL) + s(SDO),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-inflated negative binomial with depth, surface temperature, surface salinity, and surface dissolved oxygen as covariates slightly over the general additive model with the same covariates.

```
##             dAIC df
## ZINB.2       0.0 39
## GAM.NB       1.0 39.9
## ZINB.2.re    2.0 40
## ZINB          NA 67
## ZANB          NA 67
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-inflated negative binomial was selected as the final model. In order to select factors for inclusion in the model, we checked various combinations of covariates for significance.

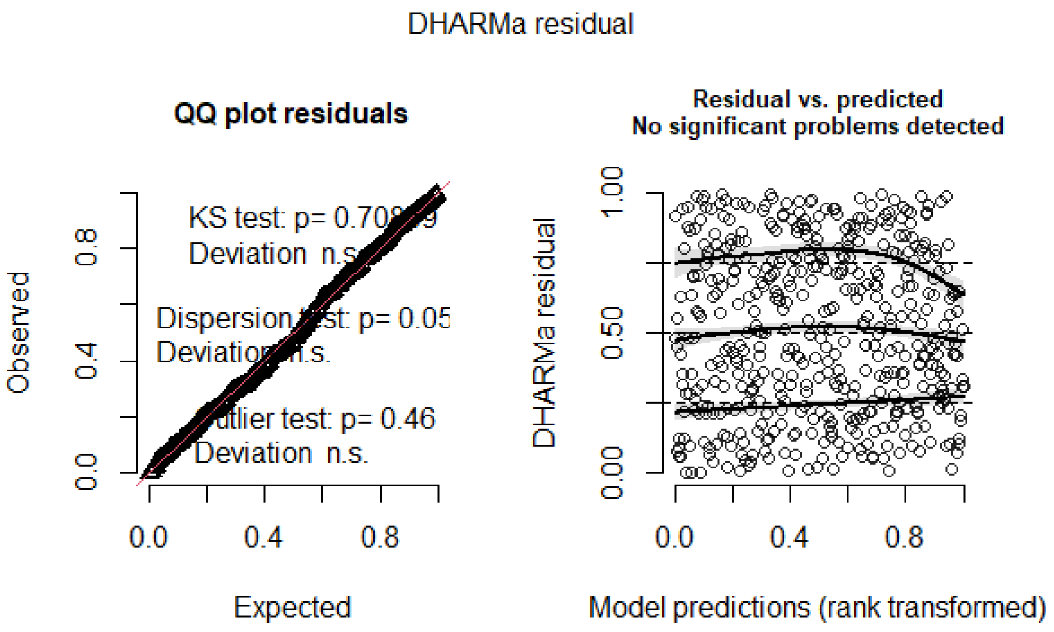
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + SDO
## Zero inflation:        ~TOW.ID + STEMP + SDO
## Data: dat
```

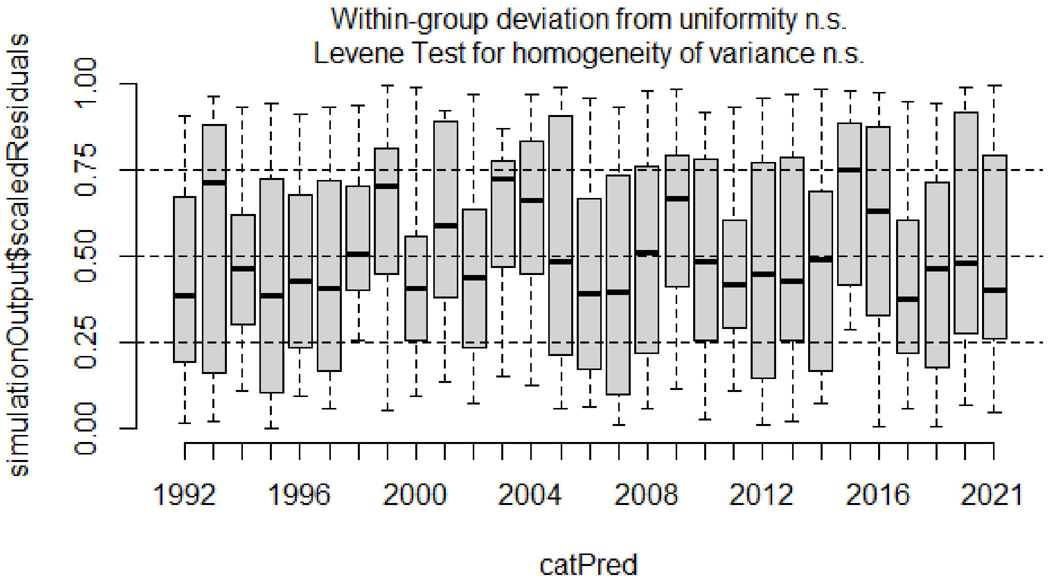
```
##
##      AIC      BIC   logLik deviance df.resid
##    561.0    739.6   -237.5    475.0      427
##
##
## Dispersion parameter for nbinom2 family (): 1.51
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)     4.0752     2.8701   1.420  0.15564
## YEAR1993       -0.9572     1.0978  -0.872  0.38323
## YEAR1994        2.1920     1.1078   1.979  0.04785 *
## YEAR1995      -22.7216 22393.4549  -0.001  0.99919
## YEAR1996        0.4536     1.3926   0.326  0.74466
## YEAR1997       -1.0941     1.1836  -0.924  0.35530
## YEAR1998      -21.4863 19448.1659  -0.001  0.99912
## YEAR1999       -1.2778     1.1129  -1.148  0.25091
## YEAR2000       -0.5268     1.1539  -0.456  0.64803
## YEAR2001        0.6456     1.1720   0.551  0.58171
## YEAR2002        3.6420     1.2630   2.884  0.00393 **
## YEAR2003       -1.0230     1.3049  -0.784  0.43305
## YEAR2004       -2.8613     1.3236  -2.162  0.03064 *
## YEAR2005      -26.0069 52789.8776   0.000  0.99961
## YEAR2006      -20.9510 15256.6738  -0.001  0.99890
## YEAR2007       -2.9632     1.4561  -2.035  0.04185 *
## YEAR2008       -1.8001     1.2669  -1.421  0.15534
## YEAR2009       -1.0625     1.0836  -0.981  0.32684
## YEAR2010      -22.6657 21603.2420  -0.001  0.99916
## YEAR2011        0.4183     1.1245   0.372  0.70990
## YEAR2012      -21.5708 15665.5022  -0.001  0.99890
## YEAR2013       -0.8002     1.0551  -0.758  0.44824
## YEAR2014       -3.3678     1.6781  -2.007  0.04476 *
## YEAR2015       -1.6726     1.2722  -1.315  0.18859
## YEAR2016      -23.7275 26771.3443  -0.001  0.99929
## YEAR2017      -23.8953 29320.2265  -0.001  0.99935
## YEAR2018       -3.2238     1.3978  -2.306  0.02109 *
## YEAR2019       -2.8899     1.4566  -1.984  0.04724 *
## YEAR2021      -23.7693 27195.3926  -0.001  0.99930
## STEMP          -0.4373     0.1123  -3.893 9.89e-05 ***
## SDO             0.3439     0.1719   2.000  0.04545 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  0.141539   1.527546   0.093    0.926
## TOW.ID21    -0.344986   0.737452  -0.468    0.640
## TOW.ID31    -0.507265   0.728222  -0.697    0.486
## TOW.ID41    -0.944589   0.728727  -1.296    0.195
## TOW.ID51     0.436691   0.793437   0.550    0.582
```

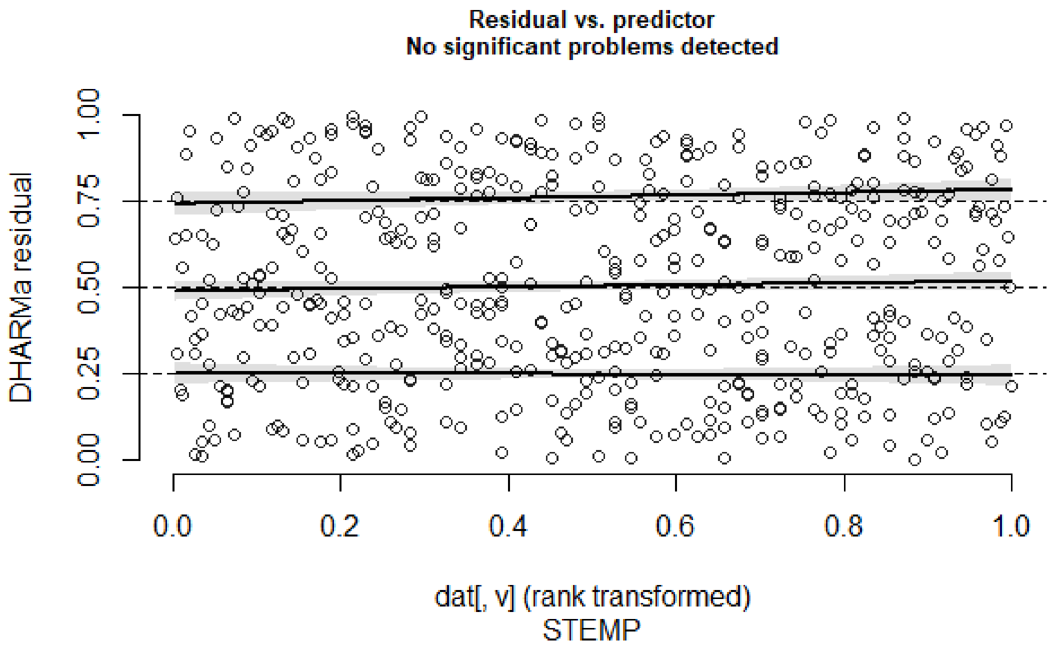
```
## TOW.ID52     0.108368   0.767675   0.141    0.888
## TOW.ID62     0.869261   0.837535   1.038    0.299
## TOW.ID71    -0.016240   0.743417  -0.022    0.983
## TOW.ID72     0.532092   0.788966   0.674    0.500
## STEMP       -0.008387   0.060853  -0.138    0.890
## SDO          0.098856   0.113756   0.869    0.385
```

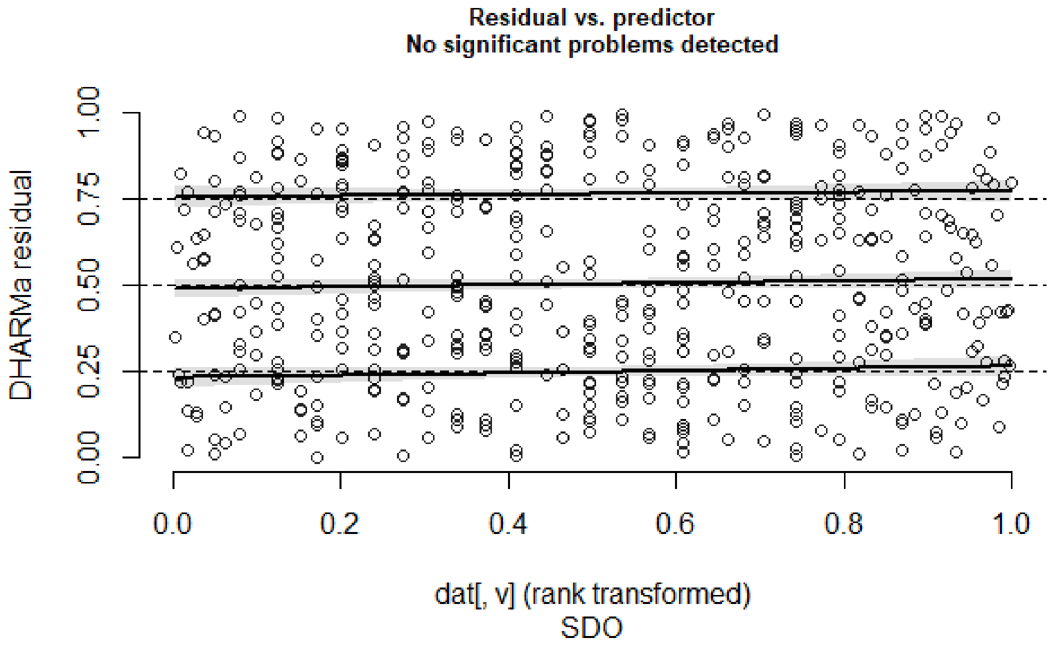
Model Diagnostics

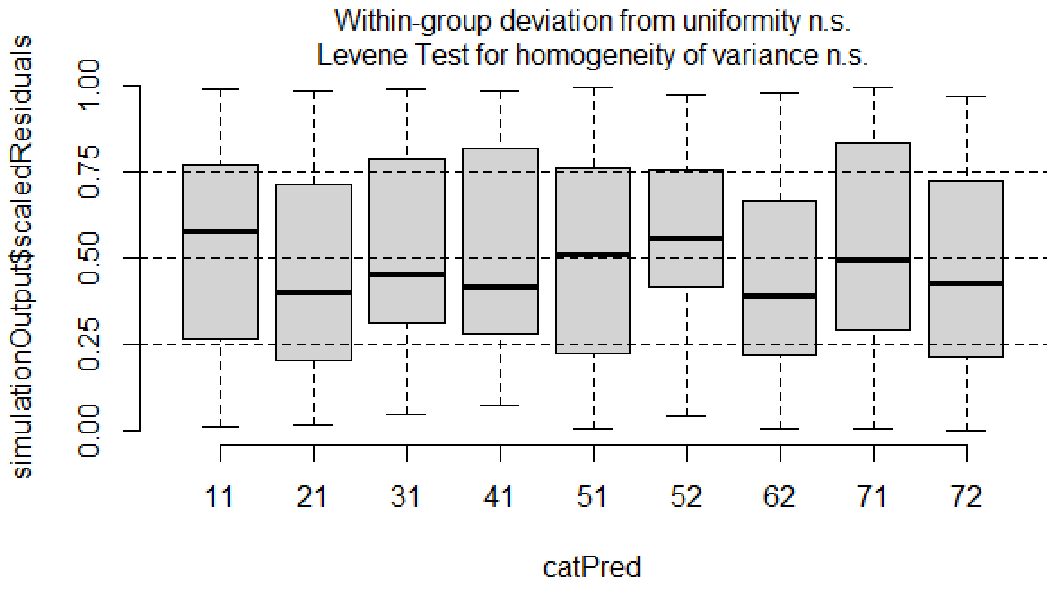
The diagnostics for the zero-inflated negative binomial were acceptable with no significant problems detected.


DHARMa residual
QQ plot residuals
KS test: p= 0.70859
Deviation n.s.
Dispersion test: p= 0.05
Deviation n.s.
Outlier test: p= 0.46
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)
0.0
0.4
0.8


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1992
1996
2000
2004
2008
2012
2016
2021
catPred

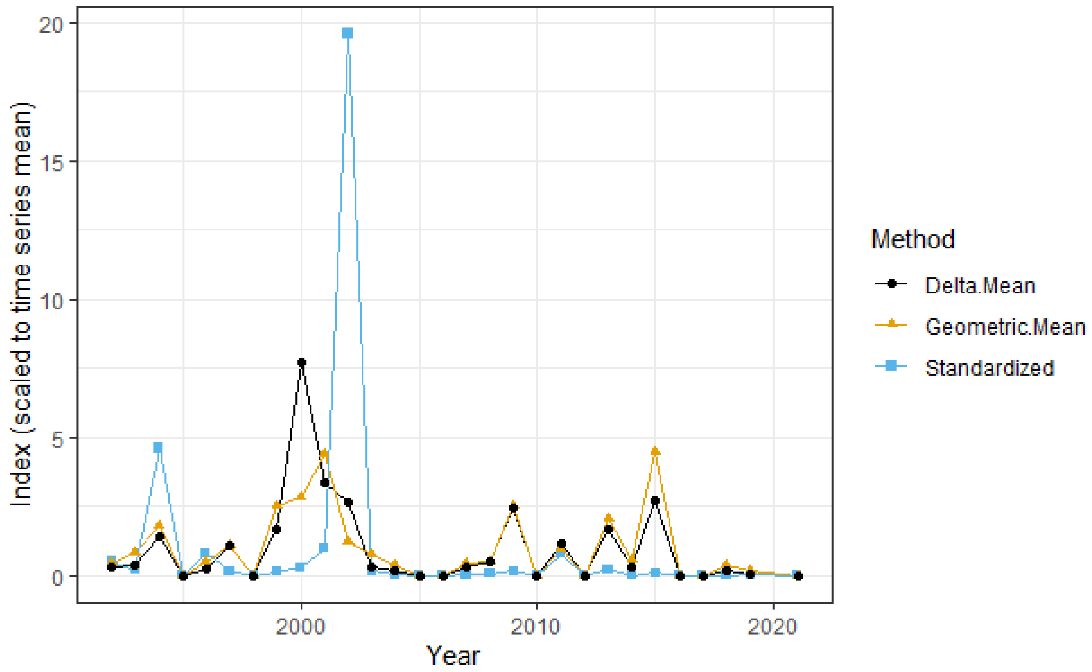

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP

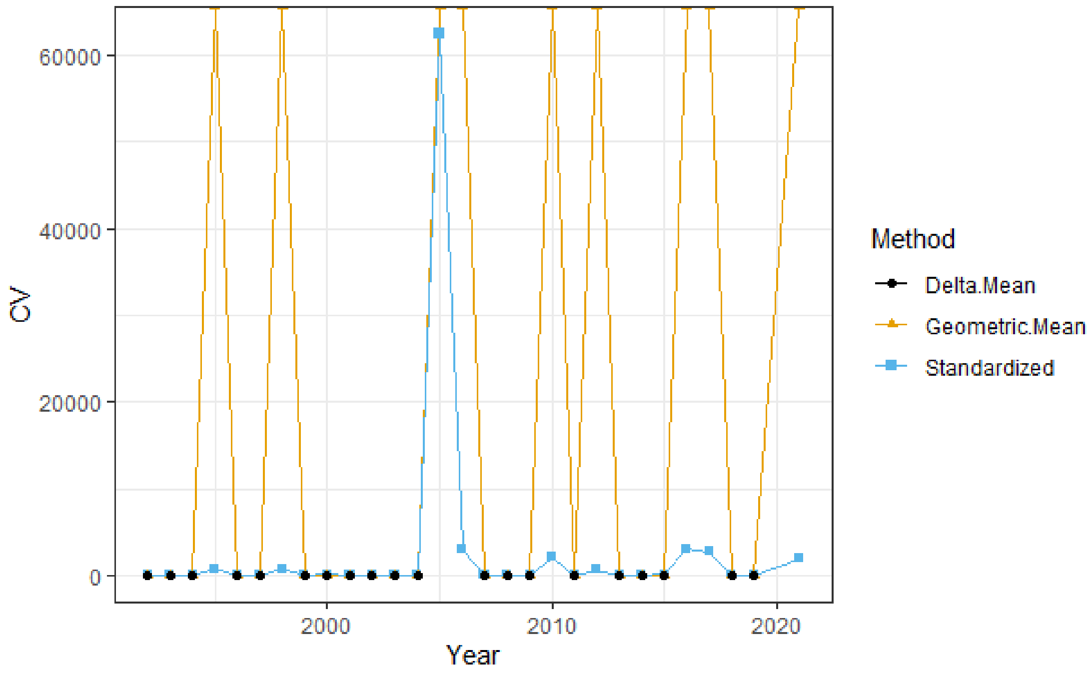

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
SDO



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. The standardized index showed different patterns than the mean indices. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
20
15
10
5
0
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
60000
40000
20000
0
2000
2010
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1992	0.896	3.50	0.094	11.49	0.222	1.00
1993	0.344	2.94	0.177	5.91	0.235	0.45
1994	8.024	7.82	0.380	3.41	0.941	0.56
1995	0.000	765.03	0.000	Inf	0.000	
1996	1.411	15.04	0.105	9.99	0.167	0.73
1997	0.300	17.04	0.239	5.11	0.714	0.90
1998	0.000	770.96	0.000	Inf	0.000	
1999	0.250	11.47	0.543	2.40	1.108	0.55
2000	0.529	102.03	0.605	3.31	5.005	0.84
2001	1.709	4.27	0.944	1.81	2.167	0.66
2002	34.208	24.29	0.258	5.41	1.722	0.97
2003	0.322	2.79	0.167	6.29	0.222	0.66
2004	0.051	7.44	0.080	12.81	0.111	0.69
2005	0.000	62529.12	0.000	Inf	0.000	
2006	0.000	2949.73	0.000	Inf	0.000	
2007	0.046	54.21	0.094	11.49	0.222	1.00
2008	0.148	66.14	0.114	9.73	0.333	1.00
2009	0.310	11.92	0.531	2.76	1.603	0.58
2010	0.000	2124.61	0.000	Inf	0.000	
2011	1.362	3.12	0.211	5.79	0.765	0.92
2012	0.000	636.56	0.000	Inf	0.000	
2013	0.403	13.94	0.438	3.02	1.106	0.57
2014	0.031	53.74	0.122	8.70	0.222	0.78
2015	0.168	108.12	0.952	1.48	1.781	0.43

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2016	0.000	2988.66	0.000	Inf	0.000	
2017	0.000	2712.65	0.000	Inf	0.000	
2018	0.036	27.52	0.080	12.81	0.111	0.69
2019	0.050	7.25	0.039	25.81	0.056	1.00
2021	0.000	1914.28	0.000	Inf	0.000	

MD Estuarine Juvenile Finfish Seine Alewife Survey Standardization - Head of Bay

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset had 40.67% positive sets.

Negative Binomial

Full model:

```r
NB1 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated model had convergience problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  data = dat,
                  family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the zero-altered negative binomial.

```
##         dAIC  df
## ZANB      0.0 111
## ZINB     22.5 111
## NB1      82.4 56
## ZINB.2     NA 68
```

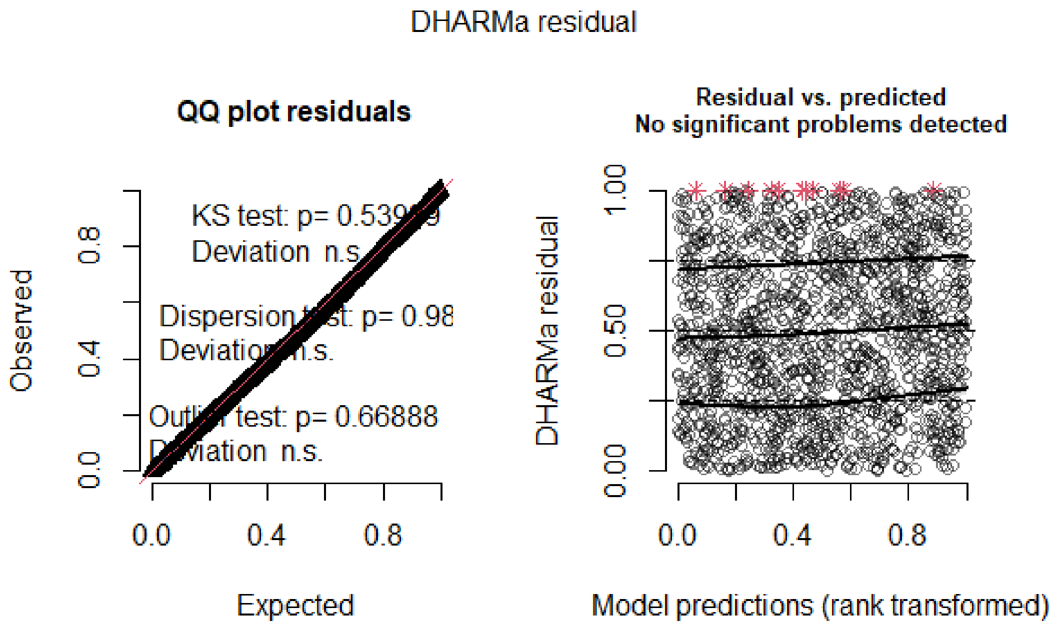
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

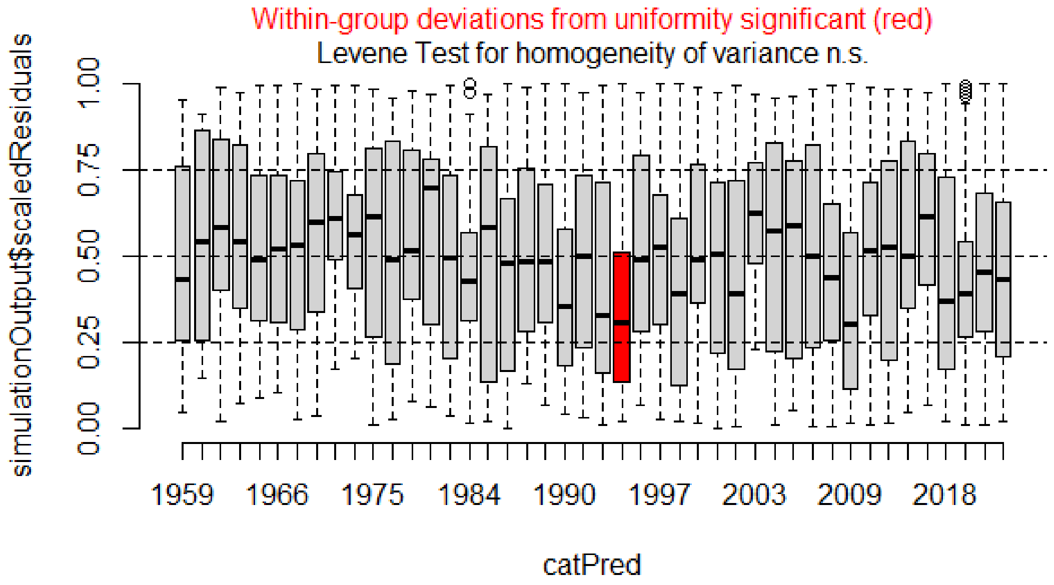
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP
## Data: dat
## 
##      AIC      BIC   logLik deviance df.resid
##   6336.8   6583.4  -3122.4   6244.8     1530
## 
## 
## Dispersion parameter for nbinom2 family (): 0.196
## 
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
```

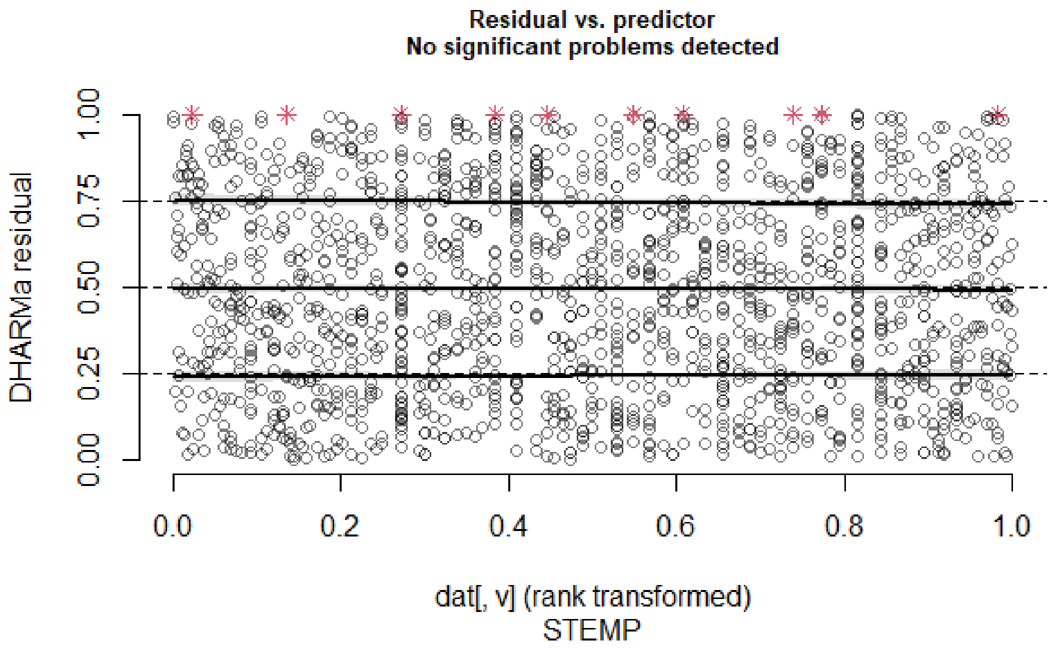
```
## (Intercept) -0.47859    1.07537  -0.445  0.65629    
## YEAR1961    -1.65781    1.31518  -1.261  0.20748    
## YEAR1962     2.37084    0.88907   2.667  0.00766 ** 
## YEAR1963     0.93755    0.87591   1.070  0.28445    
## YEAR1964    -1.25569    0.90542  -1.387  0.16548    
## YEAR1966     3.40410    0.85163   3.997 6.41e-05 ***
## YEAR1967     0.91728    0.84155   1.090  0.27572    
## YEAR1969     1.10464    0.88639   1.246  0.21268    
## YEAR1970     3.96069    0.84800   4.671 3.00e-06 ***
## YEAR1971     1.89729    0.85495   2.219  0.02647 *  
## YEAR1975     1.58307    0.84218   1.880  0.06014 .  
## YEAR1976    -0.41832    0.85889  -0.487  0.62622    
## YEAR1977     1.02079    0.83876   1.217  0.22360    
## YEAR1978     0.41080    0.83046   0.495  0.62084    
## YEAR1979     0.15648    0.83810   0.187  0.85189    
## YEAR1984    -0.69483    0.86549  -0.803  0.42208    
## YEAR1985    -2.11991    0.89533  -2.368  0.01790 *  
## YEAR1986     0.50780    0.82386   0.616  0.53765    
## YEAR1988    -3.99637    1.08173  -3.694  0.00022 ***
## YEAR1989    -1.23751    0.85111  -1.454  0.14595    
## YEAR1990    -0.10979    0.82356  -0.133  0.89395    
## YEAR1991    -2.70704    0.92336  -2.932  0.00337 ** 
## YEAR1993     1.06979    0.82534   1.296  0.19491    
## YEAR1994     2.12552    0.82418   2.579  0.00991 ** 
## YEAR1996     2.19742    0.85159   2.580  0.00987 ** 
## YEAR1997    -1.12107    0.85676  -1.308  0.19071    
## YEAR1998    -0.12912    0.82858  -0.156  0.87617    
## YEAR1999    -0.82437    0.82976  -0.994  0.32046    
## YEAR2000     1.47383    0.82314   1.790  0.07337 .  
## YEAR2001     2.62730    0.82068   3.201  0.00137 ** 
## YEAR2003     1.56142    0.84222   1.854  0.06375 .  
## YEAR2004     1.32257    0.82338   1.606  0.10821    
## YEAR2005     0.36207    0.83387   0.434  0.66414    
## YEAR2006    -1.09741    0.83581  -1.313  0.18919    
## YEAR2007     1.17068    0.81910   1.429  0.15294    
## YEAR2009    -0.63570    0.82915  -0.767  0.44326    
## YEAR2010     0.58636    0.82072   0.714  0.47496    
## YEAR2011    -1.17724    0.83989  -1.402  0.16102    
## YEAR2014    -0.15946    0.82687  -0.193  0.84708    
## YEAR2015     1.62667    0.82098   1.981  0.04755 *  
## YEAR2018     0.15893    0.82616   0.192  0.84745    
## YEAR2019    -1.40211    0.83908  -1.671  0.09472 .  
## YEAR2020    -2.36727    0.87718  -2.699  0.00696 ** 
## YEAR2021    -1.04840    0.83461  -1.256  0.20906    
## STEMP        0.05124    0.02720   1.884  0.05953 .  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model Diagnostics

The diagnostics for the final model were acceptable.

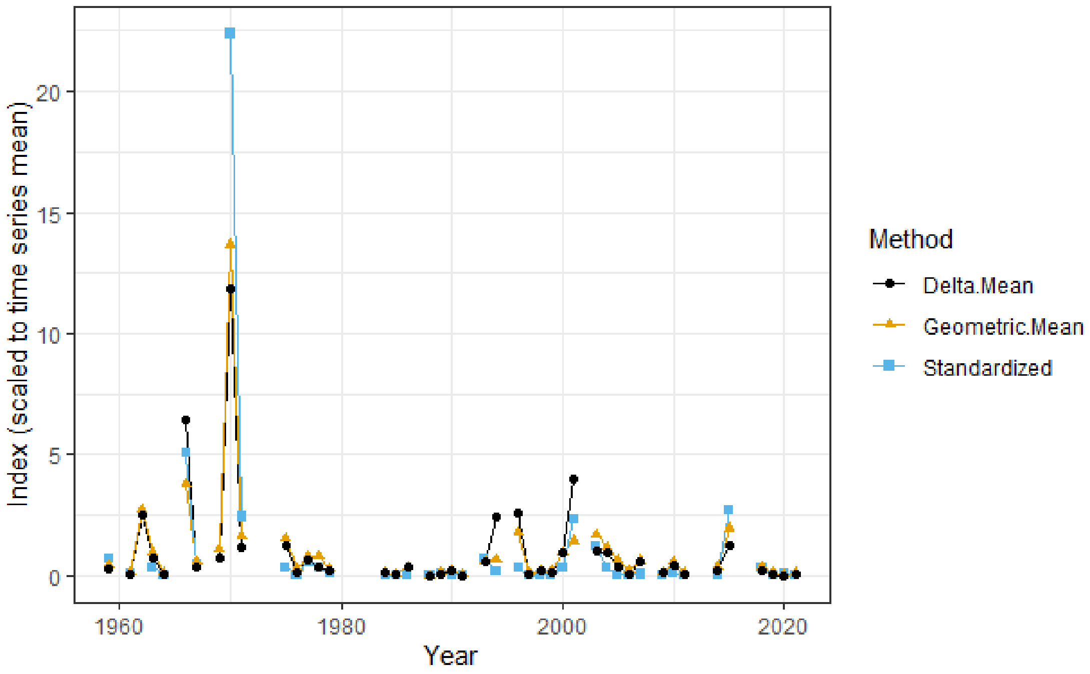

DHARMa residual
QQ plot residuals
KS test: p= 0.53969
Deviation n.s.
Dispersion test: p= 0.98
Deviation n.s.
Outlier test: p= 0.66888
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)

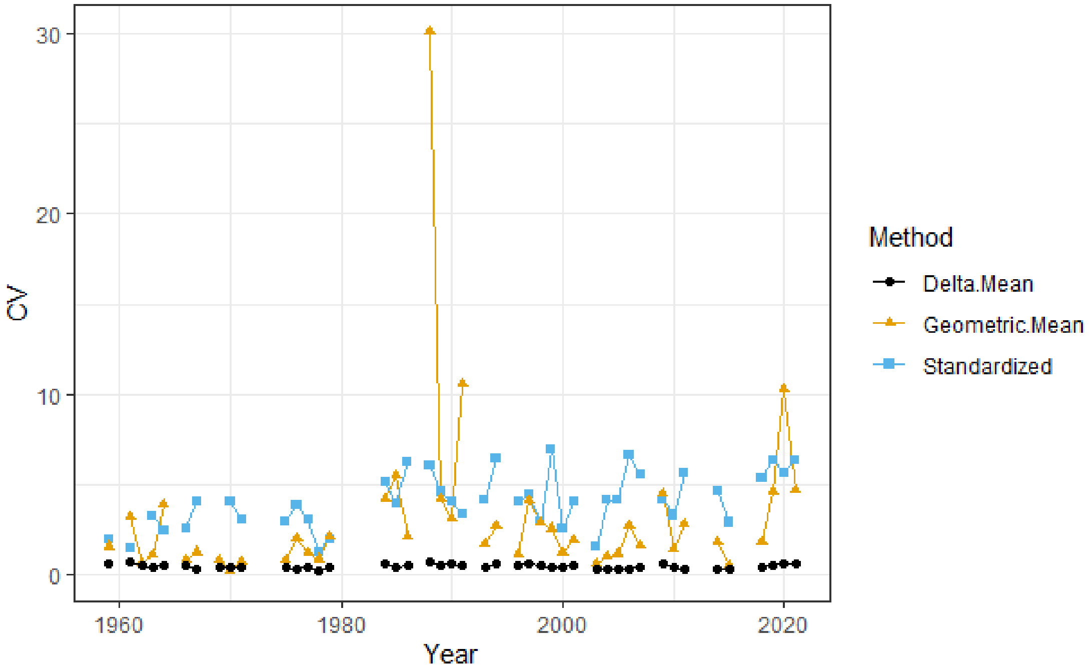

Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1959
1966
1975
1984
1990
1997
2003
2009
2018
catPred



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve appreciably upon the delta mean so the delta mean index was selected for use in modelling.


Index (scaled to time series mean)
0
5
10
15
20
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
10
20
30
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1959	6.859	1.97	1.133	1.53	2.745	0.54
1960						
1961	1.131	1.46	0.348	3.22	0.500	0.68
1962			6.566	0.60	27.109	0.47
1963	3.343	3.23	2.256	1.05	7.455	0.42
1964	0.577	2.40	0.303	3.89	0.604	0.51
1965						
1966	52.149	2.56	9.209	0.75	68.690	0.47
1967	4.541	4.02	1.494	1.23	4.062	0.32
1968						
1969			2.723	0.82	7.564	0.40
1970	230.706	4.01	33.223	0.14	125.831	0.39
1971	25.138	3.04	4.004	0.68	12.612	0.37
1972						
1973						
1974						
1975	3.346	2.96	3.750	0.78	13.108	0.36
1976	0.410	3.85	0.697	1.97	1.483	0.32
1977	6.071	3.01	1.998	1.15	7.069	0.38
1978	3.422	1.27	1.944	0.83	3.624	0.21
1979	1.000	1.96	0.768	2.04	2.192	0.41
1980						
1981						
1982						

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1983						
1984	0.145	5.11	0.321	4.16	1.180	0.59
1985	0.138	3.95	0.195	5.48	0.294	0.37
1986	0.113	6.25	0.892	2.05	3.690	0.46
1987						
1988	0.074	6.03	0.034	30.13	0.048	0.70
1989	0.956	4.57	0.284	4.21	0.695	0.48
1990	0.322	4.01	0.507	3.06	2.346	0.54
1991	0.506	3.34	0.099	10.54	0.158	0.51
1992						
1993	7.455	4.13	1.381	1.70	6.341	0.40
1994	1.802	6.43	1.604	2.72	26.205	0.62
1995						
1996	3.546	4.00	4.302	1.11	27.329	0.48
1997	0.170	4.39	0.301	4.10	0.840	0.54
1998	0.519	2.92	0.524	2.86	1.994	0.51
1999	0.090	6.94	0.518	2.53	1.159	0.34
2000	3.167	2.52	2.284	1.20	10.121	0.40
2001	24.054	4.00	3.488	1.85	42.372	0.53
2002						
2003	12.314	1.52	4.193	0.54	10.867	0.32
2004	3.051	4.12	2.824	0.98	10.322	0.32
2005	0.474	4.13	1.604	1.13	4.029	0.30
2006	0.465	6.61	0.457	2.65	0.839	0.30
2007	0.678	5.51	1.504	1.54	6.538	0.42

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2008						
2009	0.454	4.13	0.302	4.46	1.304	0.56
2010	0.745	3.29	1.411	1.39	4.656	0.37
2011	0.060	5.60	0.416	2.82	0.713	0.29
2012						
2013						
2014	0.324	4.65	0.834	1.82	2.127	0.32
2015	28.015	2.89	4.747	0.51	13.299	0.30
2016						
2017						
2018	3.094	5.33	0.905	1.78	2.546	0.35
2019	0.241	6.33	0.262	4.60	0.695	0.48
2020	0.864	5.63	0.104	10.26	0.216	0.62
2021	0.327	6.34	0.263	4.71	0.850	0.55

MD Estuarine Juvenile Finfish Seine Alewife Survey Standardization - Nanticoke

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset had 20.12% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
NB2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL,
               data = dat,
               family = nbinom2)
NB3 <- glmmTMB(FREQ~YEAR + MONTH+STEMP+SSAL,
```

```
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the zero-inflated negative binomial.

```
##         dAIC  df
## ZINB.2   0.0 71
## NB3     11.3 60
## NB2     12.5 61
## NB1     15.0 63
## ZANB    25.0 125
## ZINB      NA 125
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-inflated negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

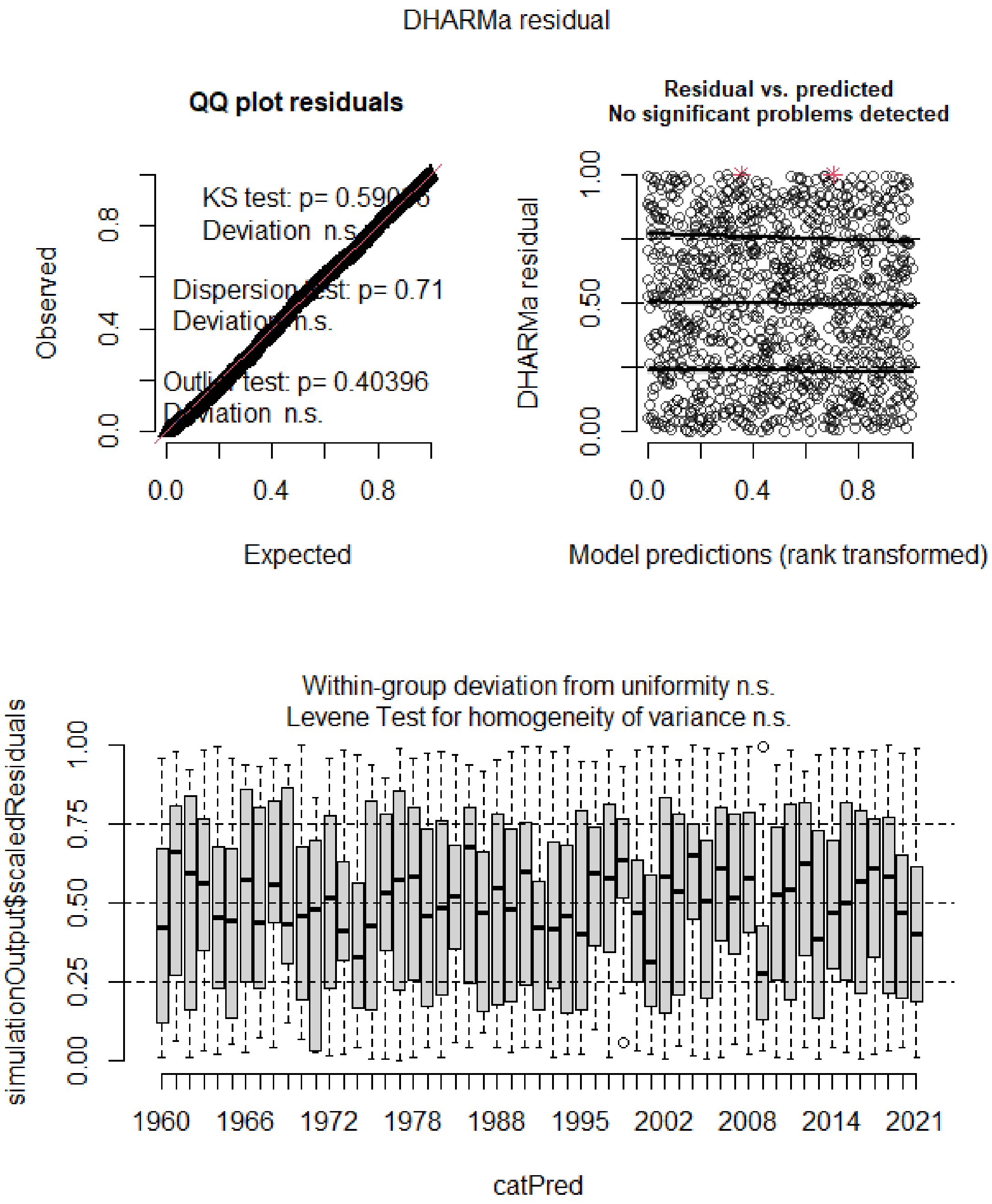
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MONTH + DEPTH + STEMP
## Zero inflation:        ~MONTH + STEMP + SSAL
## Data: dat
##
```

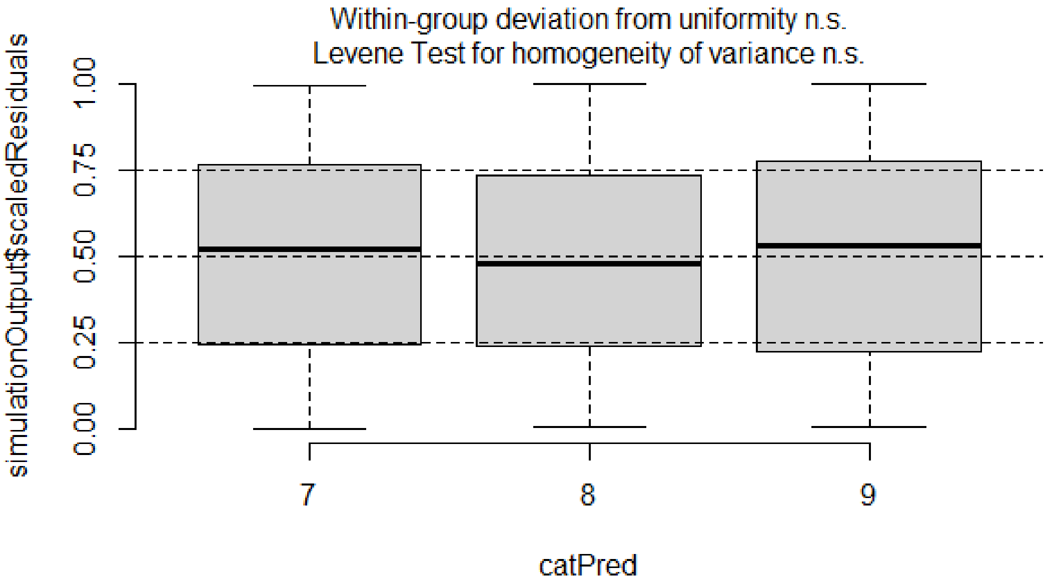
```
##      AIC      BIC   logLik deviance df.resid
##   2083.2   2411.4   -976.6   1953.2     1088
##
##
## Dispersion parameter for nbinom2 family (): 0.281
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  6.66794    2.71898   2.452 0.014192 *
## YEAR1961     0.09153    1.52452   0.060 0.952126
## YEAR1962    -2.95678    1.12489  -2.629 0.008576 **
## YEAR1963     0.15240    1.19597   0.127 0.898601
## YEAR1964    -0.72060    1.18634  -0.607 0.543575
## YEAR1965    -2.34762    1.16324  -2.018 0.043573 *
## YEAR1966    -2.46457    1.16764  -2.111 0.034796 *
## YEAR1967    -1.55678    1.04943  -1.483 0.137955
## YEAR1968     0.33859    1.07326   0.315 0.752395
## YEAR1969    -1.48605    1.16086  -1.280 0.200500
## YEAR1970    -0.06843    1.20680  -0.057 0.954783
## YEAR1971    -3.26783    1.62800  -2.007 0.044721 *
## YEAR1972    -2.55930    1.03152  -2.481 0.013098 *
## YEAR1973    -2.75658    1.15171  -2.393 0.016690 *
## YEAR1974     0.25944    1.11896   0.232 0.816647
## YEAR1975    -2.27848    1.10103  -2.069 0.038507 *
## YEAR1976    -3.74924    1.21368  -3.089 0.002007 **
## YEAR1977    -3.62920    1.31751  -2.755 0.005877 **
## YEAR1978    -3.24135    1.12718  -2.876 0.004032 **
## YEAR1979    -2.60674    1.09532  -2.380 0.017318 *
## YEAR1980    -2.01439    1.08235  -1.861 0.062727 .
## YEAR1984    -2.60755    1.18135  -2.207 0.027296 *
## YEAR1985    -0.92065    1.10710  -0.832 0.405639
## YEAR1987    -1.68531    1.36162  -1.238 0.215817
## YEAR1988    -2.96795    1.17070  -2.535 0.011239 *
## YEAR1989    -4.90619    1.41270  -3.473 0.000515 ***
## YEAR1990    -2.18960    1.12772  -1.942 0.052183 .
## YEAR1991    -1.34358    1.07471  -1.250 0.211235
## YEAR1993     0.42204    1.04761   0.403 0.687049
## YEAR1994    -2.20229    1.03726  -2.123 0.033739 *
## YEAR1995    -1.95123    1.14747  -1.700 0.089044 .
## YEAR1996    -0.41969    1.00714  -0.417 0.676885
## YEAR1998    -3.29775    1.10089  -2.996 0.002740 **
## YEAR1999    -1.54966    1.10500  -1.402 0.160791
## YEAR2000    -2.78021    1.05106  -2.645 0.008165 **
## YEAR2001    -2.19118    1.01464  -2.160 0.030807 *
## YEAR2002    -1.97812    1.11887  -1.768 0.077067 .
## YEAR2003    -1.08487    1.01590  -1.068 0.285568
## YEAR2004    -1.59701    1.02949  -1.551 0.120839
## YEAR2005    -2.94503    1.08929  -2.704 0.006859 **
## YEAR2006    -3.51297    1.12691  -3.117 0.001825 **
## YEAR2007    -0.97247    1.06606  -0.912 0.361659
```

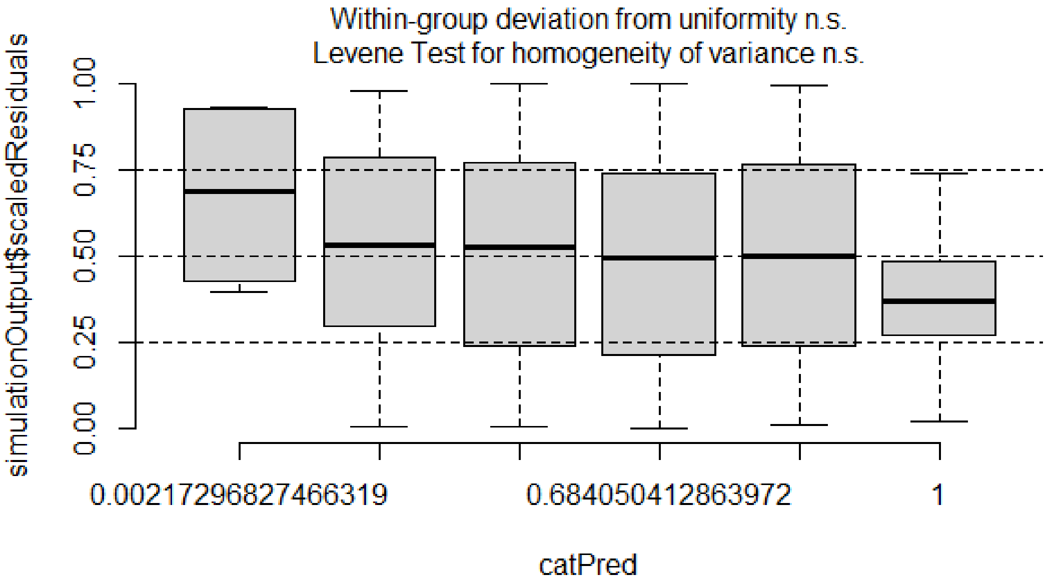
```
## YEAR2008    -4.49499    1.44735  -3.106 0.001898 **
## YEAR2009    -0.80678    1.01179  -0.797 0.425230
## YEAR2010    -0.42788    1.08658  -0.394 0.693741
## YEAR2011    -2.33345    1.07855  -2.164 0.030503 *
## YEAR2012    -1.97962    1.22908  -1.611 0.107257
## YEAR2013    -3.76046    1.14559  -3.283 0.001029 **
## YEAR2014    -5.00934    1.42225  -3.522 0.000428 ***
## YEAR2015    -0.63331    1.04650  -0.605 0.545067
## YEAR2017    -4.18701    1.22034  -3.431 0.000601 ***
## YEAR2018    -2.92444    1.16005  -2.521 0.011704 *
## YEAR2019    -3.56385    1.17452  -3.034 0.002411 **
## YEAR2020    -2.83381    1.13789  -2.490 0.012759 *
## YEAR2021    -3.81997    1.17166  -3.260 0.001113 **
## MONTH8       0.04880    0.28385   0.172 0.863495
## MONTH9      -1.11071    0.39564  -2.807 0.004994 **
## DEPTH        0.28617    0.15343   1.865 0.062150 .
## STEMP       -0.20579    0.09176  -2.243 0.024913 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -19.3624     6.7342  -2.875 0.004037 **
## MONTH8        0.9110     0.6021   1.513 0.130274
## MONTH9        1.7650     0.8251   2.139 0.032413 *
## STEMP         0.5241     0.2001   2.620 0.008804 **
## SSAL          0.5501     0.1614   3.407 0.000656 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

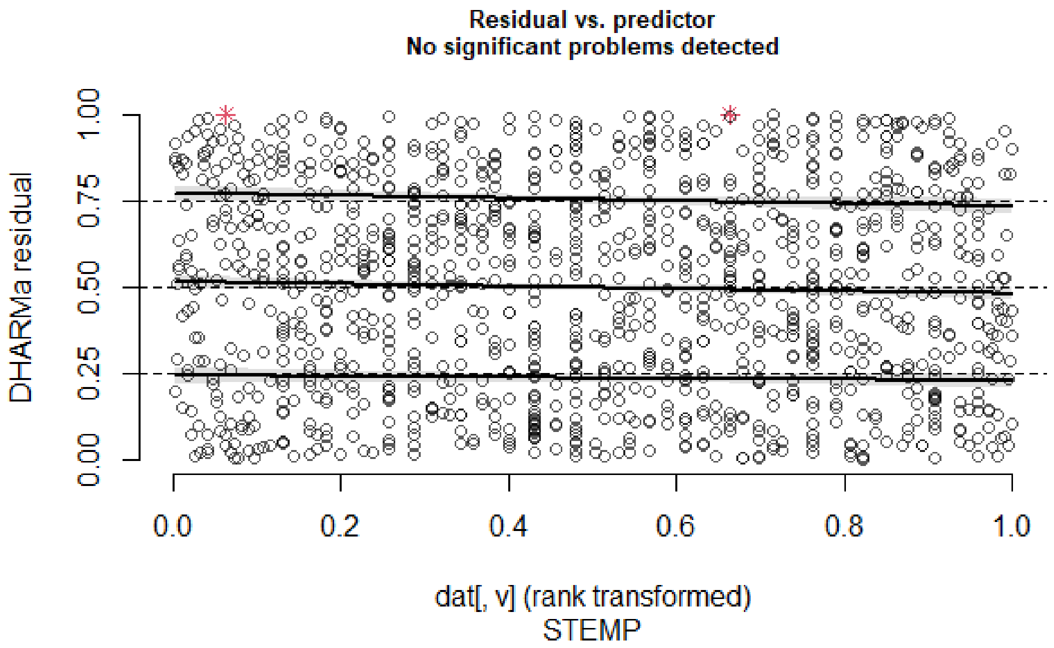
Model Diagnostics

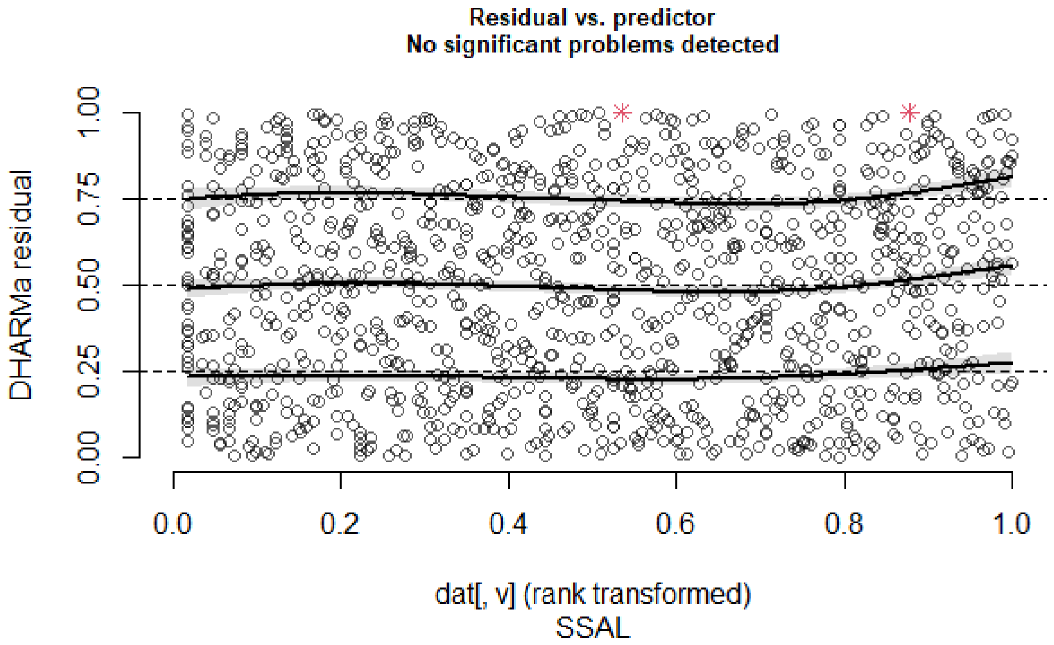
The diagnostics for the zero-inflated negative binomial were acceptable.


DHARMa residual
QQ plot residuals
KS test: p= 0.590
Deviation n.s.
Dispersion test: p= 0.71
Deviation n.s.
Outlier test: p= 0.40396
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
catPred
1960
1966
1972
1978
1988
1995
2002
2008
2014
2021


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
7
8
9
catPred

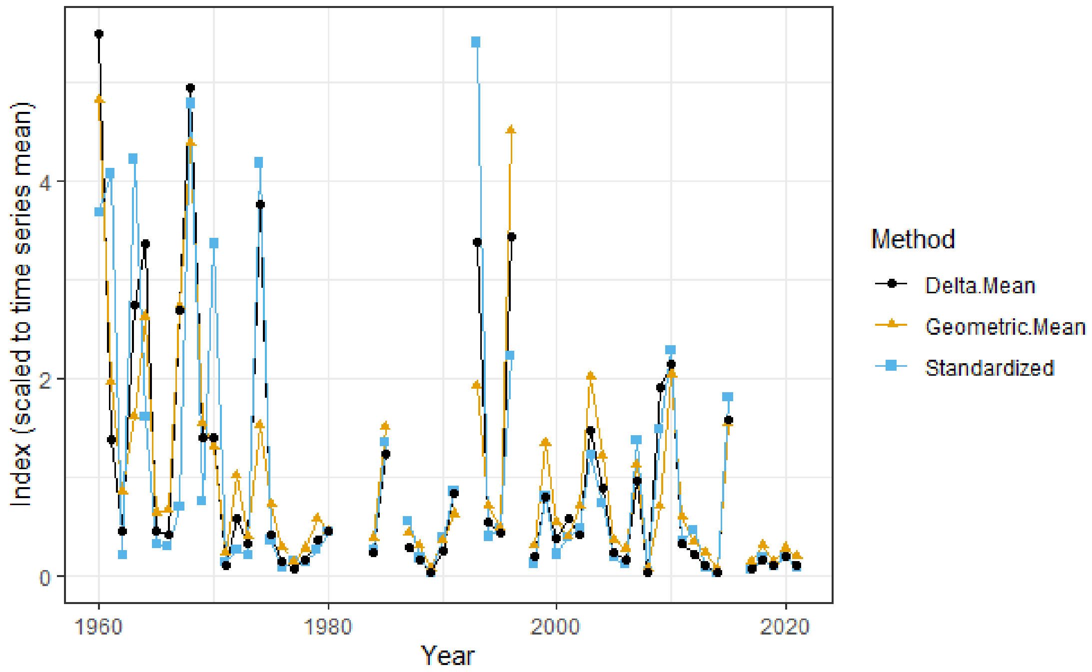

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.00217296827466319
0.684050412863972
1
catPred

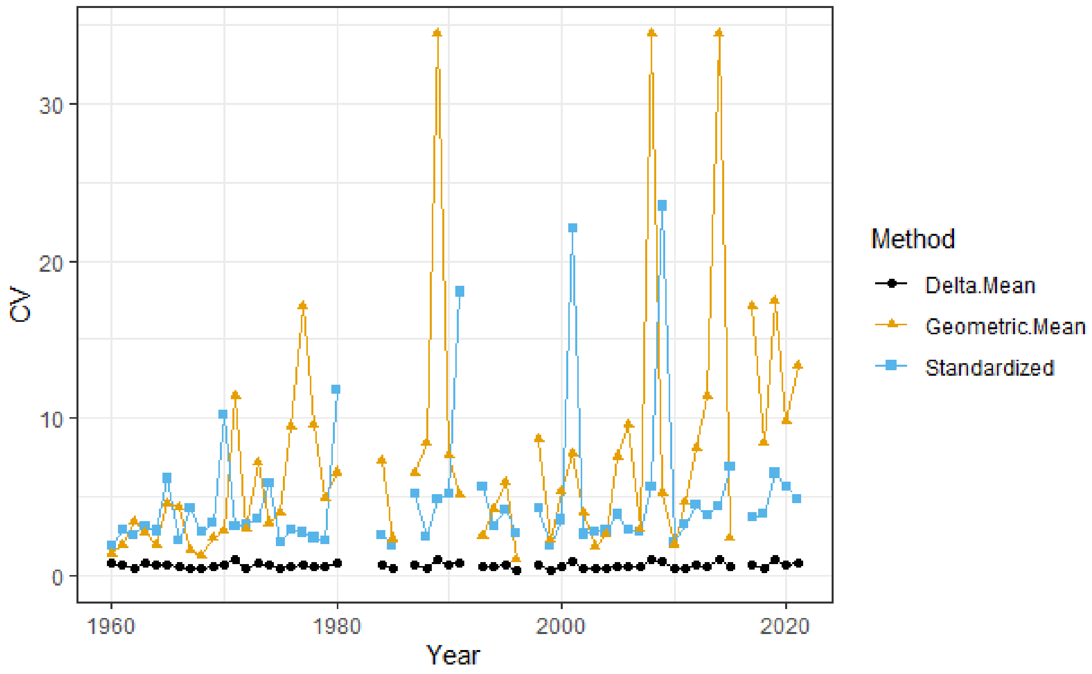




Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The delta mean index was selected for use in modelling.


Index (scaled to time series mean)
0
2
4
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
10
20
30
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1960	5.784	1.84	1.884	1.40	5.963	0.74
1961	6.391	2.89	0.763	1.93	1.500	0.64
1962	0.317	2.57	0.330	3.38	0.496	0.44
1963	6.618	3.14	0.628	2.77	2.983	0.75
1964	2.532	2.83	1.025	1.91	3.653	0.68
1965	0.486	6.16	0.251	4.57	0.497	0.65
1966	0.461	2.17	0.260	4.31	0.446	0.53
1967	1.093	4.31	1.063	1.60	2.924	0.46
1968	7.506	2.74	1.713	1.29	5.370	0.41
1969	1.191	3.31	0.600	2.37	1.515	0.59
1970	5.280	10.20	0.510	2.86	1.526	0.66
1971	0.205	3.10	0.091	11.39	0.125	1.00
1972	0.414	3.23	0.394	2.92	0.624	0.40
1973	0.330	3.60	0.155	7.15	0.350	0.76
1974	6.563	5.90	0.593	3.35	4.094	0.68
1975	0.568	2.12	0.282	3.94	0.450	0.44
1976	0.120	2.88	0.110	9.43	0.150	0.55
1977	0.245	2.72	0.059	17.14	0.083	0.69
1978	0.220	2.37	0.109	9.56	0.166	0.58
1979	0.406	2.24	0.227	4.88	0.395	0.54
1980	0.694	11.78	0.177	6.55	0.500	0.76
1981						
1982						
1983						
1984	0.409	2.56	0.147	7.29	0.250	0.68

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1985	2.118	1.92	0.588	2.32	1.346	0.49
1986						
1987	0.871	5.16	0.168	6.52	0.312	0.70
1988	0.282	2.45	0.122	8.46	0.167	0.47
1989	0.040	4.85	0.029	34.47	0.042	1.00
1990	0.600	5.16	0.142	7.66	0.280	0.68
1991	1.340	18.02	0.244	5.14	0.910	0.79
1992						
1993	8.475	5.64	0.754	2.51	3.672	0.59
1994	0.624	3.15	0.278	4.23	0.599	0.56
1995	0.751	4.16	0.194	5.90	0.475	0.69
1996	3.488	2.65	1.761	0.96	3.729	0.31
1997						
1998	0.197	4.26	0.122	8.63	0.205	0.62
1999	1.255	1.88	0.523	2.30	0.866	0.34
2000	0.338	3.53	0.209	5.35	0.415	0.58
2001	0.612	22.07	0.152	7.70	0.625	0.93
2002	0.741	2.61	0.278	4.01	0.452	0.42
2003	1.922	2.81	0.785	1.76	1.592	0.39
2004	1.142	2.85	0.478	2.64	0.967	0.42
2005	0.289	3.86	0.142	7.57	0.251	0.61
2006	0.179	2.89	0.109	9.56	0.166	0.58
2007	2.158	2.77	0.438	2.96	1.038	0.52
2008	0.060	5.64	0.029	34.47	0.042	1.00
2009	2.331	23.49	0.279	5.21	2.076	0.89
2010	3.587	2.12	0.798	1.98	2.334	0.49

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2011	0.548	3.21	0.235	4.62	0.359	0.42
2012	0.727	4.46	0.133	8.06	0.243	0.66
2013	0.130	3.81	0.091	11.36	0.125	0.55
2014	0.037	4.41	0.029	34.47	0.042	1.00
2015	2.827	6.88	0.602	2.41	1.707	0.51
2016						
2017	0.085	3.69	0.059	17.14	0.083	0.69
2018	0.294	3.92	0.122	8.46	0.167	0.47
2019	0.150	6.49	0.059	17.50	0.125	1.00
2020	0.308	5.65	0.109	9.76	0.208	0.71
2021	0.118	4.80	0.078	13.34	0.125	0.73

MD Estuarine Juvenile Finfish Seine Alewife Survey Standardization - Potomac

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset had 16.81% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered model had convergence problems.

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated model had convergence problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR +DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  data = dat,
                  family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the negative binomial.

```
##         dAIC df
## NB1      0  71
## ZINB    NA  137
## ZINB.2  NA  82
## ZANB    NA  137
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

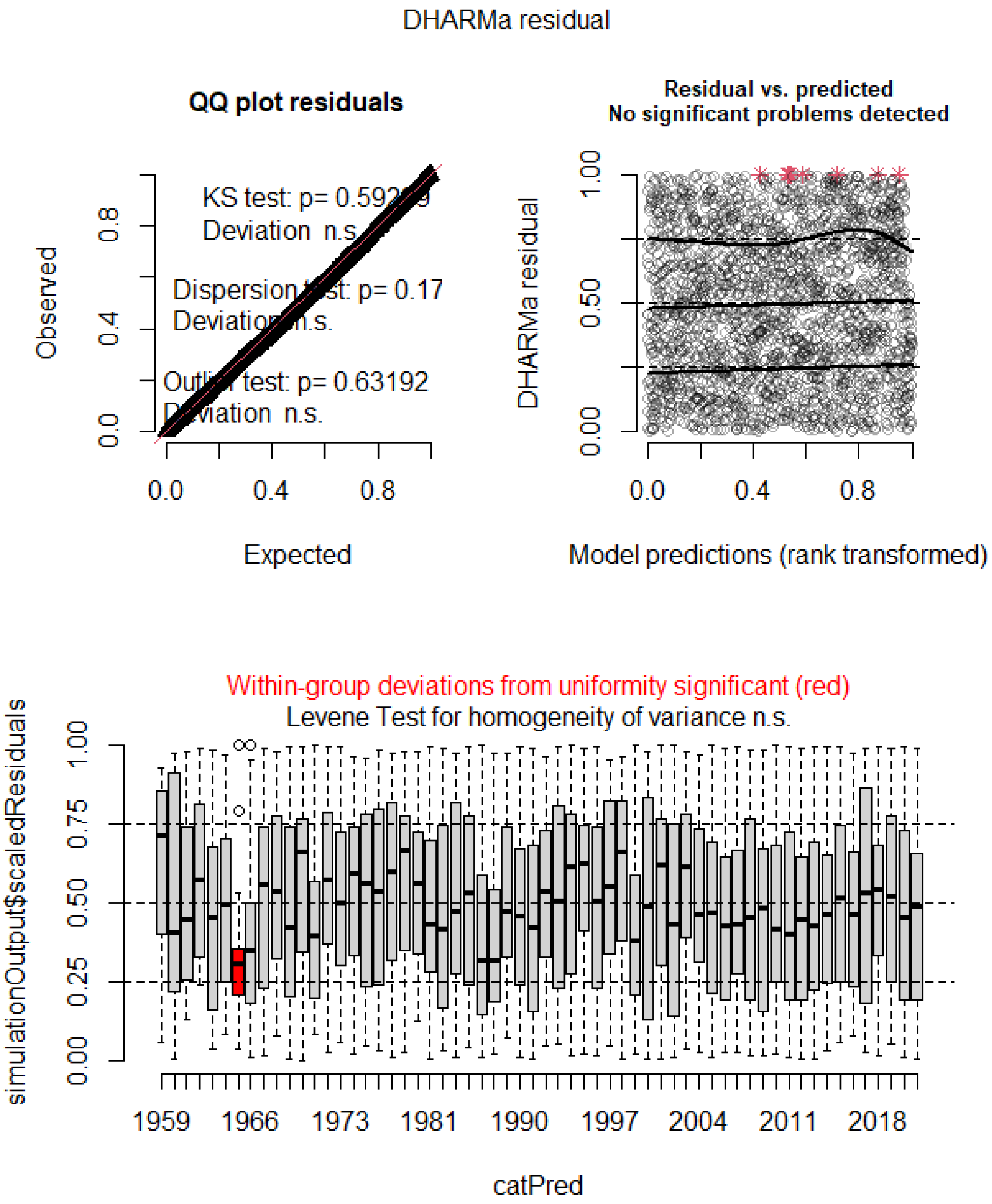
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + SSAL + SAV.Percentage
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   4023.8   4411.5  -1943.9   3887.8     2145
##
##
## Dispersion parameter for nbinom2 family (): 0.103
##
```

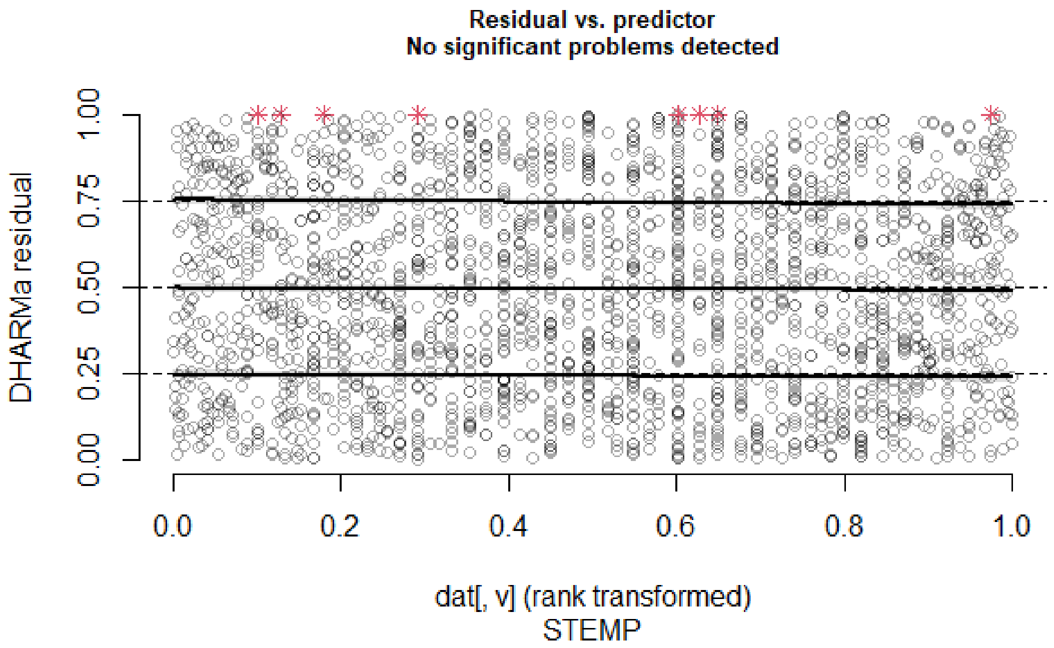
```
## Conditional model:
##                                     Estimate Std. Error z value Pr(>|z|)
## (Intercept)                        7.216e+00  1.696e+00   4.254  2.1e-05
***
## YEAR1960                          -3.987e+00  1.825e+00  -2.185 0.028887 *
## YEAR1961                          -1.248e+00  1.337e+00  -0.933 0.350752
## YEAR1962                          -1.759e+00  1.235e+00  -1.425 0.154176
## YEAR1963                          -1.773e+00  1.257e+00  -1.410 0.158479
## YEAR1964                          -5.217e-01  1.254e+00  -0.416 0.677310
## YEAR1965                           2.373e+00  1.284e+00   1.848 0.064633 .
## YEAR1966                           3.414e+00  1.156e+00   2.953 0.003147
**
## YEAR1967                          -5.429e+00  1.585e+00  -3.425 0.000616
***
## YEAR1968                          -4.794e+00  1.607e+00  -2.984 0.002845
**
## YEAR1969                          -6.999e-01  1.234e+00  -0.567 0.570763
## YEAR1970                           9.288e-01  1.171e+00   0.794 0.427480
## YEAR1971                           1.632e+00  1.185e+00   1.378 0.168268
## YEAR1972                          -7.040e-01  1.190e+00  -0.592 0.554163
## YEAR1973                          -1.033e+00  1.213e+00  -0.852 0.394330
## YEAR1975                           1.573e-01  1.188e+00   0.132 0.894647
## YEAR1976                          -4.103e+00  1.260e+00  -3.256 0.001130
**
## YEAR1977                          -3.436e-01  1.172e+00  -0.293 0.769492
## YEAR1978                           4.564e-03  1.155e+00   0.004 0.996847
## YEAR1979                          -7.826e-01  1.167e+00  -0.670 0.502556
## YEAR1980                          -2.718e-02  1.160e+00  -0.023 0.981299
## YEAR1981                          -3.269e+00  1.206e+00  -2.709 0.006740
**
## YEAR1984                          -4.350e+00  1.373e+00  -3.168 0.001536
**
## YEAR1985                          -1.940e+00  1.171e+00  -1.657 0.097527 .
## YEAR1986                          -3.082e-01  1.130e+00  -0.273 0.785131
## YEAR1987                          -2.116e+00  1.241e+00  -1.705 0.088157 .
## YEAR1988                          -5.060e+00  1.466e+00  -3.452 0.000556
***
## YEAR1989                          -4.237e+00  1.234e+00  -3.435 0.000593
***
## YEAR1990                          -2.737e+00  1.277e+00  -2.143 0.032082 *
## YEAR1991                           1.048e+00  1.217e+00   0.861 0.389333
## YEAR1992                          -3.330e+00  1.291e+00  -2.579 0.009906
**
## YEAR1993                          -2.290e+00  1.217e+00  -1.882 0.059893 .
## YEAR1994                          -2.366e+00  1.190e+00  -1.988 0.046842 *
## YEAR1995                          -3.639e+00  1.242e+00  -2.930 0.003394
**
## YEAR1996                          -2.409e+00  1.169e+00  -2.061 0.039281 *
## YEAR1997                          -2.946e+00  1.190e+00  -2.475 0.013328 *
## YEAR1998                          -2.127e+00  1.233e+00  -1.726 0.084363 .
```

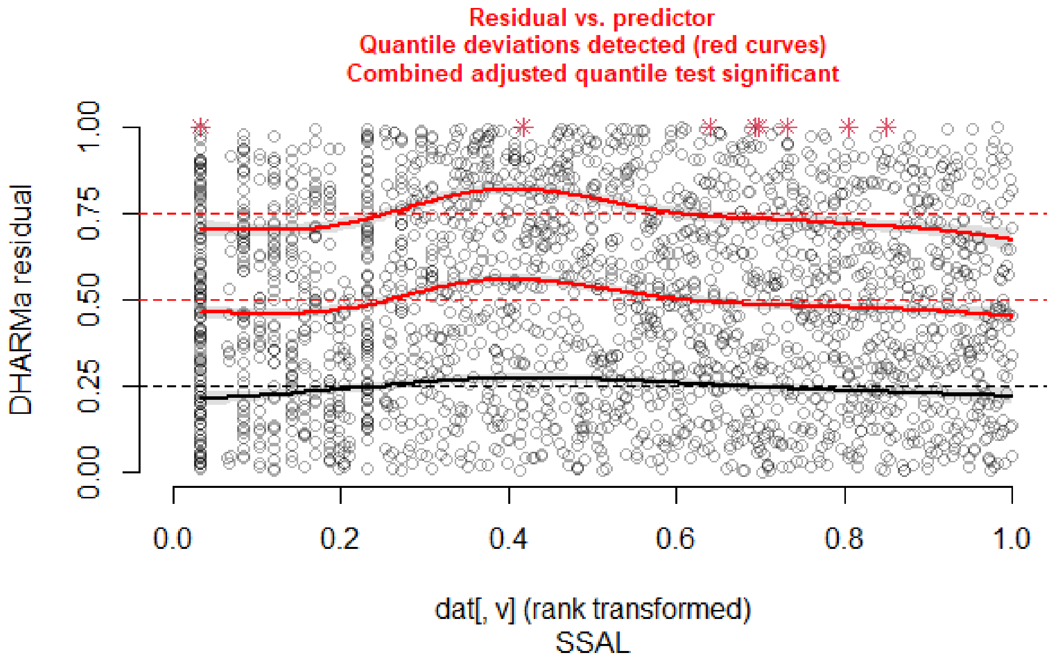
```
## YEAR1999                           -7.378e-01  1.157e+00  -0.638 0.523621    
## YEAR2000                           -1.100e+00  1.186e+00  -0.927 0.353937    
## YEAR2001                           -8.827e-01  1.156e+00  -0.764 0.444983    
## YEAR2002                           -5.569e+00  1.610e+00  -3.458 0.000544 
***
## YEAR2003                           -1.807e+00  1.142e+00  -1.582 0.113747    
## YEAR2004                           -2.111e+00  1.159e+00  -1.821 0.068561 .  
## YEAR2005                           -3.534e+00  1.227e+00  -2.880 0.003971 
**
## YEAR2006                           -4.904e+00  1.418e+00  -3.459 0.000542 
***
## YEAR2007                            1.804e-01  1.154e+00   0.156 0.875828    
## YEAR2008                           -2.275e+01  4.364e+03  -0.005 0.995841    
## YEAR2009                           -2.265e+00  1.204e+00  -1.881 0.060020 .  
## YEAR2010                           -2.343e-01  1.157e+00  -0.202 0.839552    
## YEAR2011                            1.234e+00  1.150e+00   1.073 0.283176    
## YEAR2012                           -5.319e+00  1.616e+00  -3.290 0.001000 
**
## YEAR2013                           -2.278e+01  4.411e+03  -0.005 0.995879    
## YEAR2014                           -1.739e+00  1.169e+00  -1.488 0.136720    
## YEAR2015                           -1.510e+00  1.175e+00  -1.285 0.198879    
## YEAR2016                           -2.252e+01  4.625e+03  -0.005 0.996114    
## YEAR2017                           -2.207e+01  3.030e+03  -0.007 0.994189    
## YEAR2018                           -1.245e+00  1.157e+00  -1.076 0.281974    
## YEAR2019                           -3.229e+00  1.257e+00  -2.568 0.010222 *  
## YEAR2020                           -5.312e+00  1.613e+00  -3.294 0.000989 
***
## YEAR2021                           -3.060e+00  1.241e+00  -2.465 0.013690 *  
## STEMP                              -1.472e-01  5.039e-02  -2.920 0.003495 
**
## SSAL                               -3.161e-01  3.160e-02 -10.002  < 2e-16 
***
## SAV.Percentage1 HF TO 3 FRTH PLTS  2.752e-02  8.748e-01   0.031 0.974906    
## SAV.Percentage3 FRTH TO COMP PLTS  3.025e+00  2.344e+00   1.291 0.196830    
## SAV.PercentageNO AQUATIC PLANTS   -6.772e-01  5.727e-01  -1.182 0.237037    
## SAV.PercentageUNKNOWN             -2.021e+00  8.710e-01  -2.320 0.020353 *  
## SAV.PercentageUP TO 1 FOURTH PLTS  3.206e-01  6.020e-01   0.533 0.594350    
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

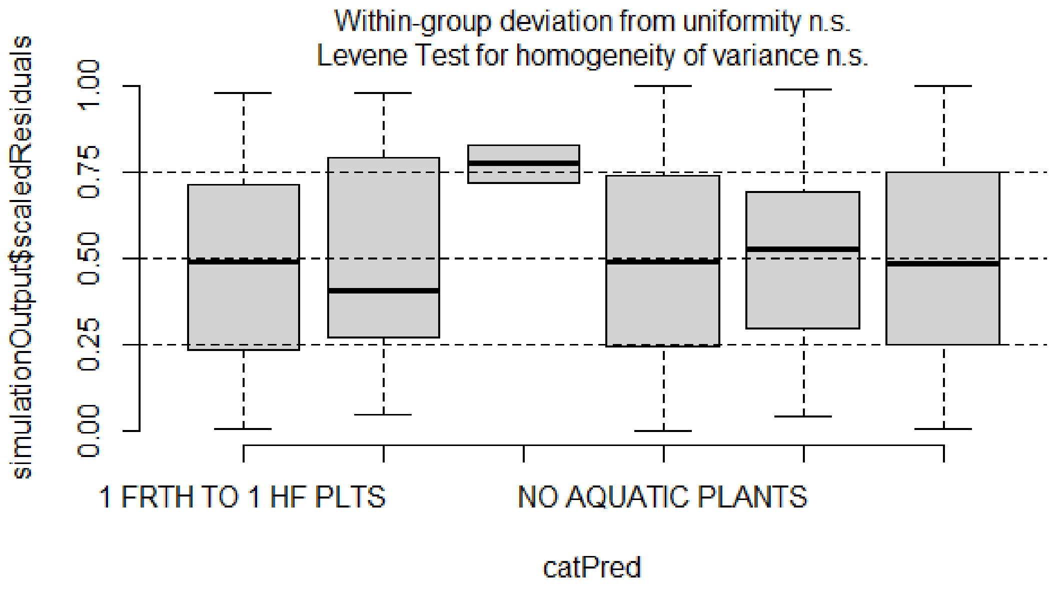
Model Diagnostics

The diagnostics for the final model were acceptable.


DHARMa residual
QQ plot residuals
KS test: p= 0.592[illegible]9
Deviation n.s.
Dispersion test: p= 0.17
Deviation n.s.
Outlier test: p= 0.63192
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)
0.0
0.4
0.8
Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1959
1966
1973
1981
1990
1997
2004
2011
2018
catPred

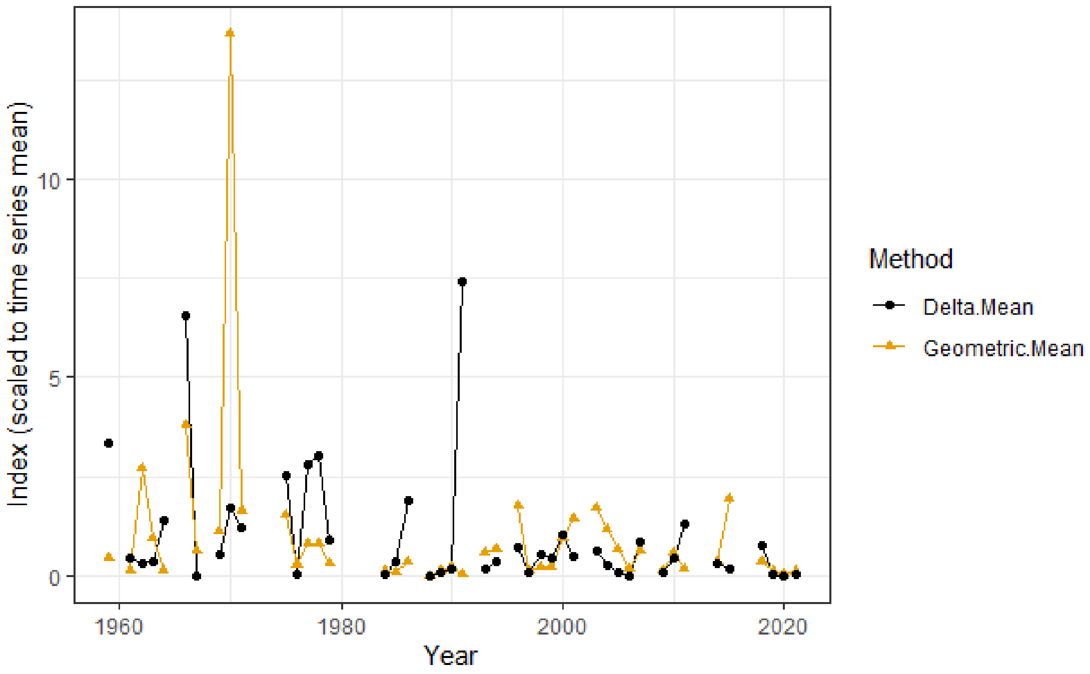

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP


Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
SSAL

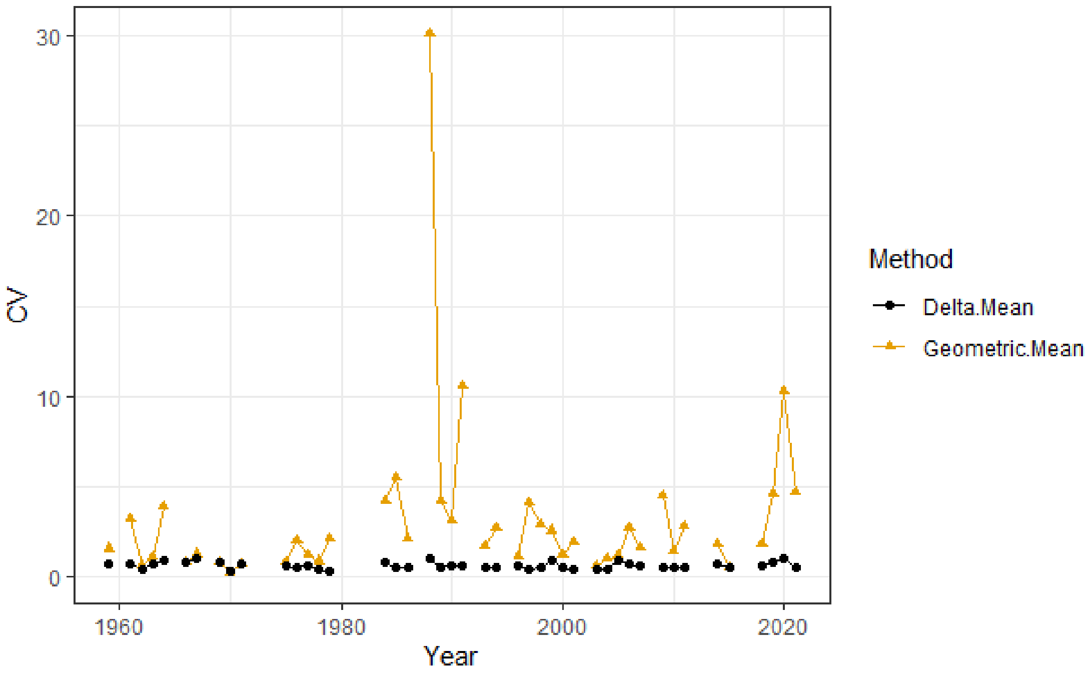


Index Comparisons

There were errors calculating the standardized index. The delta mean index was selected for use in modelling.



Index (scaled to time series mean)
0
5
10
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean



CV
0
10
20
30
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean

Nominal indices and CVs

Year	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1959	1.133	1.53	11.066	0.70
1960				
1961	0.348	3.22	1.438	0.69
1962	6.566	0.60	1.044	0.36
1963	2.256	1.05	1.125	0.64
1964	0.303	3.89	4.632	0.85
1965				
1966	9.209	0.75	21.745	0.75
1967	1.494	1.23	0.025	1.00
1968				
1969	2.723	0.82	1.736	0.75
1970	33.223	0.14	5.640	0.33
1971	4.004	0.68	4.078	0.72
1972				
1973				
1974				
1975	3.750	0.78	8.395	0.56
1976	0.697	1.97	0.201	0.45
1977	1.998	1.15	9.192	0.63
1978	1.944	0.83	9.986	0.41
1979	0.768	2.04	2.913	0.33
1980				
1981				
1982				

Year	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1983				
1984	0.321	4.16	0.094	0.74
1985	0.195	5.48	1.224	0.53
1986	0.892	2.05	6.240	0.46
1987				
1988	0.034	30.13	0.050	1.00
1989	0.284	4.21	0.210	0.49
1990	0.507	3.06	0.592	0.59
1991	0.099	10.54	24.565	0.63
1992				
1993	1.381	1.70	0.530	0.51
1994	1.604	2.72	1.247	0.51
1995				
1996	4.302	1.11	2.345	0.57
1997	0.301	4.10	0.300	0.34
1998	0.524	2.86	1.809	0.44
1999	0.518	2.53	1.468	0.87
2000	2.284	1.20	3.356	0.52
2001	3.488	1.85	1.555	0.39
2002				
2003	4.193	0.54	2.145	0.42
2004	2.824	0.98	0.924	0.42
2005	1.604	1.13	0.286	0.92
2006	0.457	2.65	0.048	0.70
2007	1.504	1.54	2.796	0.57

Year	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2008				
2009	0.302	4.46	0.229	0.51
2010	1.411	1.39	1.438	0.45
2011	0.416	2.82	4.352	0.51
2012				
2013				
2014	0.834	1.82	1.081	0.64
2015	4.747	0.51	0.575	0.46
2016				
2017				
2018	0.905	1.78	2.514	0.55
2019	0.262	4.60	0.119	0.82
2020	0.104	10.26	0.024	1.00
2021	0.263	4.71	0.191	0.45

MD Estuarine Juvenile Finfish Seine Blueback Herring Survey Standardization - Head of Bay

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset had 37.81% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-inflated negative binomial had convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial had convergence problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  data = dat,
                  family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the zero-altered negative binomial.

```
##        dAIC  df
## ZANB     0.0 137
## NB1    142.1 69
## ZINB      NA 137
## ZINB.2    NA 81
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

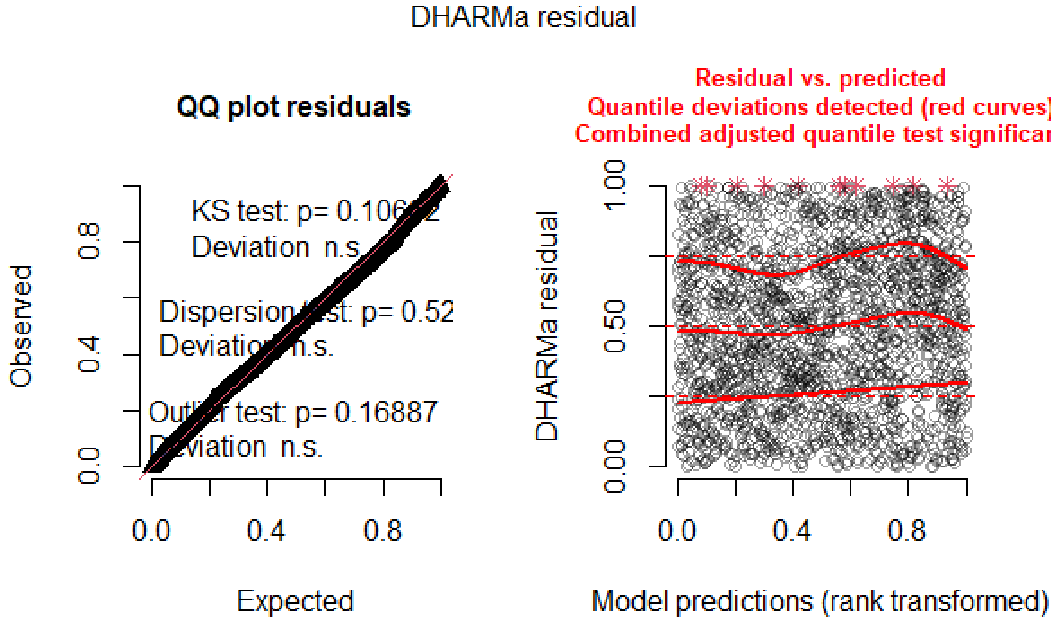
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MONTH + DEPTH + STEMP + SSAL + 
SAV.Percentage
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   9415.4   9803.5  -4638.7   9277.4     1978
##
##
## Dispersion parameter for nbinom2 family (): 0.128
##
## Conditional model:
```

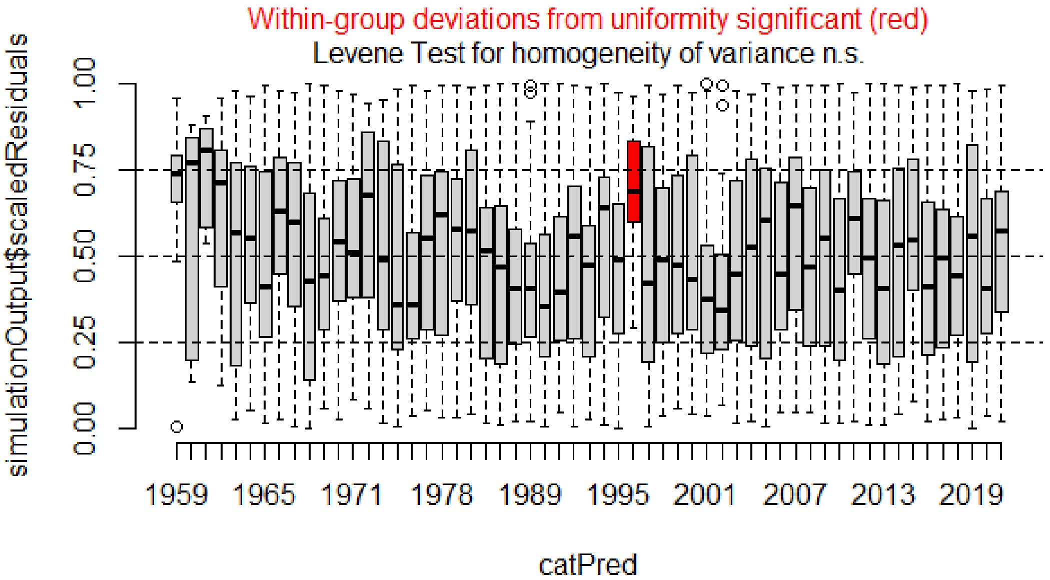
```
##                                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)                        0.60783    1.92060   0.316 0.751639
## YEAR1960                           1.82000    1.48160   1.228 0.219296
## YEAR1961                          -1.09444    1.44994  -0.755 0.450359
## YEAR1962                           2.42834    1.17532   2.066 0.038818 *
## YEAR1963                           1.59626    1.07713   1.482 0.138351
## YEAR1964                           1.58786    1.09567   1.449 0.147277
## YEAR1965                           0.25385    1.06167   0.239 0.811022
## YEAR1966                           1.67010    1.04785   1.594 0.110974
## YEAR1967                           2.32235    1.04697   2.218 0.026544 *
## YEAR1968                           2.63448    1.07241   2.457 0.014026 *
## YEAR1969                           5.90817    1.12062   5.272 1.35e-07 ***
## YEAR1970                           2.98885    1.03889   2.877 0.004015 **
## YEAR1971                          -0.37002    1.06605  -0.347 0.728520
## YEAR1972                          -0.87597    1.04813  -0.836 0.403298
## YEAR1973                          -0.06799    1.12038  -0.061 0.951607
## YEAR1975                          -2.57388    1.10849  -2.322 0.020235 *
## YEAR1976                          -2.55093    1.14318  -2.231 0.025652 *
## YEAR1977                          -3.94479    1.10043  -3.585 0.000337 ***
## YEAR1978                           0.60500    1.03100   0.587 0.557331
## YEAR1979                          -1.58124    1.09628  -1.442 0.149198
## YEAR1980                          -4.08315    1.15659  -3.530 0.000415 ***
## YEAR1984                          -2.56673    1.12115  -2.289 0.022058 *
## YEAR1986                          -1.28274    1.06781  -1.201 0.229644
## YEAR1988                          -3.09455    1.12376  -2.754 0.005892 **
## YEAR1989                          -0.92746    1.07590  -0.862 0.388674
## YEAR1990                           0.33265    1.03157   0.322 0.747097
## YEAR1991                          -0.74054    1.10405  -0.671 0.502382
## YEAR1992                          -4.05233    1.16208  -3.487 0.000488 ***
## YEAR1993                           3.91817    1.04889   3.736 0.000187 ***
## YEAR1994                           1.10658    1.06196   1.042 0.297402
## YEAR1995                           0.80532    1.04209   0.773 0.439649
## YEAR1996                           2.66039    1.06432   2.500 0.012433 *
## YEAR1997                          -0.76944    1.06522  -0.722 0.470092
## YEAR1998                           1.92297    1.01051   1.903 0.057044 .
## YEAR1999                           0.35851    1.09342   0.328 0.743001
## YEAR2000                           0.97707    1.03971   0.940 0.347347
## YEAR2001                           1.68841    1.03166   1.637 0.101713
## YEAR2002                           0.64807    1.11348   0.582 0.560549
## YEAR2003                           3.30168    1.08989   3.029 0.002451 **
## YEAR2004                           1.41422    1.09042   1.297 0.194650
## YEAR2005                          -3.35287    1.13885  -2.944 0.003239 **
## YEAR2006                          -1.70544    1.07488  -1.587 0.112596
## YEAR2007                           0.84107    1.04567   0.804 0.421201
## YEAR2008                          -4.35050    1.11315  -3.908 9.30e-05 ***
## YEAR2009                          -0.60144    1.06308  -0.566 0.571559
## YEAR2010                           0.97273    1.02366   0.950 0.341988
## YEAR2011                           0.70415    1.03142   0.683 0.494794
## YEAR2012                          -2.99856    1.07261  -2.796 0.005181 **
## YEAR2013                          -2.67594    1.02304  -2.616 0.008905 **
```

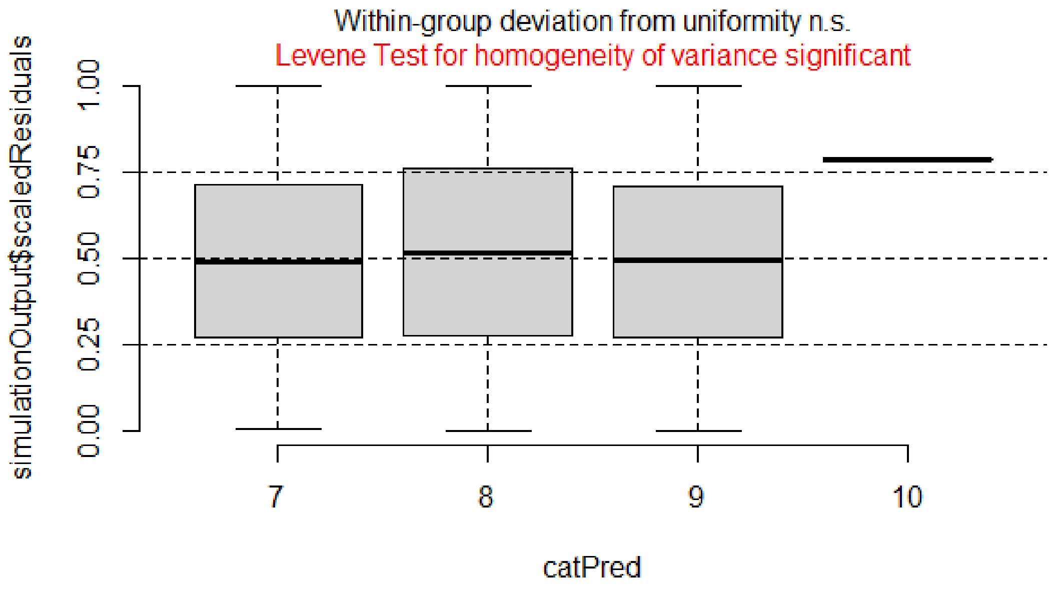
```
## YEAR2014                            -0.82120    1.02198  -0.804 0.421665    
## YEAR2015                             1.93010    1.03125   1.872 0.061260 .  
## YEAR2016                            -2.97049    1.04463  -2.844 0.004461 ** 
## YEAR2017                            -0.39125    1.05184  -0.372 0.709919    
## YEAR2018                             0.45573    1.03320   0.441 0.659151    
## YEAR2019                             1.39145    1.01129   1.376 0.168849    
## YEAR2020                            -2.02276    1.01426  -1.994 0.046116 *  
## YEAR2021                            -1.24441    1.01579  -1.225 0.220551    
## MONTH8                               0.88080    0.21658   4.067 4.77e-05 ***
## MONTH9                               1.85208    0.29280   6.325 2.53e-10 ***
## MONTH10                              5.91017    2.11096   2.800 0.005114 ** 
## DEPTH                                0.20468    0.10882   1.881 0.059995 .  
## STEMP                               -0.01004    0.04646  -0.216 0.828948    
## SSAL                                -0.32627    0.05048  -6.464 1.02e-10 ***
## SAV.Percentage1 HF TO 3 FRTH PLTS  0.72533    0.55198   1.314 0.188830    
## SAV.Percentage3 FRTH TO COMP PLTS -3.32989    1.57643  -2.112 0.034661 *  
## SAV.PercentageNO AQUATIC PLANTS    0.60401    0.38377   1.574 0.115511    
## SAV.PercentageUNKNOWN             -0.20847    0.88801  -0.235 0.814393    
## SAV.PercentageUP TO 1 FOURTH PLTS  1.33613    0.42269   3.161 0.001572 ** 
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

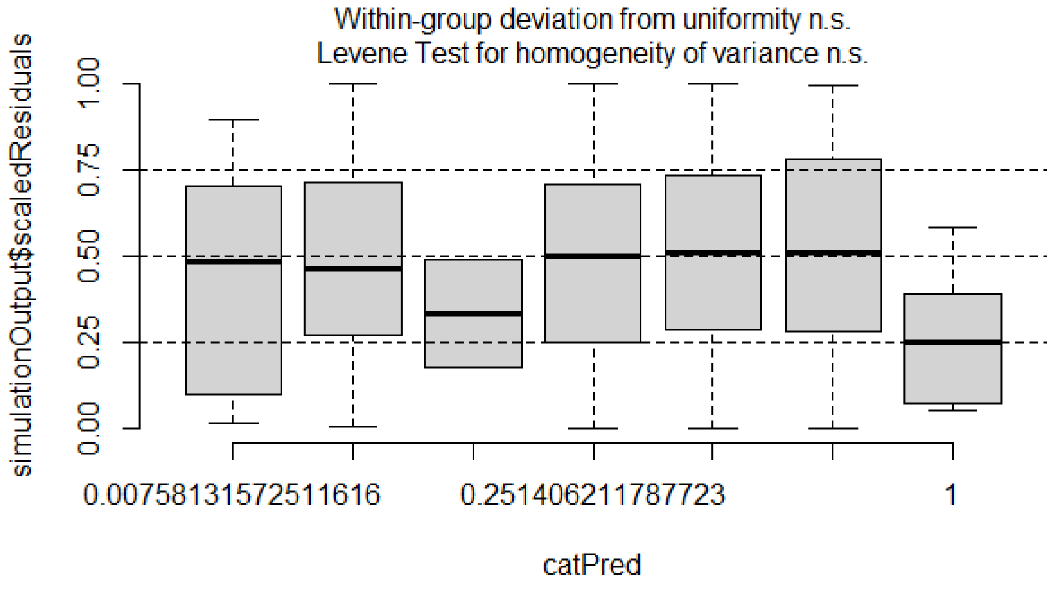
Model Diagnostics

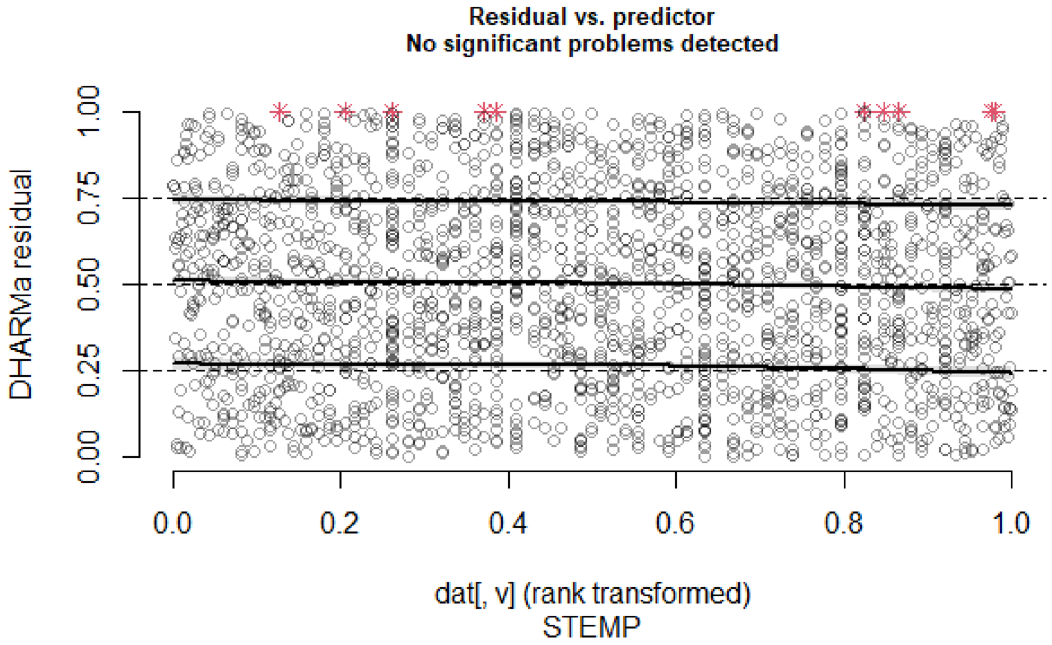
The diagnostics for the negative binomial were acceptable.

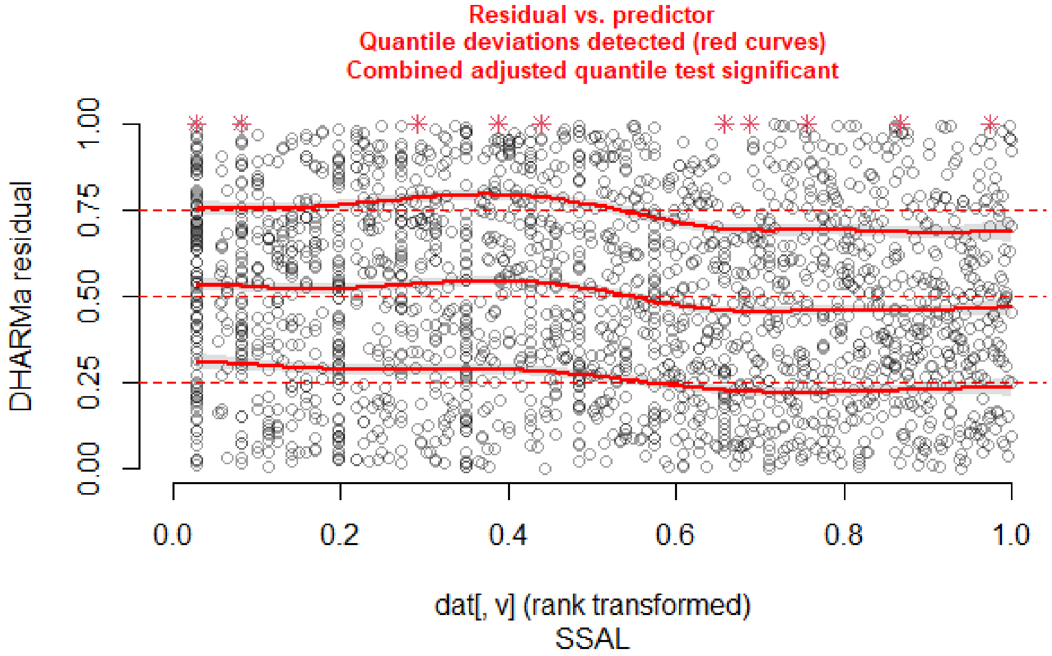

DHARMa residual
QQ plot residuals
KS test: p= 0.106[illegible]2
Deviation n.s
Dispersion test: p= 0.52
Deviation n.s.
Outlier test: p= 0.16887
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
Residual vs. predicted
Quantile deviations detected (red curves)
Combined adjusted quantile test significa
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)

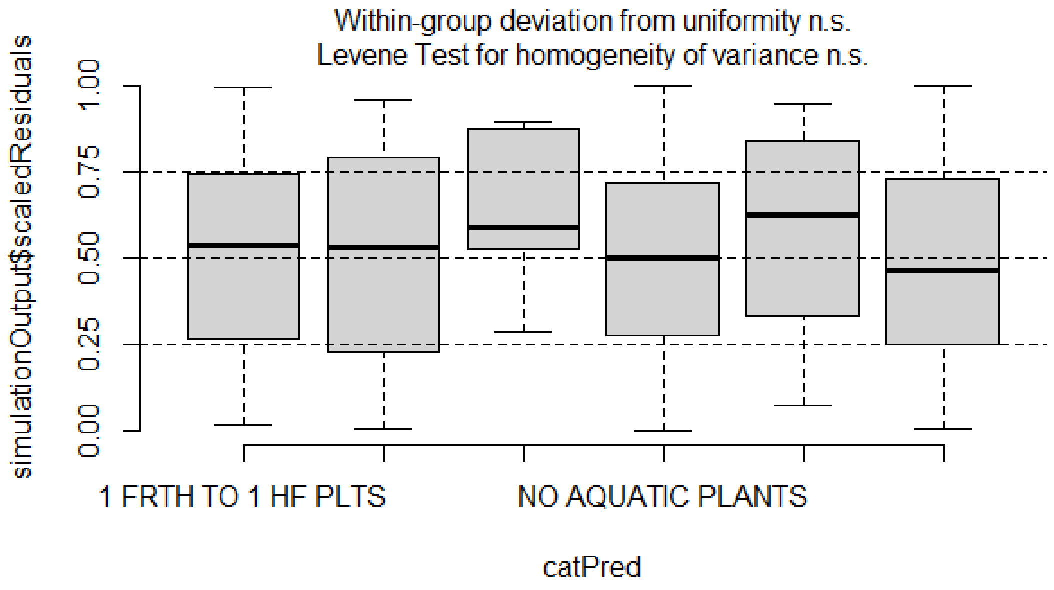

Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1959
1965
1971
1978
1989
1995
2001
2007
2013
2019
catPred


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance significant
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
7
8
9
10
catPred


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.00758131572511616
0.251406211787723
1
catPred

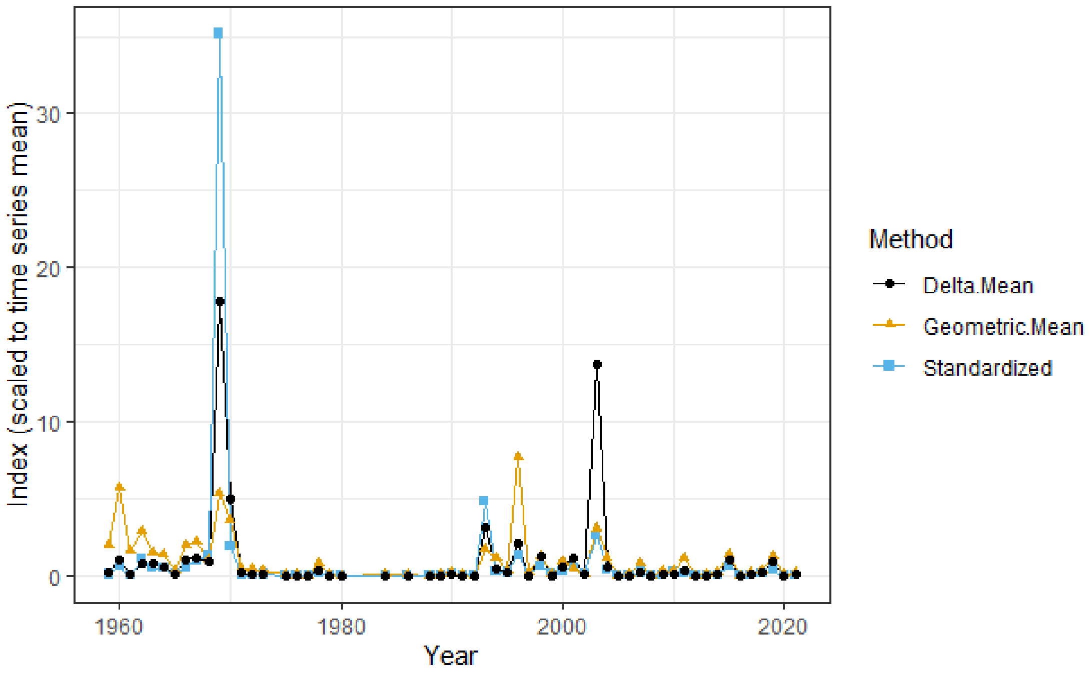

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP

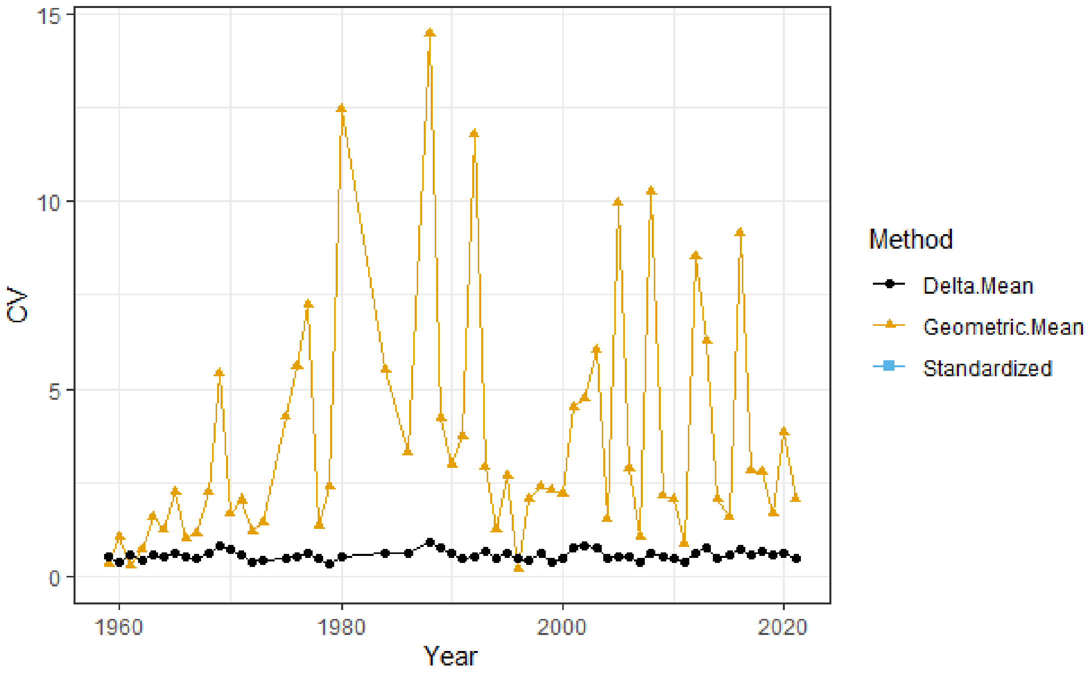

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
SSAL



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve appreciably upon the delta mean so the delta mean index was selected for use in modelling.


Index (scaled to time series mean)
0
10
20
30
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
5
10
15
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

```
## Warning: Unknown or uninitialised column: `Standardized.CV`.
```

Standardized and nominal indices and CVs

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1959	12.054	8.629	0.34	22.506	0.51
1960	74.399	25.465	1.03	95.889	0.37
1961	4.035	7.180	0.26	13.683	0.56
1962	136.698	13.256	0.73	69.496	0.41
1963	59.483	6.690	1.58	71.646	0.57
1964	58.986	6.135	1.24	46.903	0.51
1965	15.538	1.357	2.24	11.365	0.61
1966	64.042	9.055	1.02	96.179	0.53
1967	122.951	9.816	1.15	104.932	0.47
1968	167.992	4.598	2.26	87.120	0.61
1969	4436.413	24.038	5.39	1633.293	0.81
1970	239.437	16.226	1.68	462.922	0.71
1971	8.326	2.148	2.03	20.772	0.58
1972	5.020	1.902	1.21	6.827	0.40
1973	11.262	1.712	1.44	6.966	0.43
1975	0.919	0.273	4.25	0.561	0.45
1976	0.940	0.199	5.60	0.400	0.52
1977	0.233	0.153	7.25	0.365	0.62
1978	22.075	3.468	1.36	25.976	0.49
1979	2.480	0.528	2.37	1.007	0.33
1980	0.203	0.083	12.47	0.124	0.50
1984	0.926	0.220	5.51	0.693	0.62
1986	3.342	0.495	3.28	2.956	0.62
1988	0.546	0.074	14.48	0.238	0.90

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1989	4.768	0.374	4.21	3.062	0.75
1990	16.812	0.919	2.99	11.756	0.62
1991	5.748	0.328	3.73	0.766	0.45
1992	0.210	0.088	11.78	0.143	0.54
1993	606.437	7.964	2.91	283.185	0.66
1994	36.453	5.216	1.25	45.546	0.48
1995	26.971	1.399	2.67	20.161	0.64
1996	172.402	34.609	0.17	188.299	0.47
1997	5.585	0.816	2.07	2.839	0.44
1998	82.467	5.693	2.38	121.025	0.61
1999	17.252	0.643	2.30	1.871	0.40
2000	32.025	4.188	2.22	55.374	0.49
2001	65.225	1.970	4.50	109.528	0.75
2002	23.046	0.376	4.74	6.719	0.83
2003	327.377	13.867	6.04	1261.841	0.77
2004	49.583	5.330	1.51	54.351	0.47
2005	0.422	0.105	9.98	0.167	0.51
2006	2.190	0.580	2.85	2.792	0.51
2007	27.952	3.581	1.06	18.431	0.40
2008	0.156	0.104	10.26	0.216	0.62
2009	6.606	1.348	2.14	11.271	0.54
2010	31.886	1.373	2.05	9.669	0.48
2011	24.376	5.155	0.85	27.394	0.40
2012	0.601	0.128	8.51	0.309	0.63
2013	0.830	0.211	6.27	1.561	0.77

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2014	5.303	1.176	2.05	7.024	0.48
2015	83.057	6.304	1.59	94.788	0.57
2016	0.618	0.121	9.16	0.330	0.70
2017	8.151	0.939	2.83	10.026	0.59
2018	19.014	1.281	2.79	19.137	0.65
2019	48.467	5.726	1.69	82.481	0.55
2020	1.595	0.383	3.83	2.104	0.63
2021	3.473	0.977	2.04	4.603	0.49

MD Estuarine Juvenile Finfish Seine Blueback Herring Survey Standardization - Nanticoke

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset had 27.40% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-inflated negative binomial had convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial had convergence problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the negative binomial.

```
##        dAIC df
## NB1      0  69
## ZINB    NA  137
## ZINB.2  NA  77
## ZANB    NA  137
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

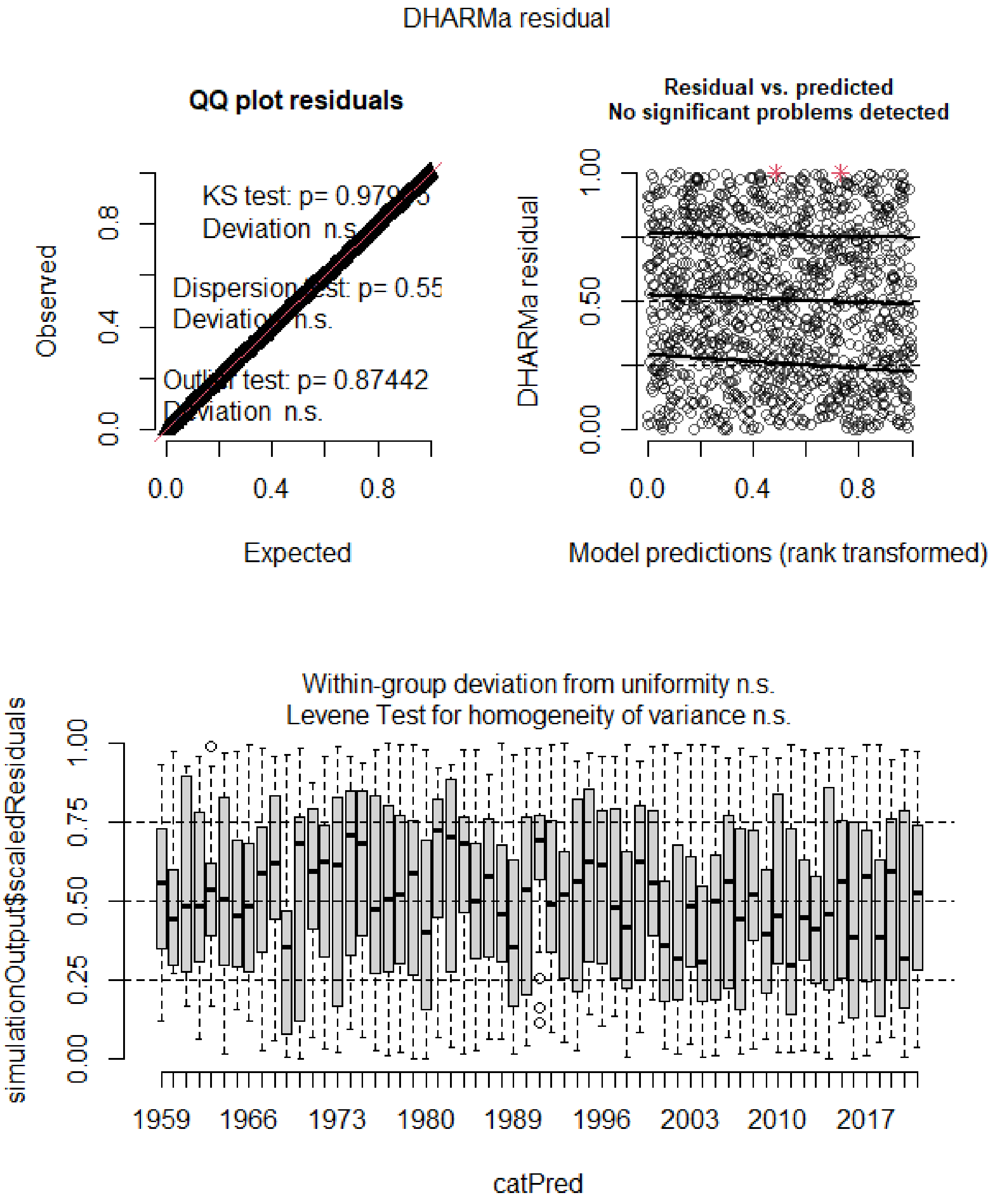
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MONTH + DEPTH + STEMP + SSAL +
SAV.Percentage
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   3669.0   4023.7  -1765.5   3531.0     1194
##
##
## Dispersion parameter for nbinom2 family (): 0.171
##
## Conditional model:
```

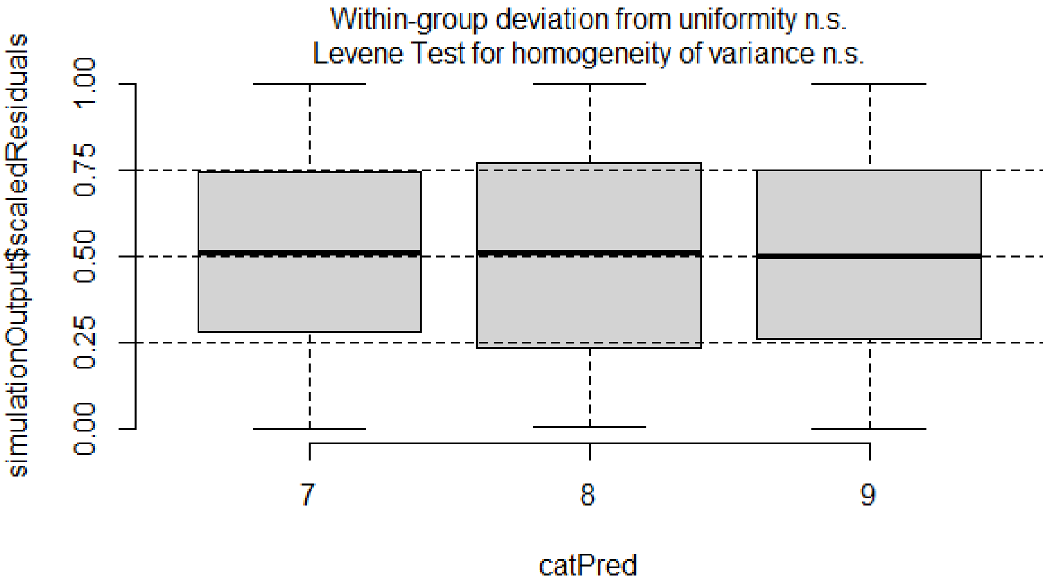
```
##                                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                              11.86986    3.05307   3.888 0.000101
***
## YEAR1960                                 -0.93098    1.80697  -0.515 0.606402
## YEAR1961                                  3.64718    1.46896   2.483 0.013034 *
## YEAR1962                                  2.12227    1.52075   1.396 0.162852
## YEAR1963                                  0.65410    1.59494   0.410 0.681726
## YEAR1964                                 -1.14603    1.68778  -0.679 0.497129
## YEAR1965                                  2.21302    1.60138   1.382 0.166987
## YEAR1966                                  5.08321    1.63233   3.114 0.001845
**
## YEAR1967                                  0.10901    1.57305   0.069 0.944751
## YEAR1968                                  0.36935    1.52731   0.242 0.808911
## YEAR1969                                  3.21030    1.61007   1.994 0.046164 *
## YEAR1970                                  2.40445    1.63945   1.467 0.142479
## YEAR1971                                 -2.10755    1.85587  -1.136 0.256119
## YEAR1972                                 -0.73863    1.57025  -0.470 0.638079
## YEAR1973                                 -2.11714    1.76715  -1.198 0.230897
## YEAR1974                                 -1.03049    1.58876  -0.649 0.516591
## YEAR1975                                 -2.49537    1.59996  -1.560 0.118842
## YEAR1976                                 -4.34786    1.75529  -2.477 0.013249 *
## YEAR1977                                  0.25797    1.49647   0.172 0.863132
## YEAR1978                                 -0.62335    1.41133  -0.442 0.658723
## YEAR1979                                 -0.02217    1.54715  -0.014 0.988565
## YEAR1980                                 -1.44092    1.53551  -0.938 0.348038
## YEAR1983                                 -1.28671    1.95451  -0.658 0.510324
## YEAR1984                                 -0.98557    1.61583  -0.610 0.541897
## YEAR1985                                 -1.17094    1.75655  -0.667 0.505021
## YEAR1986                                 -2.50279    1.78372  -1.403 0.160577
## YEAR1987                                 -1.40714    1.74206  -0.808 0.419238
## YEAR1988                                  0.93987    1.56771   0.600 0.548828
## YEAR1989                                  0.36075    1.52014   0.237 0.812411
## YEAR1990                                  0.38226    1.52924   0.250 0.802613
## YEAR1991                                 -2.11181    1.72376  -1.225 0.220530
## YEAR1992                                 -3.41046    1.92876  -1.768 0.077024 .
## YEAR1993                                  4.12875    1.55406   2.657 0.007890
**
## YEAR1994                                  0.32730    1.56223   0.210 0.834050
## YEAR1995                                  3.28869    1.63721   2.009 0.044567 *
## YEAR1996                                 -0.22409    1.54765  -0.145 0.884871
## YEAR1997                                  0.28448    1.59604   0.178 0.858534
## YEAR1998                                  0.71888    1.54305   0.466 0.641298
## YEAR1999                                 -1.82488    1.67940  -1.087 0.277203
## YEAR2000                                 -2.35216    1.57309  -1.495 0.134849
## YEAR2001                                  0.30626    1.56879   0.195 0.845219
## YEAR2002                                 -0.98209    1.69412  -0.580 0.562113
## YEAR2003                                 -1.99847    1.55293  -1.287 0.198128
## YEAR2004                                  0.13082    1.60016   0.082 0.934841
## YEAR2005                                 -1.98293    1.62872  -1.217 0.223424
## YEAR2006                                 -2.66632    1.59589  -1.671 0.094772 .
```

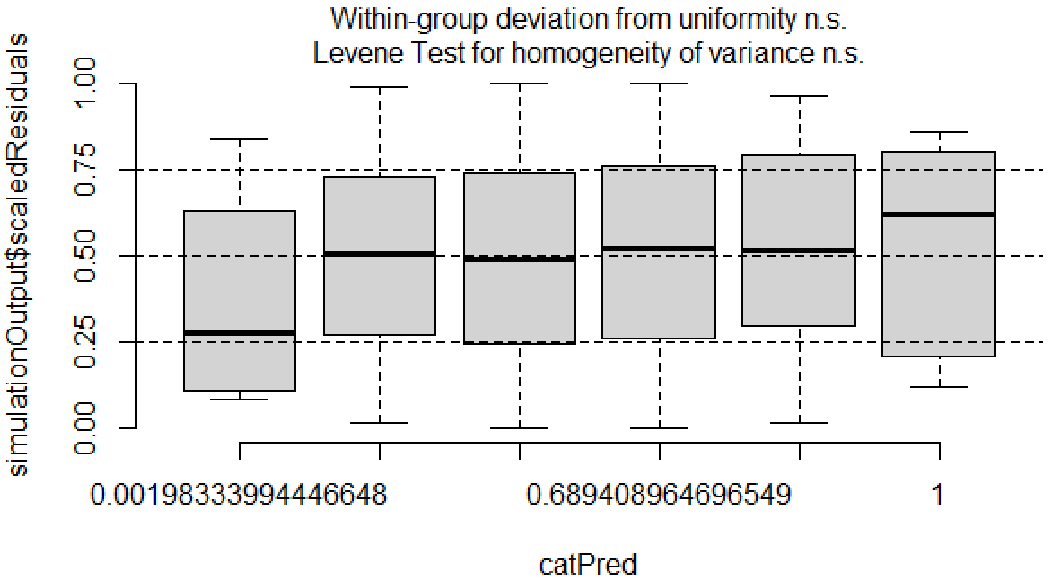
```
## YEAR2007                              1.04033    1.59513   0.652 0.514278    
## YEAR2008                             -1.98707    1.69076  -1.175 0.239895    
## YEAR2009                             -1.98094    1.57758  -1.256 0.209229    
## YEAR2010                             -1.24110    1.63132  -0.761 0.446780    
## YEAR2011                              0.93581    1.55000   0.604 0.546012    
## YEAR2012                              0.33121    1.83144   0.181 0.856488    
## YEAR2013                             -2.35893    1.56240  -1.510 0.131093    
## YEAR2014                             -2.80121    1.71976  -1.629 0.103347    
## YEAR2015                             -0.18871    1.54469  -0.122 0.902765    
## YEAR2016                             -1.74880    1.61647  -1.082 0.279312    
## YEAR2017                             -1.13367    1.56785  -0.723 0.469635    
## YEAR2018                             -0.43740    1.52618  -0.287 0.774421    
## YEAR2019                             -1.02212    1.54397  -0.662 0.507968    
## YEAR2020                              1.05564    1.55594   0.678 0.497481    
## YEAR2021                             -3.26433    1.78353  -1.830 0.067211 .  
## MONTH8                                0.62517    0.26259   2.381 0.017277 *  
## MONTH9                               -0.57848    0.38586  -1.499 0.133816    
## DEPTH                                 0.35587    0.17795   2.000 0.045522 *  
## STEMP                                -0.35484    0.07936  -4.471 7.77e-06 
***
## SSAL                                 -0.67500    0.03995 -16.897  < 2e-16 
***
## SAV.PercentageUNKNOWN               -19.10238 2292.75068  -0.008 0.993352    
## SAV.PercentageUP TO 1 FOURTH PLTS    -1.77472    0.96141  -1.846 0.064898 .  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

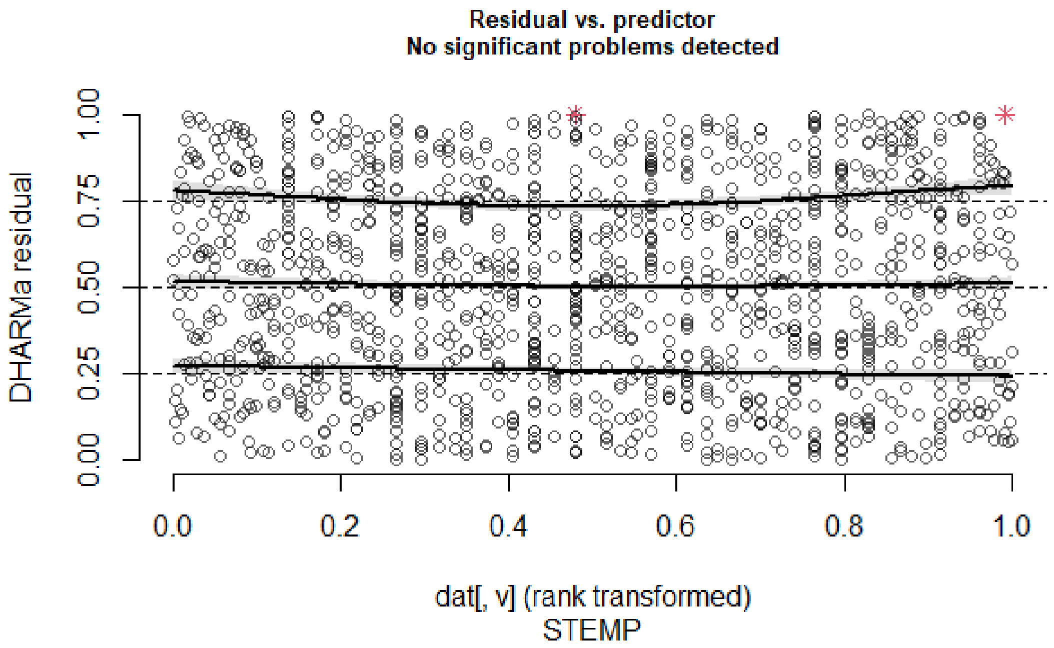
Model Diagnostics

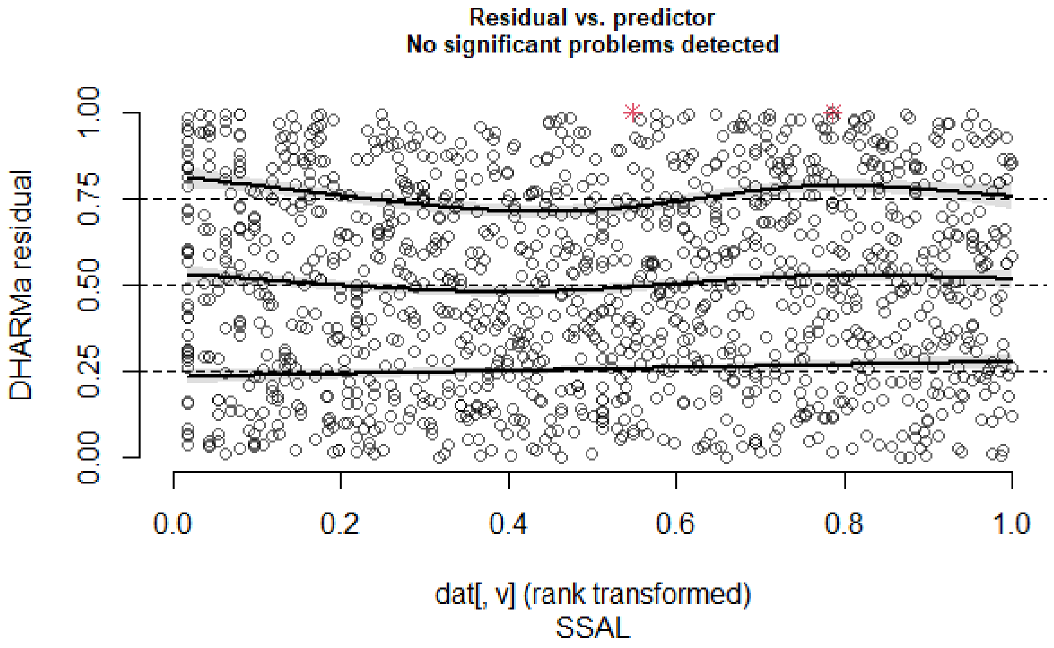
The diagnostics for the negative binomial were acceptable.

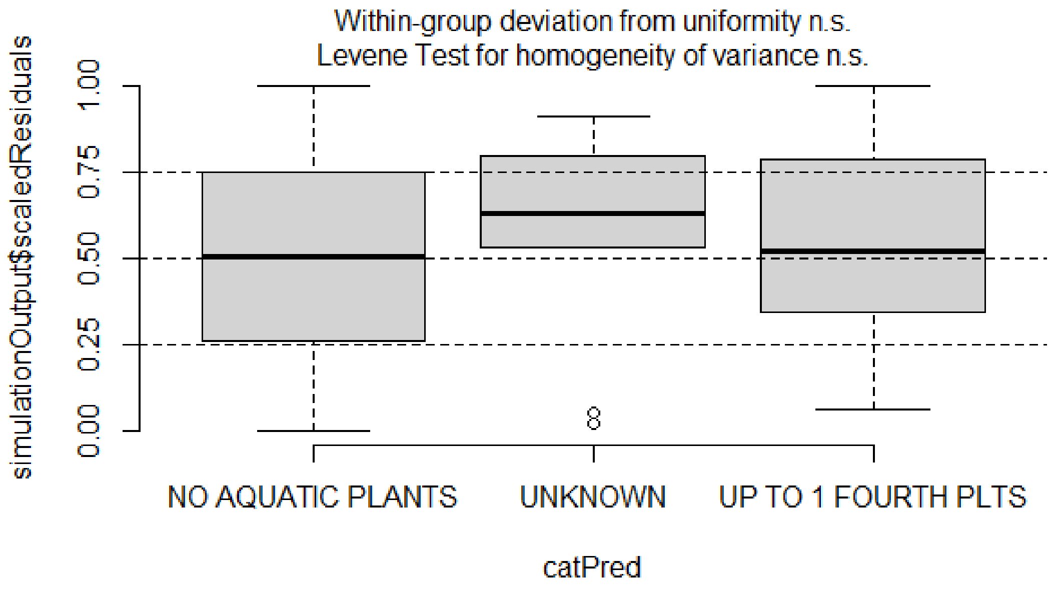

DHARMa residual
QQ plot residuals
KS test: p= 0.97965
Deviation n.s.
Dispersion test: p= 0.55
Deviation n.s.
Outlier test: p= 0.87442
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1959
1966
1973
1980
1989
1996
2003
2010
2017
catPred


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
7
8
9
catPred


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.00198333994446648
0.689408964696549
1
catPred

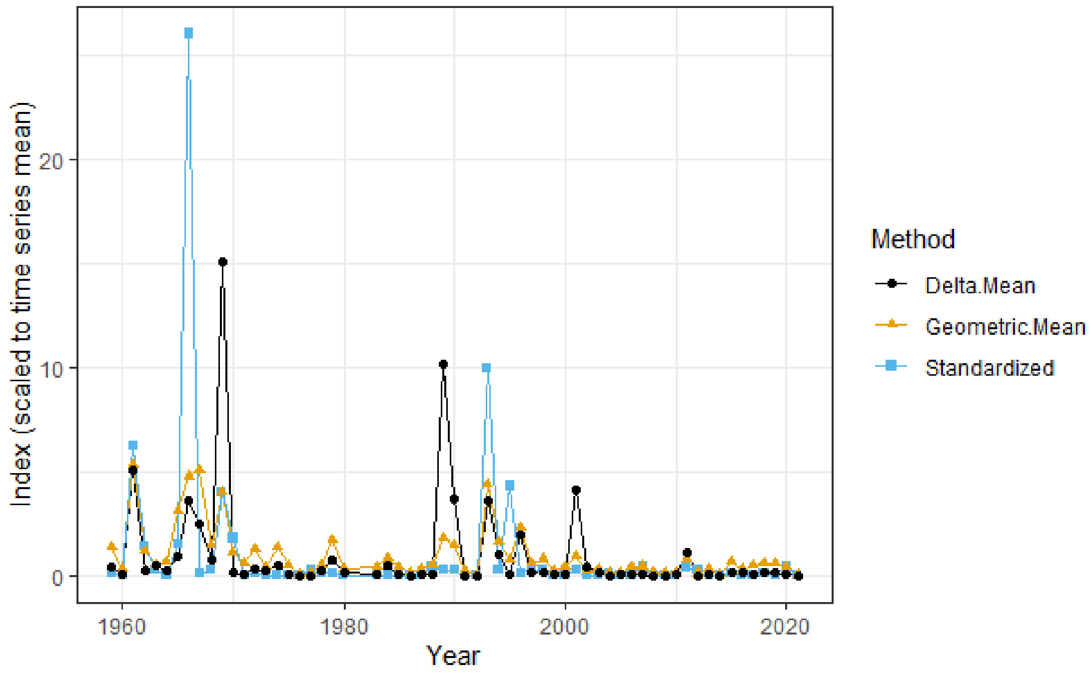

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP


Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
SSAL

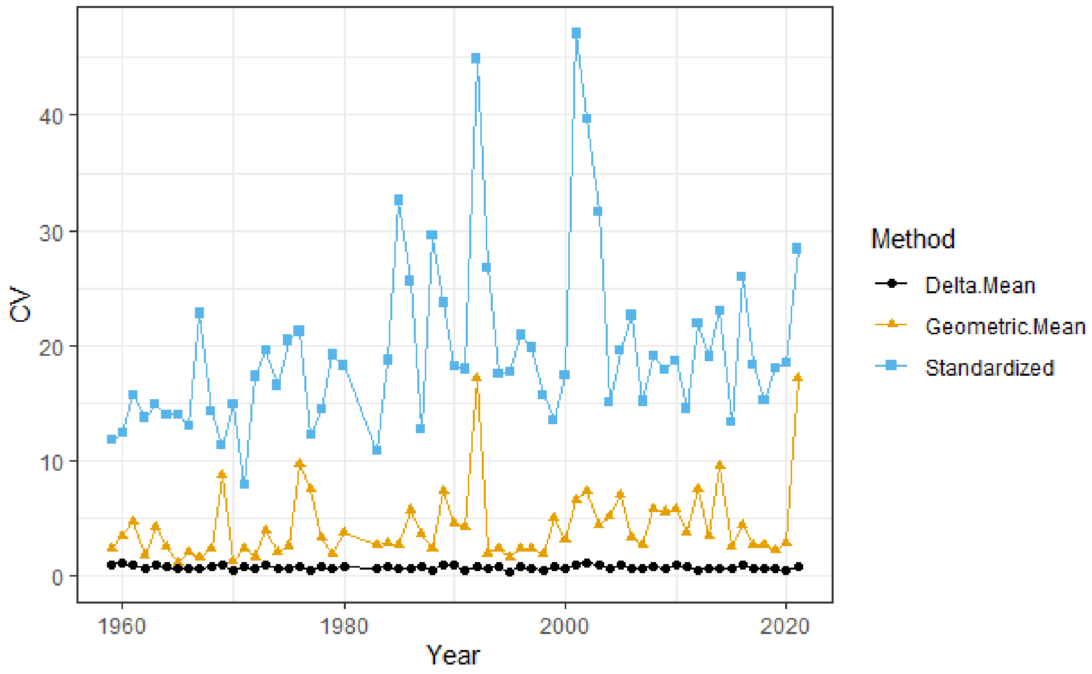


Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve appreciably upon the delta mean so the delta mean index was selected for use in modelling.



Index (scaled to time series mean)
0
10
20
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized



CV
0
10
20
30
40
1960
1980
2000
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1959	0.001	11.73	1.672	2.33	9.500	0.88
1960	0.000	12.36	0.414	3.46	1.167	1.00
1961	0.045	15.71	6.483	4.59	107.111	0.93
1962	0.010	13.72	1.446	1.64	6.056	0.62
1963	0.002	14.83	0.614	4.21	10.188	0.92
1964	0.000	13.95	0.871	2.52	4.817	0.78
1965	0.011	13.99	3.794	1.09	19.515	0.58
1966	0.188	12.96	5.804	1.97	75.682	0.67
1967	0.001	22.77	6.134	1.59	53.059	0.55
1968	0.002	14.23	1.766	2.25	16.517	0.70
1969	0.029	11.24	4.899	8.71	318.384	0.89
1970	0.013	14.83	1.304	1.19	2.491	0.37
1971	0.000	7.84	0.688	2.36	1.875	0.70
1972	0.001	17.30	1.589	1.62	7.161	0.57
1973	0.000	19.50	0.471	3.81	4.414	0.87
1974	0.000	16.51	1.624	2.00	11.472	0.62
1975	0.000	20.42	0.643	2.55	2.262	0.63
1976	0.000	21.20	0.110	9.67	0.200	0.78
1977	0.002	12.17	0.142	7.41	0.207	0.49
1978	0.001	14.38	0.635	3.30	5.649	0.78
1979	0.001	19.17	2.129	1.91	16.043	0.66
1980	0.000	18.22	0.444	3.77	2.920	0.75
1983	0.000	10.78	0.495	2.66	1.000	0.65
1984	0.000	18.71	1.028	2.84	10.133	0.79
1985	0.000	32.59	0.543	2.62	1.528	0.55

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1986	0.000	25.56	0.195	5.67	0.365	0.57
1987	0.000	12.67	0.373	3.56	1.151	0.73
1988	0.003	29.53	0.614	2.27	1.481	0.46
1989	0.002	23.68	2.168	7.38	215.057	0.86
1990	0.002	18.21	1.756	4.43	78.011	0.84
1991	0.000	17.93	0.279	4.13	0.540	0.51
1992	0.000	44.90	0.059	17.14	0.083	0.69
1993	0.072	26.79	5.350	1.93	76.597	0.66
1994	0.002	17.59	2.000	2.26	21.255	0.69
1995	0.031	17.65	0.963	1.49	1.911	0.33
1996	0.001	20.88	2.818	2.25	40.790	0.71
1997	0.002	19.78	0.752	2.35	3.081	0.59
1998	0.002	15.66	0.980	1.85	3.314	0.47
1999	0.000	13.53	0.260	4.91	1.040	0.78
2000	0.000	17.42	0.546	3.03	2.396	0.66
2001	0.002	47.11	1.132	6.50	87.343	0.93
2002	0.000	39.72	0.254	7.28	9.417	1.00
2003	0.000	31.63	0.375	4.32	3.520	0.87
2004	0.001	15.01	0.230	5.10	0.543	0.57
2005	0.000	19.55	0.183	6.94	1.167	0.96
2006	0.000	22.59	0.463	3.30	1.974	0.62
2007	0.003	15.10	0.562	2.67	1.701	0.56
2008	0.000	19.03	0.206	5.79	0.656	0.77
2009	0.000	17.89	0.203	5.51	0.400	0.59
2010	0.000	18.67	0.226	5.78	1.132	0.87
2011	0.003	14.48	0.981	3.73	23.981	0.83

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2012	0.002	21.86	0.142	7.41	0.207	0.49
2013	0.000	19.02	0.389	3.35	1.059	0.56
2014	0.000	23.00	0.109	9.56	0.166	0.58
2015	0.001	13.26	0.820	2.42	4.057	0.57
2016	0.000	26.01	0.352	4.37	2.773	0.85
2017	0.000	18.33	0.590	2.66	2.220	0.59
2018	0.001	15.18	0.724	2.69	3.719	0.65
2019	0.000	18.05	0.762	2.22	2.814	0.56
2020	0.003	18.43	0.465	2.84	1.141	0.49
2021	0.000	28.39	0.059	17.14	0.083	0.69

MD Estuarine Juvenile Finfish Seine Blueback Herring Survey Standardization - Head of Bay

Survey Description

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

Subsetting

The years were limited to non-zero years and months were not limited.

Model Selection

The final dataset has 25.62% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR +STEMP+SSAL+SAV.Percentage,
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered negative binomial had convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + DEPTH+STEMP+SSAL+SAV.Percentage,
                ziformula = ~YEAR +DEPTH+STEMP+SSAL+SAV.Percentage,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  ziformula = ~ MONTH+DEPTH+STEMP+SSAL+SAV.Percentage,
                  data = dat,
                  family = nbinom2)
```

GAM

The GAM did not converge and was not used further.

AIC Comparisons

AIC favored the zero-inflated negative binomial.

```
##        dAIC  df
## ZINB     0.0 137
## ZANB    59.7 137
## ZINB.2  89.5 82
## NB1    140.3 68
```

After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

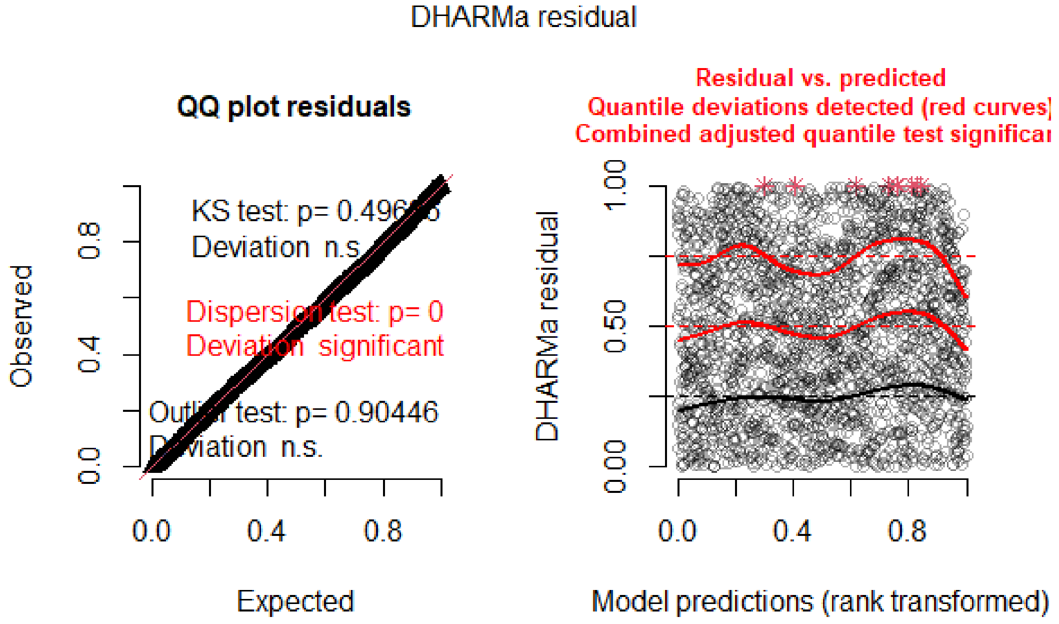
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + SSAL + SAV.Percentage
## Data: dat
## 
##      AIC      BIC   logLik deviance df.resid
##   6999.2   7387.0  -3431.6   6863.2     2145
## 
## 
## Dispersion parameter for nbinom2 family (): 0.12
## 
## Conditional model:
##                                      Estimate Std. Error z value Pr(>|z|)
## (Intercept)                           8.95341    1.73618   5.157 2.51e-07 ***
## YEAR1960                              0.60986    1.59960   0.381 0.703014
```

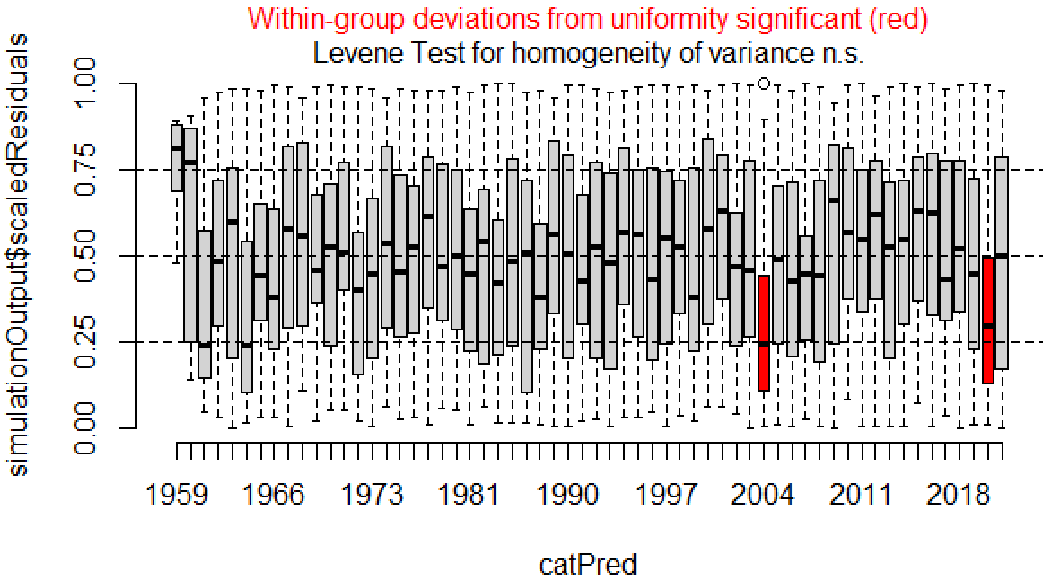
```
## YEAR1961                          -4.51702    1.83290  -2.464 0.013724 *
## YEAR1962                           0.73930    1.38361   0.534 0.593117
## YEAR1963                          -2.21147    1.53180  -1.444 0.148822
## YEAR1964                           0.67130    1.41864   0.473 0.636070
## YEAR1965                           3.59353    1.39602   2.574 0.010049 *
## YEAR1966                           2.74287    1.35070   2.031 0.042285 *
## YEAR1967                          -1.86115    1.36441  -1.364 0.172545
## YEAR1968                          -1.10652    1.41043  -0.785 0.432729
## YEAR1969                          -1.91350    1.44944  -1.320 0.186779
## YEAR1970                           0.30921    1.36636   0.226 0.820968
## YEAR1971                           0.98762    1.43270   0.689 0.490609
## YEAR1972                          -0.22288    1.36742  -0.163 0.870523
## YEAR1973                          -4.77213    1.55080  -3.077 0.002090 **
## YEAR1975                           1.53714    1.35917   1.131 0.258083
## YEAR1976                          -2.46686    1.40972  -1.750 0.080137 .
## YEAR1977                           0.98546    1.39509   0.706 0.479952
## YEAR1978                           1.33378    1.34031   0.995 0.319673
## YEAR1979                          -0.60614    1.34460  -0.451 0.652134
## YEAR1980                           1.08181    1.34142   0.806 0.419972
## YEAR1981                          -6.15850    1.74004  -3.539 0.000401 ***
## YEAR1984                          -3.28731    1.40981  -2.332 0.019714 *
## YEAR1985                           0.06108    1.34311   0.045 0.963727
## YEAR1986                          -0.49494    1.37540  -0.360 0.718955
## YEAR1987                          -2.64878    1.41390  -1.873 0.061014 .
## YEAR1988                          -0.56390    1.39599  -0.404 0.686252
## YEAR1989                           0.41905    1.35136   0.310 0.756492
## YEAR1990                          -1.49743    1.39579  -1.073 0.283351
## YEAR1991                           0.55683    1.36919   0.407 0.684240
## YEAR1992                           0.74944    1.40068   0.535 0.592614
## YEAR1993                           2.39310    1.36080   1.759 0.078646 .
## YEAR1994                           0.23109    1.34205   0.172 0.863288
## YEAR1995                           1.43431    1.44177   0.995 0.319818
## YEAR1996                           0.44139    1.34497   0.328 0.742780
## YEAR1997                           0.04496    1.37925   0.033 0.973997
## YEAR1998                          -1.32438    1.49490  -0.886 0.375654
## YEAR1999                          -4.10395    1.49117  -2.752 0.005920 **
## YEAR2000                          -1.48845    1.41023  -1.055 0.291212
## YEAR2001                          -1.47393    1.39951  -1.053 0.292259
## YEAR2002                           1.74868    1.37163   1.275 0.202348
## YEAR2003                          -4.82038    1.46068  -3.300 0.000967 ***
## YEAR2004                           4.10043    1.32078   3.105 0.001906 **
## YEAR2005                          -1.03151    1.38943  -0.742 0.457846
## YEAR2006                          -1.73633    1.39727  -1.243 0.213992
## YEAR2007                           4.01404    1.38719   2.894 0.003808 **
## YEAR2008                          -4.05967    1.44443  -2.811 0.004945 **
## YEAR2009                          -0.77468    1.37032  -0.565 0.571852
## YEAR2010                           1.72425    1.35707   1.271 0.203883
## YEAR2011                           2.98649    1.32731   2.250 0.024447 *
## YEAR2012                          -1.99225    1.38687  -1.437 0.150858
## YEAR2013                          -4.29928    1.48356  -2.898 0.003756 **
```

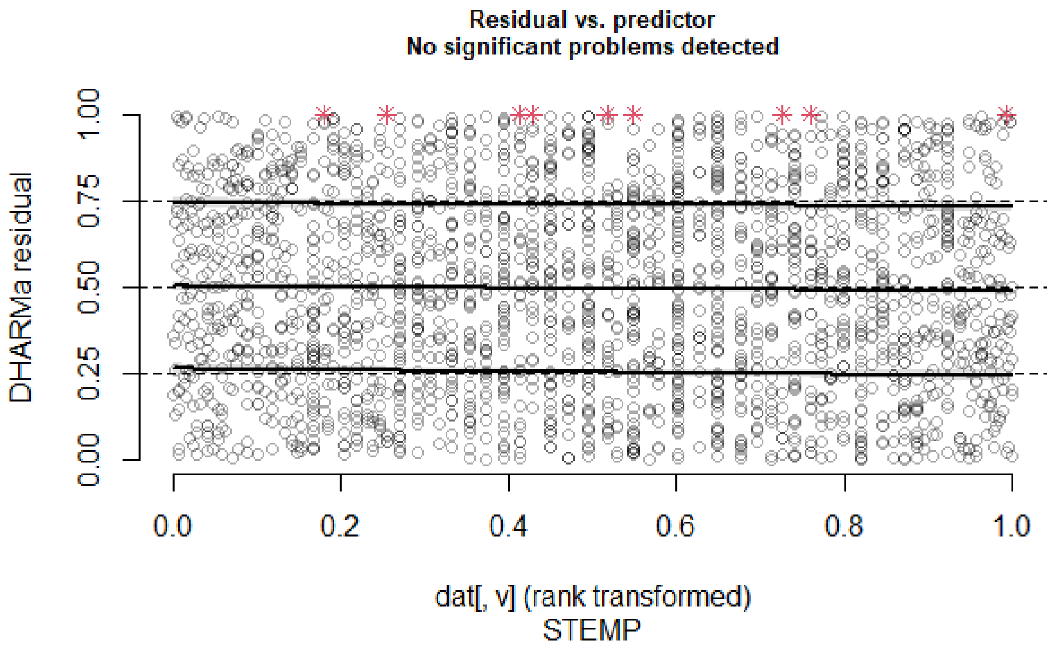
```
## YEAR2014                           0.75577    1.35576   0.557 0.577221    
## YEAR2015                           1.81503    1.33596   1.359 0.174275    
## YEAR2016                          -2.86821    1.45168  -1.976 0.048178 *  
## YEAR2017                          -4.57948    1.41474  -3.237 0.001208 ** 
## YEAR2018                          -0.96641    1.35654  -0.712 0.476213    
## YEAR2019                          -0.28994    1.34126  -0.216 0.828855    
## YEAR2020                           2.26125    1.34404   1.682 0.092487 .  
## YEAR2021                          -2.39035    1.39315  -1.716 0.086200 .  
## STEMP                             -0.17349    0.04768  -3.638 0.000274 ***
## SSAL                              -0.68544    0.03181 -21.549  < 2e-16 ***
## SAV.Percentage1 HF TO 3 FRTH PLTS -2.65889    0.77591  -3.427 0.000611 ***
## SAV.Percentage3 FRTH TO COMP PLTS  0.31729    2.15681   0.147 0.883044    
## SAV.PercentageNO AQUATIC PLANTS   -0.28338    0.47715  -0.594 0.552584    
## SAV.PercentageUNKNOWN             -0.24706    0.82747  -0.299 0.765268    
## SAV.PercentageUP TO 1 FOURTH PLTS -0.90143    0.48996  -1.840 0.065797 .  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

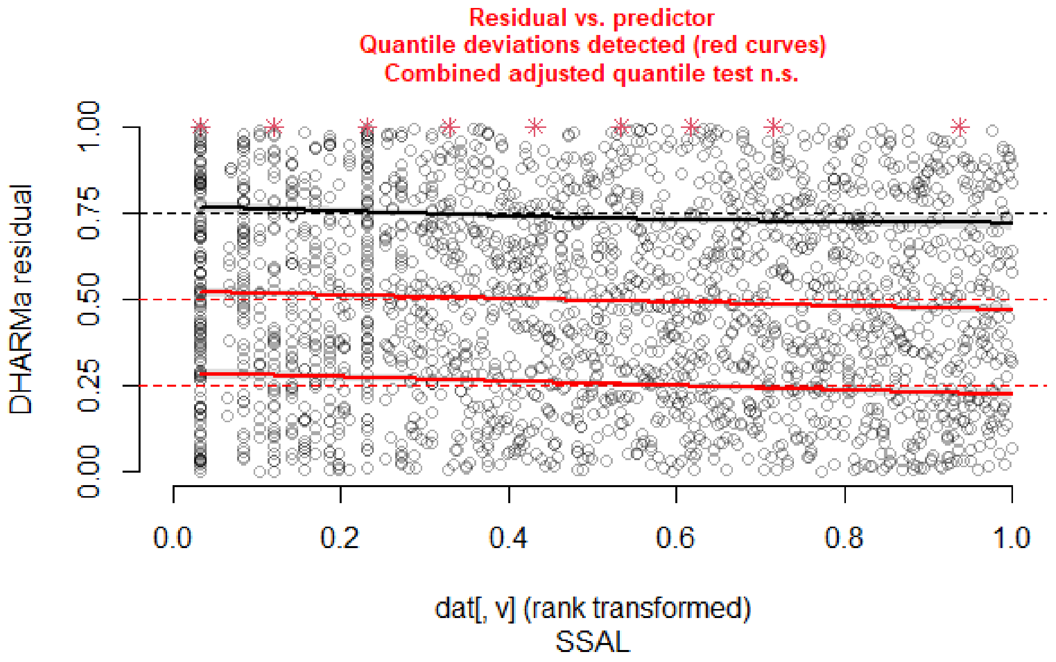
Model Diagnostics

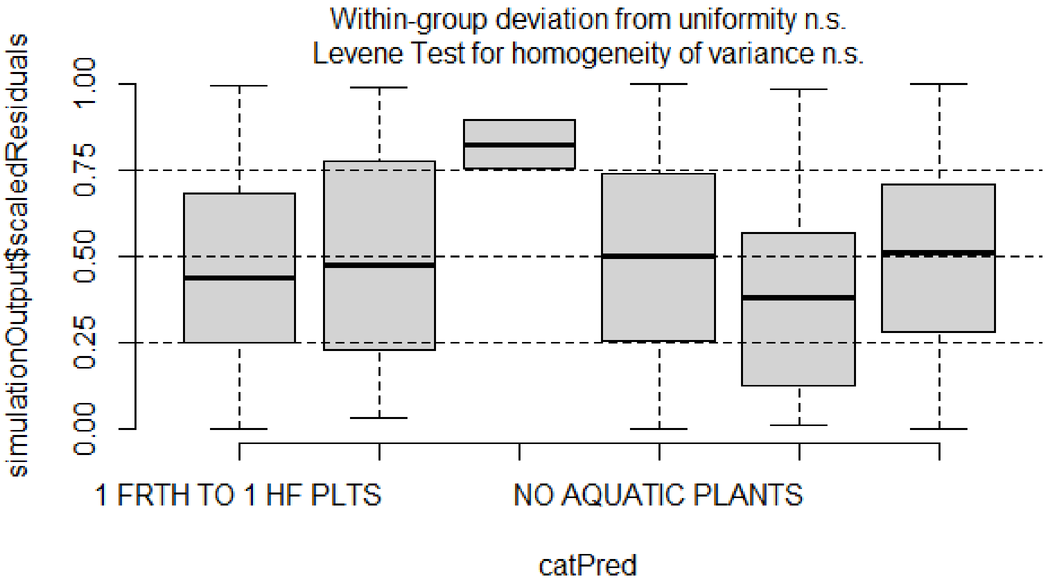
The diagnostics for the negative binomial were acceptable though not good. There are significant deviations.


DHARMa residual
QQ plot residuals
KS test: p= 0.49655
Deviation n.s.
Dispersion test: p= 0
Deviation significant
Outlier test: p= 0.90446
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
Quantile deviations detected (red curves)
Combined adjusted quantile test significa
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00


Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1959
1966
1973
1981
1990
1997
2004
2011
2018
catPred

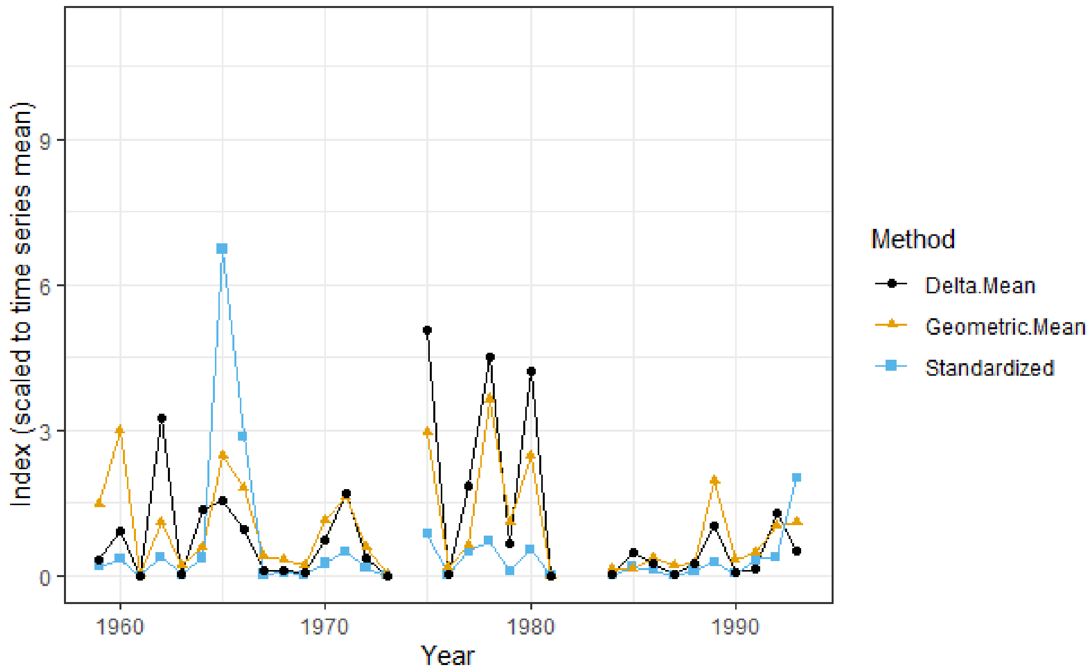

Residual vs. predictor
No significant problems detected

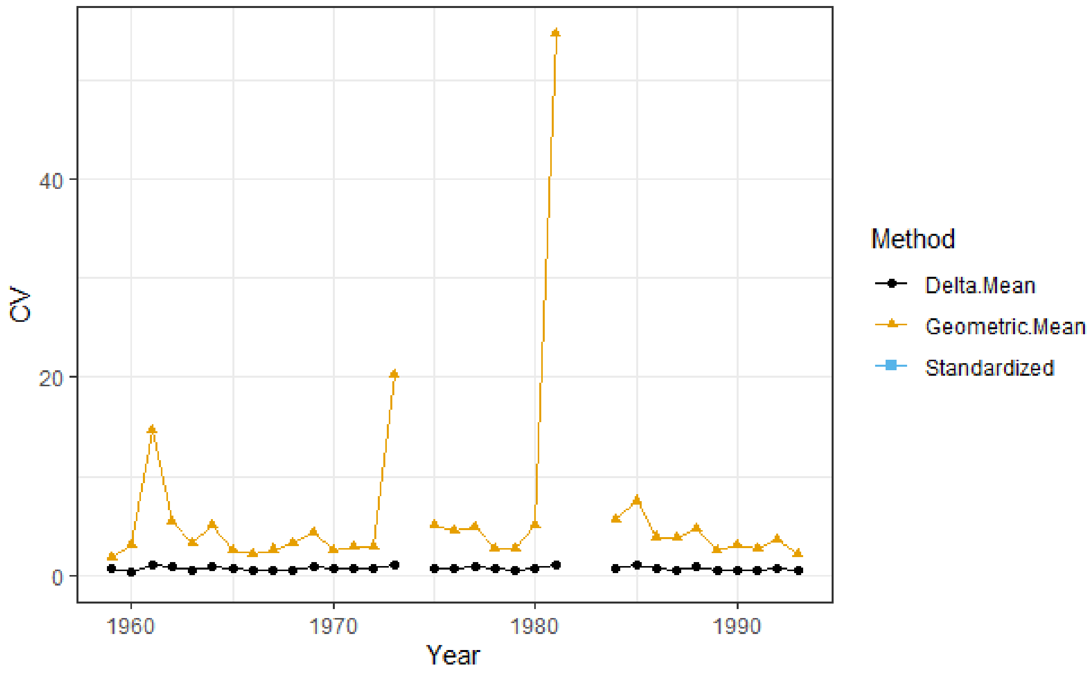

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test n.s.



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve appreciably upon the delta mean so the delta mean index was selected for use in modelling.


Index (scaled to time series mean)
0
3
6
9
1960
1970
1980
1990
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
20
40
1960
1970
1980
1990
Year
Method
Delta.Mean
Geometric.Mean
Standardized

```
## Warning: Unknown or uninitialised column: `Standardized.CV`.
```

Standardized and nominal indices and CVs

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1959	1.023	2.546	1.80	13.660	0.62
1960	1.883	5.159	3.06	37.834	0.42
1961	0.011	0.071	14.61	0.125	1.00
1962	2.143	1.905	5.44	133.384	0.85
1963	0.112	0.383	3.18	0.787	0.43
1964	2.002	1.014	5.08	56.267	0.88
1965	37.199	4.276	2.43	62.936	0.62
1966	15.889	3.116	2.18	39.141	0.54
1967	0.159	0.696	2.60	3.633	0.54
1968	0.338	0.575	3.22	4.036	0.59
1969	0.151	0.354	4.30	2.372	0.80
1970	1.394	1.956	2.49	29.585	0.64
1971	2.747	2.784	2.95	70.001	0.71
1972	0.819	1.032	2.86	14.259	0.67
1973	0.009	0.052	20.19	0.125	1.00
1974					
1975	4.758	5.121	5.01	207.383	0.67
1976	0.087	0.321	4.42	1.936	0.68
1977	2.741	1.068	4.85	74.727	0.88
1978	3.883	6.287	2.77	183.644	0.63
1979	0.558	1.897	2.69	27.167	0.57
1980	3.018	4.267	4.97	172.205	0.63
1981	0.002	0.018	54.67	0.026	1.00
1982					

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
1983					
1984	0.038	0.221	5.57	0.838	0.73
1985	1.087	0.253	7.49	19.762	0.98
1986	0.624	0.620	3.86	11.009	0.70
1987	0.072	0.353	3.81	1.322	0.60
1988	0.582	0.435	4.61	10.877	0.86
1989	1.556	3.376	2.52	42.527	0.45
1990	0.229	0.539	3.13	3.091	0.55
1991	1.785	0.826	2.62	6.338	0.60
1992	2.165	1.784	3.54	52.092	0.73
1993	11.199	1.930	2.12	21.224	0.58
	1.289				
	1.289				
	1.289				
	4.293				
	4.293				
	4.293				
	1.591				
	1.591				
	1.591				
	1.070				
	1.070				
	1.070				
	0.272				
	0.272				

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
	0.272				
	0.017				
	0.017				
	0.017				
	0.231				
	0.231				
	0.231				
	0.234				
	0.234				
	0.234				
	5.879				
	5.879				
	5.879				
	0.008				
	0.008				
	0.008				
	61.756				
	61.756				
	61.756				
	0.365				
	0.365				
	0.365				
	0.180				
	0.180				

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
	0.180				
	56.644				
	56.644				
	56.644				
	0.018				
	0.018				
	0.018				
	0.471				
	0.471				
	0.471				
	5.737				
	5.737				
	5.737				
	20.272				
	20.272				
	20.272				
	0.140				
	0.140				
	0.140				
	0.014				
	0.014				
	0.014				
	2.178				
	2.178				

Year	Standardized Index	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
	2.178				
	6.283				
	6.283				
	6.283				
	0.058				
	0.058				
	0.058				
	0.010				
	0.010				
	0.010				
	0.389				
	0.389				
	0.389				
	0.766				
	0.766				
	0.766				
	9.816				
	9.816				
	9.816				
	0.094				
	0.094				
	0.094				

MD North East River Alewife Survey Standardization

Survey Description

MD DNR has conducted a gill net survey targeting river herring in the North East River since 2013. A multi-panel sinking monofilament gill net is set perpendicular to the channel at four randomly chosen sites once a week for 10 weeks in mid-March to mid-May. For the 2013 and 2014 sampling years, the gill net had three separate panels each 100ft x 6ft with mesh sizes of 2 ½, 2 ¾, and 3”. In 2015, the 3” mesh panel was replaced with a 2 ¼” mesh panel, as there was evidence the current mesh size selection was not successful in capturing smaller sized blueback herring. Four sites are randomly chosen for each day, along with four alternate sites, from a grid of 1000ft x 1000ft squares overlaid on a map of the North East River. Determination of whether to set the net shallow or deep is also randomly chosen. The net is soaked for 30 min at each site prior to retrieval. All fish are identified and enumerated to species per gill net mesh size. All alewife and blueback herring are sexed and measured to the nearest mm FL and TL. Scales are taken from a subsample of alewife and blueback herring per panel (i.e. first 20 fish encountered of each species per panel) to determine age and spawning history.

The North East River Gill Net Survey is successful in capturing a relative sample of both alewife and blueback herring spawning stock in the North East River. This survey captures the weekly temporal differences in these species spawning runs, and provides a relative index of abundance.

Subsetting

Since the survey is only 10 weeks with river herring as the target species there is no sense limiting months. The issue here is mesh size. The survey started in 2013 with mesh 2.5, 2.75, 3.0, but in 2015 mesh size changed to 2.25, 2.5, 2.75. In order to be consistent there are really only two options: stick to only 2.5, and 2.75 mesh sizes ignoring the highest frequency mesh or standardize the index limited to 2015 and forward where mesh was consistent.

Both limited years and limited mesh were run.

Model Selection

The final limited mesh dataset had 68.67% positive sets. The final limited years dataset had 61.72% positive sets.

Limited Years

Negative Binomial

The negative binomial exhibited convergence problems. Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR+MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR + MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = nbinom2)
```

GAM

The general additive model cannot fit zero-inflated models and was not used further.

AIC Comparisons

AIC favored the zero-inflated negative binomial.

```
##      dAIC df
## ZINB  0.0 23
## ZANB 64.3 23
## NB1  91.5 12
```

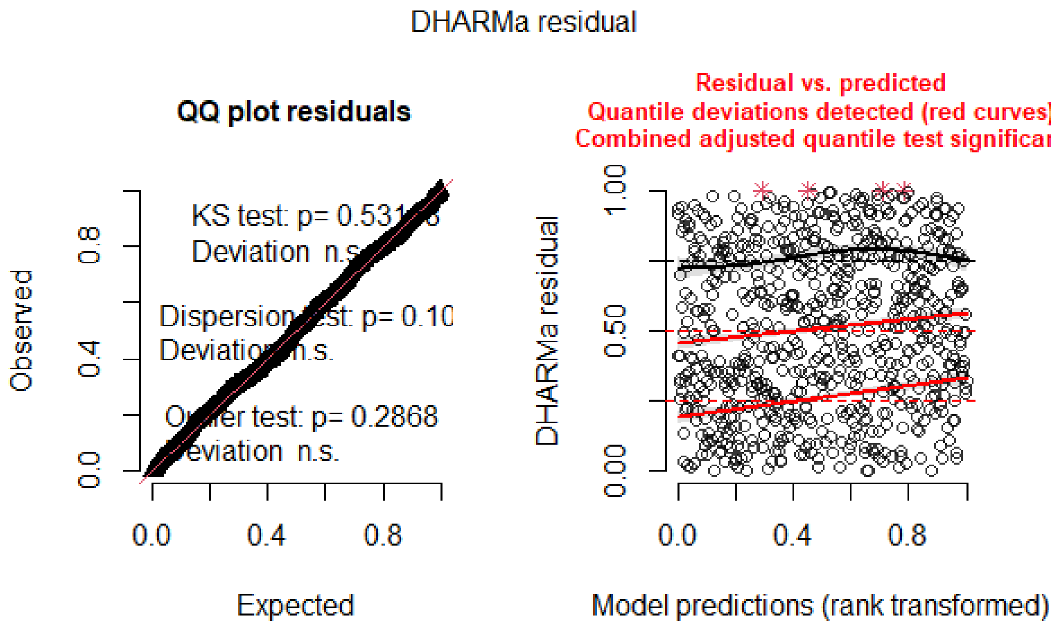
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-inflated negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

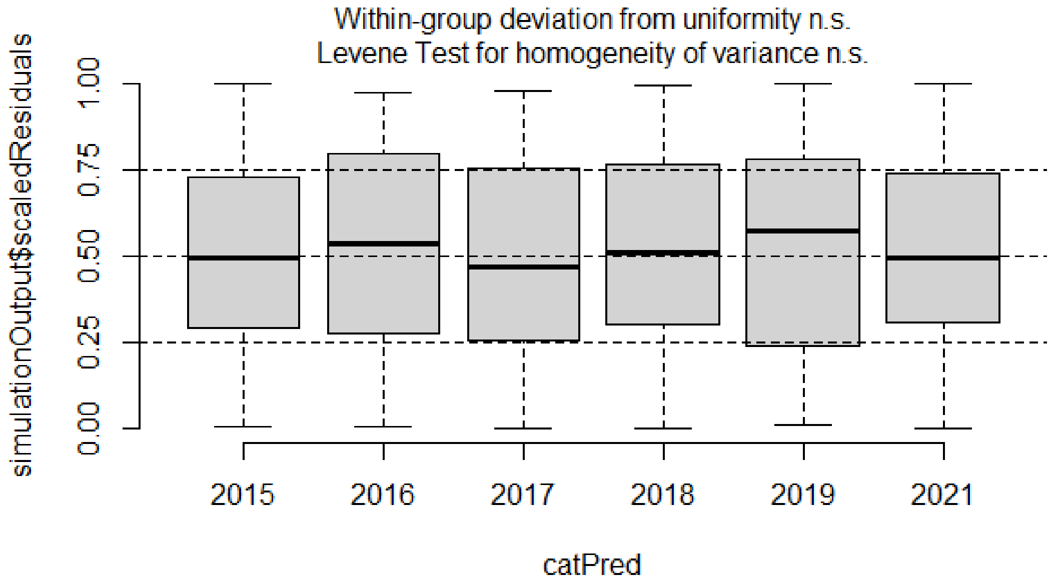
```
##  Family: nbinom2  ( log )
## Formula:
```

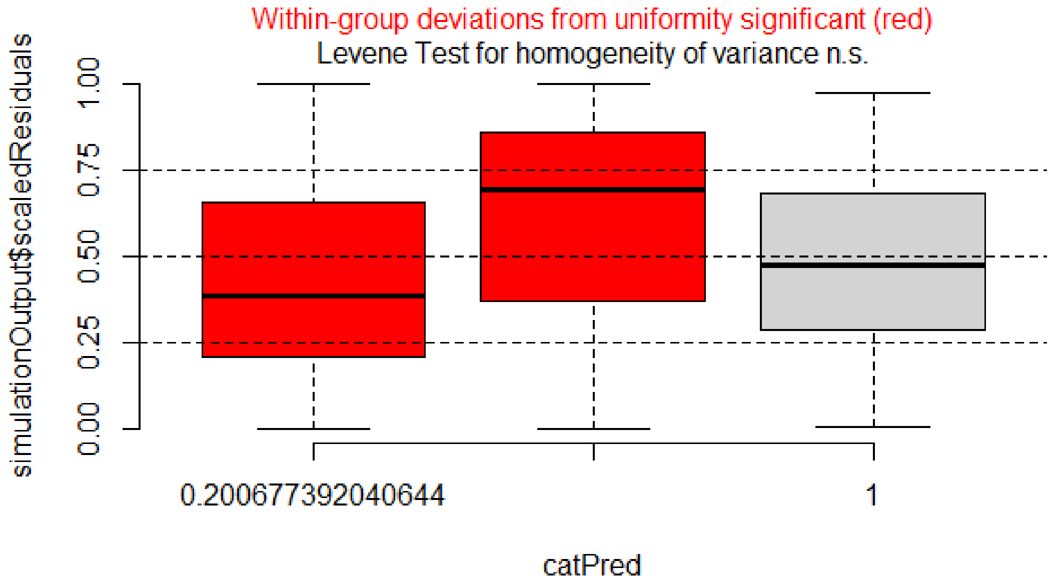
```
## FREQ ~ YEAR + MESH + DEPTH + STEMP + SAL + DO + offset(lnEffort)
## Zero inflation:        ~YEAR + MESH + STEMP + DO
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   3344.9   3440.7  -1651.5   3302.9      687
##
##
## Dispersion parameter for nbinom2 family (): 0.74
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -6.58959    1.24491  -5.293 1.20e-07 ***
## YEAR2016    -0.56104    0.21494  -2.610  0.00905 **
## YEAR2017    -0.62833    0.20825  -3.017  0.00255 **
## YEAR2018    -0.51864    0.22188  -2.337  0.01942 *
## YEAR2019    -0.48473    0.21353  -2.270  0.02320 *
## YEAR2021    -0.15951    0.18906  -0.844  0.39883
## MESH         1.82911    0.32566   5.617 1.95e-08 ***
## DEPTH        0.18822    0.03718   5.062 4.14e-07 ***
## STEMP        0.03026    0.02195   1.379  0.16805
## SAL         -3.19021    2.28120  -1.398  0.16197
## DO          -0.07183    0.06020  -1.193  0.23283
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -14.31646    3.48678  -4.106 4.03e-05 ***
## YEAR2016      2.19784    0.58322   3.768 0.000164 ***
## YEAR2017      1.16332    0.59200   1.965 0.049406 *
## YEAR2018      1.44597    0.70041   2.064 0.038975 *
## YEAR2019      1.18860    0.55995   2.123 0.033779 *
## YEAR2021     -0.01593    0.68225  -0.023 0.981372
## MESH         -0.67762    0.90725  -0.747 0.455130
## STEMP         0.70629    0.08715   8.104 5.32e-16 ***
## DO            0.26252    0.15420   1.703 0.088656 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

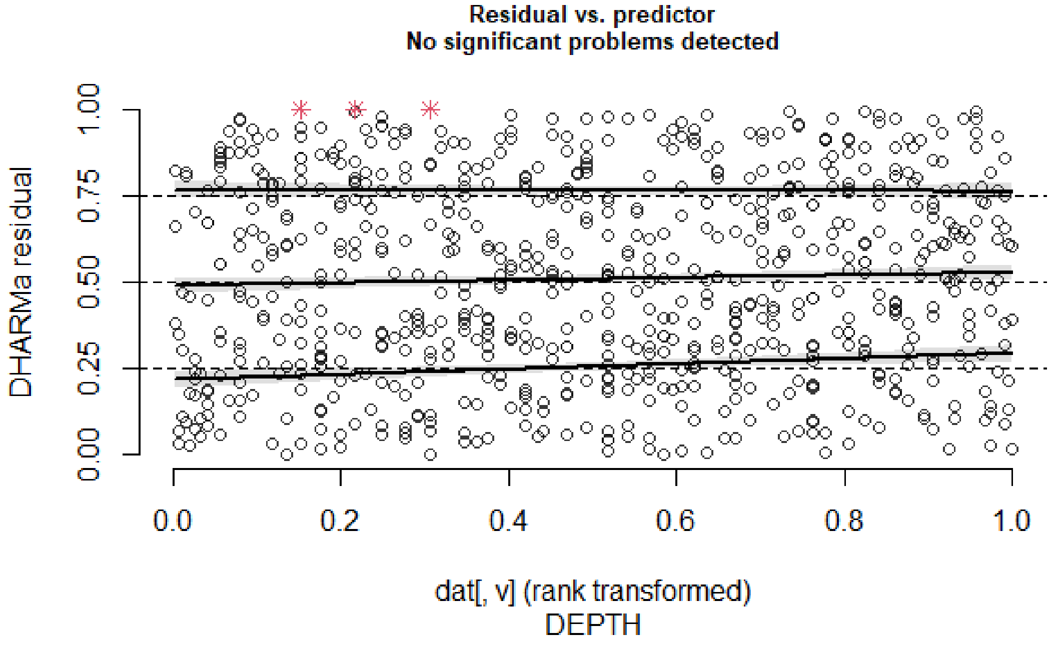
Model Diagnostics

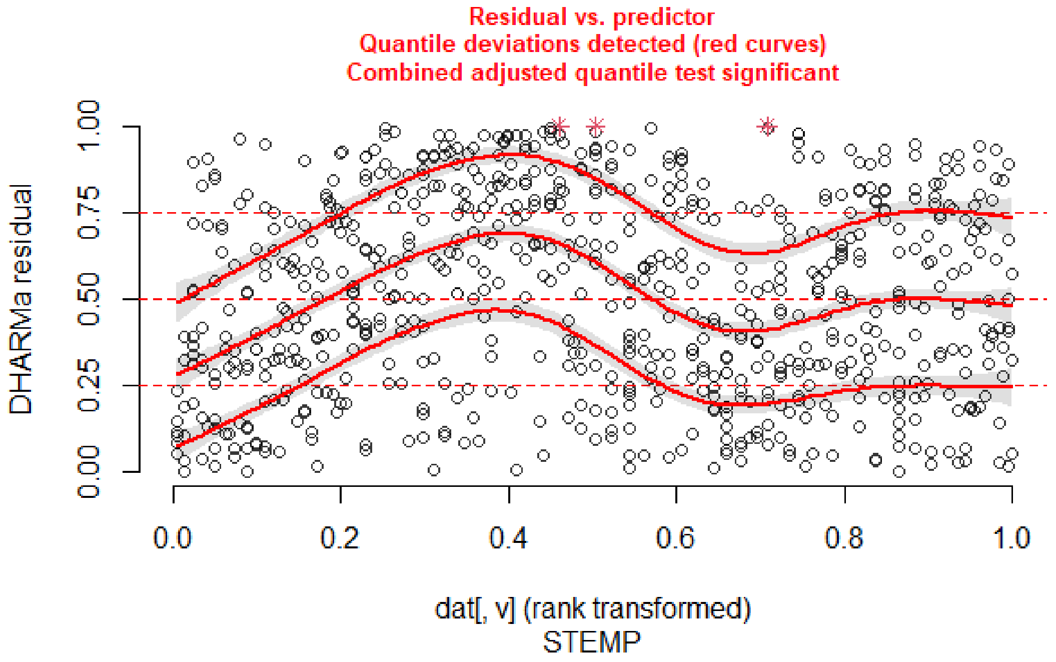
The diagnostics for the zero-inflated negative binomial were acceptable though quantile deviations were detected.

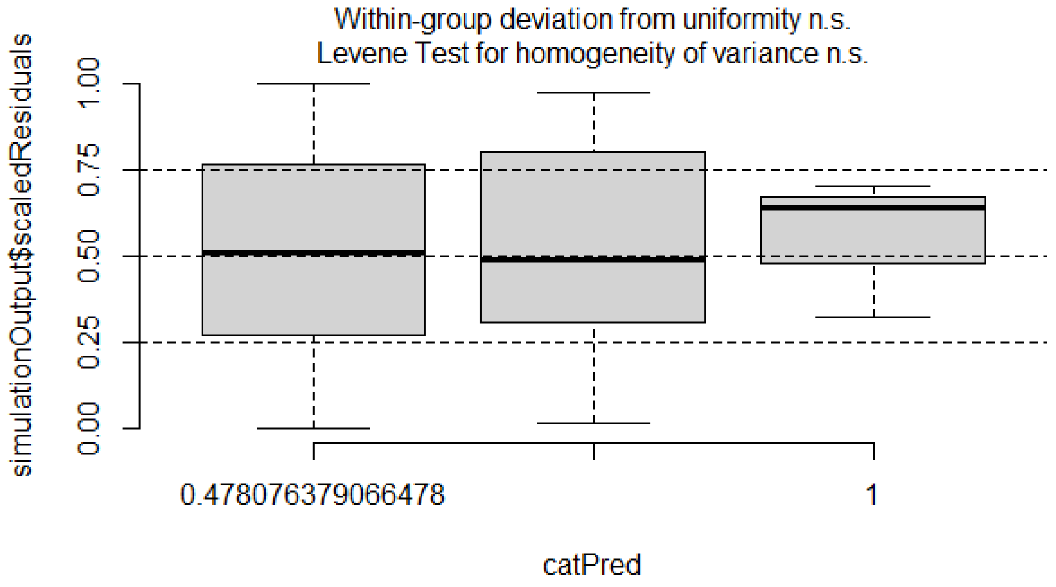

DHARMa residual
QQ plot residuals
KS test: p= 0.5318
Deviation n.s.
Dispersion test: p= 0.10
Deviation n.s.
Outlier test: p= 0.2868
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
0.0
0.4
0.8
Residual vs. predicted
Quantile deviations detected (red curves)
Combined adjusted quantile test significar
DHARMa residual
0.00
0.50
1.00
0.0
0.4
0.8
Model predictions (rank transformed)

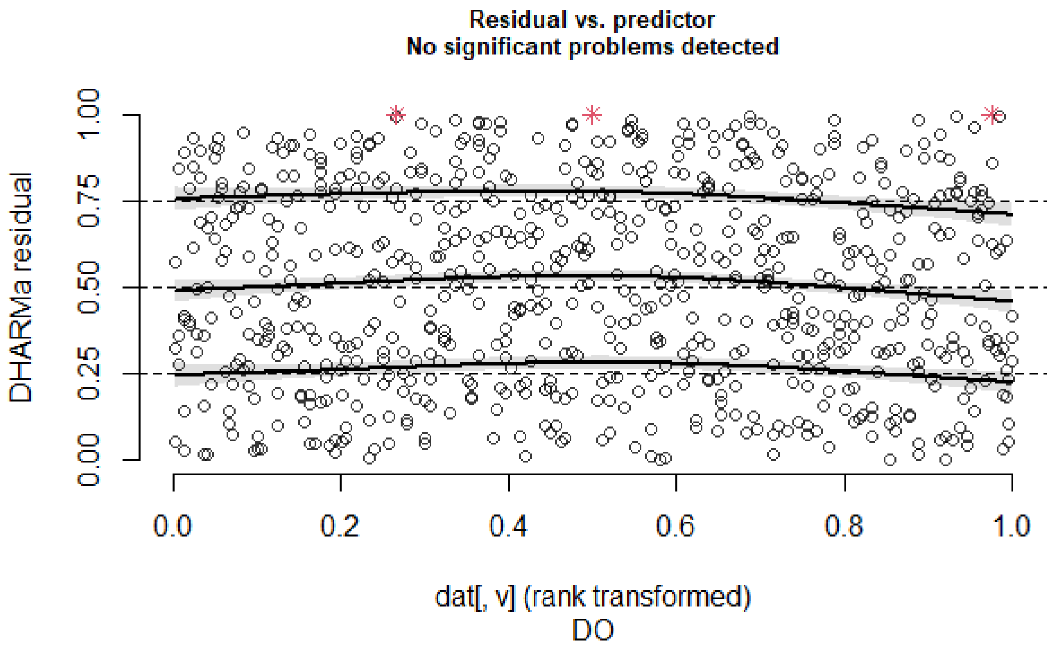

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
2015
2016
2017
2018
2019
2021
catPred


Within-group deviations from uniformity significant (red)
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.200677392040644
1
catPred


Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
DEPTH

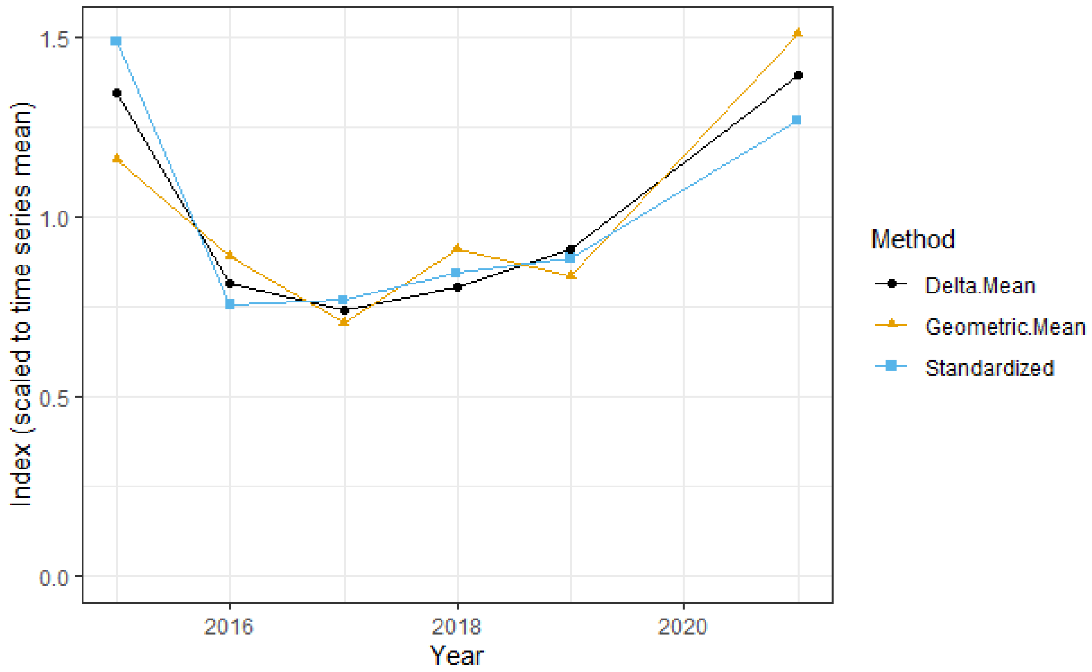

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant

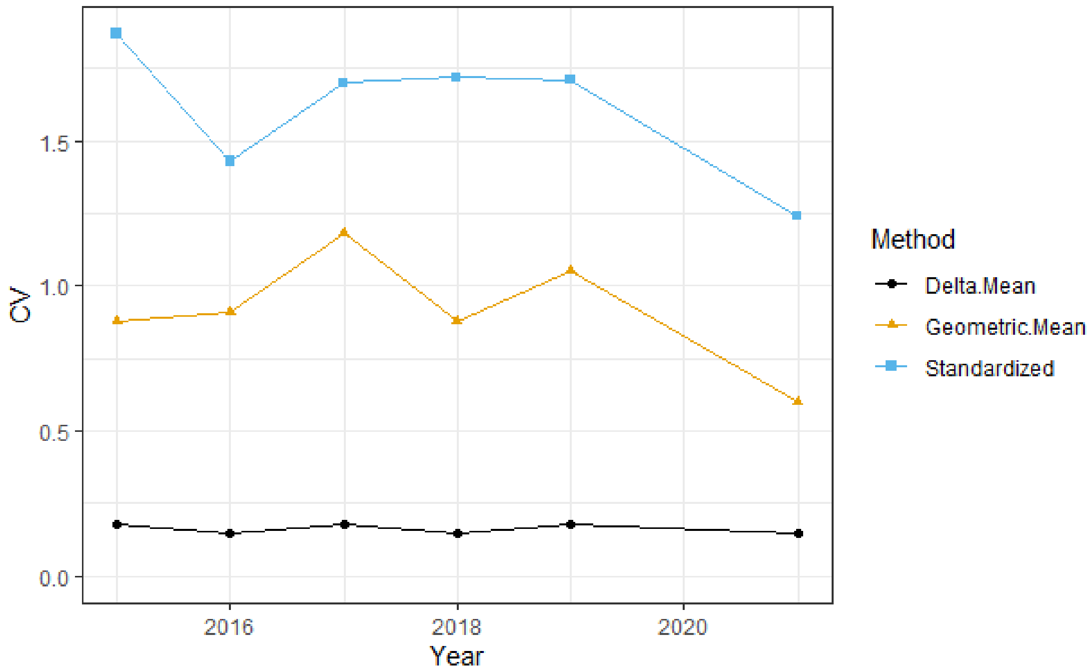

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected as best in this case.


Index (scaled to time series mean)
1.5
1.0
0.5
0.0
2016
2018
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
1.5
1.0
0.5
0.0
2016
2018
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2015	8.052	1.87	2.393	0.88	6.561	0.18
2016	4.084	1.43	1.834	0.91	3.972	0.15
2017	4.153	1.70	1.450	1.18	3.592	0.18
2018	4.562	1.72	1.877	0.88	3.911	0.15
2019	4.788	1.71	1.725	1.05	4.431	0.18
2021	6.866	1.24	3.118	0.60	6.784	0.15

Limited Mesh Sizes

Negative Binomial

The negative binomial exhibited convergence problems. Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered negative binomial exhibited convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR+MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR + MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = nbinom2)
```

GAM

The general additive model cannot fit zero-inflated models and was not used further.

AIC Comparisons

AIC favored the zero-altered negative binomial.

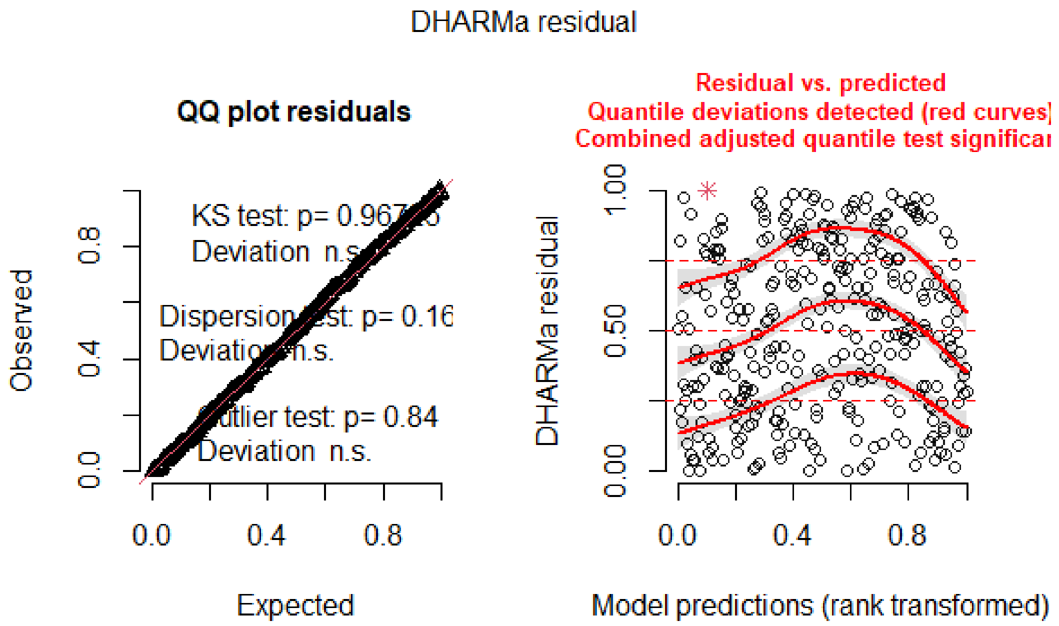
```
##      dAIC df
## ZANB  0   27
## NB1  NA   14
## ZINB NA   27
```

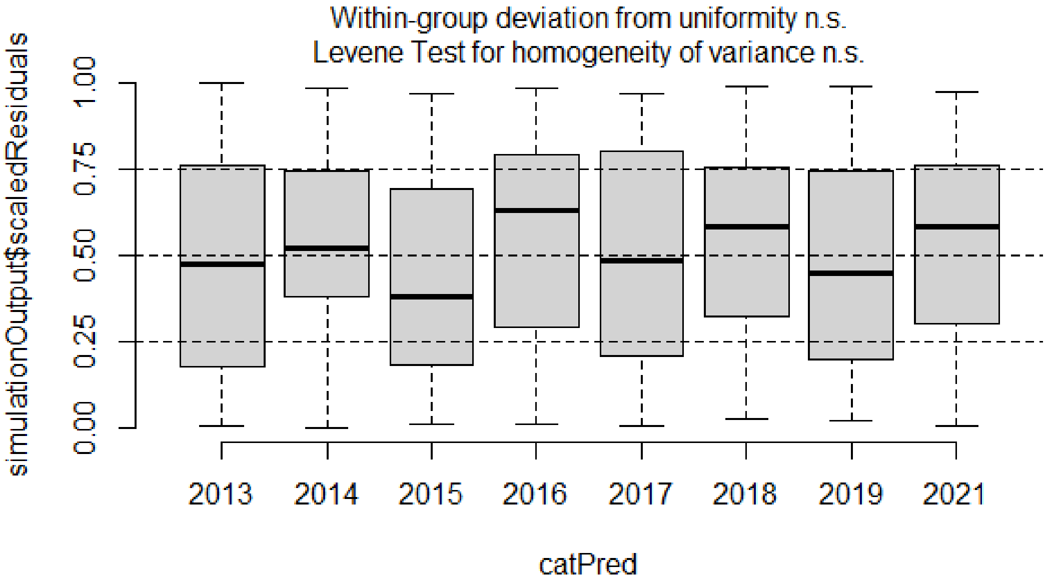
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

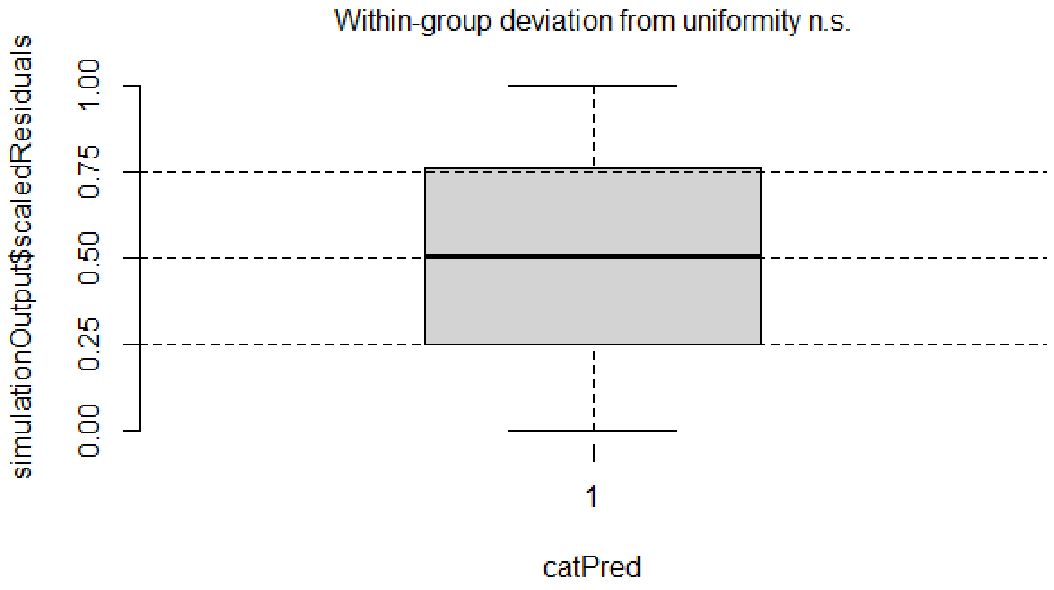
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MESH + STEMP + SAL + offset(lnEffort)
## Zero inflation:         ~STEMP + SAL
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##       NA       NA       NA       NA      301
##
##
## Dispersion parameter for nbinom2 family (): 0.648
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -0.008787        NaN     NaN      NaN
## YEAR2014     0.971232   0.337425   2.878  0.00400 **
## YEAR2015     1.701159   0.324229   5.247 1.55e-07 ***
## YEAR2016     0.403922   0.334725   1.207  0.22754
## YEAR2017     0.556225   0.335329   1.659  0.09717 .
## YEAR2018     0.231176   0.348211   0.664  0.50676
## YEAR2019     0.612664   0.330816   1.852  0.06403 .
## YEAR2021     1.243968   0.321738   3.866  0.00011 ***
## MESH        -0.021969        NaN     NaN      NaN
## STEMP       -0.124790   0.026487  -4.711 2.46e-06 ***
## SAL         -5.692887   2.014396  -2.826  0.00471 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   12.948      8.423   1.537    0.124
## STEMP         -3.457      2.345  -1.474    0.140
## SAL           13.132     14.335   0.916    0.360
```

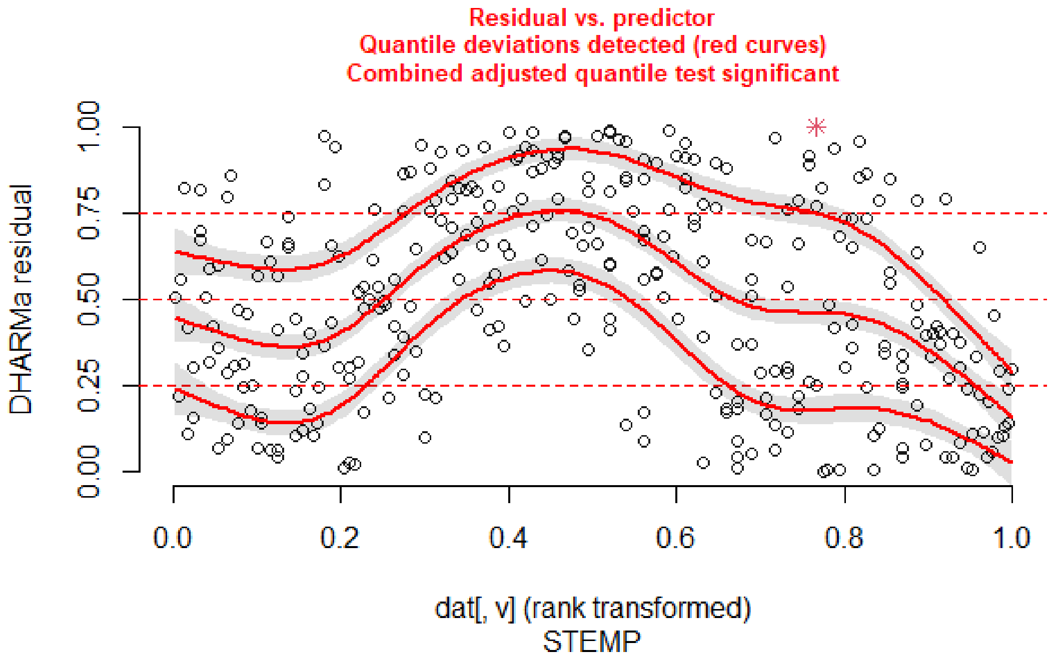
Model Diagnostics

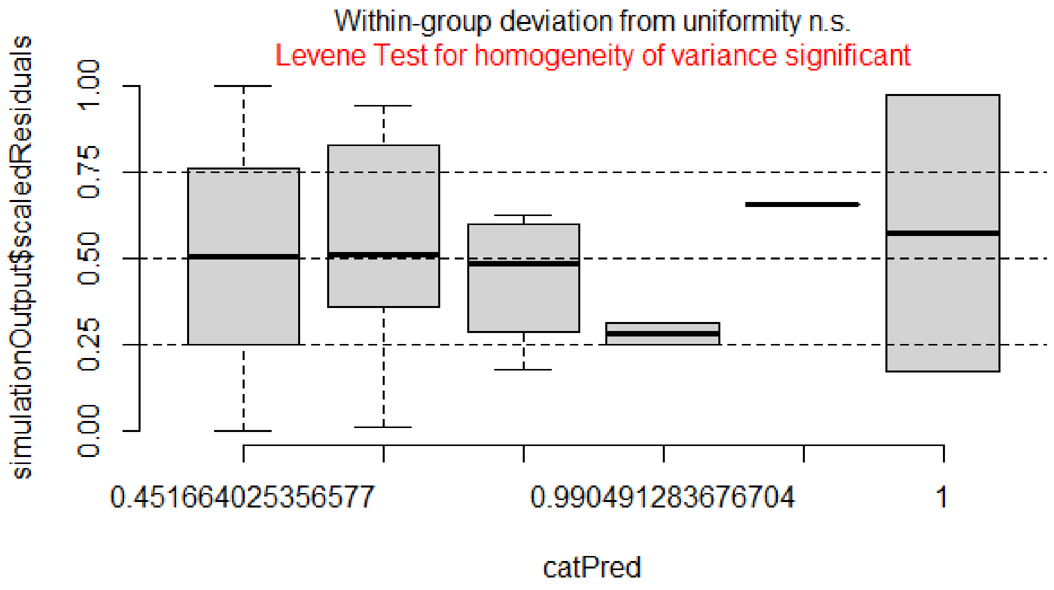
The diagnostics for the zero-inflated negative binomial were acceptable though some quantile deviations were detected.






Within-group deviation from uniformity n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1
catPred

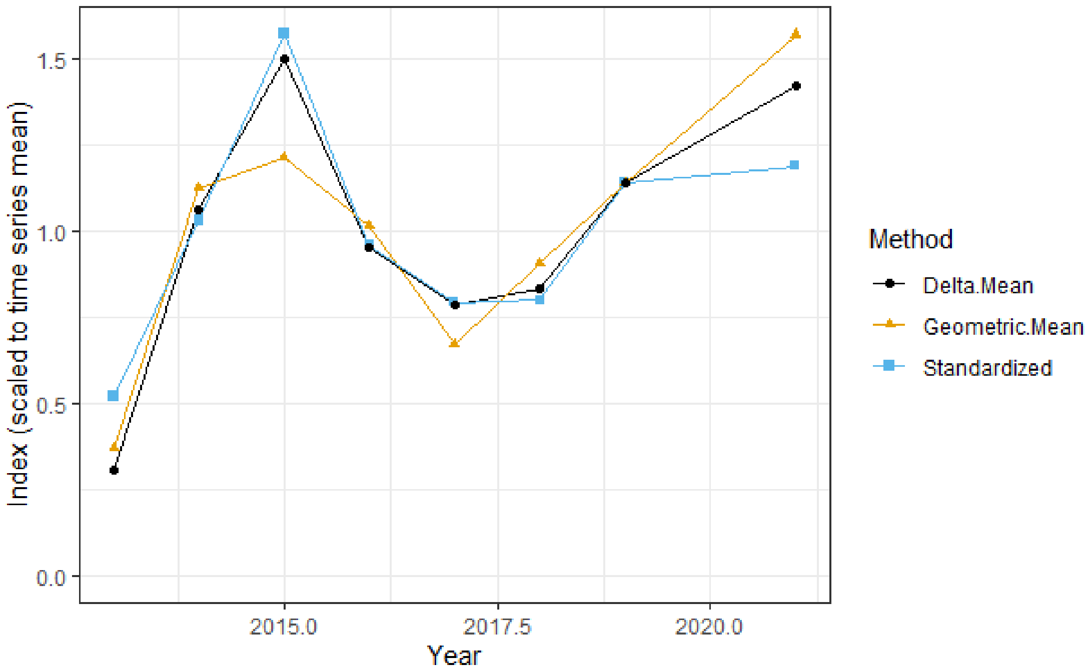

Residual vs. predictor
Quantile deviations detected (red curves)
Combined adjusted quantile test significant
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP

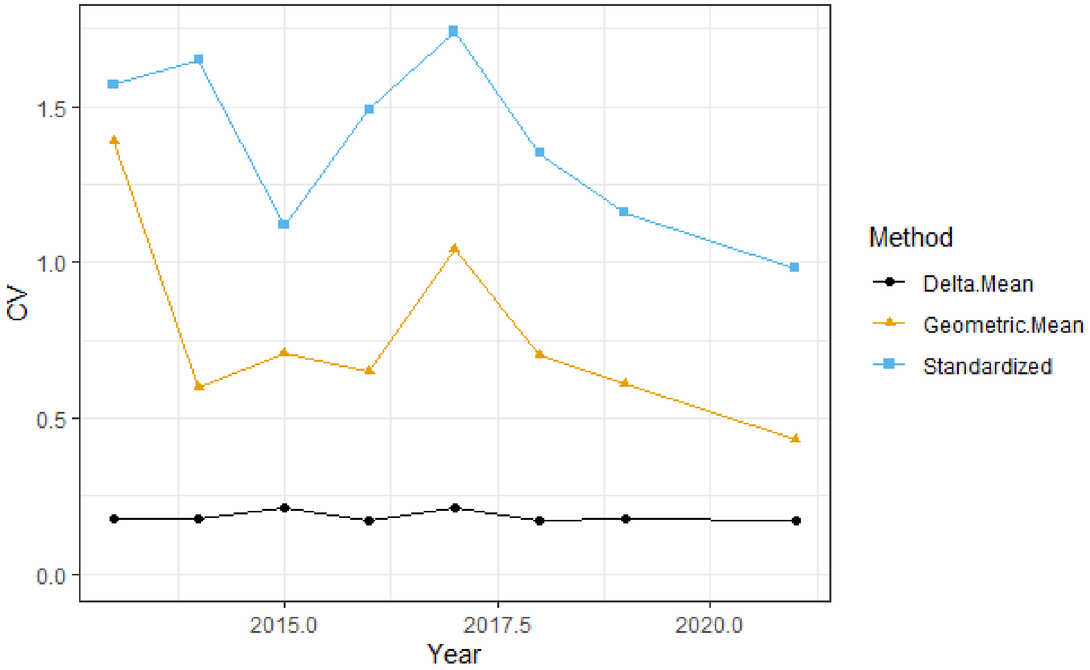


Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.

In comparing the limited year and limited mesh results, the limited year delta mean was selected for use in modelling.


Index (scaled to time series mean)
0.0
0.5
1.0
1.5
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0.0
0.5
1.0
1.5
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2013	3.298	1.57	0.978	1.39	1.776	0.18
2014	6.533	1.65	2.978	0.60	6.140	0.18
2015	9.972	1.12	3.214	0.71	8.672	0.21
2016	6.083	1.49	2.693	0.65	5.515	0.17
2017	5.027	1.74	1.784	1.04	4.542	0.21
2018	5.077	1.35	2.406	0.70	4.815	0.17
2019	7.227	1.16	3.022	0.61	6.574	0.18
2021	7.529	0.98	4.165	0.43	8.216	0.17

Final Selection for Modelling

After comparing the limited year and limited mesh results, the limited year delta mean was selected for use in modelling

MD North East River Blueback Herring Survey Standardization

Survey Description

MD DNR has conducted a gill net survey targeting river herring in the North East River since 2013. A multi-panel sinking monofilament gill net is set perpendicular to the channel at four randomly chosen sites once a week for 10 weeks in mid-March to mid-May. For the 2013 and 2014 sampling years, the gill net had three separate panels each 100ft x 6ft with mesh sizes of 2 ½, 2 ¾, and 3”. In 2015, the 3” mesh panel was replaced with a 2 ¼” mesh panel, as there was evidence the current mesh size selection was not successful in capturing smaller sized blueback herring. Four sites are randomly chosen for each day, along with four alternate sites, from a grid of 1000ft x 1000ft squares overlaid on a map of the North East River. Determination of whether to set the net shallow or deep is also randomly chosen. The net is soaked for 30 min at each site prior to retrieval. All fish are identified and enumerated to species per gill net mesh size. All alewife and blueback herring are sexed and measured to the nearest mm FL and TL. Scales are taken from a subsample of alewife and blueback herring per panel (i.e. first 20 fish encountered of each species per panel) to determine age and spawning history.

The North East River Gill Net Survey is successful in capturing a relative sample of both alewife and blueback herring spawning stock in the North East River. This survey captures the weekly temporal differences in these species spawning runs, and provides a relative index of abundance.

Subsetting

Since the survey is only 10 weeks with river herring as the target species there is no sense limiting months. The issue here is mesh size. The survey started in 2013 with mesh 2.5, 2.75, 3.0, but in 2015 mesh size changed to 2.25, 2.5, 2.75. In order to be consistent there are really only two options: stick to only 2.5, and 2.75 mesh sizes ignoring the highest frequency mesh or standardize the index limited to 2015 and forward where mesh was consistent.

Both limited years and limited mesh were run.

Model Selection

The final limited mesh dataset had 31.25% positive sets. The final limited years dataset had 37.71% positive sets.

Limited Years

Negative Binomial

The negative binomial exhibited convergence problems. Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered negative binomial exhibited convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR+MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR + MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~ MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = nbinom2)
```

GAM

The general additive model cannot fit zero-inflated models and was not used further. Full model:

AIC Comparisons

AIC favored the negative binomial. However, various zero-inflated negative binomial regressions minus non-significant factors may be best.

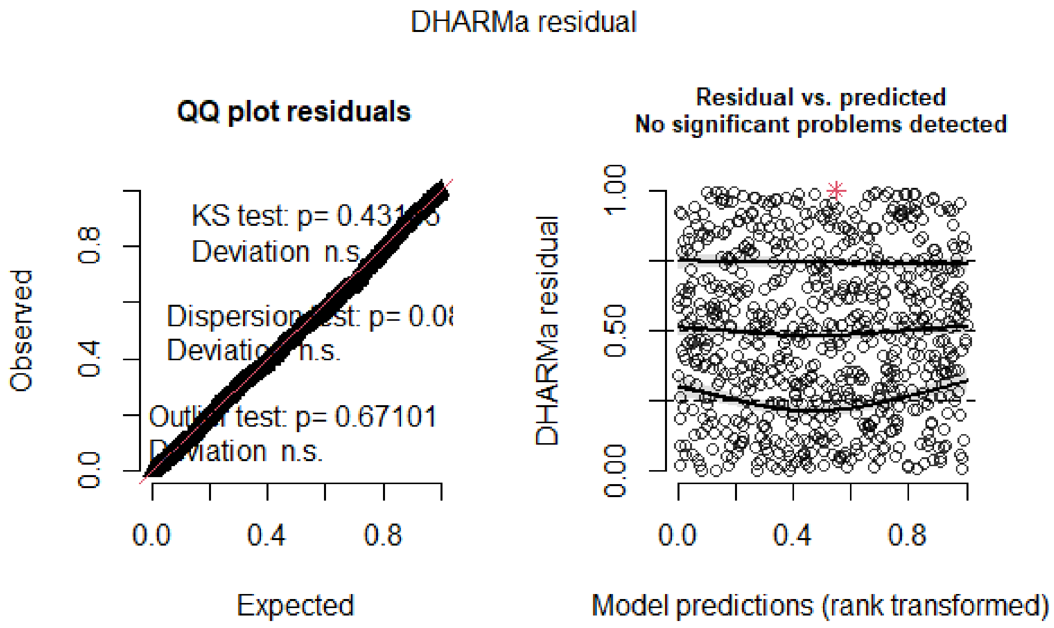
```
##        dAIC df
## NB1     0   12
## ZINB   NA   23
## ZINB.2 NA   18
## ZANB   NA   23
```

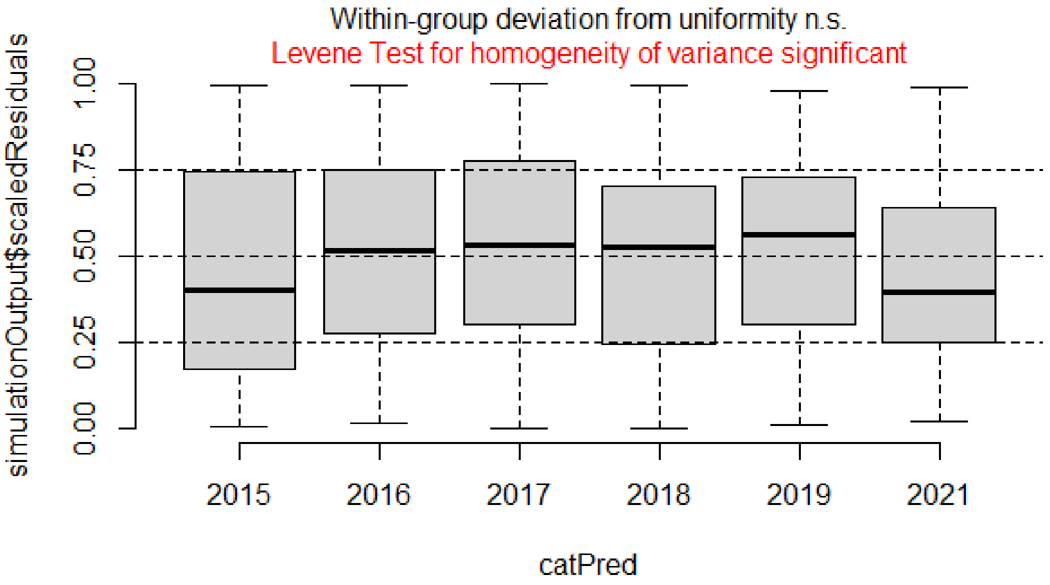
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-inflated negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

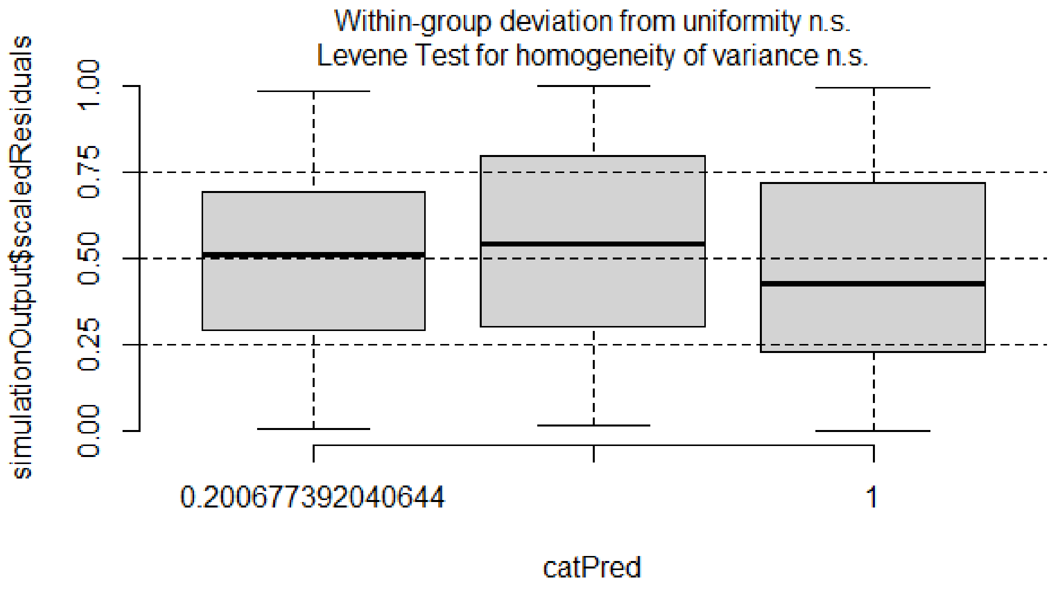
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MESH + STEMP + +offset(lnEffort)
## Zero inflation:        ~DEPTH + STEMP
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   2097.0   2151.7  -1036.5   2073.0      696
##
##
## Dispersion parameter for nbinom2 family (): 0.663
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   7.8478     1.2608   6.224 4.84e-10 ***
## YEAR2016     -0.6412     0.2409  -2.662 0.007779 **
## YEAR2017     -0.8970     0.2455  -3.653 0.000259 ***
## YEAR2018     -1.0185     0.2723  -3.741 0.000184 ***
## YEAR2019      0.4509     0.2261   1.995 0.046095 *
## YEAR2021      0.1651     0.2370   0.697 0.485888
## MESH         -4.1925     0.4064 -10.316  < 2e-16 ***
## STEMP         0.0504     0.0358   1.408 0.159134
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   8.9100     1.7627   5.055 4.31e-07 ***
## DEPTH         0.2837     0.1655   1.714   0.0865 .
## STEMP        -0.8816     0.1074  -8.207 2.26e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

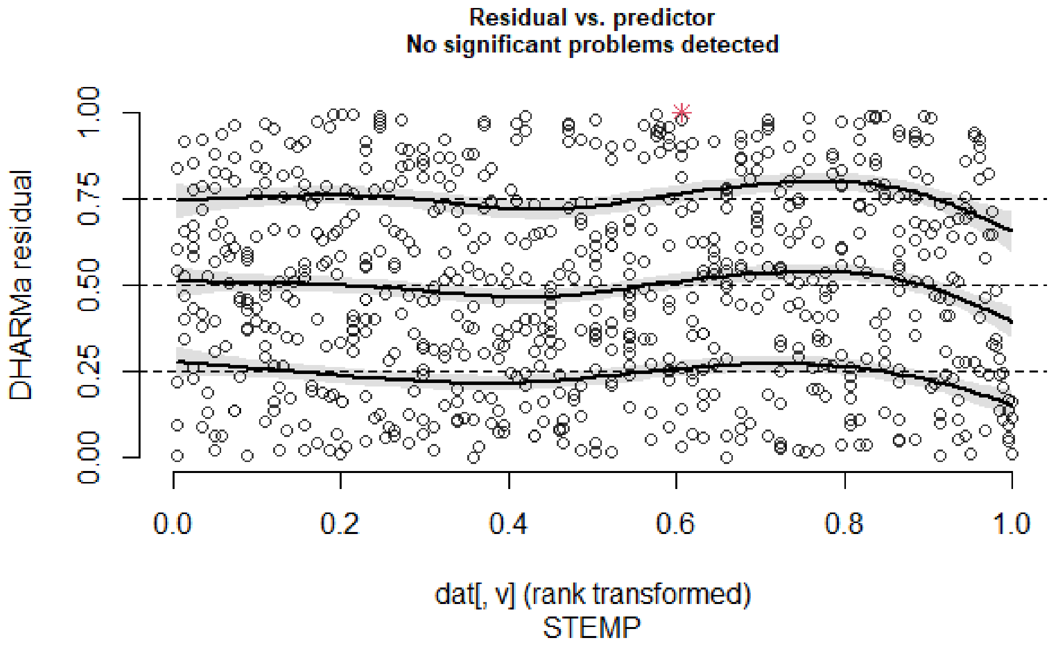
Model Diagnostics

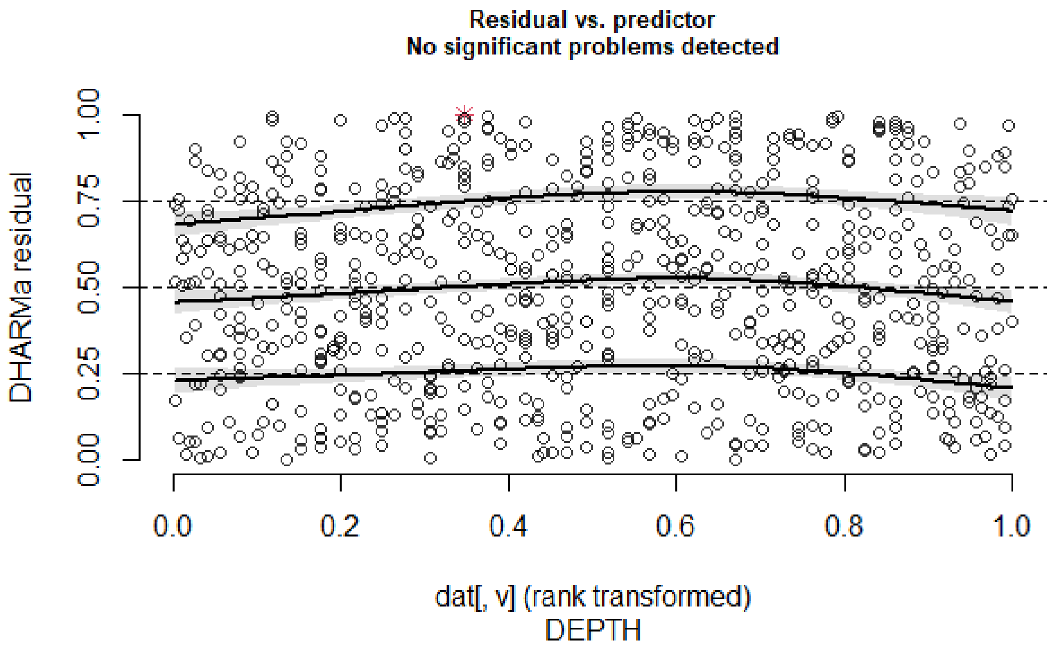
The diagnostics for the zero-inflated negative binomial were acceptable and had no significant quantile deviations.


DHARMa residual
QQ plot residuals
KS test: p= 0.431
Deviation n.s.
Dispersion test: p= 0.0
Deviation n.s.
Outlier test: p= 0.67101
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance significant
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
2015
2016
2017
2018
2019
2021
catPred

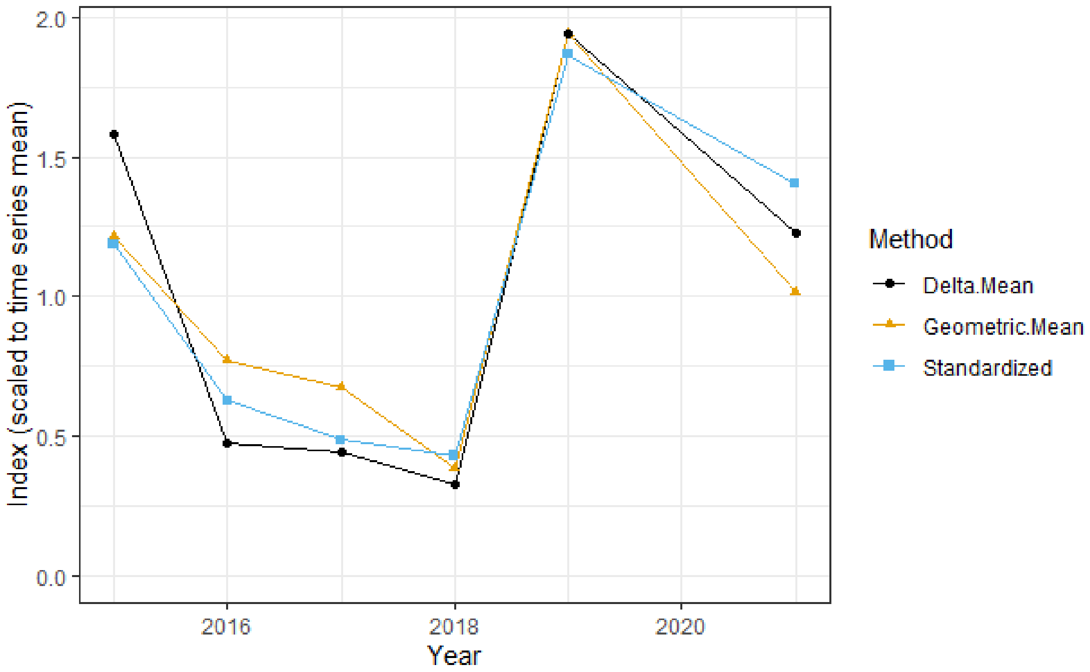

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.200677392040644
1
catPred

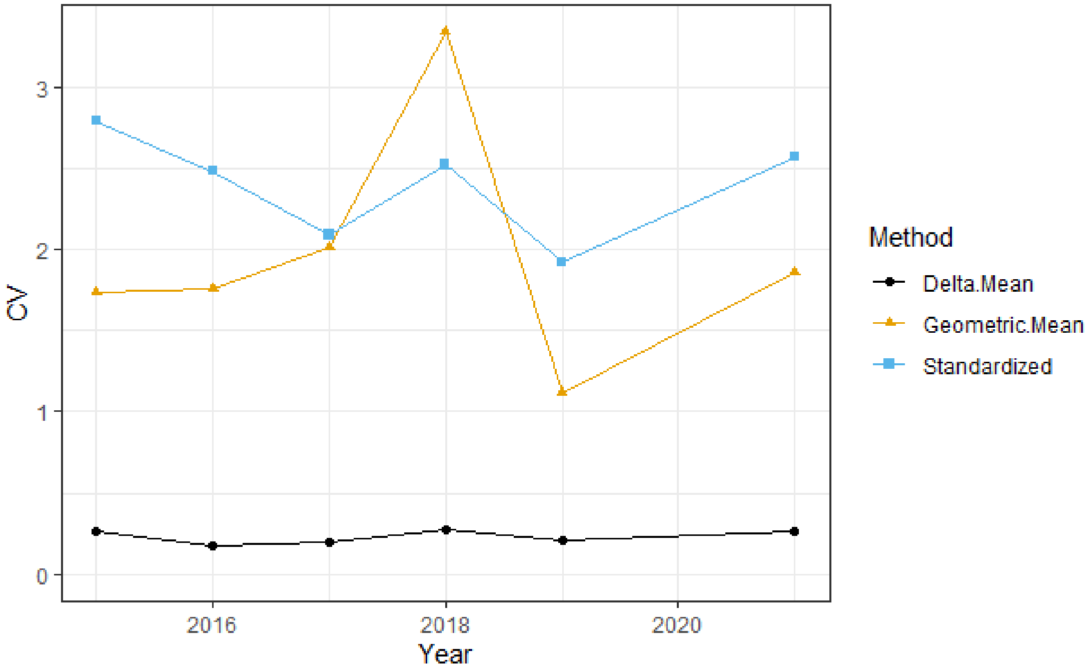

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected as best in this case.


Index (scaled to time series mean)
0.0
0.5
1.0
1.5
2.0
2016
2018
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
1
2
3
2016
2018
2020
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2015	2.507	2.79	1.221	1.73	5.278	0.26
2016	1.320	2.48	0.775	1.76	1.591	0.17
2017	1.022	2.09	0.678	2.01	1.486	0.20
2018	0.905	2.52	0.387	3.34	1.091	0.28
2019	3.935	1.92	1.952	1.12	6.484	0.21
2021	2.957	2.57	1.020	1.86	4.104	0.26

Limited Mesh Sizes

Negative Binomial

The negative binomial exhibited convergence problems. Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

The zero-altered negative binomial exhibited convergence problems. Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR+MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                ziformula = ~YEAR + MESH + DEPTH + STEMP + SAL + DO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + MESH + DEPTH + STEMP + SAL + DO +
offset(lnEffort),
                  ziformula = ~ MESH + DEPTH + STEMP + SAL + DO,
```

```
                     data = dat,
                     family = nbinom2)
```

GAM

The general additive model cannot fit zero-inflated models and was not used further. Full model:

AIC Comparisons

AIC favored the negative binomial. However, various zero-inflated negative binomial regressions minus non-significant factors may be best.

```
##        dAIC df
## NB1     0   14
## ZINB   NA   27
## ZINB.2 NA   20
## ZANB   NA   27
```

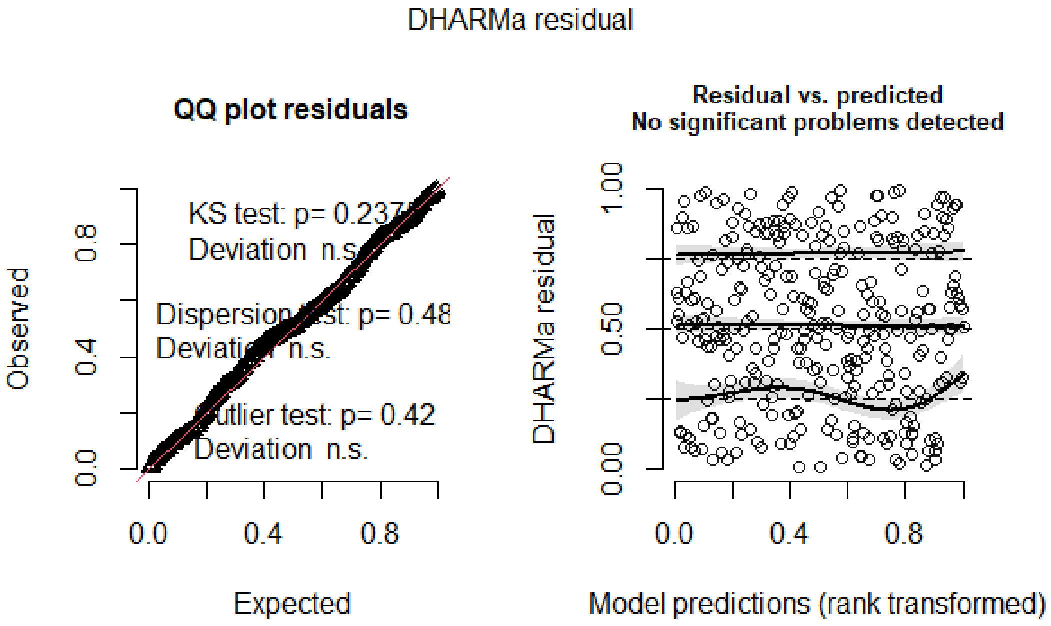
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-inflated negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

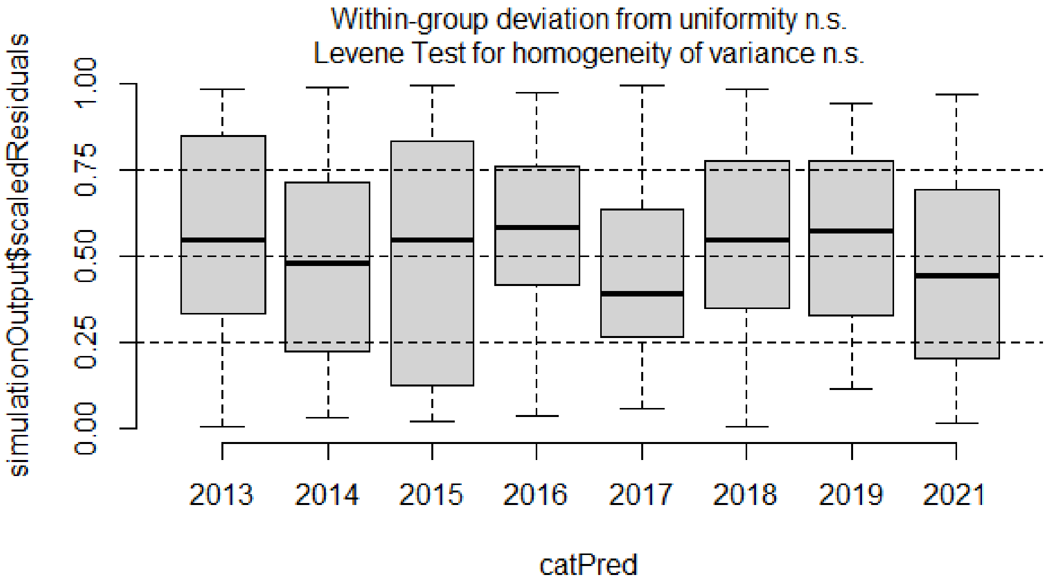
```
## Warning in .checkRankX(TMBStruc, control$rank_check): fixed effects in
## conditional model are rank deficient

## Warning in fitTMB(TMBStruc): Model convergence problem; non-positive-
definite
## Hessian matrix. See vignette('troubleshooting')

## Warning in fitTMB(TMBStruc): Model convergence problem; singular
convergence
## (7). See vignette('troubleshooting')

##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + MESH + STEMP + SAL + offset(lnEffort)
## Zero inflation:        ~STEMP + SAL
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##       NA       NA       NA       NA      301
##
##
## Dispersion parameter for nbinom2 family (): 0.872
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   1.01725        NaN     NaN      NaN
## YEAR2014      1.68532        NaN     NaN      NaN
## YEAR2015      1.74147        NaN     NaN      NaN
```

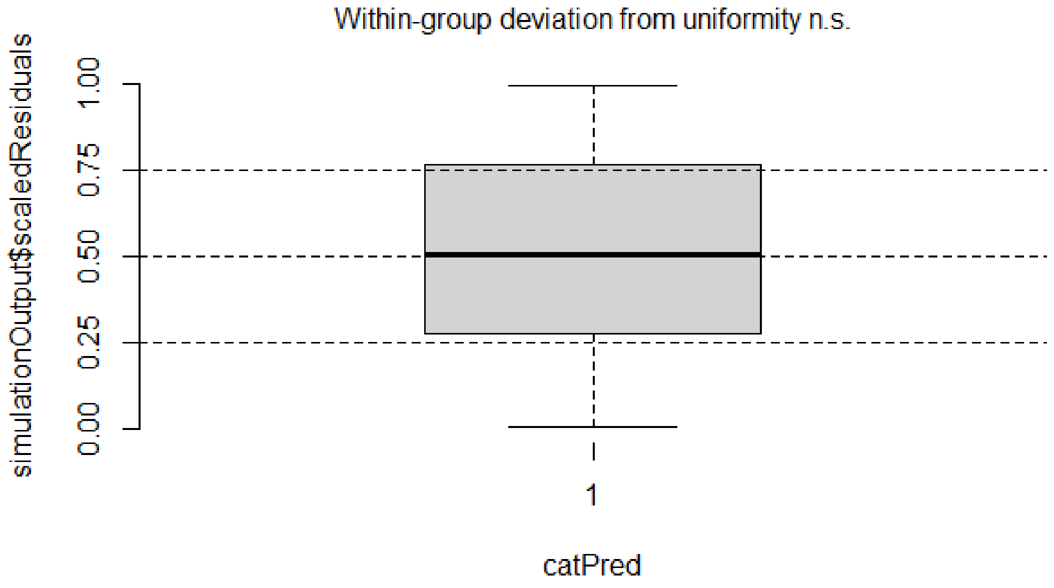
```
## YEAR2016       0.95788        NaN     NaN      NaN
## YEAR2017       0.56807        NaN     NaN      NaN
## YEAR2018       0.19497        NaN     NaN      NaN
## YEAR2019       2.06764        NaN     NaN      NaN
## YEAR2021       1.89612        NaN     NaN      NaN
## MESH           2.54313        NaN     NaN      NaN
## STEMP          0.01799        NaN     NaN      NaN
## SAL         -106.93813        NaN     NaN      NaN
## 
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   2.5189        NaN     NaN      NaN
## STEMP        -0.9734        NaN     NaN      NaN
## SAL          94.7268        NaN     NaN      NaN
```

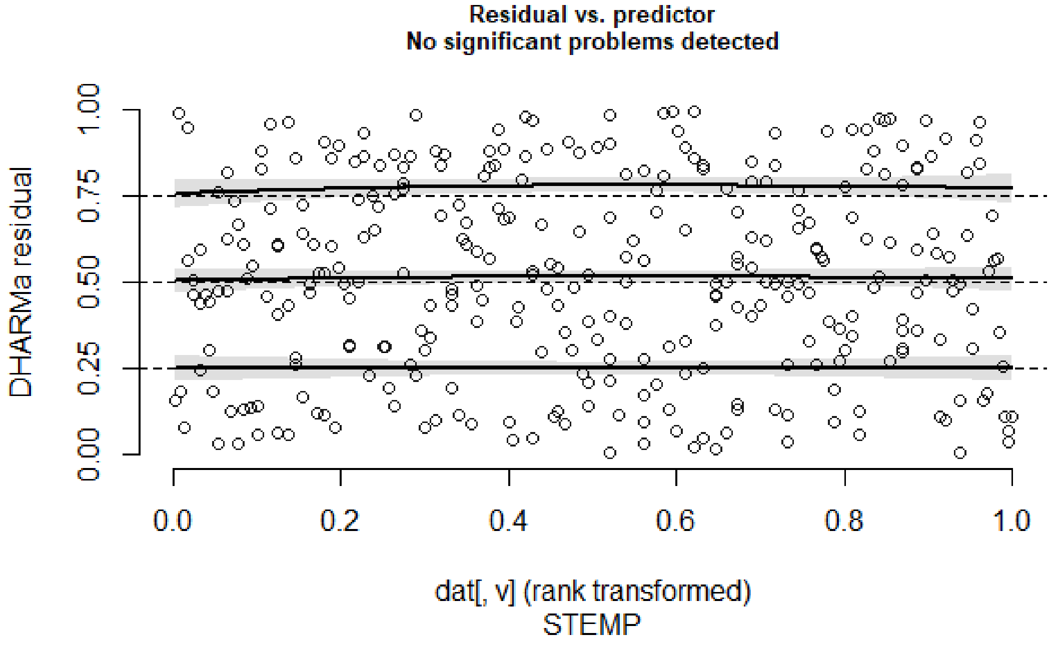
Model Diagnostics

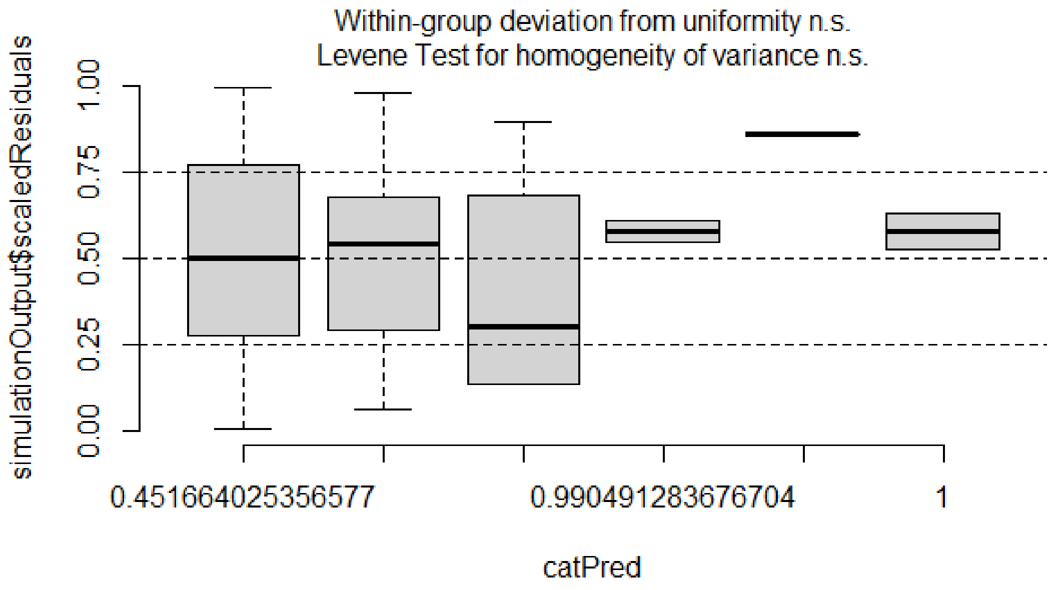
The diagnostics for the zero-inflated negative binomial were acceptable and had no significant quantile deviations.


DHARMa residual
QQ plot residuals
KS test: p= 0.237
Deviation n.s.
Dispersion test: p= 0.48
Deviation n.s.
Outlier test: p= 0.42
Deviation n.s.
Observed
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
Model predictions (rank transformed)
0.00
0.50
1.00
0.0
0.4
0.8


Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
2013
2014
2015
2016
2017
2018
2019
2021
catPred


Within-group deviation from uniformity n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
1
catPred

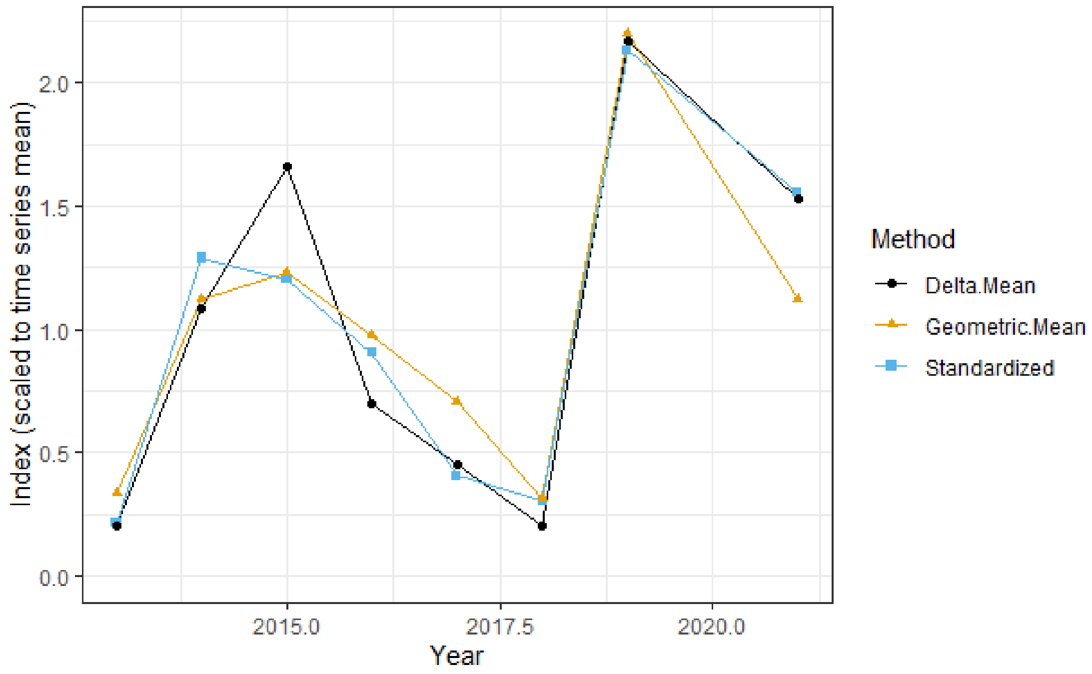

Residual vs. predictor
No significant problems detected
DHARMa residual
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
dat[, v] (rank transformed)
STEMP

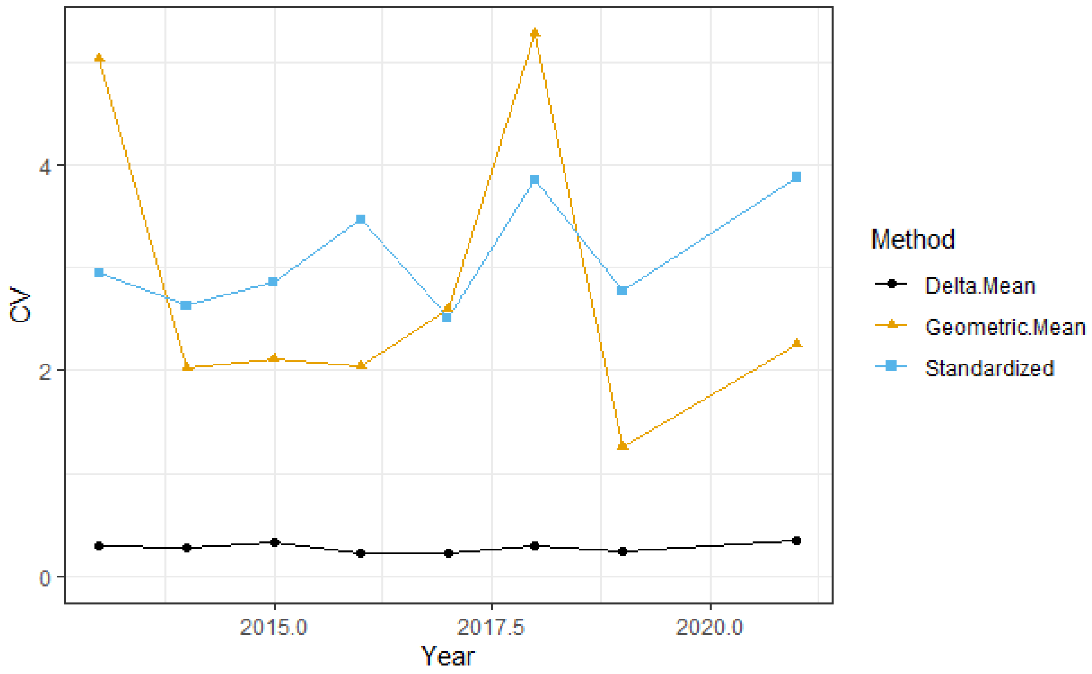


Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.

In comparing the limited year and limited mesh results, the limited year delta mean was selected for use in modelling.


Index (scaled to time series mean)
0.0
0.5
1.0
1.5
2.0
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
0
2
4
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2013	0.203	2.95	0.220	5.04	0.394	0.29
2014	1.235	2.63	0.746	2.02	2.098	0.28
2015	1.153	2.86	0.820	2.12	3.200	0.33
2016	0.868	3.47	0.650	2.04	1.345	0.22
2017	0.388	2.51	0.468	2.61	0.871	0.23
2018	0.289	3.86	0.210	5.28	0.392	0.30
2019	2.043	2.77	1.463	1.26	4.186	0.24
2021	1.488	3.88	0.744	2.25	2.951	0.34

MD Nanticoke River Alewife Survey Standardization

Survey Description

Though the current survey uses only data from 2013 forward, because of changes to the survey, there has been a survey in the Nanticoke since 1989. Alewife and blueback herring in Maryland's portion of the Nanticoke River were collected from commercial pound nets and fyke nets, and the number of nets and locations were fished at the discretion of the commercial watermen. These nets were generally sampled at least one to two times per week from early March to late April. Fish were sorted according to species and transferred to the survey boat for processing. Monitoring began in 1989, when it was still legal for commercial fishermen to harvest river herring, but has continued since the fishery closed as bycatch monitoring. Fish are sampled from commercial fyke and pound nets targeting perch and catfish (2013-2021). In 2015, there was extensive ice coverage late into the spring on the Nanticoke River that prohibited commercial fishermen from setting their gear.

A minimum of ten alewife and ten blueback herring selected at random from unculled commercial catches were counted, sexed, fork length measured and scales removed for age analysis. The total number of herring harvested was estimated by multiplying the number of bushels harvested by the number of fish per bushel from sampled nets on that particular day or by direct counts.

Subsetting

Months were subset to March and April since those are the months where the most River Herring are encountered.

Model Selection

The final dataset had 75.5% positive tows.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+offset(lnEffort),
                data = dat,
                family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+offset(lnEffort),
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

The zero-inflated negative binomial encountered convergence problems.

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+offset(lnEffort),
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO+offset(lnEffort),
                ziformula = ~STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

GAM

Full model:

```
GAM.NB <- gam(FREQ~YEAR + s(STEMP) + s(SSAL) + s(SDO)+offset(lnEffort),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-altered negative binomial.

```
##         dAIC df
## ZANB     0.0 21
## GAM.NB   9.1 14.4
## NB1     15.2 11
## ZINB.2  20.1 15
## ZINB      NA 21
```

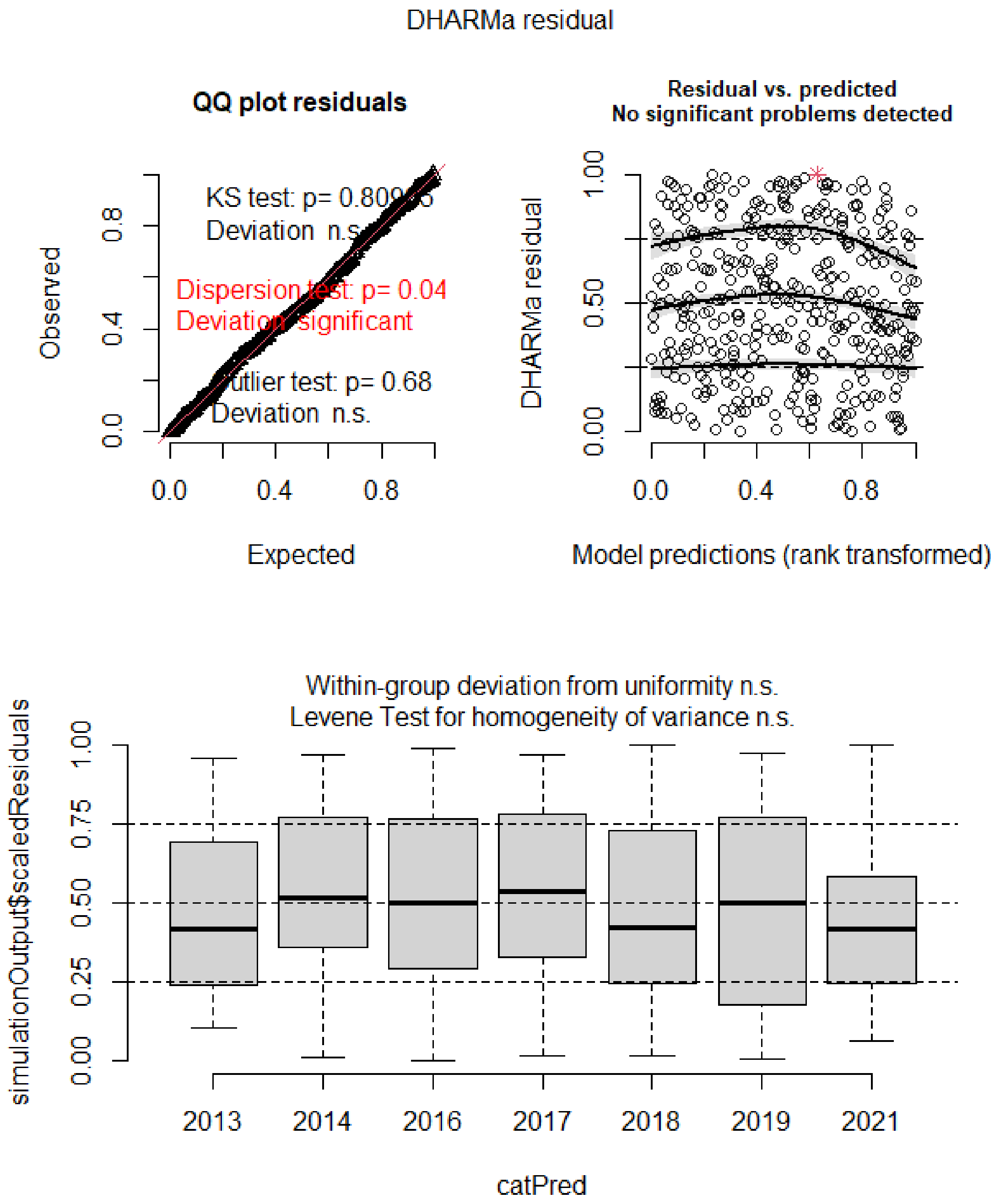
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

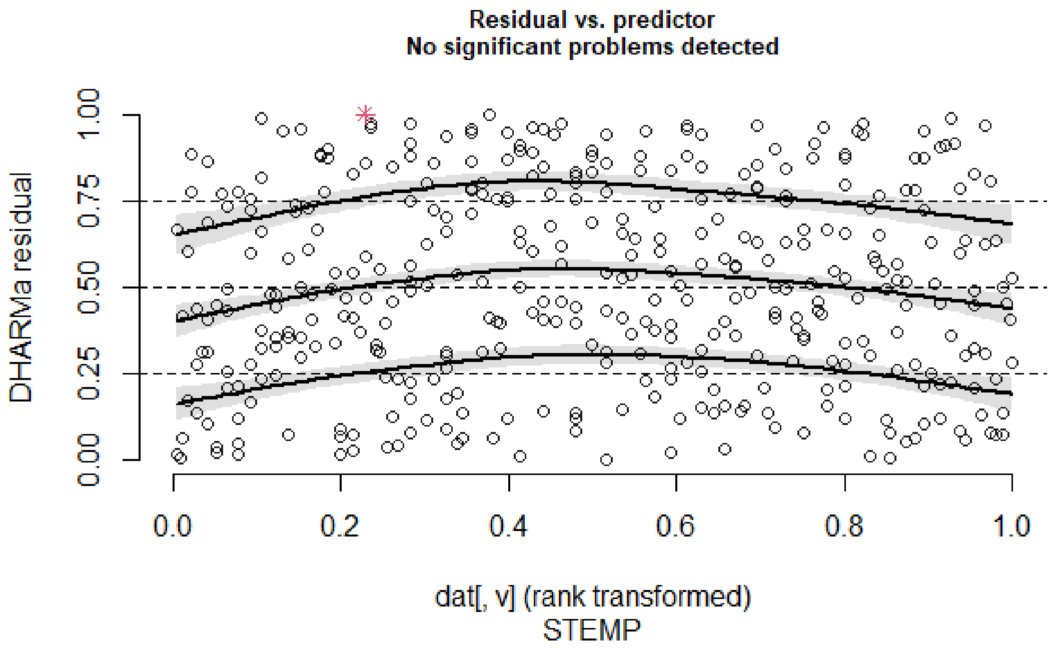
```
##  Family: truncated_nbinom2  ( log )
## Formula:          FREQ ~ YEAR + STEMP + offset(lnEffort)
## Zero inflation:        ~YEAR + STEMP
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   2080.1   2147.3  -1023.1   2046.1      367
##
```

```
##
## Dispersion parameter for truncated_nbinom2 family (): 0.397
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  2.58994    0.70529   3.672 0.000241 ***
## YEAR2014     0.70746    0.72504   0.976 0.329187
## YEAR2016     1.08409    0.71000   1.527 0.126788
## YEAR2017     0.14356    0.70137   0.205 0.837815
## YEAR2018    -0.45495    0.71024  -0.641 0.521813
## YEAR2019     0.17789    0.71191   0.250 0.802683
## YEAR2021     1.36707    0.73763   1.853 0.063836 .
## STEMP       -0.24596    0.03064  -8.026    1e-15 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -3.13154    0.91238  -3.432 0.000599 ***
## YEAR2014    -2.05750    0.93561  -2.199 0.027871 *
## YEAR2016    -2.98265    0.95829  -3.112 0.001855 **
## YEAR2017    -1.38844    0.88156  -1.575 0.115260
## YEAR2018    -0.38149    0.87243  -0.437 0.661912
## YEAR2019    -0.61757    0.87317  -0.707 0.479396
## YEAR2021    -0.96671    0.90390  -1.069 0.284849
## STEMP        0.25253    0.03845   6.568 5.11e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model Diagnostics

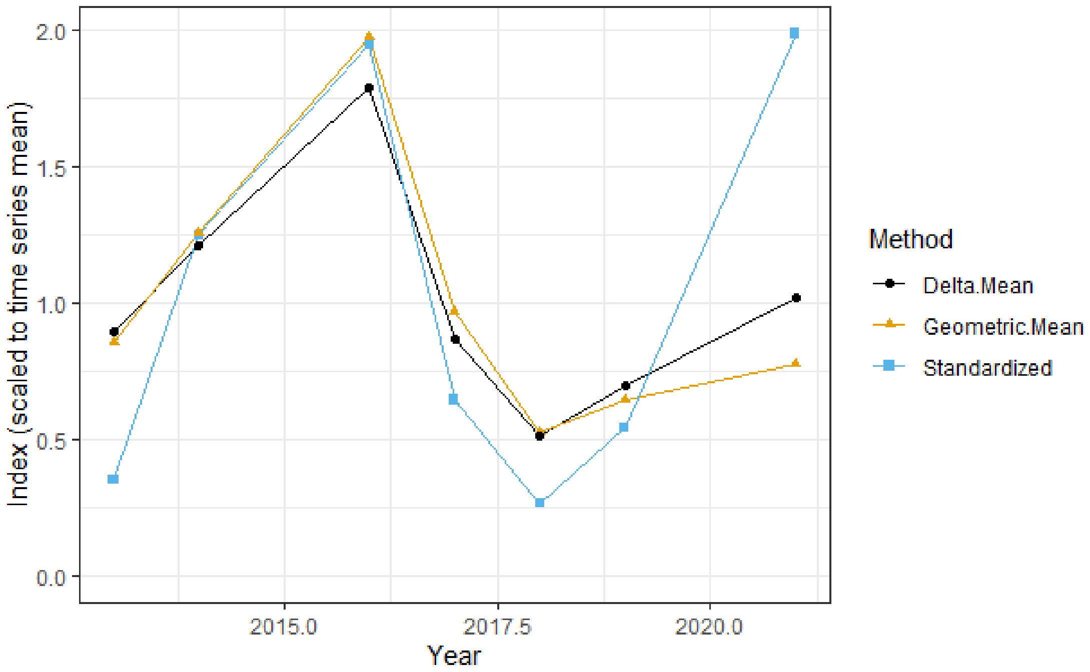
The diagnostics for the zero-altered negative binomial had some quantile deviations detected.

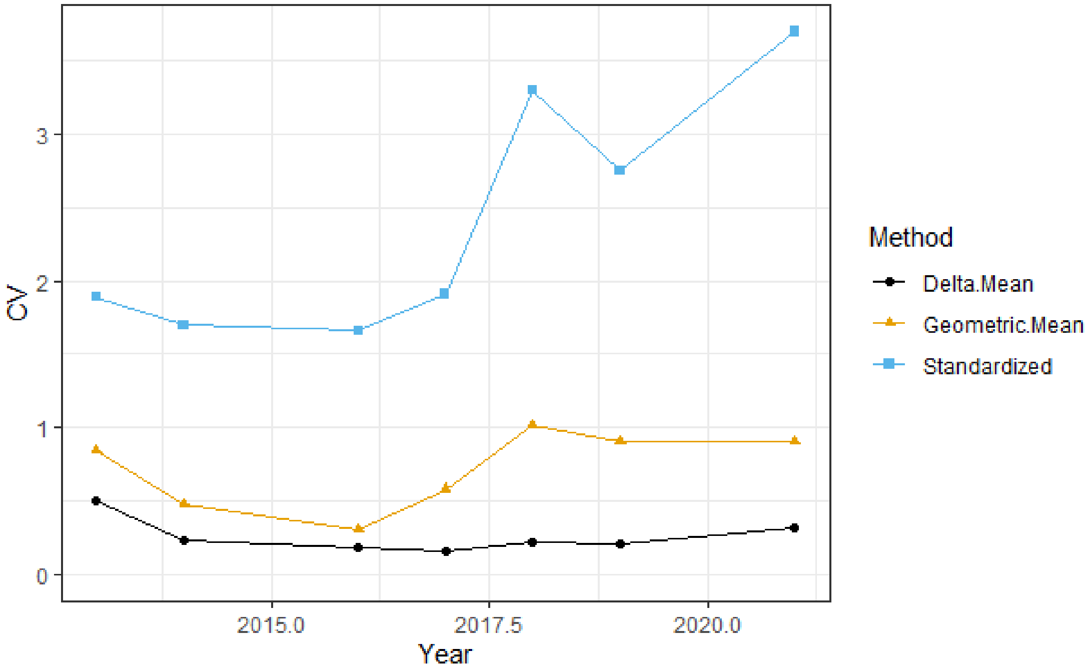

DHARMa residual
QQ plot residuals
KS test: p= 0.809[illegible]6
Deviation n.s.
Dispersion test: p= 0.04
Deviation significant
Outlier test: p= 0.68
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
0.0
0.4
0.8
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
Model predictions (rank transformed)
0.0
0.4
0.8
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
2013
2014
2016
2017
2018
2019
2021
catPred



Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
2.0
1.5
1.0
0.5
0.0
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
3
2
1
0
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2013	1.304	1.89	2.565	0.84	5.718	0.50
2014	4.603	1.70	3.780	0.48	7.703	0.23
2016	7.178	1.66	5.931	0.30	11.437	0.18
2017	2.374	1.91	2.902	0.58	5.549	0.16
2018	0.979	3.30	1.573	1.02	3.261	0.22
2019	2.009	2.75	1.941	0.90	4.425	0.21
2021	7.331	3.70	2.325	0.91	6.495	0.32

MD Nanticoke River Blueback Herring Survey Standardization

Survey Description

Though the current survey uses only data from 2013 forward, because of changes to the survey, there has been a survey in the Nanticoke since 1989. Alewife and blueback herring in Maryland's portion of the Nanticoke River were collected from commercial pound nets and fyke nets, and the number of nets and locations were fished at the discretion of the commercial watermen. These nets were generally sampled at least one to two times per week from early March to late April. Fish were sorted according to species and transferred to the survey boat for processing. Monitoring began in 1989, when it was still legal for commercial fishermen to harvest river herring, but has continued since the fishery closed as bycatch monitoring. Fish are sampled from commercial fyke and pound nets targeting perch and catfish (2013-2021). In 2015, there was extensive ice coverage late into the spring on the Nanticoke River that prohibited commercial fishermen from setting their gear.

A minimum of ten alewife and ten blueback herring selected at random from unculled commercial catches were counted, sexed, fork length measured and scales removed for age analysis. The total number of herring harvested was estimated by multiplying the number of bushels harvested by the number of fish per bushel from sampled nets on that particular day or by direct counts.

Subsetting

Months were subset to March and April since those are the months where the most River Herring are encountered.

Model Selection

The final dataset had 41.1% positive sets.

Negative Binomial

Full model:

```
NB1 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO + offset(lnEffort),
               data = dat,
               family = nbinom2)
```

Zero-Altered Negative Binomial

Full model:

```
ZANB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO + offset(lnEffort),
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = truncated_nbinom2(link = "log"))
```

Zero-Inflated Negative Binomial

Full model:

```
ZINB <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO + offset(lnEffort),
                ziformula = ~YEAR+STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
ZINB.2 <- glmmTMB(FREQ~YEAR + STEMP + SSAL + SDO + offset(lnEffort),
                ziformula = ~STEMP+SSAL+SDO,
                data = dat,
                family = nbinom2)
```

GAM

Full model:

```
GAM.NB <- gam(FREQ~YEAR + s(STEMP) + s(SSAL) + s(SDO) + offset(lnEffort),
              data = dat, family = 'nb')
```

AIC Comparisons

AIC favored the zero-inflated negative binomial.

```
##        dAIC df
## ZINB    0.0 21
## GAM.NB 16.2 18.9
## ZINB.2 25.3 15
## ZANB   39.0 21
## NB1    65.1 11
```

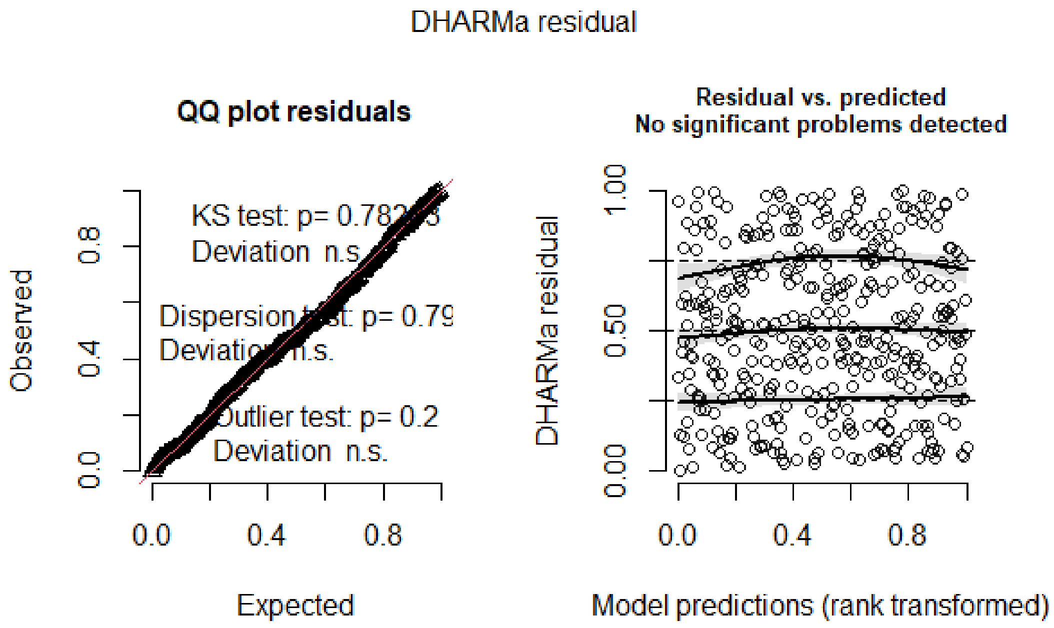
After analyzing the relative AIC and the DHARMa residual diagnostics and taking into account the degrees of freedom, the zero-altered negative binomial was selected as the final model. In order to select factors for inclusion in the model, various combinations of covariates were checked for significance.

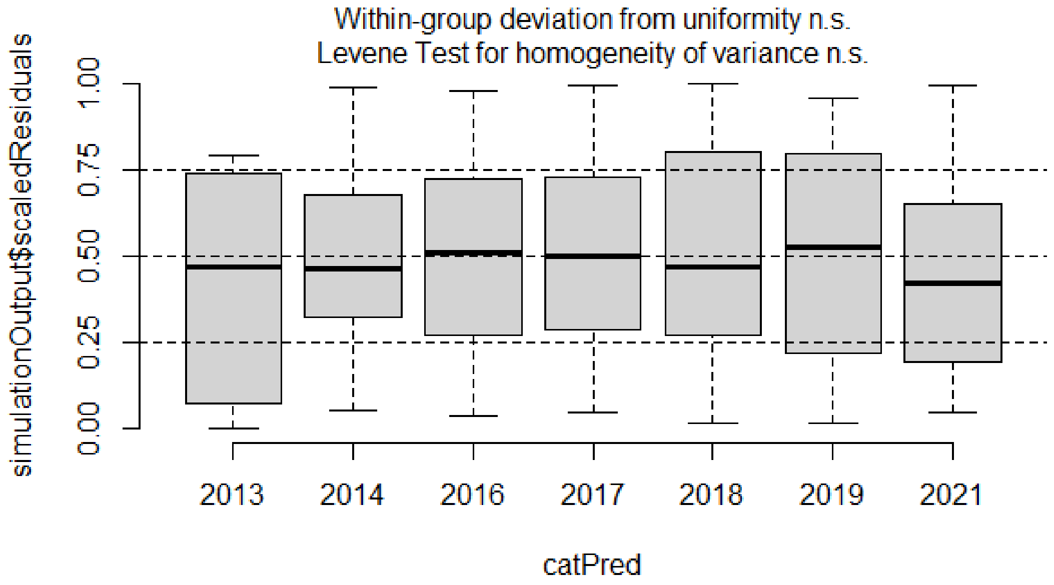
```
##  Family: nbinom2  ( log )
## Formula:          FREQ ~ YEAR + SDO + offset(lnEffort)
## Zero inflation:        ~YEAR + STEMP
## Data: dat
##
##      AIC      BIC   logLik deviance df.resid
##   1169.9   1237.1   -568.0   1135.9      367
##
##
## Dispersion parameter for nbinom2 family (): 0.546
```

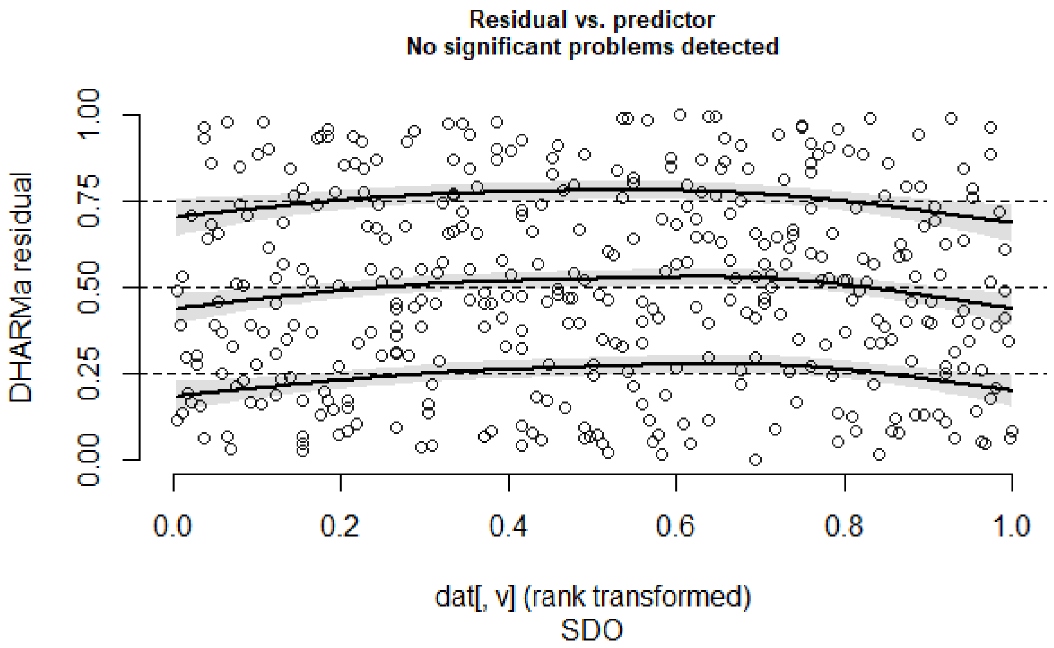
```
##
## Conditional model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -2.82752    1.40167  -2.017   0.0437 *
## YEAR2014     0.47135    1.10817   0.425   0.6706
## YEAR2016    -0.15665    1.10278  -0.142   0.8870
## YEAR2017    -0.70160    1.12333  -0.625   0.5323
## YEAR2018    -0.21735    1.11651  -0.195   0.8457
## YEAR2019    -0.28457    1.12047  -0.254   0.7995
## YEAR2021     0.09451    1.18440   0.080   0.9364
## SDO          0.28996    0.11658   2.487   0.0129 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Zero-inflation model:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  16.0971     6.9132   2.328  0.01989 *
## YEAR2014     -9.4101     5.9527  -1.581  0.11392
## YEAR2016     -3.9594     3.8853  -1.019  0.30817
## YEAR2017     -3.5072     3.6579  -0.959  0.33765
## YEAR2018     -6.2437     4.8677  -1.283  0.19961
## YEAR2019     -4.2808     3.7687  -1.136  0.25600
## YEAR2021      2.3213     3.3798   0.687  0.49219
## STEMP        -1.2104     0.4467  -2.709  0.00674 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

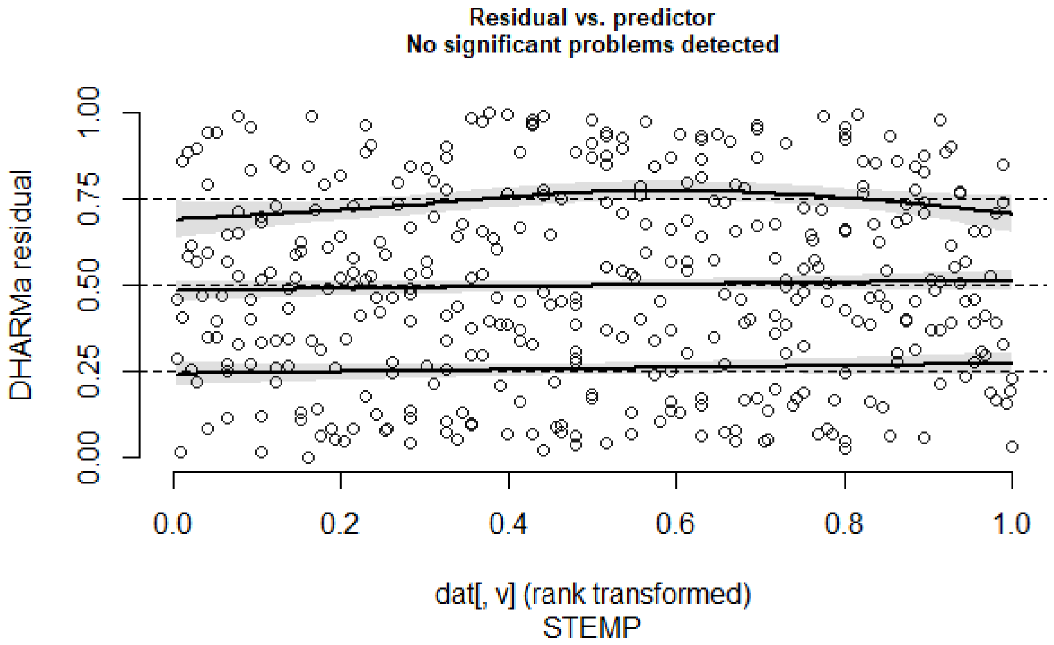
Model Diagnostics

The diagnostics for the zero-inflated negative binomial were acceptable and had no significant quantile deviations.


DHARMa residual
QQ plot residuals
KS test: p= 0.782
Deviation n.s.
Dispersion test: p= 0.79
Deviation n.s.
Outlier test: p= 0.2
Deviation n.s.
Observed
0.0
0.4
0.8
Expected
Residual vs. predicted
No significant problems detected
DHARMa residual
0.00
0.50
1.00
0.0
0.4
0.8
Model predictions (rank transformed)

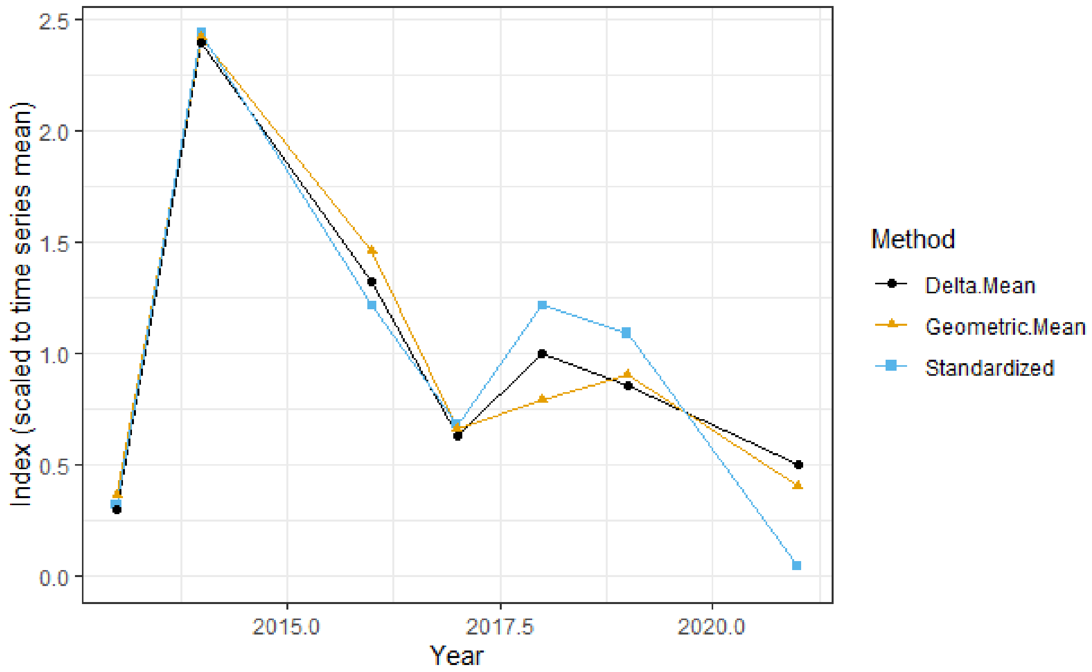

Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
2013
2014
2016
2017
2018
2019
2021
catPred

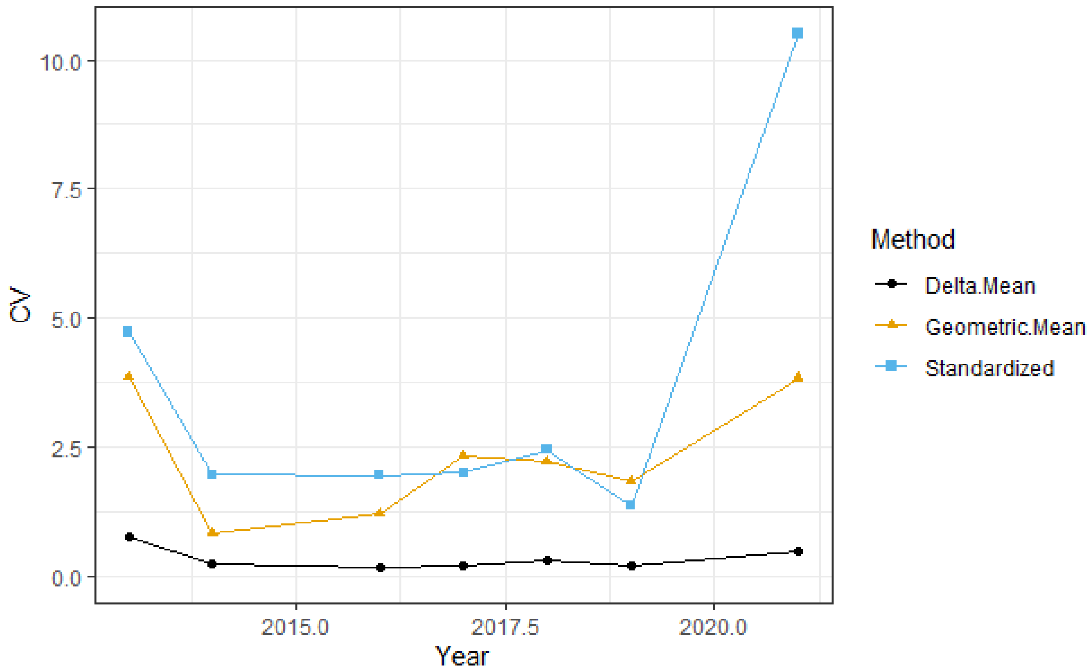




Index Comparisons

The standardized index was compared to the mean index calculated using the geometric mean and the delta distribution. All showed similar patterns. The CVs were lowest for the delta mean. The standardized index did not improve upon the delta mean so the delta mean was selected for use in modelling.


Index (scaled to time series mean)
2.5
2.0
1.5
1.0
0.5
0.0
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized


CV
10.0
7.5
5.0
2.5
0.0
2015.0
2017.5
2020.0
Year
Method
Delta.Mean
Geometric.Mean
Standardized

Standardized and nominal indices and CVs

Year	Standardized Index	Standardized CV	Geometric Mean	Geometric Mean CV	Delta Mean	Delta Mean CV
2013	0.683	4.73	0.297	3.85	0.500	0.76
2014	5.205	1.97	1.972	0.84	4.053	0.24
2016	2.593	1.95	1.188	1.21	2.239	0.17
2017	1.448	2.00	0.539	2.34	1.060	0.22
2018	2.596	2.44	0.644	2.21	1.700	0.31
2019	2.324	1.36	0.734	1.83	1.451	0.21
2021	0.091	10.51	0.325	3.84	0.848	0.48

Appendix 2: Supplemental ARIMA Results

Table 1. Results of autoregressive integrated moving average (ARIMA) model fits for alewife surveys in the Northern New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
Cocheco Run Count	2004 - 2021	0.94	0.34	18	-0.10	0.15	-0.29	0.06	0.22	1.04	7.26	8.62	0.00	10.21	0.00
Damariscotta Run Count	1977 - 2021	0.89	0.00	45	-0.26	-0.20	-0.12	0.53	0.14	0.53	14.08	12.16	0.96	12.71	0.97
Exeter Run Count	2004 - 2016	0.95	0.60	13	-0.29	-0.20	-0.19	0.20	0.30	1.24	8.19	4.70	1.00	5.74	1.00
Lamprey Run Count	2004 - 2021	0.92	0.16	18	-0.36	0.17	-0.27	0.53	0.40	0.19	11.02	10.73	0.92	10.70	0.91
Oyster Run Count	2004 - 2021	0.97	0.76	18	0.01	-0.13	-0.44	0.05	0.33	2.02	8.58	5.86	0.95	7.48	0.89
Union Run Count	1982 - 2022	0.90	0.00	41	-0.14	-0.24	-0.13	0.30	0.21	0.63	13.83	12.57	0.98	13.11	0.95
Juvenile															
ME Merrymeeting Bay Juvenile Alosine	1982 - 2021	0.96	0.18	40	-0.31	-0.28	-0.02	0.96	0.14	0.59	2.95	2.90	0.97	2.99	0.83
NH Juvenile Finfish Seine	1997 - 2021	0.96	0.50	25	-0.51	-0.06	0.08	1.00	0.14	2.20	-0.25	-0.79	1.00	-0.33	0.93

Table 2. Results of autoregressive integrated moving average (ARIMA) model fits for alewife surveys in the Southern New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	σ^2_c	i_f	Q_{25}	$P(i_f>Q_{25})$	i_{2009}	$P(i_f>i_{2009})$
Adult															
BrideLake Run Count	2011 - 2022	0.93	0.39	12	-0.13	-0.24	0.05	1.00	0.29	0.13	12.51	12.35	0.99		
BuckeyeBrook Run Count	2003 - 2021	0.91	0.07	19	-0.33	0.05	-0.13	0.50	0.38	0.92	11.38	10.03	1.00	10.22	0.99
GilbertStuart Run Count	1981 - 2021	0.94	0.03	41	-0.25	0.01	-0.11	0.29	0.17	0.71	10.70	10.42	0.80	10.84	0.63
HuntForge Run Count	2010 - 2021	0.96	0.72	12	-0.75	0.28	-0.09	1.00	0.25	2.56	7.20	7.14	0.79		
LatimerBrook Run Count	2006 - 2022	0.93	0.24	17	0.25	-0.30	-0.56	0.39	0.30	0.63	8.35	8.18	0.82	8.10	0.84
MillBrook Run Count	2003 - 2022	0.93	0.16	20	-0.33	-0.06	0.10	0.76	0.20	2.29	8.98	8.05	0.91	8.12	0.89
Nonquit Run Count	1999 - 2022	0.95	0.24	24	0.04	-0.16	-0.45	0.06	0.22	0.56	10.11	10.21	0.18	10.87	0.16
QueachBrook Run Count	2006 - 2022	0.91	0.11	17	-0.36	-0.17	0.05	0.59	0.20	0.87	5.80	6.12	0.29	7.35	0.00
Quinnipiac Run Count	2013 - 2022	0.98	0.94	10	-0.20	-0.11	-0.44	0.13	0.39	0.80	5.97	6.31	0.25	0.00	0.90
Shetucket Run Count	2007 - 2022	0.96	0.75	16	-0.42	0.04	0.12	0.86	0.26	1.14	6.56	6.41	0.85	6.83	0.37
Woonasquatucket Run Count	2010 - 2021	0.96	0.76	12	-0.32	-0.29	0.19	1.00	0.32	0.34	9.51	9.49	0.87		
Juvenile															
RI Coastal Pond Survey Narrow River	1994 - 2022	0.94	0.12	29	0.06	-0.40	-0.22	0.21	0.29	5.17	-3.00	-1.82	0.28	0.29	0.06

Table 3. Results of autoregressive integrated moving average (ARIMA) model fits for alewife surveys in the Mid-Atlantic region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
MD Nanticoke Commercial Fyke Net	1990 - 2021	0.94	0.12	32	-0.37	-0.25	0.40	0.43	0.16	0.47	0.01	0.14	0.36	0.20	0.20
MD North East River Gillnet	2015 - 2021	0.76	0.03	7	0.17	-0.30	-0.37	1.00	1.15	0.04	1.78	1.43	0.75		
NC Albemarle Independent Gillnet Survey	1991 - 2019	0.95	0.15	29	-0.04	-0.41	-0.03	0.14	0.39	0.77	1.93	-0.59	1.00	0.95	0.94
NC Albemarle Trawl	1982 - 2021	0.95	0.06	40	-0.47	0.02	0.10	1.00	0.22	5.45	-1.88	-1.87	0.79	-1.78	0.75
NC Chowan River Efish	2006 - 2022	0.92	0.13	17	-0.19	-0.24	-0.05	0.64	0.22	1.07	3.05	2.18	1.00	2.09	1.00
NY DEC 300 ft Haul Seine Survey	2012 - 2022	0.87	0.09	11	0.10	-0.31	-0.22	1.00	0.30	0.33	3.99	3.55	0.91		
VDWR Appomattox Spawning Stock Survey	2000 - 2018	0.95	0.62	19	0.84		-0.28	1.00	1.02	0.31	0.27	1.22	0.11	1.41	0.14
VDWR Chickahominy Spawning Stock Survey	2011 - 2022	0.89	0.20	12	0.07	0.07	-0.06	1.00	0.48	2.29	2.19	1.85	0.74		
VDWR James River Spawning Stock Survey	2002 - 2022	0.95	0.35	21	-0.69	0.34	-0.07	1.00	0.16	2.63	0.59	0.36	0.98	0.57	0.92
VDWR Rappahannock Spawning Stock Survey	2001 - 2022	0.73	0.00	22	-0.55	0.04	-0.08	1.00	0.15	1.14	3.12	3.07	0.90	3.25	0.42

VIMS James River SSB Survey	2015 - 2021	0.96	0.81	7	-0.51	0.03	0.18	1.00	0.44	0.24	2.19	2.21	0.80		
Juvenile															
DE 16 ft Trawl Age 1	1991 - 2021	0.91	0.01	31	-0.46	-0.07	0.07	0.84	0.12	3.77	-2.76	-3.16	0.77	-3.08	0.61
DE 30 ft Trawl Age 1	1990 - 2021	0.95	0.16	32	-0.21	-0.22	-0.22	0.90	0.15	1.33	0.05	-0.21	0.93	0.00	0.84
DE Nanticoke Juvenile Seine	1999 - 2021	0.93	0.10	23	0.04	-0.37	-0.14	0.16	0.31	0.93	-3.23	-1.93	0.14	-2.13	0.35
MD Estuarine Finfish Survey Choptank YOY	1959 - 2021	0.96	0.04	64	-0.43	-0.05	0.11	0.92	0.07	4.79	-1.59	-1.73	0.73	-1.71	0.71
MD Estuarine Finfish Survey Head of Bay YOY	1959 - 2021	0.87	0.00	63	-0.31	-0.29	-0.02	1.00	0.05	11.39	-0.89	-1.00	0.89	-0.86	0.97
MD Estuarine Finfish Survey Nanticoke YOY	1959 - 2021	0.95	0.02	63	-0.46	-0.07	0.16	0.83	0.08	4.14	-1.93	-1.78	0.68	-1.36	0.38
MD Estuarine Finfish Survey Potomac YOY	1959 - 2021	0.88	0.00	63	-0.41	-0.11	0.00	1.00	0.05	10.63	-1.83	-1.82	0.82	-1.77	0.85
NC Albemarle YOY Seine	1972 - 2021	0.95	0.04	50	-0.45	0.04	-0.01	0.61	0.13	5.19	-0.22	-1.53	0.89	-1.04	0.83
NJ Juvenile Striped Bass Seine	1987 - 2021	0.95	0.11	35	-0.64	0.16	-0.13	0.89	0.07	4.73	-1.89	-1.99	0.66	-1.86	0.58
NY Beach Seine YOY	1980 - 2022	0.94	0.04	43	-0.61	0.11	0.13	0.80	0.08	1.71	0.97	0.57	0.97	1.64	0.26
VIMS YOY Surface Trawl	2014 - 2022	0.92	0.43	9	-0.18	-0.26	0.27	0.63	0.52	2.78	-2.66	-2.68	0.65		

Table 4. Results of autoregressive integrated moving average (ARIMA) model fits for mixed stock alewife surveys conducted in the ocean. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	Years	W	p	n	r1	r2	r3	θ	SE	σ^2_c	i_f	Q_{25}	$P(i_f>Q_{25})$	i_{2009}	$P(i_f>i_{2009})$
Adult															
CT DEEP LIST Spring	1984 - 2021	0.93	0.02	38	-0.48	-0.10	0.13	0.74	0.10	1.03	0.95	0.82	0.92	1.53	0.40
ME-NH Inshore Trawl Fall	2000 - 2021	0.88	0.01	22	-0.35	-0.11	-0.23	0.90	0.22	0.13	5.58	5.56	0.97	5.59	0.89
ME-NH Inshore Trawl Spring	2001 - 2021	0.97	0.83	21	-0.60	0.32	-0.41	0.63	0.18	0.17	5.43	5.06	0.96	5.17	0.94
NEFSC Albatross Fall	1975 - 2008	0.96	0.28	34	-0.51	0.02	-0.18	0.83	0.08	0.50	0.66	0.06	1.00		
NEFSC Albatross Spring	1976 - 2008	0.98	0.78	33	-0.34	0.13	-0.17	0.36	0.19	0.15	2.44	1.68	1.00		
NEFSC Bigelow Fall	2009 - 2022	0.88	0.07	14	-0.57	0.18	0.10	0.70	0.24	0.24	1.89	2.08	0.63	2.07	0.62
NEFSC Bigelow Spring	2009 - 2022	0.55	0.00	14	-0.45	-0.06	0.03	0.74	0.20	0.74	2.31	2.24	0.74	2.92	0.00
NEFSC Summer Shrimp	1983 - 2022	0.85	0.00	40	-0.55	0.07	0.02	0.76	0.09	2.47	1.29	-1.21	0.97	0.59	0.93
NJ Ocean Trawl	1989 - 2020	0.99	0.98	32	-0.31	-0.23	-0.09	0.75	0.14	0.68	2.33	2.52	0.51	2.71	0.30
RI DEM Trawl Survey Spring	2012 - 2022	0.96	0.75	11	-0.20	-0.65	0.26	1.00	0.30	7.07	1.78	1.72	0.88		
VIMS NEAMAP	2008 - 2022	0.72	0.00	15	-0.47	-0.19	-0.05	1.00	0.20	1.04	3.23	3.15	0.87	3.21	0.90
Juvenile															
MA DMF Coastal Trawl North of Cape Cod Spring	1978 - 2021	0.96	0.16	44	-0.31	-0.36	0.28	0.88	0.09	0.86	0.89	0.60	0.98	1.00	0.82

Table 5. Results of autoregressive integrated moving average (ARIMA) model fits for blueback herring surveys in the Canada-Northern New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Juvenile															
ME Merrymeeting Bay Juvenile Alosine	1982 - 2021	0.93	0.01	40	-0.45	0.03	0.07	0.46	0.13	2.92	2.31	-0.69	1.00	1.00	0.98

Table 6. Results of autoregressive integrated moving average (ARIMA) model fits for blueback herring surveys in the Mid-New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
Cocheco Run Count	2004 - 2021	0.98	0.90	18	-0.22	-0.23	-0.10	0.62	0.37	4.21	6.86	5.85	0.91	6.19	0.85
Exeter Run Count	2004 - 2016	0.96	0.83	13	0.16	-0.15	-0.42	0.24	0.28	10.53	7.83	-0.97	1.00	2.26	1.00
Lamprey Run Count	2004 - 2021	0.84	0.01	18	-0.47	-0.11	0.31	1.00	0.26	3.45	4.79	4.22	1.00	4.38	0.99
Oyster Run Count	2004 - 2021	0.93	0.23	18	-0.03	-0.42	0.15	0.09	0.60	0.69	8.34	7.40	0.92	9.20	0.16
Juvenile															
NH Juvenile Finfish Seine	1997 - 2021	0.85	0.00	25	-0.52	0.32	-0.25	0.49	0.16	2.01	1.41	-0.26	0.97	-0.15	0.96

Table 7. Results of autoregressive integrated moving average (ARIMA) model fits for blueback herring surveys in the Mid-Atlantic region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	Years	W	p	n	r1	r2	r3	θ	SE	σ^2_c	i_f	Q_{25}	$P(i_f>Q_{25})$	i_{2009}	$P(i_f>i_{2009})$
Adult															
Connecticut_Holyoke Run Count	1976 - 2022	0.98	0.57	47	-0.30	0.11	0.03	0.26	0.13	1.48	6.02	5.91	0.75	4.05	1.00
MD Nanticoke Commercial Fyke Net	1989 - 2021	0.93	0.07	33	-0.55	0.17	-0.23	0.52	0.13	0.47	-0.68	-0.64	0.26	-0.57	0.21
MD North East River Gillnet	2015 - 2021	0.92	0.51	7	-0.09	0.05	-0.46	1.00	0.75	0.57	0.94	1.05	0.67		
NC Albemarle Independent Gillnet Survey	1991 - 2019	0.96	0.26	29	-0.38	0.15	-0.04	0.37	0.18	0.32	2.01	0.99	1.00	0.66	1.00
NC Albemarle Spawning Survey	2012 - 2021	0.90	0.22	10	-0.44	0.20	0.11	0.42	0.35	1.23	1.01	0.75	0.94		
NC Albemarle Trawl	1982 - 2021	0.95	0.09	40	-0.34	-0.21	0.03	0.85	0.09	12.58	-1.96	-2.05	0.62	-1.95	0.49
NC Chowan River Efish	2006 - 2022	0.97	0.79	17	-0.41	0.25	-0.40	0.43	0.24	0.96	4.40	2.71	1.00	2.88	1.00
NC Neuse River Efish	2004 - 2021	0.87	0.02	18	-0.41	-0.07	0.30	0.56	0.20	2.29	3.56	1.57	1.00	1.55	1.00
NY DEC 300 ft Haul Seine Survey	2012 - 2022	0.92	0.39	11	-0.20	-0.07	0.02	0.88	0.61	0.69	3.34	3.13	0.85		
Quinnipiac Run Count	2013 - 2022	0.85	0.06	10	-0.35	-0.15	0.25	0.32	0.30	0.69	4.62	4.20	0.75		
USFWS CT River Efish	2013 - 2022	0.97	0.89	10	-0.41	-0.17	0.09	1.00	0.42	0.35	3.37	3.11	0.87		

VDWR Appomattox Spawning Stock Survey	2000 - 2018	0.84	0.03	19	-0.33		0.40	1.00	0.21	0.82	3.19	3.03	0.58	3.22	0.53
VDWR Chickahominy Spawning Stock Survey	2011 - 2022	0.86	0.10	12	-0.35	-0.39	0.32	0.74	0.32	0.48	3.82	3.46	0.76		
VDWR James River Spawning Stock Survey	2002 - 2022	0.95	0.28	21	-0.48	0.10	0.10	0.53	0.18	0.52	4.56	3.52	1.00	3.57	1.00
VDWR Rappahannock Spawning Stock Survey	2001 - 2022	0.83	0.00	22	-0.01	-0.32	-0.05	0.01	0.35	1.94	3.50	2.70	0.90	3.45	0.74
VIMS James River SSB Survey	2015 - 2021	0.93	0.53	7	-0.56	0.38	-0.18	1.00	0.51	0.59	2.19	1.75	0.99		
Juvenile															
CT River Juvenile Beach Seine	1979 - 2021	0.96	0.20	43	-0.48	-0.10	0.14	0.78	0.09	1.07	5.10	5.08	0.67	5.05	0.86
DE 30 ft Trawl Age 1	1992 - 2021	0.90	0.01	30	-0.53	0.17	-0.17	0.92	0.12	5.94	-2.59	-2.65	0.75	-2.48	0.69
DE Nanticoke Juvenile Seine	1999 - 2021	0.97	0.74	23	-0.42	-0.08	-0.01	1.00	0.14	0.77	1.73	1.65	0.90	1.74	0.76
MD Estuarine Finfish Survey Choptank YOY	1959 - 2021	0.94	0.00	64	-0.48	0.12	-0.18	0.93	0.06	4.59	0.97	0.38	0.99	0.92	0.81
MD Estuarine Finfish Survey Head of Bay YOY	1959 - 2021	0.99	0.93	63	-0.47	0.01	0.05	0.63	0.10	6.74	1.90	0.34	0.94	1.61	0.81
MD Estuarine Finfish Survey Nanticoke YOY	1959 - 2021	0.98	0.39	63	-0.19	-0.30	-0.20	0.81	0.10	4.60	0.00	0.35	0.46	0.34	0.54
MD Estuarine Finfish Survey Potomac YOY	1959 - 2021	0.91	0.00	63	-0.37	-0.01	-0.14	1.00	0.05	7.60	1.54	1.52	0.84	1.58	0.87
NC Albemarle YOY Seine	1972 - 2021	0.88	0.00	50	-0.52	-0.04	0.14	0.76	0.07	4.75	1.65	0.47	0.89	0.44	0.87

NJ Juvenile Striped Bass Seine	1987 - 2021	0.95	0.09	35	-0.60	0.11	-0.17	0.81	0.08	1.77	2.11	2.04	0.55	2.16	0.39
NY Beach Seine YOY	1980 - 2022	0.91	0.00	43	-0.68	0.21	-0.09	0.92	0.07	1.27	4.65	4.64	0.80	4.71	0.64
VADWR Rappahannock Push Net YOY	2005 - 2021	0.90	0.07	17	-0.41	0.01	-0.07	1.00	0.25	5.22	2.16	1.69	0.91	1.75	0.94
VIMS James River Striped Bass YOY Seine Survey	1967 - 2022	0.94	0.01	56	-0.52	-0.03	-0.08	0.82	0.11	3.74	1.35	0.07	0.87	0.47	0.86
VIMS Rappahannock River Striped Bass YOY Seine Survey	1967 - 2022	0.96	0.06	56	-0.32	-0.25	0.05	0.92	0.06	3.10	1.45	0.97	0.91	1.55	0.79
VIMS YOY Surface Trawl	2014 - 2022	0.85	0.07	9	0.02	-0.23	-0.02	0.23	0.60	1.34	1.80	3.55	0.02		

Table 8. Results of autoregressive integrated moving average (ARIMA) model fits for blueback herring surveys in the South Atlantic region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
FL St Johns Efish	2008 - 2021	0.98	0.99	14	-0.18	-0.39	0.12	1.00	0.30	1.32	-0.46	-0.56	0.91	0.20	0.20
NC Cape Fear Town Rice Creek Efish	2006 - 2021	0.85	0.02	16	-0.36	-0.08	-0.03	0.34	0.24	0.45	2.58	2.23	0.88	2.31	0.88
SanteeCooper Run Count	1986 - 2021	0.97	0.45	36	-0.30	-0.27	-0.14	0.74	0.12	1.43	10.48	11.30	0.16	11.73	0.03
Juvenile															
FL St Johns YOY Push Net	2006 - 2021	0.96	0.69	16	-0.06	-0.52	0.19	0.50	0.30	1.21	4.54	2.86	1.00	2.50	1.00

Table 9. Results of autoregressive integrated moving average (ARIMA) model fits for mixed stock blueback herring surveys conducted in the ocean. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
CT DEEP LIST Spring	1984 - 2021	0.98	0.87	38	-0.38	-0.21	0.36	0.98	0.26	0.99	-0.24	-0.26	0.73	-0.25	0.69
ME-NH Inshore Trawl Fall	2000 - 2021	0.93	0.10	22	-0.52	0.13	0.20	0.47	0.20	2.02	2.13	1.42	0.95	2.46	0.32
ME-NH Inshore Trawl Spring	2001 - 2021	0.93	0.13	21	-0.35	-0.16	0.01	0.60	0.18	0.90	4.20	2.78	0.96	2.69	0.96
NEFS Bigelow Fall	2009 - 2022	0.96	0.77	14	-0.39	-0.22	0.44	0.43	0.26	0.40	-0.75	0.11	0.08	0.45	0.00
NEFSC Albatross Fall	1975 - 2008	0.98	0.73	34	-0.52	0.16	-0.01	0.75	0.15	2.56	-2.18	-3.41	0.99		
NEFSC Albatross Spring	1976 - 2008	0.97	0.51	33	-0.44	-0.08	0.14	0.89	0.14	0.51	0.62	0.52	0.83		
NEFSC Bigelow Spring	2009 - 2022	0.96	0.74	14	0.00	-0.21	-0.04	0.09	0.90	0.70	1.65	1.17	0.84	2.96	0.00
NJ Ocan Trawl	1989 - 2020	0.98	0.72	32	-0.39	-0.10	0.00	0.85	0.09	0.34	3.35	3.07	1.00	3.31	0.91
RI DEM Trawl Survey Spring	2012 - 2022	0.92	0.29	11	-0.12	-0.60	0.15	1.00	0.30	3.18	0.39	-0.19	1.00		
VIMS NEAMAP	2008 - 2022	0.98	0.94	15	-0.19	-0.36	-0.18	1.00	0.74	1.39	3.73	3.35	0.92	3.20	0.93

Table 10. Results of autoregressive integrated moving average (ARIMA) model fits for combined river herring species run counts in the Northern New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	Years	W	p	n	r1	r2	r3	θ	SE	σ^2_c	i_f	Q_{25}	$P(i_f>Q_{25})$	i_{2009}	$P(i_f>i_{2009})$
Adult															
Androscoggin Run Count	1983 - 2022	0.97	0.27	40	-0.13	-0.07	-0.03	0.16	0.19	0.89	11.70	10.01	0.97	10.99	0.94
Cocheco Run Count	1976 - 2003	0.96	0.43	28	-0.06	-0.36	0.09	0.15	0.29	1.02	11.15	8.24	1.00		
Exeter Run Count	1975 - 2003	0.87	0.01	29	0.11	-0.27	-0.34	1.00	0.13	3.90	6.37	6.26	0.62		
Kennebec Run Count	2006 - 2022	0.95	0.43	17	-0.37	0.24	-0.35	0.26	0.23	0.97	11.34	11.04	0.95	10.94	0.95
Lamprey Run Count	1972 - 2003	0.97	0.49	32	0.03	0.30	-0.03	0.06	0.14	0.17	11.07	9.61	1.00		
Oyster Run Count	1976 - 2003	0.92	0.03	28	-0.10	0.00	-0.30	0.19	0.30	1.07	10.88	8.82	0.96		
Saco Run Count	1993 - 2021	0.84	0.00	29	-0.40	-0.13	0.05	0.62	0.17	1.63	11.12	9.56	0.99	9.90	0.98
Sebasticook Run Count	2000 - 2021	0.96	0.43	22	-0.47	0.13	-0.08	0.41	0.19	0.06	15.17	14.57	1.00	14.65	1.00
StCroix Run Count	1981 - 2022	0.84	0.00	42	-0.43	0.17	0.10	0.34	0.12	2.12	13.38	9.82	1.00	9.52	1.00
Taylor Run Count	1976 - 2014	0.98	0.74	39	-0.21	-0.17	0.11	0.17	0.18	0.75	4.17	8.50	0.00	5.52	0.00
Winnicut Run Count	1977 - 2012	0.96	0.50	36	0.46	0.06	-0.14	0.50	0.22	0.69	2.51	6.03	0.00		

Table 11. Results of autoregressive integrated moving average (ARIMA) model fits for combined river herring species run counts in the Southern New England region. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; σ^2_c is the variance of the index; i_f is the terminal year's fitted index value; Q_{25} is the bootstrapped 25th percentile of the fitted index; $P(i_f>Q_{25})$ is the probability that i_f is greater than Q_{25}; i_{2009} is the bootstrapped value for the 2009 reference year; and $P(i_f>i_{2009})$ is the probability that i_f is greater than the 2009 reference year.

Survey	**Years**	**W**	**p**	**n**	**r1**	**r2**	**r3**	**θ**	**SE**	**σ^2_c**	**i_f**	**Q_{25}**	**$P(i_f>Q_{25})$**	**i_{2009}**	**$P(i_f>i_{2009})$**
Adult															
Agawam Run Count	2006 - 2021	0.94	0.36	16	-0.44	0.16	-0.17	0.66	0.37	0.30	10.97	10.58	0.97	10.67	0.94
Back Run Count	1986 - 2021	0.96	0.23	36	-0.01	-0.20	-0.39	0.00	0.21	0.26	12.35	12.03	0.85	12.19	0.83
Herring Run Count	2012 - 2021	0.97	0.91	10	-0.17	-0.35	-0.16	1.00	0.31	0.42	9.93	9.69	1.00		
Mattapoisett Run Count	1988 - 2021	0.93	0.04	34	-0.10	-0.08	0.11	0.16	0.21	0.53	7.88	9.25	0.04	9.19	0.04
Monument Run Count	1980 - 2021	0.96	0.24	42	-0.01	-0.39	-0.16	0.15	0.87	0.26	11.82	11.82	0.64	11.86	0.70
Nemasket Run Count	2005 - 2021	0.77	0.00	17	-0.32	-0.14	0.04	0.57	0.28	0.23	13.17	12.86	0.95	12.88	0.94
StonyBrook Run Count	2007 - 2019	0.89	0.10	13	-0.25	-0.13	-0.07	0.32	0.35	0.84	11.48	10.62	0.95	10.25	0.95
TownBrook Run Count	2011 - 2021	0.97	0.93	11	0.04	-0.46	0.01	0.22	0.52	0.04	11.83	11.79	0.79		
TownRiver Run Count	2000 - 2021	0.97	0.78	22	-0.47	-0.02	0.11	0.64	0.17	1.12	9.22	9.33	0.48	10.13	0.14
Wankinco Run Count	2007 - 2021	0.96	0.75	15	-0.59	0.33	-0.05	0.50	0.21	0.27	9.60	9.38	1.00	9.13	1.00

Appendix 3: Growth Model Supplemental Results

Table S 1. Estimated river-specific parameters for female alewife aged with otoliths from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE). Rivers are organized alphabetically within regions.

Region	River	K	L_∞	t_0
MAT	Albemarle Sound	0.44 (0.43—0.45)	322.95 (321.08—324.86)	-0.52 (-0.53—-0.51)
MAT	Alligator	0.46 (0.44—0.48)	322.17 (320.05—324.50)	-0.58 (-0.60—-0.56)
MAT	Chickahominy	0.53 (0.51—0.55)	303.43 (301.73—305.25)	-0.59 (-0.61—-0.57)
MAT	Choptank	0.48 (0.36—0.65)	316.81 (286.46—348.96)	-0.51 (-0.67—-0.37)
MAT	Chowan	0.49 (0.48—0.51)	313.68 (312.31—315.10)	-0.43 (-0.44—-0.42)
MAT	Hudson	0.34 (0.33—0.36)	327.86 (325.08—330.74)	-1.10 (-1.17—-1.03)
MAT	Little	0.44 (0.36—0.55)	315.04 (305.41—327.55)	-0.59 (-0.69—-0.49)
MAT	Nanticoke	0.46 (0.44—0.47)	312.12 (310.58—313.76)	-0.62 (-0.68—-0.57)
MAT	Neuse	0.51 (0.40—0.66)	325.98 (311.90—344.18)	-0.42 (-0.52—-0.33)
MAT	North East	0.58 (0.56—0.60)	304.05 (302.30—305.87)	-0.42 (-0.47—-0.38)
MAT	Pamlico	0.52 (0.42—0.66)	326.23 (314.76—340.84)	-0.50 (-0.60—-0.40)
MAT	Pasquotank	0.54 (0.47—0.63)	330.27 (322.42—339.40)	-0.42 (-0.47—-0.37)
MAT	Patapsco	0.50 (0.39—0.67)	318.52 (289.79—350.19)	-0.56 (-0.72—-0.42)
MAT	Perquimans	0.45 (0.40—0.51)	319.61 (312.49—327.62)	-0.47 (-0.51—-0.43)
MAT	Rappahannock	0.51 (0.48—0.53)	306.43 (304.18—308.89)	-0.56 (-0.58—-0.54)
MAT	Roanoke	0.45 (0.42—0.49)	321.77 (316.56—327.37)	-0.44 (-0.46—-0.41)
MAT	Scuppernong	0.51 (0.49—0.53)	314.17 (311.88—316.54)	-0.46 (-0.48—-0.45)
MAT	Susquehanna	0.69 (0.60—0.80)	290.83 (285.54—296.93)	-0.39 (-0.46—-0.34)
MAT	Yeopim	0.44 (0.38—0.52)	310.13 (301.17—320.73)	-0.51 (-0.57—-0.45)
SNE	Back	0.62 (0.61—0.64)	316.13 (314.80—317.49)	-0.20 (-0.22—-0.19)
SNE	Bride Lake	0.72 (0.68—0.77)	290.07 (287.48—292.92)	-0.42 (-0.46—-0.38)
SNE	Charles	0.55 (0.50—0.60)	299.60 (293.09—306.51)	-0.46 (-0.52—-0.41)
SNE	Chicopee	0.49 (0.40—0.61)	320.01 (301.01—341.60)	-0.46 (-0.54—-0.39)
SNE	Farmington	0.65 (0.57—0.75)	305.00 (296.55—314.81)	-0.37 (-0.42—-0.32)
SNE	Gilbert Stuart	0.75 (0.68—0.82)	291.12 (288.58—293.86)	-0.35 (-0.39—-0.31)
SNE	Mattabesset	0.58 (0.56—0.61)	307.00 (304.51—309.50)	-0.45 (-0.50—-0.41)
SNE	Monument	0.77 (0.75—0.79)	287.88 (286.83—288.93)	-0.21 (-0.22—-0.19)
SNE	Mystic	0.68 (0.66—0.70)	290.86 (289.55—292.17)	-0.22 (-0.23—-0.21)
SNE	Nemasket	0.67 (0.65—0.69)	303.99 (302.91—305.14)	-0.40 (-0.47—-0.33)
SNE	Nonquit	0.70 (0.64—0.76)	294.51 (292.02—297.14)	-0.38 (-0.43—-0.34)
SNE	Parker	0.60 (0.58—0.62)	300.94 (299.35—302.57)	-0.44 (-0.49—-0.40)
SNE	Town Brook	0.66 (0.65—0.68)	292.43 (291.38—293.47)	-0.24 (-0.26—-0.22)
SNE	Wethersfield Cove	0.60 (0.56—0.64)	303.59 (299.49—307.89)	-0.47 (-0.52—-0.43)
NNE	Cocheco	0.46 (0.44—0.48)	325.11 (323.14—327.14)	-0.59 (-0.64—-0.54)

NNE	Exeter	0.58 (0.56—0.61)	311.77 (309.70—313.86)	-0.46 (-0.51—-0.42)
NNE	Lamprey	0.45 (0.43—0.47)	328.20 (326.30—330.20)	-0.65 (-0.71—-0.60)
NNE	ME C1	0.46 (0.41—0.51)	329.06 (320.71—338.57)	-0.49 (-0.56—-0.44)
NNE	ME C10	0.39 (0.37—0.41)	343.68 (340.07—347.57)	-0.58 (-0.64—-0.53)
NNE	ME C11	0.42 (0.38—0.46)	326.41 (319.68—333.82)	-0.65 (-0.72—-0.58)
NNE	ME C12	0.48 (0.43—0.53)	311.49 (305.10—318.50)	-0.57 (-0.64—-0.51)
NNE	ME C13	0.48 (0.44—0.52)	324.12 (318.62—330.29)	-0.50 (-0.55—-0.44)
NNE	ME C14	0.54 (0.49—0.60)	310.72 (305.31—317.01)	-0.49 (-0.55—-0.43)
NNE	ME C15	0.41 (0.39—0.43)	335.20 (331.01—339.69)	-0.57 (-0.62—-0.51)
NNE	ME C16	0.39 (0.35—0.43)	341.67 (333.16—351.17)	-0.59 (-0.65—-0.53)
NNE	ME C17	0.47 (0.42—0.53)	313.11 (305.67—322.01)	-0.52 (-0.58—-0.46)
NNE	ME C18	0.43 (0.39—0.47)	331.48 (323.84—339.89)	-0.54 (-0.60—-0.48)
NNE	ME C19	0.39 (0.35—0.43)	337.13 (328.86—346.76)	-0.62 (-0.69—-0.55)
NNE	ME C2	0.46 (0.44—0.49)	313.83 (310.24—317.51)	-0.56 (-0.61—-0.51)
NNE	ME C20	0.43 (0.36—0.52)	320.93 (306.49—337.75)	-0.56 (-0.65—-0.48)
NNE	ME C21	0.51 (0.43—0.61)	320.07 (310.67—331.72)	-0.45 (-0.53—-0.39)
NNE	ME C3	0.47 (0.45—0.49)	310.24 (307.42—313.22)	-0.61 (-0.66—-0.55)
NNE	ME C4	0.41 (0.39—0.43)	336.04 (331.79—340.51)	-0.53 (-0.59—-0.48)
NNE	ME C5	0.41 (0.38—0.43)	330.44 (325.31—336.08)	-0.52 (-0.58—-0.47)
NNE	ME C6	0.42 (0.40—0.45)	327.18 (322.01—333.03)	-0.52 (-0.58—-0.47)
NNE	ME C7	0.45 (0.43—0.47)	321.42 (318.05—325.12)	-0.56 (-0.61—-0.51)
NNE	ME C8	0.45 (0.43—0.48)	333.37 (329.47—337.52)	-0.46 (-0.51—-0.41)
NNE	ME C9	0.40 (0.36—0.44)	344.55 (336.87—353.27)	-0.58 (-0.64—-0.52)
NNE	ME N10	0.53 (0.43—0.66)	321.12 (309.34—336.33)	-0.46 (-0.55—-0.38)
NNE	ME N11	0.46 (0.39—0.55)	325.00 (309.86—342.55)	-0.47 (-0.54—-0.40)
NNE	ME N12	0.50 (0.41—0.62)	333.76 (319.06—352.05)	-0.44 (-0.52—-0.36)
NNE	ME N13	0.39 (0.37—0.42)	330.43 (325.17—336.15)	-0.66 (-0.72—-0.60)
NNE	ME N14	0.47 (0.44—0.51)	311.26 (306.46—316.61)	-0.55 (-0.61—-0.49)
NNE	ME N15	0.36 (0.33—0.39)	335.77 (328.16—344.16)	-0.64 (-0.70—-0.57)
NNE	ME N16	0.39 (0.36—0.42)	331.67 (325.24—338.82)	-0.58 (-0.64—-0.52)
NNE	ME N17	0.47 (0.40—0.58)	317.08 (304.95—331.91)	-0.54 (-0.62—-0.45)
NNE	ME N18	0.49 (0.46—0.52)	319.54 (315.25—323.90)	-0.51 (-0.56—-0.46)
NNE	ME N19	0.38 (0.35—0.41)	293.81 (287.45—300.48)	-0.69 (-0.76—-0.62)
NNE	ME N2	0.56 (0.53—0.59)	313.70 (310.69—316.84)	-0.48 (-0.52—-0.43)
NNE	ME N20	0.41 (0.38—0.45)	338.05 (331.50—345.36)	-0.55 (-0.61—-0.49)
NNE	ME N21	0.49 (0.41—0.60)	323.53 (311.13—338.79)	-0.50 (-0.58—-0.43)
NNE	ME N22	0.48 (0.40—0.59)	321.68 (309.75—336.03)	-0.53 (-0.61—-0.45)
NNE	ME N23	0.45 (0.41—0.50)	274.85 (270.74—279.52)	-0.61 (-0.68—-0.54)
NNE	ME N24	0.55 (0.47—0.65)	310.23 (302.75—319.22)	-0.44 (-0.51—-0.37)
NNE	ME N25	0.45 (0.41—0.50)	328.87 (322.55—336.17)	-0.50 (-0.55—-0.44)
NNE	ME N26	0.47 (0.43—0.52)	320.93 (314.43—328.04)	-0.49 (-0.55—-0.44)
NNE	ME N27	0.48 (0.42—0.55)	312.22 (302.89—323.15)	-0.51 (-0.58—-0.45)
NNE	ME N29	0.38 (0.33—0.43)	307.43 (296.89—319.99)	-0.66 (-0.75—-0.59)

NNE	ME N3	0.44 (0.36—0.55)	321.24 (305.59—341.01)	-0.60 (-0.70—-0.50)
NNE	ME N30	0.46 (0.40—0.53)	293.82 (285.64—303.41)	-0.55 (-0.63—-0.48)
NNE	ME N31	0.44 (0.41—0.48)	326.35 (320.95—332.26)	-0.57 (-0.63—-0.51)
NNE	ME N32	0.51 (0.45—0.58)	312.15 (305.24—320.05)	-0.48 (-0.55—-0.42)
NNE	ME N33	0.41 (0.37—0.45)	337.84 (329.58—346.99)	-0.53 (-0.60—-0.47)
NNE	ME N4	0.42 (0.38—0.45)	334.57 (328.20—341.31)	-0.63 (-0.69—-0.57)
NNE	ME N5	0.39 (0.34—0.44)	335.23 (324.40—348.26)	-0.59 (-0.67—-0.52)
NNE	ME N6	0.44 (0.41—0.47)	332.16 (327.56—337.27)	-0.56 (-0.61—-0.50)
NNE	ME N7	0.45 (0.39—0.51)	324.20 (315.03—334.86)	-0.53 (-0.60—-0.46)
NNE	ME N8	0.44 (0.42—0.47)	336.66 (332.50—341.08)	-0.46 (-0.51—-0.42)
NNE	ME N9	0.49 (0.41—0.61)	327.42 (315.73—341.99)	-0.48 (-0.57—-0.40)
NNE	Oyster	0.40 (0.38—0.43)	324.31 (320.06—328.97)	-0.64 (-0.71—-0.58)
NNE	Pickpocket	0.46 (0.38—0.55)	323.28 (314.16—334.13)	-0.54 (-0.63—-0.45)
NNE	Taylor	0.46 (0.39—0.54)	315.17 (304.53—327.65)	-0.56 (-0.64—-0.48)
NNE	Winnicut	0.49 (0.46—0.51)	300.92 (298.11—303.88)	-0.50 (-0.56—-0.45)

Table S 2. Estimated river-specific parameters for male alewife aged with otoliths from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE). Rivers are organized alphabetically within regions.

Region	River	*K*	L_∞	t_0
MAT	Albemarle Sound	0.47 (0.46—0.49)	308.21 (306.39—310.08)	-0.51 (-0.53—-0.50)
MAT	Alligator	0.49 (0.47—0.51)	307.47 (305.39—309.72)	-0.58 (-0.60—-0.56)
MAT	Chickahominy	0.56 (0.54—0.58)	289.58 (287.90—291.38)	-0.58 (-0.60—-0.56)
MAT	Choptank	0.51 (0.39—0.69)	302.34 (273.45—333.01)	-0.50 (-0.67—-0.36)
MAT	Chowan	0.53 (0.51—0.54)	299.36 (298.03—300.75)	-0.42 (-0.43—-0.41)
MAT	Hudson	0.37 (0.35—0.38)	312.89 (310.22—315.69)	-1.09 (-1.17—-1.02)
MAT	Little	0.48 (0.39—0.59)	300.65 (291.50—312.55)	-0.58 (-0.68—-0.48)
MAT	Nanticoke	0.49 (0.47—0.50)	297.86 (296.30—299.53)	-0.62 (-0.67—-0.56)
MAT	Neuse	0.54 (0.42—0.71)	311.09 (297.78—328.50)	-0.41 (-0.51—-0.33)
MAT	North East	0.62 (0.60—0.65)	290.16 (288.44—291.95)	-0.42 (-0.46—-0.38)
MAT	Pamlico	0.56 (0.45—0.70)	311.33 (300.34—325.23)	-0.49 (-0.59—-0.40)
MAT	Pasquotank	0.58 (0.50—0.68)	315.21 (307.76—323.94)	-0.41 (-0.46—-0.36)
MAT	Patapsco	0.54 (0.42—0.72)	304.01 (276.74—334.19)	-0.55 (-0.71—-0.41)
MAT	Perquimans	0.48 (0.43—0.54)	305.05 (298.26—312.63)	-0.46 (-0.51—-0.42)
MAT	Rappahannock	0.54 (0.52—0.57)	292.46 (290.26—294.81)	-0.55 (-0.57—-0.53)
MAT	Roanoke	0.48 (0.45—0.53)	307.07 (302.14—312.39)	-0.43 (-0.46—-0.40)
MAT	Scuppernong	0.54 (0.52—0.56)	299.81 (297.58—302.13)	-0.46 (-0.47—-0.44)
MAT	Susquehanna	0.73 (0.64—0.86)	277.57 (272.54—283.45)	-0.39 (-0.45—-0.33)
MAT	Yeopim	0.47 (0.41—0.55)	295.98 (287.47—306.06)	-0.50 (-0.56—-0.44)
SNE	Back	0.67 (0.65—0.68)	301.71 (300.47—302.99)	-0.20 (-0.21—-0.19)
SNE	Bride Lake	0.77 (0.72—0.82)	276.83 (274.34—279.59)	-0.41 (-0.45—-0.37)
SNE	Charles	0.59 (0.54—0.64)	285.91 (279.71—292.53)	-0.45 (-0.51—-0.40)
SNE	Chicopee	0.52 (0.43—0.65)	305.35 (287.37—325.97)	-0.46 (-0.53—-0.38)
SNE	Farmington	0.70 (0.61—0.80)	291.10 (283.02—300.44)	-0.36 (-0.42—-0.31)
SNE	Gilbert Stuart	0.80 (0.73—0.87)	277.85 (275.38—280.49)	-0.34 (-0.38—-0.30)
SNE	Mattabesset	0.62 (0.60—0.65)	293.00 (290.59—295.36)	-0.45 (-0.49—-0.40)
SNE	Monument	0.82 (0.80—0.84)	274.75 (273.72—275.77)	-0.20 (-0.22—-0.18)
SNE	Mystic	0.73 (0.71—0.74)	277.58 (276.33—278.83)	-0.21 (-0.22—-0.20)
SNE	Nemasket	0.71 (0.69—0.74)	290.13 (289.11—291.19)	-0.39 (-0.46—-0.33)
SNE	Nonquit	0.75 (0.69—0.82)	281.08 (278.69—283.57)	-0.37 (-0.42—-0.33)
SNE	Parker	0.64 (0.62—0.67)	287.20 (285.69—288.74)	-0.44 (-0.48—-0.40)
SNE	Town Brook	0.71 (0.69—0.72)	279.08 (278.06—280.14)	-0.24 (-0.25—-0.22)
SNE	Wethersfield Cove	0.64 (0.60—0.68)	289.75 (285.83—293.86)	-0.47 (-0.52—-0.42)

NNE	Cocheco	0.49 (0.47—0.51)	310.27 (308.34—312.22)	-0.58 (-0.63—-0.53)
NNE	Exeter	0.62 (0.60—0.65)	297.54 (295.56—299.53)	-0.45 (-0.50—-0.41)
NNE	Lamprey	0.48 (0.46—0.50)	313.21 (311.32—315.11)	-0.65 (-0.70—-0.59)
NNE	ME C1	0.49 (0.44—0.55)	314.06 (306.11—323.23)	-0.49 (-0.55—-0.43)
NNE	ME C10	0.42 (0.40—0.44)	328.00 (324.53—331.76)	-0.58 (-0.63—-0.52)
NNE	ME C11	0.45 (0.41—0.50)	311.55 (305.13—318.60)	-0.64 (-0.71—-0.58)
NNE	ME C12	0.51 (0.46—0.56)	297.27 (291.24—303.99)	-0.57 (-0.63—-0.50)
NNE	ME C13	0.51 (0.47—0.56)	309.33 (304.07—315.17)	-0.49 (-0.55—-0.44)
NNE	ME C14	0.58 (0.53—0.64)	296.51 (291.34—302.56)	-0.48 (-0.54—-0.43)
NNE	ME C15	0.44 (0.42—0.47)	319.91 (315.85—324.22)	-0.56 (-0.62—-0.51)
NNE	ME C16	0.42 (0.38—0.46)	326.08 (317.90—335.14)	-0.58 (-0.65—-0.52)
NNE	ME C17	0.51 (0.45—0.56)	298.81 (291.71—307.34)	-0.52 (-0.58—-0.46)
NNE	ME C18	0.46 (0.42—0.50)	316.35 (309.13—324.34)	-0.53 (-0.59—-0.47)
NNE	ME C19	0.42 (0.38—0.46)	321.73 (313.82—330.89)	-0.61 (-0.68—-0.55)
NNE	ME C2	0.50 (0.47—0.53)	299.54 (296.11—303.04)	-0.55 (-0.61—-0.50)
NNE	ME C20	0.46 (0.39—0.56)	306.30 (292.67—322.28)	-0.55 (-0.64—-0.47)
NNE	ME C21	0.55 (0.46—0.66)	305.46 (296.49—316.71)	-0.45 (-0.53—-0.38)
NNE	ME C3	0.50 (0.48—0.53)	296.07 (293.41—298.91)	-0.60 (-0.66—-0.54)
NNE	ME C4	0.44 (0.41—0.46)	320.70 (316.68—325.00)	-0.53 (-0.58—-0.48)
NNE	ME C5	0.44 (0.41—0.46)	315.36 (310.44—320.81)	-0.52 (-0.57—-0.46)
NNE	ME C6	0.45 (0.42—0.49)	312.23 (307.28—317.87)	-0.51 (-0.57—-0.46)
NNE	ME C7	0.48 (0.46—0.50)	306.77 (303.52—310.30)	-0.55 (-0.60—-0.50)
NNE	ME C8	0.48 (0.46—0.51)	318.12 (314.34—322.16)	-0.45 (-0.50—-0.41)
NNE	ME C9	0.43 (0.39—0.47)	328.83 (321.53—337.25)	-0.57 (-0.64—-0.51)
NNE	ME N10	0.57 (0.46—0.71)	306.45 (295.19—320.91)	-0.45 (-0.54—-0.37)
NNE	ME N11	0.50 (0.42—0.59)	310.20 (295.70—326.91)	-0.46 (-0.53—-0.39)
NNE	ME N12	0.53 (0.43—0.66)	318.51 (304.48—336.18)	-0.44 (-0.52—-0.36)
NNE	ME N13	0.42 (0.39—0.45)	315.36 (310.30—320.76)	-0.65 (-0.71—-0.59)
NNE	ME N14	0.51 (0.47—0.54)	297.06 (292.47—302.10)	-0.54 (-0.60—-0.49)
NNE	ME N15	0.39 (0.36—0.42)	320.46 (313.15—328.56)	-0.63 (-0.70—-0.57)
NNE	ME N16	0.42 (0.39—0.45)	316.55 (310.34—323.49)	-0.57 (-0.63—-0.51)
NNE	ME N17	0.51 (0.42—0.62)	302.64 (291.07—316.66)	-0.53 (-0.62—-0.45)
NNE	ME N18	0.52 (0.49—0.55)	304.96 (300.86—309.14)	-0.51 (-0.56—-0.46)
NNE	ME N19	0.40 (0.37—0.44)	280.40 (274.30—286.77)	-0.68 (-0.75—-0.61)
NNE	ME N2	0.60 (0.56—0.63)	299.38 (296.52—302.39)	-0.47 (-0.52—-0.42)
NNE	ME N20	0.44 (0.40—0.48)	322.64 (316.35—329.68)	-0.54 (-0.61—-0.49)
NNE	ME N21	0.52 (0.44—0.64)	308.79 (296.86—323.44)	-0.50 (-0.58—-0.42)
NNE	ME N22	0.51 (0.43—0.63)	306.95 (295.49—320.77)	-0.52 (-0.61—-0.44)
NNE	ME N23	0.49 (0.44—0.54)	262.30 (258.38—266.82)	-0.60 (-0.67—-0.53)
NNE	ME N24	0.58 (0.50—0.70)	296.04 (288.93—304.64)	-0.43 (-0.50—-0.37)
NNE	ME N25	0.48 (0.44—0.53)	313.86 (307.90—320.81)	-0.49 (-0.55—-0.44)
NNE	ME N26	0.50 (0.46—0.55)	306.29 (300.02—313.09)	-0.49 (-0.54—-0.43)
NNE	ME N27	0.51 (0.45—0.59)	297.98 (289.15—308.46)	-0.51 (-0.58—-0.44)

NNE	ME N29	0.40 (0.35—0.46)	293.43 (283.41—305.39)	-0.66 (-0.74—-0.58)
NNE	ME N3	0.47 (0.38—0.59)	306.62 (291.58—325.53)	-0.60 (-0.70—-0.50)
NNE	ME N30	0.49 (0.43—0.57)	280.40 (272.63—289.62)	-0.54 (-0.62—-0.47)
NNE	ME N31	0.47 (0.44—0.51)	311.44 (306.34—317.05)	-0.56 (-0.62—-0.50)
NNE	ME N32	0.55 (0.48—0.62)	297.90 (291.34—305.44)	-0.47 (-0.54—-0.41)
NNE	ME N33	0.44 (0.39—0.49)	322.43 (314.50—331.15)	-0.53 (-0.59—-0.47)
NNE	ME N4	0.44 (0.41—0.48)	319.31 (313.24—325.77)	-0.62 (-0.68—-0.56)
NNE	ME N5	0.42 (0.37—0.47)	319.92 (309.59—332.37)	-0.59 (-0.66—-0.52)
NNE	ME N6	0.47 (0.44—0.50)	317.01 (312.55—321.90)	-0.55 (-0.61—-0.50)
NNE	ME N7	0.48 (0.42—0.55)	309.38 (300.66—319.62)	-0.52 (-0.59—-0.45)
NNE	ME N8	0.47 (0.45—0.50)	321.29 (317.31—325.47)	-0.46 (-0.51—-0.41)
NNE	ME N9	0.53 (0.44—0.65)	312.47 (301.38—326.34)	-0.47 (-0.56—-0.39)
NNE	Oyster	0.43 (0.40—0.46)	309.52 (305.48—313.94)	-0.64 (-0.70—-0.57)
NNE	Pickpocket	0.49 (0.41—0.59)	308.53 (299.80—319.01)	-0.53 (-0.62—-0.44)
NNE	Taylor	0.49 (0.42—0.58)	300.81 (290.62—312.75)	-0.55 (-0.64—-0.47)
NNE	Winnicut	0.52 (0.49—0.55)	287.18 (284.47—290.00)	-0.50 (-0.55—-0.45)

Table S 3. Estimated river-specific parameters for female alewife scales from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE). Rivers are organized alphabetically within regions.

Region	River	K	L_∞	t_0
MAT	Albemarle Sound	0.46 (0.45—0.47)	313.94 (312.45—315.48)	-0.52 (-0.53—-0.51)
MAT	Alligator	0.48 (0.46—0.49)	313.20 (311.31—315.18)	-0.58 (-0.60—-0.57)
MAT	Chickahominy	0.55 (0.52—0.57)	294.97 (293.04—296.99)	-0.59 (-0.61—-0.57)
MAT	Choptank	0.49 (0.38—0.67)	308.03 (278.30—339.12)	-0.51 (-0.67—-0.37)
MAT	Chowan	0.51 (0.50—0.52)	304.93 (303.94—305.86)	-0.43 (-0.43—-0.42)
MAT	Hudson	0.35 (0.34—0.37)	318.69 (316.30—321.25)	-1.09 (-1.17—-1.03)
MAT	Little	0.46 (0.38—0.57)	306.30 (296.96—318.25)	-0.59 (-0.69—-0.49)
MAT	Nanticoke	0.47 (0.46—0.48)	303.41 (302.22—304.62)	-0.62 (-0.68—-0.57)
MAT	Neuse	0.53 (0.41—0.68)	316.83 (303.19—334.51)	-0.42 (-0.51—-0.33)
MAT	North East	0.60 (0.58—0.62)	295.55 (294.10—297.09)	-0.42 (-0.46—-0.38)
MAT	Pamlico	0.54 (0.44—0.68)	317.11 (306.06—331.13)	-0.50 (-0.60—-0.40)
MAT	Pasquotank	0.56 (0.49—0.66)	321.10 (313.52—329.82)	-0.42 (-0.47—-0.37)
MAT	Patapsco	0.52 (0.40—0.70)	309.69 (281.75—340.18)	-0.56 (-0.72—-0.42)
MAT	Perquimans	0.47 (0.42—0.52)	310.70 (303.81—318.35)	-0.47 (-0.51—-0.43)
MAT	Rappahannock	0.52 (0.50—0.55)	297.89 (295.47—300.41)	-0.56 (-0.58—-0.54)
MAT	Roanoke	0.47 (0.44—0.51)	312.79 (307.94—318.16)	-0.43 (-0.46—-0.41)
MAT	Scuppernong	0.52 (0.51—0.54)	305.39 (303.39—307.47)	-0.46 (-0.48—-0.45)
MAT	Susquehanna	0.71 (0.62—0.83)	282.74 (277.58—288.74)	-0.39 (-0.46—-0.33)
MAT	Yeopim	0.46 (0.40—0.53)	301.49 (292.85—311.89)	-0.51 (-0.56—-0.45)
SNE	Back	0.65 (0.63—0.67)	307.32 (305.68—308.98)	-0.20 (-0.22—-0.19)
SNE	Bride Lake	0.75 (0.71—0.79)	281.95 (279.90—284.34)	-0.42 (-0.46—-0.38)
SNE	Charles	0.57 (0.52—0.62)	291.24 (284.76—298.13)	-0.46 (-0.51—-0.41)
SNE	Chicopee	0.51 (0.41—0.63)	311.01 (292.53—331.93)	-0.46 (-0.54—-0.38)
SNE	Farmington	0.68 (0.59—0.78)	296.47 (288.26—306.06)	-0.37 (-0.42—-0.32)
SNE	Gilbert Stuart	0.77 (0.71—0.85)	282.99 (280.68—285.56)	-0.34 (-0.39—-0.30)
SNE	Mattabesset	0.60 (0.57—0.63)	298.45 (295.90—301.10)	-0.45 (-0.50—-0.41)
SNE	Monument	0.80 (0.78—0.82)	279.84 (278.89—280.81)	-0.21 (-0.22—-0.19)
SNE	Mystic	0.70 (0.68—0.73)	282.73 (281.17—284.34)	-0.22 (-0.23—-0.21)
SNE	Nemasket	0.69 (0.67—0.72)	295.50 (294.41—296.64)	-0.40 (-0.46—-0.33)
SNE	Nonquit	0.72 (0.67—0.79)	286.27 (284.03—288.71)	-0.38 (-0.42—-0.34)
SNE	Parker	0.62 (0.60—0.65)	292.55 (290.69—294.40)	-0.44 (-0.49—-0.40)
SNE	Town Brook	0.69 (0.67—0.70)	284.26 (283.23—285.35)	-0.24 (-0.26—-0.22)
SNE	Wethersfield Cove	0.62 (0.58—0.67)	295.11 (290.94—299.40)	-0.47 (-0.52—-0.42)
NNE	Cocheco	0.48 (0.46—0.49)	316.04 (314.43—317.70)	-0.59 (-0.64—-0.54)

NNE	Exeter	0.61 (0.58—0.63)	303.05 (301.31—304.86)	-0.46 (-0.50—-0.42)
NNE	Lamprey	0.47 (0.45—0.48)	319.03 (317.50—320.62)	-0.65 (-0.71—-0.60)
NNE	ME C1	0.47 (0.43—0.53)	319.84 (311.82—329.14)	-0.49 (-0.55—-0.44)
NNE	ME C10	0.40 (0.39—0.42)	334.10 (330.78—337.69)	-0.58 (-0.64—-0.53)
NNE	ME C11	0.44 (0.40—0.48)	317.34 (310.74—324.50)	-0.65 (-0.72—-0.58)
NNE	ME C12	0.49 (0.45—0.54)	302.85 (296.70—309.44)	-0.57 (-0.63—-0.51)
NNE	ME C13	0.50 (0.46—0.54)	315.11 (309.69—320.85)	-0.50 (-0.55—-0.44)
NNE	ME C14	0.56 (0.51—0.62)	302.03 (296.90—308.04)	-0.49 (-0.55—-0.43)
NNE	ME C15	0.43 (0.41—0.45)	325.86 (321.91—330.11)	-0.57 (-0.62—-0.51)
NNE	ME C16	0.40 (0.37—0.44)	332.16 (323.93—341.33)	-0.59 (-0.65—-0.53)
NNE	ME C17	0.49 (0.44—0.54)	304.37 (297.23—312.99)	-0.52 (-0.58—-0.46)
NNE	ME C18	0.45 (0.41—0.49)	322.25 (314.89—330.41)	-0.53 (-0.59—-0.48)
NNE	ME C19	0.40 (0.37—0.44)	327.68 (319.89—336.89)	-0.62 (-0.68—-0.55)
NNE	ME C2	0.48 (0.46—0.51)	305.06 (301.79—308.54)	-0.56 (-0.61—-0.51)
NNE	ME C20	0.45 (0.38—0.54)	311.98 (298.23—328.33)	-0.56 (-0.64—-0.48)
NNE	ME C21	0.53 (0.45—0.64)	311.14 (302.22—322.36)	-0.45 (-0.53—-0.38)
NNE	ME C3	0.49 (0.47—0.51)	301.56 (299.04—304.31)	-0.60 (-0.66—-0.55)
NNE	ME C4	0.42 (0.40—0.45)	326.64 (322.72—330.91)	-0.53 (-0.59—-0.48)
NNE	ME C5	0.42 (0.40—0.45)	321.21 (316.38—326.71)	-0.52 (-0.58—-0.47)
NNE	ME C6	0.44 (0.41—0.47)	318.05 (313.12—323.59)	-0.52 (-0.58—-0.47)
NNE	ME C7	0.46 (0.44—0.49)	312.47 (309.24—315.86)	-0.56 (-0.61—-0.51)
NNE	ME C8	0.47 (0.44—0.49)	324.06 (320.39—327.99)	-0.46 (-0.50—-0.41)
NNE	ME C9	0.41 (0.38—0.45)	334.91 (327.51—343.35)	-0.58 (-0.64—-0.52)
NNE	ME N10	0.55 (0.45—0.69)	312.21 (300.70—326.85)	-0.46 (-0.55—-0.38)
NNE	ME N11	0.48 (0.41—0.57)	315.89 (301.33—332.94)	-0.47 (-0.54—-0.40)
NNE	ME N12	0.51 (0.42—0.64)	324.47 (310.17—342.32)	-0.44 (-0.52—-0.36)
NNE	ME N13	0.40 (0.38—0.43)	321.18 (316.15—326.60)	-0.66 (-0.72—-0.60)
NNE	ME N14	0.49 (0.46—0.53)	302.58 (298.01—307.69)	-0.55 (-0.61—-0.49)
NNE	ME N15	0.37 (0.35—0.40)	326.37 (319.04—334.51)	-0.63 (-0.70—-0.57)
NNE	ME N16	0.40 (0.38—0.43)	322.39 (316.25—329.35)	-0.58 (-0.64—-0.52)
NNE	ME N17	0.49 (0.41—0.60)	308.27 (296.46—322.46)	-0.54 (-0.62—-0.45)
NNE	ME N18	0.50 (0.48—0.54)	310.61 (306.52—314.78)	-0.51 (-0.56—-0.46)
NNE	ME N19	0.39 (0.36—0.42)	285.61 (279.65—292.19)	-0.69 (-0.76—-0.62)
NNE	ME N2	0.58 (0.55—0.61)	304.93 (302.19—307.86)	-0.48 (-0.52—-0.43)
NNE	ME N20	0.43 (0.39—0.47)	328.57 (322.38—335.71)	-0.55 (-0.61—-0.49)
NNE	ME N21	0.51 (0.42—0.62)	314.49 (302.50—329.25)	-0.50 (-0.58—-0.43)
NNE	ME N22	0.50 (0.42—0.61)	312.65 (301.21—326.63)	-0.53 (-0.61—-0.45)
NNE	ME N23	0.47 (0.43—0.52)	267.17 (263.26—271.67)	-0.60 (-0.68—-0.54)
NNE	ME N24	0.57 (0.48—0.67)	301.58 (294.33—310.29)	-0.44 (-0.51—-0.37)
NNE	ME N25	0.47 (0.43—0.51)	319.71 (313.67—326.74)	-0.49 (-0.55—-0.44)
NNE	ME N26	0.49 (0.45—0.53)	311.97 (305.85—318.72)	-0.49 (-0.54—-0.44)
NNE	ME N27	0.50 (0.44—0.57)	303.49 (294.57—314.28)	-0.51 (-0.58—-0.45)
NNE	ME N29	0.39 (0.34—0.45)	298.82 (288.70—311.05)	-0.66 (-0.75—-0.58)

NNE	ME N3	0.45 (0.37—0.57)	312.29 (297.01—331.50)	-0.60 (-0.70—-0.50)
NNE	ME N30	0.48 (0.42—0.54)	285.61 (277.74—294.84)	-0.55 (-0.63—-0.48)
NNE	ME N31	0.46 (0.42—0.49)	317.24 (312.14—322.89)	-0.57 (-0.63—-0.51)
NNE	ME N32	0.53 (0.47—0.60)	303.43 (296.83—311.00)	-0.48 (-0.55—-0.42)
NNE	ME N33	0.42 (0.38—0.47)	328.39 (320.46—337.23)	-0.53 (-0.60—-0.47)
NNE	ME N4	0.43 (0.40—0.46)	325.23 (319.15—331.68)	-0.63 (-0.69—-0.57)
NNE	ME N5	0.40 (0.35—0.46)	325.86 (315.36—338.61)	-0.59 (-0.67—-0.52)
NNE	ME N6	0.45 (0.43—0.49)	322.89 (318.45—327.76)	-0.55 (-0.61—-0.50)
NNE	ME N7	0.47 (0.41—0.53)	315.14 (306.29—325.49)	-0.53 (-0.60—-0.46)
NNE	ME N8	0.46 (0.44—0.48)	327.28 (323.28—331.35)	-0.46 (-0.51—-0.42)
NNE	ME N9	0.51 (0.43—0.63)	318.29 (306.90—332.49)	-0.48 (-0.56—-0.40)
NNE	Oyster	0.42 (0.39—0.44)	315.27 (311.33—319.70)	-0.64 (-0.70—-0.58)
NNE	Pickpocket	0.47 (0.40—0.57)	314.25 (305.55—324.80)	-0.53 (-0.62—-0.45)
NNE	Taylor	0.48 (0.40—0.56)	306.35 (296.20—318.38)	-0.55 (-0.64—-0.48)
NNE	Winnicut	0.50 (0.48—0.53)	292.53 (289.96—295.24)	-0.50 (-0.56—-0.45)
MAT	Albemarle Sound	0.46 (0.45—0.47)	313.94 (312.45—315.48)	-0.52 (-0.53—-0.51)
MAT	Alligator	0.48 (0.46—0.49)	313.20 (311.31—315.18)	-0.58 (-0.60—-0.57)
MAT	Chickahominy	0.55 (0.52—0.57)	294.97 (293.04—296.99)	-0.59 (-0.61—-0.57)
MAT	Choptank	0.49 (0.38—0.67)	308.03 (278.30—339.12)	-0.51 (-0.67—-0.37)
MAT	Chowan	0.51 (0.50—0.52)	304.93 (303.94—305.86)	-0.43 (-0.43—-0.42)
MAT	Hudson	0.35 (0.34—0.37)	318.69 (316.30—321.25)	-1.09 (-1.17—-1.03)
MAT	Little	0.46 (0.38—0.57)	306.30 (296.96—318.25)	-0.59 (-0.69—-0.49)
MAT	Nanticoke	0.47 (0.46—0.48)	303.41 (302.22—304.62)	-0.62 (-0.68—-0.57)
MAT	Neuse	0.53 (0.41—0.68)	316.83 (303.19—334.51)	-0.42 (-0.51—-0.33)
MAT	North East	0.60 (0.58—0.62)	295.55 (294.10—297.09)	-0.42 (-0.46—-0.38)
MAT	Pamlico	0.54 (0.44—0.68)	317.11 (306.06—331.13)	-0.50 (-0.60—-0.40)
MAT	Pasquotank	0.56 (0.49—0.66)	321.10 (313.52—329.82)	-0.42 (-0.47—-0.37)
MAT	Patapsco	0.52 (0.40—0.70)	309.69 (281.75—340.18)	-0.56 (-0.72—-0.42)
MAT	Perquimans	0.47 (0.42—0.52)	310.70 (303.81—318.35)	-0.47 (-0.51—-0.43)
MAT	Rappahannock	0.52 (0.50—0.55)	297.89 (295.47—300.41)	-0.56 (-0.58—-0.54)
MAT	Roanoke	0.47 (0.44—0.51)	312.79 (307.94—318.16)	-0.43 (-0.46—-0.41)
MAT	Scuppernong	0.52 (0.51—0.54)	305.39 (303.39—307.47)	-0.46 (-0.48—-0.45)
MAT	Susquehanna	0.71 (0.62—0.83)	282.74 (277.58—288.74)	-0.39 (-0.46—-0.33)
MAT	Yeopim	0.46 (0.40—0.53)	301.49 (292.85—311.89)	-0.51 (-0.56—-0.45)
SNE	Back	0.65 (0.63—0.67)	307.32 (305.68—308.98)	-0.20 (-0.22—-0.19)
SNE	Bride Lake	0.75 (0.71—0.79)	281.95 (279.90—284.34)	-0.42 (-0.46—-0.38)
SNE	Charles	0.57 (0.52—0.62)	291.24 (284.76—298.13)	-0.46 (-0.51—-0.41)
SNE	Chicopee	0.51 (0.41—0.63)	311.01 (292.53—331.93)	-0.46 (-0.54—-0.38)
SNE	Farmington	0.68 (0.59—0.78)	296.47 (288.26—306.06)	-0.37 (-0.42—-0.32)
SNE	Gilbert Stuart	0.77 (0.71—0.85)	282.99 (280.68—285.56)	-0.34 (-0.39—-0.30)
SNE	Mattabesset	0.60 (0.57—0.63)	298.45 (295.90—301.10)	-0.45 (-0.50—-0.41)
SNE	Monument	0.80 (0.78—0.82)	279.84 (278.89—280.81)	-0.21 (-0.22—-0.19)
SNE	Mystic	0.70 (0.68—0.73)	282.73 (281.17—284.34)	-0.22 (-0.23—-0.21)

SNE	Nemasket	0.69 (0.67—0.72)	295.50 (294.41—296.64)	-0.40 (-0.46—-0.33)
SNE	Nonquit	0.72 (0.67—0.79)	286.27 (284.03—288.71)	-0.38 (-0.42—-0.34)
SNE	Parker	0.62 (0.60—0.65)	292.55 (290.69—294.40)	-0.44 (-0.49—-0.40)
SNE	Town Brook	0.69 (0.67—0.70)	284.26 (283.23—285.35)	-0.24 (-0.26—-0.22)
SNE	Wethersfield Cove	0.62 (0.58—0.67)	295.11 (290.94—299.40)	-0.47 (-0.52—-0.42)
NNE	Cocheco	0.48 (0.46—0.49)	316.04 (314.43—317.70)	-0.59 (-0.64—-0.54)
NNE	Exeter	0.61 (0.58—0.63)	303.05 (301.31—304.86)	-0.46 (-0.50—-0.42)
NNE	Lamprey	0.47 (0.45—0.48)	319.03 (317.50—320.62)	-0.65 (-0.71—-0.60)
NNE	ME C1	0.47 (0.43—0.53)	319.84 (311.82—329.14)	-0.49 (-0.55—-0.44)
NNE	ME C10	0.40 (0.39—0.42)	334.10 (330.78—337.69)	-0.58 (-0.64—-0.53)
NNE	ME C11	0.44 (0.40—0.48)	317.34 (310.74—324.50)	-0.65 (-0.72—-0.58)
NNE	ME C12	0.49 (0.45—0.54)	302.85 (296.70—309.44)	-0.57 (-0.63—-0.51)
NNE	ME C13	0.50 (0.46—0.54)	315.11 (309.69—320.85)	-0.50 (-0.55—-0.44)
NNE	ME C14	0.56 (0.51—0.62)	302.03 (296.90—308.04)	-0.49 (-0.55—-0.43)
NNE	ME C15	0.43 (0.41—0.45)	325.86 (321.91—330.11)	-0.57 (-0.62—-0.51)
NNE	ME C16	0.40 (0.37—0.44)	332.16 (323.93—341.33)	-0.59 (-0.65—-0.53)
NNE	ME C17	0.49 (0.44—0.54)	304.37 (297.23—312.99)	-0.52 (-0.58—-0.46)
NNE	ME C18	0.45 (0.41—0.49)	322.25 (314.89—330.41)	-0.53 (-0.59—-0.48)
NNE	ME C19	0.40 (0.37—0.44)	327.68 (319.89—336.89)	-0.62 (-0.68—-0.55)
NNE	ME C2	0.48 (0.46—0.51)	305.06 (301.79—308.54)	-0.56 (-0.61—-0.51)
NNE	ME C20	0.45 (0.38—0.54)	311.98 (298.23—328.33)	-0.56 (-0.64—-0.48)
NNE	ME C21	0.53 (0.45—0.64)	311.14 (302.22—322.36)	-0.45 (-0.53—-0.38)
NNE	ME C3	0.49 (0.47—0.51)	301.56 (299.04—304.31)	-0.60 (-0.66—-0.55)
NNE	ME C4	0.42 (0.40—0.45)	326.64 (322.72—330.91)	-0.53 (-0.59—-0.48)
NNE	ME C5	0.42 (0.40—0.45)	321.21 (316.38—326.71)	-0.52 (-0.58—-0.47)
NNE	ME C6	0.44 (0.41—0.47)	318.05 (313.12—323.59)	-0.52 (-0.58—-0.47)
NNE	ME C7	0.46 (0.44—0.49)	312.47 (309.24—315.86)	-0.56 (-0.61—-0.51)
NNE	ME C8	0.47 (0.44—0.49)	324.06 (320.39—327.99)	-0.46 (-0.50—-0.41)
NNE	ME C9	0.41 (0.38—0.45)	334.91 (327.51—343.35)	-0.58 (-0.64—-0.52)
NNE	ME N10	0.55 (0.45—0.69)	312.21 (300.70—326.85)	-0.46 (-0.55—-0.38)
NNE	ME N11	0.48 (0.41—0.57)	315.89 (301.33—332.94)	-0.47 (-0.54—-0.40)
NNE	ME N12	0.51 (0.42—0.64)	324.47 (310.17—342.32)	-0.44 (-0.52—-0.36)
NNE	ME N13	0.40 (0.38—0.43)	321.18 (316.15—326.60)	-0.66 (-0.72—-0.60)
NNE	ME N14	0.49 (0.46—0.53)	302.58 (298.01—307.69)	-0.55 (-0.61—-0.49)
NNE	ME N15	0.37 (0.35—0.40)	326.37 (319.04—334.51)	-0.63 (-0.70—-0.57)
NNE	ME N16	0.40 (0.38—0.43)	322.39 (316.25—329.35)	-0.58 (-0.64—-0.52)
NNE	ME N17	0.49 (0.41—0.60)	308.27 (296.46—322.46)	-0.54 (-0.62—-0.45)
NNE	ME N18	0.50 (0.48—0.54)	310.61 (306.52—314.78)	-0.51 (-0.56—-0.46)
NNE	ME N19	0.39 (0.36—0.42)	285.61 (279.65—292.19)	-0.69 (-0.76—-0.62)
NNE	ME N2	0.58 (0.55—0.61)	304.93 (302.19—307.86)	-0.48 (-0.52—-0.43)
NNE	ME N20	0.43 (0.39—0.47)	328.57 (322.38—335.71)	-0.55 (-0.61—-0.49)
NNE	ME N21	0.51 (0.42—0.62)	314.49 (302.50—329.25)	-0.50 (-0.58—-0.43)
NNE	ME N22	0.50 (0.42—0.61)	312.65 (301.21—326.63)	-0.53 (-0.61—-0.45)

NNE	ME N23	0.47 (0.43—0.52)	267.17 (263.26—271.67)	-0.60 (-0.68—-0.54)
NNE	ME N24	0.57 (0.48—0.67)	301.58 (294.33—310.29)	-0.44 (-0.51—-0.37)
NNE	ME N25	0.47 (0.43—0.51)	319.71 (313.67—326.74)	-0.49 (-0.55—-0.44)
NNE	ME N26	0.49 (0.45—0.53)	311.97 (305.85—318.72)	-0.49 (-0.54—-0.44)
NNE	ME N27	0.50 (0.44—0.57)	303.49 (294.57—314.28)	-0.51 (-0.58—-0.45)
NNE	ME N29	0.39 (0.34—0.45)	298.82 (288.70—311.05)	-0.66 (-0.75—-0.58)
NNE	ME N3	0.45 (0.37—0.57)	312.29 (297.01—331.50)	-0.60 (-0.70—-0.50)
NNE	ME N30	0.48 (0.42—0.54)	285.61 (277.74—294.84)	-0.55 (-0.63—-0.48)
NNE	ME N31	0.46 (0.42—0.49)	317.24 (312.14—322.89)	-0.57 (-0.63—-0.51)
NNE	ME N32	0.53 (0.47—0.60)	303.43 (296.83—311.00)	-0.48 (-0.55—-0.42)
NNE	ME N33	0.42 (0.38—0.47)	328.39 (320.46—337.23)	-0.53 (-0.60—-0.47)
NNE	ME N4	0.43 (0.40—0.46)	325.23 (319.15—331.68)	-0.63 (-0.69—-0.57)
NNE	ME N5	0.40 (0.35—0.46)	325.86 (315.36—338.61)	-0.59 (-0.67—-0.52)
NNE	ME N6	0.45 (0.43—0.49)	322.89 (318.45—327.76)	-0.55 (-0.61—-0.50)
NNE	ME N7	0.47 (0.41—0.53)	315.14 (306.29—325.49)	-0.53 (-0.60—-0.46)
NNE	ME N8	0.46 (0.44—0.48)	327.28 (323.28—331.35)	-0.46 (-0.51—-0.42)
NNE	ME N9	0.51 (0.43—0.63)	318.29 (306.90—332.49)	-0.48 (-0.56—-0.40)
NNE	Oyster	0.42 (0.39—0.44)	315.27 (311.33—319.70)	-0.64 (-0.70—-0.58)
NNE	Pickpocket	0.47 (0.40—0.57)	314.25 (305.55—324.80)	-0.53 (-0.62—-0.45)
NNE	Taylor	0.48 (0.40—0.56)	306.35 (296.20—318.38)	-0.55 (-0.64—-0.48)
NNE	Winnicut	0.50 (0.48—0.53)	292.53 (289.96—295.24)	-0.50 (-0.56—-0.45)

Table S 4. Estimated regional parameters for male alewife aged with scales from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_{∞}) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE). Rivers are organized alphabetically within regions.

Region	River	*K*	L_{∞}	t_0
MAT	Albemarle Sound	0.49 (0.48—0.50)	299.62 (298.18—301.09)	-0.51 (-0.52—-0.50)
MAT	Alligator	0.51 (0.49—0.53)	298.90 (297.11—300.78)	-0.58 (-0.59—-0.56)
MAT	Chickahominy	0.58 (0.56—0.61)	281.50 (279.63—283.47)	-0.58 (-0.60—-0.56)
MAT	Choptank	0.53 (0.40—0.72)	293.98 (265.79—323.61)	-0.50 (-0.67—-0.36)
MAT	Chowan	0.55 (0.54—0.55)	291.02 (290.10—291.91)	-0.42 (-0.43—-0.41)
MAT	Hudson	0.38 (0.36—0.39)	304.16 (301.83—306.62)	-1.09 (-1.16—-1.02)
MAT	Little	0.49 (0.40—0.61)	292.34 (283.46—303.71)	-0.58 (-0.68—-0.48)
MAT	Nanticoke	0.51 (0.49—0.52)	289.55 (288.39—290.81)	-0.61 (-0.67—-0.56)
MAT	Neuse	0.56 (0.44—0.73)	302.38 (289.32—319.22)	-0.41 (-0.51—-0.32)
MAT	North East	0.64 (0.62—0.67)	282.06 (280.68—283.53)	-0.42 (-0.46—-0.38)
MAT	Pamlico	0.58 (0.47—0.72)	302.63 (292.10—316.02)	-0.49 (-0.59—-0.40)
MAT	Pasquotank	0.60 (0.52—0.70)	306.46 (299.19—314.84)	-0.41 (-0.46—-0.36)
MAT	Patapsco	0.56 (0.43—0.74)	295.54 (268.97—324.75)	-0.55 (-0.71—-0.41)
MAT	Perquimans	0.50 (0.45—0.56)	296.55 (289.96—303.84)	-0.46 (-0.50—-0.42)
MAT	Rappahannock	0.56 (0.53—0.59)	284.30 (281.99—286.69)	-0.55 (-0.57—-0.53)
MAT	Roanoke	0.50 (0.47—0.54)	298.50 (293.83—303.59)	-0.43 (-0.45—-0.40)
MAT	Scuppernong	0.56 (0.54—0.58)	291.46 (289.52—293.42)	-0.46 (-0.47—-0.44)
MAT	Susquehanna	0.76 (0.66—0.89)	269.83 (264.94—275.60)	-0.39 (-0.45—-0.33)
MAT	Yeopim	0.49 (0.43—0.57)	287.72 (279.52—297.54)	-0.50 (-0.56—-0.44)
SNE	Back	0.69 (0.67—0.71)	293.29 (291.73—294.89)	-0.20 (-0.21—-0.18)
SNE	Bride Lake	0.80 (0.76—0.84)	269.10 (267.06—271.37)	-0.41 (-0.45—-0.37)
SNE	Charles	0.61 (0.55—0.67)	277.94 (271.77—284.44)	-0.45 (-0.51—-0.40)
SNE	Chicopee	0.54 (0.44—0.67)	296.80 (279.28—316.82)	-0.45 (-0.53—-0.38)
SNE	Farmington	0.72 (0.63—0.83)	282.94 (275.12—292.20)	-0.36 (-0.42—-0.31)
SNE	Gilbert Stuart	0.83 (0.76—0.90)	270.08 (267.88—272.54)	-0.34 (-0.38—-0.30)
SNE	Mattabesset	0.65 (0.61—0.68)	284.83 (282.41—287.31)	-0.45 (-0.49—-0.40)
SNE	Monument	0.85 (0.83—0.87)	267.07 (266.18—267.96)	-0.20 (-0.22—-0.18)
SNE	Mystic	0.75 (0.73—0.78)	269.83 (268.38—271.35)	-0.21 (-0.22—-0.20)
SNE	Nemasket	0.74 (0.71—0.76)	282.02 (281.00—283.06)	-0.39 (-0.46—-0.33)
SNE	Nonquit	0.77 (0.71—0.84)	273.21 (271.07—275.52)	-0.37 (-0.42—-0.33)
SNE	Parker	0.67 (0.64—0.69)	279.19 (277.43—280.92)	-0.44 (-0.48—-0.40)
SNE	Town Brook	0.73 (0.72—0.75)	271.30 (270.31—272.30)	-0.23 (-0.25—-0.22)
SNE	Wethersfield Cove	0.66 (0.61—0.71)	281.66 (277.69—285.75)	-0.46 (-0.52—-0.42)
NNE	Cocheco	0.51 (0.49—0.53)	301.61 (300.10—303.18)	-0.58 (-0.63—-0.53)

NNE	Exeter	0.65 (0.62—0.68)	289.22 (287.58—290.93)	-0.45 (-0.50—-0.41)
NNE	Lamprey	0.50 (0.49—0.52)	304.47 (303.03—305.98)	-0.64 (-0.70—-0.59)
NNE	ME C1	0.51 (0.45—0.57)	305.27 (297.61—314.06)	-0.49 (-0.55—-0.43)
NNE	ME C10	0.43 (0.41—0.45)	318.85 (315.63—322.34)	-0.58 (-0.63—-0.52)
NNE	ME C11	0.47 (0.43—0.51)	302.87 (296.65—309.74)	-0.64 (-0.71—-0.58)
NNE	ME C12	0.53 (0.48—0.58)	289.00 (283.20—295.30)	-0.56 (-0.63—-0.50)
NNE	ME C13	0.53 (0.49—0.58)	300.75 (295.59—306.27)	-0.49 (-0.54—-0.44)
NNE	ME C14	0.60 (0.55—0.67)	288.24 (283.25—293.96)	-0.48 (-0.54—-0.43)
NNE	ME C15	0.46 (0.43—0.48)	311.00 (307.11—315.03)	-0.56 (-0.61—-0.51)
NNE	ME C16	0.43 (0.39—0.47)	317.00 (309.12—325.74)	-0.58 (-0.64—-0.52)
NNE	ME C17	0.53 (0.47—0.58)	290.47 (283.66—298.68)	-0.51 (-0.58—-0.45)
NNE	ME C18	0.48 (0.43—0.52)	307.54 (300.46—315.28)	-0.53 (-0.59—-0.47)
NNE	ME C19	0.43 (0.39—0.48)	312.73 (305.23—321.51)	-0.61 (-0.68—-0.55)
NNE	ME C2	0.52 (0.49—0.54)	291.11 (287.98—294.45)	-0.55 (-0.61—-0.50)
NNE	ME C20	0.48 (0.40—0.58)	297.73 (284.68—313.30)	-0.55 (-0.64—-0.47)
NNE	ME C21	0.57 (0.48—0.68)	296.95 (288.40—307.62)	-0.45 (-0.52—-0.38)
NNE	ME C3	0.52 (0.50—0.55)	287.81 (285.43—290.40)	-0.60 (-0.65—-0.54)
NNE	ME C4	0.45 (0.43—0.48)	311.74 (307.98—315.79)	-0.53 (-0.58—-0.48)
NNE	ME C5	0.45 (0.43—0.48)	306.55 (301.96—311.76)	-0.52 (-0.57—-0.46)
NNE	ME C6	0.47 (0.44—0.50)	303.54 (298.85—308.88)	-0.51 (-0.57—-0.46)
NNE	ME C7	0.50 (0.47—0.52)	298.22 (295.15—301.43)	-0.55 (-0.60—-0.50)
NNE	ME C8	0.50 (0.47—0.53)	309.26 (305.74—313.01)	-0.45 (-0.50—-0.40)
NNE	ME C9	0.44 (0.40—0.48)	319.65 (312.56—327.71)	-0.57 (-0.64—-0.51)
NNE	ME N10	0.59 (0.48—0.74)	297.95 (286.85—311.91)	-0.45 (-0.54—-0.37)
NNE	ME N11	0.51 (0.43—0.61)	301.47 (287.62—317.76)	-0.46 (-0.53—-0.39)
NNE	ME N12	0.55 (0.45—0.69)	309.67 (296.07—326.73)	-0.43 (-0.51—-0.36)
NNE	ME N13	0.43 (0.41—0.46)	306.52 (301.72—311.62)	-0.65 (-0.71—-0.59)
NNE	ME N14	0.52 (0.49—0.56)	288.76 (284.41—293.65)	-0.54 (-0.60—-0.49)
NNE	ME N15	0.40 (0.37—0.43)	311.50 (304.48—319.30)	-0.63 (-0.69—-0.57)
NNE	ME N16	0.43 (0.40—0.46)	307.69 (301.75—314.45)	-0.57 (-0.63—-0.51)
NNE	ME N17	0.53 (0.44—0.64)	294.23 (282.97—307.72)	-0.53 (-0.61—-0.45)
NNE	ME N18	0.54 (0.51—0.57)	296.43 (292.56—300.41)	-0.50 (-0.56—-0.46)
NNE	ME N19	0.42 (0.39—0.45)	272.56 (266.89—278.78)	-0.68 (-0.75—-0.61)
NNE	ME N2	0.62 (0.59—0.65)	291.01 (288.45—293.76)	-0.47 (-0.51—-0.42)
NNE	ME N20	0.46 (0.42—0.50)	313.57 (307.67—320.30)	-0.54 (-0.60—-0.49)
NNE	ME N21	0.54 (0.45—0.66)	300.16 (288.70—314.17)	-0.50 (-0.58—-0.42)
NNE	ME N22	0.53 (0.45—0.65)	298.36 (287.43—311.76)	-0.52 (-0.61—-0.44)
NNE	ME N23	0.50 (0.46—0.55)	254.96 (251.29—259.34)	-0.60 (-0.67—-0.53)
NNE	ME N24	0.61 (0.52—0.72)	287.79 (280.90—296.18)	-0.43 (-0.50—-0.36)
NNE	ME N25	0.50 (0.45—0.55)	305.13 (299.37—311.80)	-0.49 (-0.54—-0.44)
NNE	ME N26	0.52 (0.48—0.57)	297.69 (291.82—304.20)	-0.48 (-0.54—-0.43)
NNE	ME N27	0.53 (0.47—0.61)	289.63 (281.11—299.96)	-0.51 (-0.58—-0.44)
NNE	ME N29	0.42 (0.37—0.48)	285.20 (275.55—296.80)	-0.66 (-0.74—-0.58)

NNE	ME N3	0.49 (0.40—0.61)	298.07 (283.48—316.34)	-0.59 (-0.70—-0.50)
NNE	ME N30	0.51 (0.45—0.58)	272.56 (265.06—281.48)	-0.54 (-0.62—-0.47)
NNE	ME N31	0.49 (0.45—0.53)	302.76 (297.86—308.11)	-0.56 (-0.62—-0.50)
NNE	ME N32	0.57 (0.50—0.65)	289.58 (283.23—296.77)	-0.47 (-0.54—-0.41)
NNE	ME N33	0.45 (0.41—0.50)	313.41 (305.80—321.83)	-0.53 (-0.59—-0.47)
NNE	ME N4	0.46 (0.43—0.50)	310.40 (304.61—316.60)	-0.62 (-0.68—-0.56)
NNE	ME N5	0.43 (0.38—0.49)	310.98 (300.95—323.11)	-0.58 (-0.66—-0.52)
NNE	ME N6	0.49 (0.46—0.52)	308.14 (303.87—312.84)	-0.55 (-0.60—-0.50)
NNE	ME N7	0.50 (0.44—0.57)	300.76 (292.37—310.73)	-0.52 (-0.59—-0.45)
NNE	ME N8	0.49 (0.47—0.52)	312.35 (308.55—316.19)	-0.45 (-0.50—-0.41)
NNE	ME N9	0.55 (0.45—0.68)	303.78 (292.92—317.24)	-0.47 (-0.56—-0.39)
NNE	Oyster	0.44 (0.42—0.47)	300.88 (297.11—305.08)	-0.63 (-0.70—-0.57)
NNE	Pickpocket	0.51 (0.43—0.61)	299.90 (291.57—310.00)	-0.53 (-0.62—-0.44)
NNE	Taylor	0.51 (0.43—0.60)	292.37 (282.64—303.87)	-0.55 (-0.64—-0.47)
NNE	Winnicut	0.54 (0.51—0.57)	279.18 (276.76—281.73)	-0.50 (-0.55—-0.45)

Table S 5. Estimated regional parameters for female blueback herring aged with otoliths from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

Region	River	*K*	L_∞	t_0
SAT	Cape Fear	0.59 (0.54—0.64)	313.72 (309.16—318.78)	-0.27 (-0.31—-0.24)
SAT	Great Pee Dee	0.75 (0.68—0.84)	286.16 (284.17—288.24)	-0.35 (-0.40—-0.31)
SAT	Santee-Cooper	0.56 (0.54—0.58)	301.35 (299.91—302.79)	-0.40 (-0.43—-0.36)
MAT	Albemarle Sound	0.47 (0.45—0.48)	311.35 (309.57—313.13)	-0.39 (-0.40—-0.38)
MAT	Alligator	0.47 (0.45—0.50)	320.58 (317.44—323.99)	-0.36 (-0.39—-0.34)
MAT	Chickahominy	0.53 (0.51—0.56)	297.47 (295.32—299.74)	-0.36 (-0.37—-0.35)
MAT	Chicopee	0.62 (0.60—0.65)	291.77 (289.82—293.72)	-0.37 (-0.40—-0.34)
MAT	Choptank	0.50 (0.39—0.65)	293.77 (264.84—325.58)	-0.44 (-0.56—-0.34)
MAT	Chowan	0.42 (0.41—0.43)	319.28 (317.85—320.69)	-0.40 (-0.41—-0.39)
MAT	Connecticut	0.85 (0.81—0.89)	282.83 (280.88—284.77)	-0.29 (-0.32—-0.27)
MAT	Farmington	0.58 (0.56—0.59)	296.13 (294.97—297.28)	-0.46 (-0.49—-0.42)
MAT	Hudson	0.44 (0.43—0.46)	305.60 (303.61—307.58)	-0.73 (-0.76—-0.70)
MAT	Little	0.49 (0.41—0.58)	317.62 (309.37—328.41)	-0.37 (-0.42—-0.32)
MAT	Mattabesset	0.62 (0.54—0.74)	289.50 (282.78—297.46)	-0.42 (-0.48—-0.36)
MAT	Nanticoke	0.38 (0.37—0.39)	321.06 (319.39—322.69)	-0.59 (-0.64—-0.55)
MAT	Neuse	0.35 (0.33—0.37)	337.42 (332.41—342.50)	-0.79 (-0.92—-0.67)
MAT	North East	0.51 (0.49—0.53)	301.89 (299.91—303.95)	-0.48 (-0.52—-0.45)
MAT	Pamlico	0.56 (0.44—0.72)	310.56 (299.74—323.70)	-0.39 (-0.49—-0.31)
MAT	Pasquotank	0.46 (0.42—0.50)	320.69 (315.61—326.39)	-0.37 (-0.40—-0.35)
MAT	Patapsco	0.54 (0.42—0.70)	296.16 (267.58—327.45)	-0.43 (-0.56—-0.34)
MAT	Perquimans	0.54 (0.49—0.60)	305.35 (300.98—310.18)	-0.35 (-0.38—-0.32)
MAT	Rappahannock	0.52 (0.50—0.54)	302.86 (301.30—304.47)	-0.37 (-0.38—-0.36)
MAT	Roanoke	0.50 (0.47—0.52)	316.30 (313.62—319.19)	-0.31 (-0.33—-0.30)
MAT	Scuppernong	0.50 (0.48—0.52)	315.13 (313.29—316.99)	-0.37 (-0.38—-0.36)
MAT	Susquehanna	0.53 (0.49—0.59)	290.61 (285.66—296.01)	-0.43 (-0.48—-0.38)
MAT	Westfield	0.63 (0.59—0.66)	290.13 (287.86—292.54)	-0.38 (-0.41—-0.34)
MAT	Wethersfield Cove	0.61 (0.60—0.63)	291.78 (290.68—292.89)	-0.37 (-0.40—-0.34)
MAT	Yeopim	0.45 (0.40—0.51)	314.16 (306.83—322.83)	-0.38 (-0.42—-0.35)
SNE	Charles	0.65 (0.63—0.68)	280.64 (278.65—282.67)	-0.39 (-0.42—-0.36)
SNE	Monument	0.66 (0.65—0.68)	270.17 (269.05—271.27)	-0.38 (-0.41—-0.35)
SNE	Mystic	0.73 (0.71—0.75)	270.17 (269.16—271.19)	-0.35 (-0.38—-0.32)
SNE	Town Brook	0.50 (0.40—0.62)	288.65 (275.38—304.68)	-0.44 (-0.51—-0.36)
MNE	Cocheco	0.61 (0.57—0.65)	294.92 (292.50—297.38)	-0.36 (-0.39—-0.33)
MNE	Exeter	0.58 (0.55—0.61)	303.24 (300.71—305.76)	-0.39 (-0.42—-0.35)

MNE	Lamprey	0.61 (0.54—0.70)	300.66 (295.39—306.47)	-0.32 (-0.37—-0.28)
MNE	Oyster	0.55 (0.53—0.57)	300.41 (298.85—301.96)	-0.41 (-0.44—-0.38)
MNE	Parker	0.70 (0.68—0.72)	285.17 (283.85—286.48)	-0.33 (-0.36—-0.30)
MNE	Pickpocket	0.52 (0.41—0.68)	300.05 (280.19—321.03)	-0.43 (-0.53—-0.34)
MNE	Taylor	0.51 (0.48—0.54)	304.87 (301.69—308.24)	-0.49 (-0.53—-0.45)
MNE	Winnicut	0.55 (0.52—0.58)	295.33 (292.58—298.16)	-0.39 (-0.42—-0.35)
CAN-NNE	ME C1	0.56 (0.44—0.74)	292.42 (274.11—312.23)	-0.42 (-0.52—-0.33)
CAN-NNE	ME C10	0.48 (0.46—0.51)	296.22 (292.91—299.78)	-0.41 (-0.45—-0.37)
CAN-NNE	ME C12	0.52 (0.41—0.67)	300.38 (281.19—321.62)	-0.42 (-0.50—-0.34)
CAN-NNE	ME C15	0.55 (0.43—0.72)	302.62 (282.99—326.14)	-0.37 (-0.46—-0.30)
CAN-NNE	ME C16	0.50 (0.41—0.62)	285.69 (273.94—300.16)	-0.45 (-0.53—-0.38)
CAN-NNE	ME C17	0.56 (0.50—0.63)	290.54 (284.39—297.45)	-0.42 (-0.47—-0.38)
CAN-NNE	ME C18	0.53 (0.48—0.60)	285.61 (279.03—293.03)	-0.49 (-0.54—-0.43)
CAN-NNE	ME C19	0.53 (0.43—0.67)	287.86 (271.58—306.15)	-0.47 (-0.56—-0.38)
CAN-NNE	ME C2	0.54 (0.41—0.71)	300.85 (281.11—321.70)	-0.40 (-0.51—-0.31)
CAN-NNE	ME C3	0.60 (0.54—0.68)	287.00 (282.76—291.90)	-0.36 (-0.41—-0.32)
CAN-NNE	ME C7	0.58 (0.46—0.76)	316.71 (298.12—338.95)	-0.34 (-0.41—-0.27)
CAN-NNE	ME C8	0.54 (0.45—0.64)	290.13 (279.42—303.29)	-0.39 (-0.45—-0.33)
CAN-NNE	ME C9	0.53 (0.42—0.68)	296.79 (275.50—321.45)	-0.42 (-0.52—-0.34)
CAN-NNE	ME N13	0.49 (0.39—0.61)	293.76 (274.78—316.59)	-0.44 (-0.52—-0.37)
CAN-NNE	ME N14	0.50 (0.40—0.65)	285.68 (267.57—305.64)	-0.47 (-0.58—-0.38)
CAN-NNE	ME N16	0.57 (0.46—0.75)	289.24 (277.31—304.17)	-0.41 (-0.49—-0.33)
CAN-NNE	ME N18	0.54 (0.42—0.71)	283.32 (266.10—303.25)	-0.44 (-0.55—-0.35)
CAN-NNE	ME N20	0.53 (0.48—0.58)	287.39 (281.93—293.23)	-0.44 (-0.49—-0.40)
CAN-NNE	ME N25	0.55 (0.49—0.62)	286.74 (281.03—293.26)	-0.37 (-0.42—-0.33)
CAN-NNE	ME N26	0.49 (0.38—0.64)	293.83 (274.00—317.62)	-0.39 (-0.48—-0.31)
CAN-NNE	ME N29	0.44 (0.37—0.53)	263.69 (252.17—277.34)	-0.57 (-0.65—-0.49)
CAN-NNE	ME N30	0.52 (0.41—0.66)	265.57 (254.79—279.48)	-0.50 (-0.61—-0.41)
CAN-NNE	ME N33	0.47 (0.41—0.53)	291.56 (283.33—300.73)	-0.47 (-0.53—-0.41)
CAN-NNE	ME N4	0.54 (0.46—0.65)	289.44 (281.65—299.27)	-0.46 (-0.53—-0.40)
CAN-NNE	ME N6	0.55 (0.43—0.71)	289.84 (274.78—307.71)	-0.43 (-0.52—-0.34)
CAN-NNE	ME N7	0.56 (0.48—0.67)	287.88 (278.71—299.05)	-0.40 (-0.46—-0.35)
CAN-NNE	ME N8	0.58 (0.53—0.64)	283.40 (278.85—288.33)	-0.41 (-0.45—-0.37)

Table S 6. Estimated regional parameters for male blueback herring aged with otoliths from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

Region	River	K	L_∞	t_0
SAT	Cape Fear	0.66 (0.61—0.72)	295.41 (291.09—300.17)	-0.26 (-0.29—-0.23)
SAT	Great Pee Dee	0.85 (0.77—0.95)	269.45 (267.58—271.40)	-0.34 (-0.38—-0.30)
SAT	Santee-Cooper	0.63 (0.61—0.65)	283.74 (282.35—285.09)	-0.38 (-0.41—-0.35)
MAT	Albemarle Sound	0.53 (0.51—0.54)	293.16 (291.44—294.88)	-0.38 (-0.39—-0.37)
MAT	Alligator	0.53 (0.50—0.56)	301.83 (298.90—305.04)	-0.34 (-0.37—-0.32)
MAT	Chickahominy	0.60 (0.57—0.63)	280.07 (278.05—282.23)	-0.34 (-0.35—-0.33)
MAT	Chicopee	0.70 (0.67—0.73)	274.72 (272.94—276.52)	-0.35 (-0.38—-0.32)
MAT	Choptank	0.56 (0.44—0.73)	276.62 (249.37—306.57)	-0.42 (-0.54—-0.32)
MAT	Chowan	0.47 (0.46—0.48)	300.62 (299.29—301.96)	-0.38 (-0.39—-0.37)
MAT	Connecticut	0.95 (0.91—1.00)	266.30 (264.49—268.14)	-0.28 (-0.31—-0.25)
MAT	Farmington	0.65 (0.63—0.66)	278.82 (277.77—279.88)	-0.44 (-0.47—-0.40)
MAT	Hudson	0.50 (0.48—0.52)	287.73 (285.89—289.57)	-0.71 (-0.74—-0.68)
MAT	Little	0.55 (0.46—0.65)	299.08 (291.24—309.14)	-0.35 (-0.40—-0.30)
MAT	Mattabesset	0.70 (0.60—0.83)	272.57 (266.23—280.10)	-0.40 (-0.46—-0.34)
MAT	Nanticoke	0.43 (0.41—0.44)	302.30 (300.68—303.91)	-0.57 (-0.62—-0.53)
MAT	Neuse	0.39 (0.37—0.42)	317.73 (312.89—322.46)	-0.77 (-0.90—-0.66)
MAT	North East	0.57 (0.55—0.60)	284.23 (282.30—286.26)	-0.47 (-0.51—-0.43)
MAT	Pamlico	0.62 (0.49—0.81)	292.40 (282.24—304.80)	-0.38 (-0.47—-0.29)
MAT	Pasquotank	0.51 (0.47—0.56)	301.96 (297.16—307.36)	-0.36 (-0.38—-0.33)
MAT	Patapsco	0.61 (0.47—0.79)	278.93 (252.00—308.18)	-0.42 (-0.54—-0.32)
MAT	Perquimans	0.61 (0.55—0.67)	287.49 (283.42—292.03)	-0.33 (-0.36—-0.31)
MAT	Rappahannock	0.58 (0.56—0.60)	285.16 (283.71—286.72)	-0.35 (-0.36—-0.34)
MAT	Roanoke	0.56 (0.53—0.59)	297.83 (295.30—300.51)	-0.30 (-0.31—-0.28)
MAT	Scuppernong	0.56 (0.54—0.58)	296.72 (294.99—298.46)	-0.36 (-0.37—-0.34)
MAT	Susquehanna	0.60 (0.55—0.67)	273.65 (268.98—278.74)	-0.41 (-0.46—-0.36)
MAT	Westfield	0.70 (0.67—0.74)	273.17 (271.05—275.36)	-0.36 (-0.39—-0.33)
MAT	Wethersfield Cove	0.69 (0.67—0.71)	274.72 (273.70—275.73)	-0.35 (-0.38—-0.32)
MAT	Yeopim	0.51 (0.45—0.57)	295.83 (288.80—304.00)	-0.37 (-0.40—-0.33)
SNE	Charles	0.73 (0.71—0.76)	264.24 (262.37—266.11)	-0.37 (-0.40—-0.34)
SNE	Monument	0.75 (0.73—0.77)	254.38 (253.35—255.42)	-0.36 (-0.39—-0.33)
SNE	Mystic	0.82 (0.80—0.84)	254.39 (253.48—255.31)	-0.33 (-0.36—-0.31)
SNE	Town Brook	0.56 (0.46—0.70)	271.76 (259.28—286.90)	-0.42 (-0.50—-0.35)
MNE	Cocheco	0.68 (0.65—0.73)	277.69 (275.47—280.01)	-0.34 (-0.38—-0.31)
MNE	Exeter	0.65 (0.61—0.69)	285.52 (283.17—287.85)	-0.37 (-0.41—-0.34)

MNE	Lamprey	0.69 (0.61—0.79)	283.08 (278.14—288.56)	-0.31 (-0.35—-0.27)
MNE	Oyster	0.62 (0.60—0.64)	282.84 (281.39—284.31)	-0.39 (-0.42—-0.36)
MNE	Parker	0.79 (0.76—0.81)	268.50 (267.34—269.68)	-0.31 (-0.34—-0.29)
MNE	Pickpocket	0.59 (0.46—0.77)	282.55 (263.86—302.30)	-0.41 (-0.51—-0.32)
MNE	Taylor	0.57 (0.54—0.61)	287.04 (284.01—290.21)	-0.47 (-0.52—-0.43)
MNE	Winnicut	0.61 (0.58—0.65)	278.08 (275.53—280.64)	-0.37 (-0.41—-0.33)
CAN-NNE	ME C1	0.63 (0.50—0.83)	275.31 (258.06—294.00)	-0.40 (-0.50—-0.32)
CAN-NNE	ME C10	0.54 (0.51—0.58)	278.92 (275.77—282.29)	-0.39 (-0.44—-0.35)
CAN-NNE	ME C12	0.58 (0.46—0.75)	282.83 (264.72—302.86)	-0.40 (-0.48—-0.32)
CAN-NNE	ME C15	0.62 (0.48—0.81)	284.88 (266.47—306.87)	-0.36 (-0.44—-0.28)
CAN-NNE	ME C16	0.56 (0.46—0.69)	269.02 (257.97—282.65)	-0.44 (-0.52—-0.36)
CAN-NNE	ME C17	0.63 (0.57—0.71)	273.54 (267.78—280.10)	-0.40 (-0.45—-0.36)
CAN-NNE	ME C18	0.60 (0.54—0.68)	268.91 (262.66—275.94)	-0.47 (-0.53—-0.41)
CAN-NNE	ME C19	0.60 (0.48—0.75)	271.06 (255.76—288.34)	-0.45 (-0.54—-0.36)
CAN-NNE	ME C2	0.60 (0.46—0.80)	283.32 (264.62—302.95)	-0.38 (-0.49—-0.29)
CAN-NNE	ME C3	0.68 (0.61—0.76)	270.25 (266.24—274.85)	-0.34 (-0.39—-0.30)
CAN-NNE	ME C7	0.65 (0.51—0.85)	298.18 (280.55—319.02)	-0.32 (-0.40—-0.25)
CAN-NNE	ME C8	0.60 (0.51—0.72)	273.18 (263.12—285.58)	-0.37 (-0.43—-0.32)
CAN-NNE	ME C9	0.59 (0.47—0.77)	279.46 (259.30—302.78)	-0.40 (-0.50—-0.32)
CAN-NNE	ME N13	0.55 (0.44—0.69)	276.59 (258.61—298.10)	-0.42 (-0.50—-0.35)
CAN-NNE	ME N14	0.56 (0.45—0.73)	268.97 (252.03—287.84)	-0.45 (-0.56—-0.36)
CAN-NNE	ME N16	0.65 (0.51—0.84)	272.32 (261.08—286.41)	-0.39 (-0.47—-0.31)
CAN-NNE	ME N18	0.61 (0.47—0.80)	266.76 (250.58—285.65)	-0.43 (-0.53—-0.33)
CAN-NNE	ME N20	0.59 (0.54—0.65)	270.60 (265.44—276.08)	-0.43 (-0.48—-0.38)
CAN-NNE	ME N25	0.62 (0.55—0.70)	269.98 (264.58—276.18)	-0.35 (-0.40—-0.31)
CAN-NNE	ME N26	0.55 (0.43—0.72)	276.63 (258.04—299.03)	-0.37 (-0.46—-0.29)
CAN-NNE	ME N29	0.49 (0.41—0.59)	248.22 (237.49—261.09)	-0.55 (-0.64—-0.47)
CAN-NNE	ME N30	0.58 (0.46—0.75)	250.01 (239.98—263.06)	-0.48 (-0.59—-0.39)
CAN-NNE	ME N33	0.53 (0.46—0.60)	274.54 (266.84—283.21)	-0.45 (-0.51—-0.40)
CAN-NNE	ME N4	0.61 (0.52—0.73)	272.51 (265.17—281.84)	-0.44 (-0.51—-0.38)
CAN-NNE	ME N6	0.62 (0.48—0.80)	272.93 (258.67—289.72)	-0.41 (-0.50—-0.32)
CAN-NNE	ME N7	0.63 (0.54—0.75)	271.06 (262.47—281.58)	-0.39 (-0.45—-0.33)
CAN-NNE	ME N8	0.66 (0.60—0.72)	266.84 (262.52—271.48)	-0.39 (-0.44—-0.35)

Table S 7. Estimated regional parameters for female blueback herring aged with scales from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

Region	River	*K*	L_∞	t_0
SAT	Cape Fear	0.65 (0.60—0.71)	303.72 (299.49—308.57)	-0.25 (-0.28—-0.22)
SAT	Great Pee Dee	0.84 (0.76—0.94)	277.06 (275.36—278.95)	-0.33 (-0.37—-0.29)
SAT	Santee-Cooper	0.62 (0.60—0.64)	291.76 (290.65—292.90)	-0.37 (-0.41—-0.34)
MAT	Albemarle Sound	0.52 (0.51—0.53)	301.45 (300.02—302.93)	-0.37 (-0.38—-0.36)
MAT	Alligator	0.53 (0.50—0.56)	310.39 (307.52—313.45)	-0.34 (-0.36—-0.31)
MAT	Chickahominy	0.59 (0.57—0.62)	288.01 (285.79—290.34)	-0.33 (-0.35—-0.32)
MAT	Chicopee	0.69 (0.66—0.72)	282.51 (280.38—284.67)	-0.34 (-0.38—-0.31)
MAT	Choptank	0.55 (0.43—0.72)	284.41 (256.36—315.07)	-0.42 (-0.54—-0.32)
MAT	Chowan	0.46 (0.46—0.47)	309.13 (308.28—310.00)	-0.38 (-0.38—-0.37)
MAT	Connecticut	0.94 (0.90—0.99)	273.84 (272.13—275.63)	-0.27 (-0.30—-0.24)
MAT	Farmington	0.64 (0.62—0.66)	286.71 (285.25—288.23)	-0.43 (-0.47—-0.40)
MAT	Hudson	0.49 (0.48—0.51)	295.87 (294.21—297.55)	-0.71 (-0.73—-0.68)
MAT	Little	0.54 (0.46—0.64)	307.54 (299.55—317.84)	-0.34 (-0.39—-0.30)
MAT	Mattabesset	0.69 (0.60—0.82)	280.34 (273.74—287.99)	-0.39 (-0.45—-0.34)
MAT	Nanticoke	0.42 (0.41—0.43)	310.85 (309.71—312.03)	-0.57 (-0.61—-0.52)
MAT	Neuse	0.39 (0.37—0.41)	326.72 (322.18—331.37)	-0.76 (-0.90—-0.65)
MAT	North East	0.56 (0.54—0.58)	292.31 (290.58—294.07)	-0.46 (-0.50—-0.42)
MAT	Pamlico	0.62 (0.48—0.81)	300.69 (290.26—313.40)	-0.37 (-0.46—-0.29)
MAT	Pasquotank	0.51 (0.46—0.55)	310.47 (305.70—316.00)	-0.35 (-0.38—-0.32)
MAT	Patapsco	0.60 (0.47—0.78)	286.75 (258.96—316.98)	-0.41 (-0.53—-0.31)
MAT	Perquimans	0.60 (0.55—0.66)	295.63 (291.60—300.26)	-0.33 (-0.35—-0.30)
MAT	Rappahannock	0.57 (0.55—0.60)	293.24 (291.50—295.08)	-0.34 (-0.36—-0.33)
MAT	Roanoke	0.55 (0.52—0.58)	306.25 (303.89—308.85)	-0.29 (-0.30—-0.28)
MAT	Scuppernong	0.56 (0.54—0.57)	305.12 (303.64—306.64)	-0.35 (-0.36—-0.34)
MAT	Susquehanna	0.59 (0.54—0.66)	281.37 (276.73—286.61)	-0.40 (-0.45—-0.36)
MAT	Westfield	0.70 (0.66—0.74)	280.92 (278.49—283.40)	-0.35 (-0.39—-0.32)
MAT	Wethersfield Cove	0.68 (0.66—0.71)	282.50 (281.04—283.97)	-0.34 (-0.37—-0.31)
MAT	Yeopim	0.50 (0.45—0.56)	304.14 (297.13—312.44)	-0.36 (-0.39—-0.33)
SNE	Charles	0.72 (0.70—0.75)	271.72 (269.81—273.63)	-0.36 (-0.40—-0.33)
SNE	Monument	0.74 (0.72—0.76)	261.57 (260.45—262.76)	-0.35 (-0.38—-0.32)
SNE	Mystic	0.81 (0.78—0.84)	261.57 (260.42—262.78)	-0.33 (-0.36—-0.30)
SNE	Town Brook	0.55 (0.45—0.69)	279.45 (266.65—294.99)	-0.41 (-0.49—-0.34)
MNE	Cocheco	0.68 (0.64—0.72)	285.54 (283.43—287.78)	-0.33 (-0.37—-0.30)
MNE	Exeter	0.64 (0.61—0.68)	293.60 (291.41—295.85)	-0.36 (-0.40—-0.33)

MNE	Lamprey	0.68 (0.60—0.78)	291.10 (286.05—296.66)	-0.30 (-0.34—-0.26)
MNE	Oyster	0.61 (0.60—0.63)	290.84 (289.71—292.04)	-0.38 (-0.42—-0.35)
MNE	Parker	0.78 (0.75—0.81)	276.10 (274.57—277.70)	-0.30 (-0.33—-0.28)
MNE	Pickpocket	0.58 (0.45—0.76)	290.61 (271.35—311.01)	-0.40 (-0.51—-0.31)
MNE	Taylor	0.57 (0.54—0.60)	295.16 (292.22—298.30)	-0.47 (-0.51—-0.43)
MNE	Winnicut	0.61 (0.57—0.64)	285.93 (283.54—288.56)	-0.36 (-0.40—-0.33)
CAN-NNE	ME C1	0.63 (0.49—0.83)	283.15 (265.21—302.08)	-0.40 (-0.50—-0.31)
CAN-NNE	ME C10	0.54 (0.51—0.57)	286.81 (283.79—290.08)	-0.39 (-0.43—-0.35)
CAN-NNE	ME C12	0.58 (0.46—0.74)	290.86 (272.19—311.27)	-0.39 (-0.48—-0.31)
CAN-NNE	ME C15	0.61 (0.48—0.80)	292.95 (274.03—315.62)	-0.35 (-0.43—-0.28)
CAN-NNE	ME C16	0.55 (0.45—0.68)	276.62 (265.16—290.64)	-0.43 (-0.51—-0.36)
CAN-NNE	ME C17	0.63 (0.56—0.70)	281.27 (275.38—287.88)	-0.40 (-0.45—-0.35)
CAN-NNE	ME C18	0.60 (0.53—0.67)	276.50 (270.08—283.62)	-0.46 (-0.52—-0.41)
CAN-NNE	ME C19	0.59 (0.47—0.74)	278.73 (263.06—296.49)	-0.44 (-0.53—-0.36)
CAN-NNE	ME C2	0.60 (0.46—0.79)	291.35 (272.23—311.52)	-0.38 (-0.48—-0.29)
CAN-NNE	ME C3	0.67 (0.60—0.75)	277.94 (273.86—282.59)	-0.34 (-0.38—-0.30)
CAN-NNE	ME C7	0.65 (0.51—0.84)	306.69 (288.55—328.05)	-0.31 (-0.39—-0.25)
CAN-NNE	ME C8	0.60 (0.50—0.71)	280.91 (270.57—293.60)	-0.36 (-0.42—-0.31)
CAN-NNE	ME C9	0.59 (0.46—0.76)	287.36 (266.85—311.43)	-0.40 (-0.49—-0.31)
CAN-NNE	ME N13	0.54 (0.44—0.68)	284.42 (266.19—306.49)	-0.42 (-0.49—-0.35)
CAN-NNE	ME N14	0.56 (0.44—0.72)	276.64 (259.10—295.77)	-0.45 (-0.55—-0.36)
CAN-NNE	ME N16	0.64 (0.51—0.83)	279.99 (268.48—294.47)	-0.38 (-0.47—-0.30)
CAN-NNE	ME N18	0.60 (0.46—0.79)	274.33 (257.70—293.51)	-0.42 (-0.53—-0.33)
CAN-NNE	ME N20	0.59 (0.53—0.65)	278.25 (273.07—283.79)	-0.42 (-0.47—-0.38)
CAN-NNE	ME N25	0.61 (0.55—0.69)	277.65 (272.11—283.84)	-0.35 (-0.39—-0.30)
CAN-NNE	ME N26	0.54 (0.42—0.71)	284.47 (265.17—307.70)	-0.37 (-0.45—-0.29)
CAN-NNE	ME N29	0.49 (0.41—0.58)	255.33 (244.16—268.33)	-0.54 (-0.63—-0.47)
CAN-NNE	ME N30	0.58 (0.45—0.74)	257.05 (246.85—270.65)	-0.48 (-0.58—-0.39)
CAN-NNE	ME N33	0.52 (0.46—0.59)	282.29 (274.41—291.22)	-0.44 (-0.50—-0.39)
CAN-NNE	ME N4	0.60 (0.51—0.72)	280.27 (272.67—289.53)	-0.44 (-0.51—-0.37)
CAN-NNE	ME N6	0.61 (0.48—0.79)	280.61 (266.15—297.99)	-0.40 (-0.50—-0.32)
CAN-NNE	ME N7	0.63 (0.53—0.74)	278.74 (269.92—289.45)	-0.38 (-0.44—-0.32)
CAN-NNE	ME N8	0.65 (0.60—0.71)	274.39 (270.04—279.00)	-0.39 (-0.43—-0.35)

Table S 8. Estimated regional parameters for male blueback herring with aged withscales from the sex-specific von Bertalanffy growth functions. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

Region	River	*K*	L_∞	t_0
SAT	Cape Fear	0.74 (0.68—0.80)	285.98 (282.00—290.50)	-0.23 (-0.26—-0.20)
SAT	Great Pee Dee	0.94 (0.85—1.06)	260.86 (259.27—262.64)	-0.31 (-0.35—-0.27)
SAT	Santee-Cooper	0.70 (0.68—0.72)	274.72 (273.69—275.79)	-0.35 (-0.39—-0.32)
MAT	Albemarle Sound	0.58 (0.57—0.60)	283.82 (282.45—285.25)	-0.35 (-0.36—-0.34)
MAT	Alligator	0.59 (0.56—0.63)	292.25 (289.57—295.11)	-0.32 (-0.34—-0.29)
MAT	Chickahominy	0.67 (0.64—0.70)	271.16 (269.12—273.36)	-0.32 (-0.33—-0.30)
MAT	Chicopee	0.78 (0.75—0.81)	266.00 (264.06—267.99)	-0.32 (-0.36—-0.29)
MAT	Choptank	0.62 (0.48—0.81)	267.88 (241.47—296.83)	-0.40 (-0.52—-0.30)
MAT	Chowan	0.52 (0.51—0.53)	291.06 (290.30—291.86)	-0.36 (-0.36—-0.35)
MAT	Connecticut	1.06 (1.01—1.11)	257.84 (256.20—259.54)	-0.25 (-0.28—-0.23)
MAT	Farmington	0.72 (0.70—0.74)	269.96 (268.59—271.34)	-0.41 (-0.45—-0.38)
MAT	Hudson	0.56 (0.54—0.57)	278.58 (277.05—280.15)	-0.69 (-0.72—-0.66)
MAT	Little	0.61 (0.51—0.72)	289.55 (282.08—299.32)	-0.32 (-0.37—-0.28)
MAT	Mattabesset	0.78 (0.67—0.92)	263.94 (257.80—271.13)	-0.38 (-0.43—-0.32)
MAT	Nanticoke	0.47 (0.46—0.48)	292.67 (291.54—293.87)	-0.55 (-0.59—-0.51)
MAT	Neuse	0.44 (0.41—0.46)	307.63 (303.18—312.03)	-0.75 (-0.88—-0.63)
MAT	North East	0.63 (0.61—0.66)	275.21 (273.56—276.93)	-0.44 (-0.48—-0.40)
MAT	Pamlico	0.69 (0.54—0.91)	283.09 (273.32—295.11)	-0.35 (-0.44—-0.27)
MAT	Pasquotank	0.57 (0.52—0.62)	292.34 (287.79—297.53)	-0.33 (-0.36—-0.30)
MAT	Patapsco	0.68 (0.53—0.88)	270.08 (243.94—298.49)	-0.39 (-0.51—-0.29)
MAT	Perquimans	0.68 (0.62—0.75)	278.32 (274.64—282.59)	-0.31 (-0.34—-0.28)
MAT	Rappahannock	0.65 (0.62—0.67)	276.11 (274.50—277.82)	-0.33 (-0.34—-0.32)
MAT	Roanoke	0.62 (0.59—0.65)	288.37 (286.12—290.75)	-0.27 (-0.28—-0.26)
MAT	Scuppernong	0.63 (0.61—0.64)	287.29 (285.92—288.69)	-0.33 (-0.34—-0.32)
MAT	Susquehanna	0.67 (0.61—0.74)	264.94 (260.58—269.89)	-0.39 (-0.44—-0.34)
MAT	Westfield	0.78 (0.74—0.83)	264.51 (262.28—266.79)	-0.33 (-0.37—-0.30)
MAT	Wethersfield Cove	0.77 (0.74—0.79)	265.99 (264.68—267.32)	-0.33 (-0.36—-0.30)
MAT	Yeopim	0.56 (0.50—0.63)	286.36 (279.75—294.27)	-0.34 (-0.37—-0.31)
SNE	Charles	0.82 (0.78—0.85)	255.82 (254.05—257.63)	-0.34 (-0.38—-0.31)
SNE	Monument	0.83 (0.81—0.86)	246.29 (245.29—247.34)	-0.33 (-0.37—-0.30)
SNE	Mystic	0.91 (0.88—0.94)	246.29 (245.27—247.35)	-0.31 (-0.34—-0.28)
SNE	Town Brook	0.62 (0.51—0.78)	263.15 (251.02—277.72)	-0.39 (-0.47—-0.32)
MNE	Cocheco	0.76 (0.72—0.80)	268.85 (266.88—270.95)	-0.32 (-0.35—-0.28)
MNE	Exeter	0.72 (0.69—0.76)	276.44 (274.43—278.52)	-0.34 (-0.38—-0.31)

MNE	Lamprey	0.77 (0.68—0.87)	274.09 (269.26—279.26)	-0.28 (-0.32—-0.24)
MNE	Oyster	0.69 (0.67—0.71)	273.85 (272.82—274.93)	-0.37 (-0.40—-0.33)
MNE	Parker	0.88 (0.85—0.91)	259.97 (258.59—261.39)	-0.29 (-0.32—-0.26)
MNE	Pickpocket	0.65 (0.51—0.85)	273.62 (255.55—292.80)	-0.39 (-0.49—-0.29)
MNE	Taylor	0.64 (0.60—0.68)	277.91 (275.11—280.86)	-0.45 (-0.49—-0.41)
MNE	Winnicut	0.68 (0.65—0.72)	269.23 (266.99—271.60)	-0.34 (-0.38—-0.31)
CAN-NNE	ME C1	0.70 (0.55—0.93)	266.58 (249.74—284.49)	-0.38 (-0.48—-0.29)
CAN-NNE	ME C10	0.60 (0.57—0.64)	270.06 (267.14—273.14)	-0.37 (-0.41—-0.33)
CAN-NNE	ME C12	0.65 (0.52—0.83)	273.84 (256.37—293.06)	-0.37 (-0.46—-0.29)
CAN-NNE	ME C15	0.69 (0.54—0.90)	275.82 (258.02—296.98)	-0.33 (-0.41—-0.26)
CAN-NNE	ME C16	0.62 (0.51—0.77)	260.43 (249.73—273.69)	-0.41 (-0.49—-0.34)
CAN-NNE	ME C17	0.71 (0.63—0.79)	264.87 (259.30—271.06)	-0.38 (-0.43—-0.33)
CAN-NNE	ME C18	0.67 (0.60—0.76)	260.37 (254.29—267.09)	-0.44 (-0.50—-0.39)
CAN-NNE	ME C19	0.66 (0.53—0.83)	262.45 (247.71—279.11)	-0.42 (-0.51—-0.34)
CAN-NNE	ME C2	0.67 (0.51—0.89)	274.34 (256.27—293.37)	-0.36 (-0.46—-0.27)
CAN-NNE	ME C3	0.75 (0.68—0.85)	261.69 (257.90—266.07)	-0.32 (-0.36—-0.28)
CAN-NNE	ME C7	0.73 (0.57—0.95)	288.80 (271.60—308.89)	-0.30 (-0.37—-0.23)
CAN-NNE	ME C8	0.67 (0.57—0.80)	264.48 (254.81—276.51)	-0.35 (-0.41—-0.29)
CAN-NNE	ME C9	0.66 (0.52—0.85)	270.58 (251.20—293.19)	-0.38 (-0.47—-0.29)
CAN-NNE	ME N13	0.61 (0.49—0.77)	267.77 (250.58—288.64)	-0.40 (-0.47—-0.33)
CAN-NNE	ME N14	0.63 (0.50—0.81)	260.48 (243.98—278.72)	-0.43 (-0.53—-0.34)
CAN-NNE	ME N16	0.72 (0.57—0.93)	263.62 (252.77—277.23)	-0.36 (-0.45—-0.28)
CAN-NNE	ME N18	0.67 (0.52—0.89)	258.27 (242.61—276.50)	-0.40 (-0.51—-0.31)
CAN-NNE	ME N20	0.66 (0.60—0.73)	261.99 (257.14—267.21)	-0.40 (-0.45—-0.36)
CAN-NNE	ME N25	0.69 (0.61—0.77)	261.41 (256.26—267.30)	-0.33 (-0.37—-0.29)
CAN-NNE	ME N26	0.61 (0.48—0.80)	267.86 (249.72—289.59)	-0.35 (-0.43—-0.27)
CAN-NNE	ME N29	0.55 (0.46—0.66)	240.39 (229.96—252.73)	-0.53 (-0.61—-0.45)
CAN-NNE	ME N30	0.65 (0.51—0.83)	242.02 (232.48—254.72)	-0.46 (-0.57—-0.37)
CAN-NNE	ME N33	0.58 (0.52—0.66)	265.78 (258.41—274.12)	-0.43 (-0.48—-0.37)
CAN-NNE	ME N4	0.68 (0.58—0.81)	263.87 (256.74—272.67)	-0.42 (-0.49—-0.36)
CAN-NNE	ME N6	0.68 (0.53—0.89)	264.24 (250.60—280.58)	-0.38 (-0.48—-0.30)
CAN-NNE	ME N7	0.70 (0.60—0.84)	262.46 (254.11—272.56)	-0.36 (-0.42—-0.30)
CAN-NNE	ME N8	0.73 (0.67—0.80)	258.37 (254.31—262.67)	-0.37 (-0.41—-0.33)

Table S 9. Estimated coastwide parameters from the sex-aggregated von Bertalanffy growth functions for alewife within aging structures. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Structure	*K*	L_∞	t_0
Otolith	0.46 (0.36—0.69)	315.88 (283.85—341.41)	-0.53 (-0.71—-0.22)
Scale	0.48 (0.37—0.72)	306.05 (275.01—330.76)	-0.52 (-0.71—-0.22)

Table S 10. Estimated regional parameters from the sex-aggregated von Bertalanffy growth function for alewife within aging structures. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE).

Region	Structure	*K*	L_∞	t_0
MAT	Otolith	0.47 (0.33—0.69)	313.61 (283.97—335.09)	-0.51 (-1.14—-0.39)
MAT	Scale	0.49 (0.35—0.72)	303.76 (275.12—324.67)	-0.50 (-1.14—-0.39)
SNE	Otolith	0.63 (0.47—0.75)	293.10 (283.43—316.22)	-0.41 (-0.53—-0.20)
SNE	Scale	0.66 (0.49—0.78)	284.00 (274.61—306.40)	-0.40 (-0.52—-0.20)
NNE	Otolith	0.45 (0.36—0.59)	320.31 (286.06—343.95)	-0.54 (-0.70—-0.42)
NNE	Scale	0.47 (0.38—0.61)	310.34 (277.13—333.23)	-0.54 (-0.70—-0.42)

Table S 11. Estimated river-specific parameters from the sex-aggregated von Bertalanffy growth function for alewife aged with otoliths. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE).

Region	River	K	L_∞	t_0
MAT	Albemarle Sound	0.43 (0.41—0.44)	321.34 (319.30—323.40)	-0.54 (-0.55—-0.52)
MAT	Alligator	0.45 (0.43—0.47)	318.53 (316.08—321.01)	-0.61 (-0.63—-0.59)
MAT	Chickahominy	0.50 (0.48—0.51)	303.38 (301.40—305.37)	-0.63 (-0.65—-0.61)
MAT	Choptank	0.47 (0.36—0.62)	313.32 (282.70—346.44)	-0.52 (-0.68—-0.39)
MAT	Chowan	0.48 (0.46—0.49)	310.95 (309.41—312.46)	-0.45 (-0.46—-0.44)
MAT	Hudson	0.33 (0.32—0.35)	325.73 (322.61—328.94)	-1.14 (-1.23—-1.06)
MAT	Little	0.42 (0.34—0.51)	315.50 (304.90—328.81)	-0.63 (-0.73—-0.53)
MAT	Nanticoke	0.42 (0.41—0.44)	313.14 (311.33—315.05)	-0.70 (-0.76—-0.64)
MAT	Neuse	0.50 (0.39—0.64)	323.59 (309.12—341.65)	-0.47 (-0.57—-0.38)
MAT	North East	0.55 (0.53—0.57)	302.50 (300.47—304.56)	-0.49 (-0.54—-0.45)
MAT	Pamlico	0.49 (0.40—0.60)	326.97 (314.06—342.80)	-0.43 (-0.51—-0.35)
MAT	Pasquotank	0.53 (0.46—0.62)	327.14 (318.88—336.93)	-0.43 (-0.48—-0.38)
MAT	Patapsco	0.47 (0.36—0.63)	313.49 (283.65—345.65)	-0.53 (-0.70—-0.40)
MAT	Perquimans	0.46 (0.41—0.52)	312.79 (305.61—321.15)	-0.47 (-0.51—-0.43)
MAT	Rappahannock	0.48 (0.46—0.50)	305.36 (302.79—308.04)	-0.59 (-0.61—-0.57)
MAT	Roanoke	0.44 (0.40—0.47)	320.83 (315.32—326.89)	-0.45 (-0.48—-0.43)
MAT	Scuppernong	0.48 (0.46—0.50)	312.71 (310.12—315.44)	-0.49 (-0.51—-0.47)
MAT	Susquehanna	0.68 (0.59—0.80)	284.65 (279.17—291.17)	-0.43 (-0.49—-0.36)
MAT	Yeopim	0.45 (0.39—0.53)	302.03 (292.68—313.04)	-0.52 (-0.57—-0.46)
SNE	Back	0.62 (0.60—0.63)	312.06 (310.66—313.46)	-0.21 (-0.22—-0.20)
SNE	Bride Lake	0.67 (0.63—0.72)	288.70 (285.69—291.78)	-0.47 (-0.51—-0.42)
SNE	Charles	0.57 (0.51—0.62)	292.75 (286.16—300.20)	-0.43 (-0.48—-0.38)
SNE	Chicopee	0.49 (0.40—0.62)	311.95 (292.60—334.96)	-0.50 (-0.58—-0.41)
SNE	Farmington	0.63 (0.55—0.74)	302.27 (292.40—313.66)	-0.38 (-0.43—-0.32)
SNE	Gilbert Stuart	0.69 (0.64—0.76)	286.44 (283.50—289.66)	-0.37 (-0.42—-0.33)
SNE	Mattabesset	0.59 (0.56—0.61)	299.41 (296.88—302.14)	-0.45 (-0.50—-0.41)
SNE	Monument	0.75 (0.73—0.77)	283.69 (282.57—284.79)	-0.22 (-0.23—-0.20)
SNE	Mystic	0.67 (0.65—0.69)	286.84 (285.47—288.17)	-0.22 (-0.23—-0.21)
SNE	Nemasket	0.67 (0.65—0.69)	298.39 (297.29—299.53)	-0.40 (-0.47—-0.33)
SNE	Nonquit	0.62 (0.58—0.68)	292.20 (289.32—295.31)	-0.43 (-0.48—-0.38)
SNE	Parker	0.62 (0.60—0.64)	292.72 (291.12—294.36)	-0.43 (-0.47—-0.39)
SNE	Town Brook	0.66 (0.64—0.67)	287.93 (286.83—289.06)	-0.25 (-0.27—-0.23)
SNE	Wethersfield Cove	0.58 (0.54—0.62)	300.00 (295.32—304.95)	-0.49 (-0.55—-0.44)
NNE	Cocheco	0.45 (0.43—0.47)	320.38 (318.28—322.59)	-0.67 (-0.73—-0.61)
NNE	Exeter	0.59 (0.56—0.62)	305.56 (303.39—307.79)	-0.45 (-0.50—-0.41)
NNE	Lamprey	0.47 (0.45—0.49)	321.82 (319.86—323.83)	-0.55 (-0.60—-0.50)
NNE	ME C1	0.43 (0.39—0.49)	329.01 (320.02—339.58)	-0.55 (-0.62—-0.49)

NNE	ME C10	0.36 (0.34—0.38)	346.03 (341.95—350.34)	-0.70 (-0.76—-0.64)
NNE	ME C11	0.42 (0.38—0.46)	324.22 (317.05—332.33)	-0.58 (-0.65—-0.51)
NNE	ME C12	0.48 (0.43—0.53)	306.42 (299.49—314.04)	-0.54 (-0.61—-0.48)
NNE	ME C13	0.47 (0.43—0.52)	320.44 (314.37—327.09)	-0.55 (-0.61—-0.49)
NNE	ME C14	0.54 (0.49—0.60)	306.68 (301.03—313.26)	-0.46 (-0.52—-0.41)
NNE	ME C15	0.40 (0.37—0.42)	333.71 (329.18—338.65)	-0.61 (-0.67—-0.55)
NNE	ME C16	0.38 (0.35—0.42)	340.51 (331.33—351.09)	-0.57 (-0.63—-0.50)
NNE	ME C17	0.45 (0.41—0.50)	313.96 (306.18—323.26)	-0.50 (-0.57—-0.45)
NNE	ME C18	0.42 (0.38—0.46)	329.13 (321.23—338.02)	-0.56 (-0.63—-0.50)
NNE	ME C19	0.40 (0.36—0.44)	332.21 (323.39—342.38)	-0.56 (-0.63—-0.49)
NNE	ME C2	0.46 (0.43—0.49)	309.96 (306.19—313.99)	-0.60 (-0.66—-0.54)
NNE	ME C20	0.44 (0.37—0.53)	315.26 (301.51—332.41)	-0.55 (-0.64—-0.47)
NNE	ME C21	0.49 (0.41—0.59)	317.40 (307.00—330.50)	-0.50 (-0.59—-0.42)
NNE	ME C3	0.49 (0.46—0.51)	305.45 (302.63—308.33)	-0.49 (-0.54—-0.44)
NNE	ME C4	0.42 (0.40—0.45)	329.81 (325.24—334.66)	-0.52 (-0.58—-0.47)
NNE	ME C5	0.40 (0.38—0.43)	327.62 (321.90—333.52)	-0.53 (-0.59—-0.47)
NNE	ME C6	0.41 (0.39—0.44)	325.65 (320.05—331.45)	-0.54 (-0.60—-0.48)
NNE	ME C7	0.45 (0.42—0.47)	317.84 (314.22—321.80)	-0.57 (-0.63—-0.52)
NNE	ME C8	0.44 (0.41—0.47)	329.80 (325.54—334.36)	-0.53 (-0.58—-0.47)
NNE	ME C9	0.40 (0.36—0.44)	340.01 (331.84—349.47)	-0.59 (-0.65—-0.53)
NNE	ME N10	0.51 (0.42—0.64)	317.25 (304.01—334.00)	-0.46 (-0.55—-0.38)
NNE	ME N11	0.47 (0.39—0.56)	317.96 (301.98—336.87)	-0.53 (-0.61—-0.45)
NNE	ME N12	0.49 (0.40—0.61)	329.80 (314.34—349.53)	-0.45 (-0.53—-0.37)
NNE	ME N13	0.40 (0.37—0.42)	324.66 (319.48—330.29)	-0.65 (-0.71—-0.59)
NNE	ME N14	0.46 (0.43—0.50)	308.88 (303.73—314.66)	-0.54 (-0.60—-0.49)
NNE	ME N15	0.37 (0.34—0.40)	330.68 (322.65—339.17)	-0.59 (-0.66—-0.52)
NNE	ME N16	0.37 (0.34—0.40)	330.40 (323.08—338.60)	-0.69 (-0.76—-0.62)
NNE	ME N17	0.45 (0.38—0.54)	314.82 (301.84—330.71)	-0.55 (-0.64—-0.47)
NNE	ME N18	0.49 (0.45—0.52)	314.94 (310.32—319.63)	-0.52 (-0.58—-0.47)
NNE	ME N19	0.39 (0.35—0.42)	288.79 (282.32—295.98)	-0.69 (-0.76—-0.61)
NNE	ME N2	0.57 (0.53—0.61)	306.69 (303.56—310.04)	-0.49 (-0.54—-0.44)
NNE	ME N20	0.42 (0.38—0.46)	332.63 (325.69—340.36)	-0.58 (-0.64—-0.52)
NNE	ME N21	0.44 (0.37—0.53)	326.38 (312.18—344.90)	-0.56 (-0.65—-0.48)
NNE	ME N22	0.48 (0.40—0.59)	317.65 (305.55—332.46)	-0.53 (-0.62—-0.45)
NNE	ME N23	0.46 (0.41—0.50)	269.38 (264.99—274.44)	-0.60 (-0.68—-0.53)
NNE	ME N24	0.57 (0.48—0.68)	303.72 (296.18—313.29)	-0.42 (-0.50—-0.35)
NNE	ME N25	0.48 (0.43—0.53)	320.12 (313.67—327.15)	-0.53 (-0.60—-0.47)
NNE	ME N26	0.47 (0.43—0.52)	315.86 (309.08—323.64)	-0.52 (-0.58—-0.46)
NNE	ME N27	0.50 (0.44—0.58)	305.46 (296.22—316.75)	-0.46 (-0.53—-0.40)
NNE	ME N29	0.38 (0.33—0.44)	302.73 (291.66—315.90)	-0.62 (-0.71—-0.55)
NNE	ME N3	0.43 (0.35—0.54)	320.96 (304.26—341.94)	-0.53 (-0.63—-0.44)
NNE	ME N30	0.46 (0.40—0.53)	289.12 (280.50—299.12)	-0.57 (-0.65—-0.49)
NNE	ME N31	0.46 (0.42—0.50)	319.70 (314.22—325.84)	-0.52 (-0.58—-0.46)
NNE	ME N32	0.52 (0.46—0.60)	306.13 (299.18—314.13)	-0.48 (-0.54—-0.41)
NNE	ME N33	0.40 (0.36—0.45)	333.91 (324.89—343.24)	-0.59 (-0.67—-0.53)

NNE	ME N4	0.42 (0.39—0.46)	330.35 (324.04—337.26)	-0.56 (-0.62—-0.51)
NNE	ME N5	0.40 (0.35—0.46)	329.15 (317.89—341.93)	-0.54 (-0.61—-0.47)
NNE	ME N6	0.44 (0.41—0.48)	327.50 (322.35—332.75)	-0.52 (-0.58—-0.46)
NNE	ME N7	0.46 (0.40—0.52)	318.84 (309.39—329.47)	-0.51 (-0.58—-0.44)
NNE	ME N8	0.45 (0.42—0.48)	330.05 (325.67—334.66)	-0.52 (-0.57—-0.47)
NNE	ME N9	0.51 (0.42—0.63)	320.78 (308.94—335.93)	-0.46 (-0.55—-0.38)
NNE	Oyster	0.41 (0.39—0.44)	319.53 (315.20—324.17)	-0.54 (-0.60—-0.48)
NNE	Pickpocket	0.47 (0.39—0.57)	316.54 (307.72—327.76)	-0.56 (-0.66—-0.47)
NNE	Taylor	0.47 (0.40—0.56)	308.44 (298.11—320.89)	-0.56 (-0.65—-0.48)
NNE	Winnicut	0.48 (0.45—0.51)	294.02 (291.02—297.25)	-0.57 (-0.63—-0.51)

Table S 12. Estimated river-specific parameters from the sex-aggregated von Bertalanffy growth function for alewife aged with scales. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_{∞}) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE).

Region	River	K	L_{∞}	t_0
MAT	Albemarle Sound	0.45 (0.44—0.46)	311.32 (309.74—312.99)	-0.53 (-0.54—-0.52)
MAT	Alligator	0.47 (0.46—0.48)	308.61 (306.57—310.74)	-0.60 (-0.62—-0.58)
MAT	Chickahominy	0.52 (0.50—0.54)	293.93 (291.79—296.11)	-0.62 (-0.65—-0.60)
MAT	Choptank	0.49 (0.38—0.65)	303.63 (273.91—335.58)	-0.52 (-0.68—-0.38)
MAT	Chowan	0.50 (0.49—0.50)	301.24 (300.24—302.25)	-0.45 (-0.45—-0.44)
MAT	Hudson	0.35 (0.33—0.36)	315.55 (312.95—318.31)	-1.14 (-1.22—-1.06)
MAT	Little	0.43 (0.36—0.53)	305.67 (295.54—318.61)	-0.63 (-0.73—-0.53)
MAT	Nanticoke	0.44 (0.43—0.45)	303.39 (301.99—304.84)	-0.70 (-0.76—-0.64)
MAT	Neuse	0.52 (0.41—0.67)	313.41 (299.52—330.97)	-0.47 (-0.57—-0.38)
MAT	North East	0.57 (0.55—0.59)	293.08 (291.45—294.79)	-0.49 (-0.54—-0.45)
MAT	Pamlico	0.51 (0.42—0.63)	316.77 (304.30—332.05)	-0.42 (-0.50—-0.35)
MAT	Pasquotank	0.56 (0.48—0.64)	316.97 (308.91—326.36)	-0.43 (-0.48—-0.38)
MAT	Patapsco	0.49 (0.38—0.66)	303.70 (274.61—335.00)	-0.53 (-0.70—-0.39)
MAT	Perquimans	0.48 (0.43—0.54)	303.08 (296.08—311.11)	-0.47 (-0.51—-0.42)
MAT	Rappahannock	0.50 (0.48—0.53)	295.87 (293.14—298.59)	-0.59 (-0.61—-0.56)
MAT	Roanoke	0.46 (0.42—0.49)	310.85 (305.59—316.50)	-0.45 (-0.48—-0.42)
MAT	Scuppernong	0.50 (0.49—0.52)	302.96 (300.72—305.35)	-0.49 (-0.50—-0.47)
MAT	Susquehanna	0.71 (0.62—0.83)	275.75 (270.42—282.19)	-0.42 (-0.49—-0.36)
MAT	Yeopim	0.47 (0.41—0.55)	292.60 (283.48—303.24)	-0.51 (-0.57—-0.45)
SNE	Back	0.64 (0.62—0.66)	302.33 (300.63—304.07)	-0.21 (-0.22—-0.19)
SNE	Bride Lake	0.70 (0.67—0.74)	279.70 (277.22—282.21)	-0.46 (-0.51—-0.42)
SNE	Charles	0.59 (0.54—0.65)	283.63 (277.27—290.95)	-0.43 (-0.48—-0.38)
SNE	Chicopee	0.51 (0.42—0.65)	302.20 (283.65—324.52)	-0.49 (-0.58—-0.41)
SNE	Farmington	0.66 (0.57—0.77)	292.85 (283.26—303.89)	-0.37 (-0.43—-0.32)
SNE	Gilbert Stuart	0.72 (0.67—0.79)	277.49 (274.77—280.46)	-0.37 (-0.42—-0.32)
SNE	Mattabesset	0.61 (0.58—0.64)	290.09 (287.32—292.94)	-0.45 (-0.49—-0.40)
SNE	Monument	0.78 (0.76—0.80)	274.85 (273.87—275.90)	-0.21 (-0.23—-0.20)
SNE	Mystic	0.70 (0.68—0.72)	277.90 (276.23—279.53)	-0.22 (-0.23—-0.21)
SNE	Nemasket	0.70 (0.67—0.72)	289.09 (288.00—290.20)	-0.40 (-0.47—-0.33)
SNE	Nonquit	0.65 (0.60—0.70)	283.10 (280.49—285.96)	-0.42 (-0.47—-0.38)
SNE	Parker	0.65 (0.62—0.67)	283.59 (281.74—285.54)	-0.43 (-0.47—-0.38)
SNE	Town Brook	0.68 (0.67—0.70)	278.94 (277.87—280.06)	-0.25 (-0.26—-0.23)
SNE	Wethersfield Cove	0.60 (0.56—0.65)	290.66 (286.10—295.57)	-0.49 (-0.54—-0.44)
NNE	Cocheco	0.47 (0.46—0.49)	310.39 (308.65—312.20)	-0.67 (-0.73—-0.61)
NNE	Exeter	0.61 (0.59—0.64)	296.04 (294.24—297.89)	-0.45 (-0.49—-0.40)
NNE	Lamprey	0.49 (0.48—0.51)	311.79 (310.29—313.36)	-0.54 (-0.60—-0.50)
NNE	ME C1	0.45 (0.40—0.51)	318.77 (310.05—328.97)	-0.55 (-0.62—-0.49)

NNE	ME C10	0.38 (0.36—0.39)	335.25 (331.48—339.22)	-0.69 (-0.76—-0.63)
NNE	ME C11	0.44 (0.40—0.48)	314.09 (307.18—321.83)	-0.58 (-0.64—-0.51)
NNE	ME C12	0.50 (0.45—0.56)	296.90 (290.15—304.35)	-0.54 (-0.61—-0.48)
NNE	ME C13	0.49 (0.45—0.54)	310.47 (304.73—316.76)	-0.54 (-0.60—-0.49)
NNE	ME C14	0.57 (0.52—0.63)	297.13 (291.84—303.42)	-0.45 (-0.51—-0.40)
NNE	ME C15	0.41 (0.39—0.44)	323.30 (319.06—327.98)	-0.60 (-0.66—-0.55)
NNE	ME C16	0.40 (0.36—0.43)	329.87 (321.08—340.02)	-0.56 (-0.62—-0.50)
NNE	ME C17	0.47 (0.43—0.52)	304.13 (296.73—313.16)	-0.50 (-0.56—-0.44)
NNE	ME C18	0.44 (0.40—0.48)	318.88 (311.22—327.43)	-0.56 (-0.62—-0.50)
NNE	ME C19	0.41 (0.37—0.46)	321.85 (313.32—331.60)	-0.55 (-0.62—-0.49)
NNE	ME C2	0.48 (0.45—0.51)	300.34 (296.86—304.02)	-0.59 (-0.65—-0.54)
NNE	ME C20	0.46 (0.39—0.55)	305.43 (292.23—322.15)	-0.55 (-0.64—-0.47)
NNE	ME C21	0.51 (0.43—0.61)	307.52 (297.51—320.02)	-0.50 (-0.58—-0.42)
NNE	ME C3	0.51 (0.49—0.53)	295.94 (293.42—298.55)	-0.48 (-0.54—-0.44)
NNE	ME C4	0.44 (0.42—0.46)	319.52 (315.32—324.08)	-0.52 (-0.58—-0.47)
NNE	ME C5	0.42 (0.40—0.45)	317.43 (312.12—323.06)	-0.53 (-0.58—-0.47)
NNE	ME C6	0.43 (0.40—0.46)	315.51 (310.21—320.95)	-0.53 (-0.59—-0.48)
NNE	ME C7	0.46 (0.44—0.49)	307.94 (304.61—311.56)	-0.57 (-0.62—-0.51)
NNE	ME C8	0.46 (0.43—0.48)	319.52 (315.52—323.75)	-0.52 (-0.58—-0.47)
NNE	ME C9	0.41 (0.38—0.45)	329.46 (321.55—338.31)	-0.58 (-0.65—-0.52)
NNE	ME N10	0.54 (0.44—0.67)	307.32 (294.60—323.46)	-0.46 (-0.54—-0.38)
NNE	ME N11	0.49 (0.41—0.59)	308.01 (292.70—326.18)	-0.53 (-0.61—-0.45)
NNE	ME N12	0.51 (0.42—0.64)	319.59 (304.42—338.61)	-0.44 (-0.52—-0.37)
NNE	ME N13	0.42 (0.39—0.44)	314.52 (309.67—319.88)	-0.65 (-0.71—-0.58)
NNE	ME N14	0.48 (0.45—0.52)	299.26 (294.40—304.68)	-0.54 (-0.60—-0.48)
NNE	ME N15	0.38 (0.36—0.42)	320.39 (312.69—328.63)	-0.58 (-0.65—-0.52)
NNE	ME N16	0.39 (0.36—0.42)	320.13 (313.06—327.86)	-0.68 (-0.75—-0.62)
NNE	ME N17	0.47 (0.40—0.56)	304.97 (292.47—320.40)	-0.55 (-0.64—-0.47)
NNE	ME N18	0.51 (0.48—0.54)	305.12 (300.84—309.62)	-0.52 (-0.58—-0.47)
NNE	ME N19	0.40 (0.37—0.44)	279.79 (273.59—286.68)	-0.68 (-0.76—-0.61)
NNE	ME N2	0.59 (0.56—0.63)	297.11 (294.28—300.18)	-0.49 (-0.54—-0.44)
NNE	ME N20	0.43 (0.39—0.48)	322.29 (315.71—329.73)	-0.57 (-0.64—-0.51)
NNE	ME N21	0.46 (0.39—0.56)	316.25 (302.42—334.00)	-0.56 (-0.64—-0.48)
NNE	ME N22	0.50 (0.42—0.61)	307.77 (296.24—322.19)	-0.52 (-0.61—-0.44)
NNE	ME N23	0.48 (0.43—0.52)	260.99 (256.84—265.69)	-0.60 (-0.67—-0.53)
NNE	ME N24	0.59 (0.50—0.71)	294.24 (287.00—303.61)	-0.42 (-0.49—-0.35)
NNE	ME N25	0.50 (0.45—0.56)	310.14 (304.00—316.97)	-0.53 (-0.59—-0.47)
NNE	ME N26	0.49 (0.45—0.54)	306.02 (299.57—313.53)	-0.52 (-0.58—-0.46)
NNE	ME N27	0.52 (0.46—0.60)	296.00 (287.03—306.77)	-0.46 (-0.53—-0.40)
NNE	ME N29	0.40 (0.35—0.46)	293.29 (282.73—305.92)	-0.62 (-0.70—-0.54)
NNE	ME N3	0.45 (0.37—0.56)	310.95 (294.89—331.30)	-0.53 (-0.62—-0.44)
NNE	ME N30	0.48 (0.42—0.55)	280.08 (271.70—289.73)	-0.56 (-0.64—-0.49)
NNE	ME N31	0.48 (0.44—0.52)	309.79 (304.54—315.61)	-0.52 (-0.58—-0.46)
NNE	ME N32	0.55 (0.48—0.63)	296.55 (289.92—304.28)	-0.47 (-0.54—-0.41)
NNE	ME N33	0.42 (0.38—0.47)	323.51 (314.72—332.51)	-0.59 (-0.66—-0.52)

NNE	ME N4	0.44 (0.41—0.48)	320.07 (314.06—326.63)	-0.56 (-0.62—-0.50)
NNE	ME N5	0.42 (0.37—0.48)	318.89 (308.10—331.13)	-0.54 (-0.61—-0.47)
NNE	ME N6	0.46 (0.43—0.49)	317.28 (312.47—322.25)	-0.51 (-0.57—-0.46)
NNE	ME N7	0.48 (0.42—0.54)	308.87 (299.83—319.10)	-0.50 (-0.57—-0.44)
NNE	ME N8	0.47 (0.44—0.50)	319.74 (315.58—324.04)	-0.52 (-0.57—-0.47)
NNE	ME N9	0.53 (0.43—0.66)	310.82 (299.28—325.32)	-0.46 (-0.54—-0.38)
NNE	Oyster	0.43 (0.40—0.46)	309.58 (305.55—313.92)	-0.54 (-0.60—-0.48)
NNE	Pickpocket	0.49 (0.41—0.59)	306.69 (298.22—317.58)	-0.56 (-0.65—-0.47)
NNE	Taylor	0.49 (0.42—0.59)	298.84 (288.85—310.95)	-0.56 (-0.65—-0.47)
NNE	Winnicut	0.50 (0.47—0.53)	284.87 (282.17—287.84)	-0.57 (-0.63—-0.51)

Table S 13. Estimated coastwide parameters from the sex-aggregated von Bertalanffy growth functions for blueback herring within aging structures. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Structure	*K*	L_∞	t_0
Otolith	0.56 (0.38—0.84)	287.43 (261.12—318.83)	-0.39 (-0.72—-0.28)
Scale	0.61 (0.42—0.92)	278.39 (252.86—308.76)	-0.37 (-0.71—-0.26)

Table S 14. Estimated regional parameters from the sex-aggregated von Bertalanffy growth function for blueback herring within aging structures. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

Region	Structure	*K*	L_∞	t_0
SAT	Otolith	0.58 (0.54—0.98)	294.27 (277.48—313.49)	-0.29 (-0.42—-0.24)
SAT	Scale	0.63 (0.58—1.06)	285.01 (268.91—303.55)	-0.28 (-0.41—-0.23)
MAT	Otolith	0.53 (0.35—0.87)	298.55 (275.07—335.10)	-0.37 (-0.82—-0.28)
MAT	Scale	0.57 (0.38—0.94)	289.22 (266.41—324.62)	-0.36 (-0.80—-0.26)
SNE	Otolith	0.66 (0.46—0.78)	265.29 (261.88—289.79)	-0.37 (-0.46—-0.27)
SNE	Scale	0.71 (0.50—0.85)	256.97 (253.48—280.58)	-0.36 (-0.44—-0.25)
MNE	Otolith	0.60 (0.49—0.78)	291.08 (272.41—306.32)	-0.35 (-0.44—-0.30)
MNE	Scale	0.65 (0.53—0.85)	282.07 (263.66—296.65)	-0.34 (-0.42—-0.28)
CAN-NNE	Otolith	0.55 (0.43—0.72)	282.50 (252.69—312.08)	-0.42 (-0.57—-0.32)
CAN-NNE	Scale	0.60 (0.47—0.77)	273.59 (244.76—302.22)	-0.40 (-0.56—-0.31)

Table S 15. Estimated river-specific parameters from the sex-aggregated von Bertalanffy growth function for blueback herring aged with otoliths. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Southern Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE). Rivers are organized alphabetically within regions.

Region	River	K	L_∞	t_0
SAT	Cape Fear	0.58 (0.53—0.63)	309.07 (303.69—314.94)	-0.28 (-0.32—-0.25)
SAT	Great Pee Dee	0.88 (0.77—1.02)	278.88 (277.03—280.97)	-0.28 (-0.32—-0.23)
SAT	Santee-Cooper	0.56 (0.54—0.58)	294.27 (292.74—295.89)	-0.39 (-0.43—-0.36)
MAT	Albemarle Sound	0.47 (0.45—0.48)	308.81 (306.72—310.89)	-0.40 (-0.41—-0.39)
MAT	Alligator	0.50 (0.47—0.53)	312.10 (308.80—315.64)	-0.35 (-0.38—-0.33)
MAT	Chickahominy	0.57 (0.54—0.61)	291.03 (288.80—293.51)	-0.34 (-0.36—-0.33)
MAT	Chicopee	0.68 (0.65—0.71)	278.06 (276.23—280.01)	-0.36 (-0.39—-0.33)
MAT	Choptank	0.54 (0.41—0.74)	287.67 (258.01—320.80)	-0.38 (-0.51—-0.28)
MAT	Chowan	0.43 (0.42—0.44)	312.77 (311.30—314.26)	-0.40 (-0.40—-0.39)
MAT	Connecticut	0.88 (0.84—0.92)	276.36 (274.36—278.43)	-0.28 (-0.31—-0.25)
MAT	Farmington	0.61 (0.59—0.62)	285.68 (284.58—286.82)	-0.42 (-0.45—-0.38)
MAT	Hudson	0.47 (0.45—0.49)	296.47 (294.43—298.60)	-0.73 (-0.76—-0.70)
MAT	Little	0.51 (0.43—0.63)	310.56 (301.18—322.59)	-0.36 (-0.41—-0.30)
MAT	Mattabesset	0.60 (0.52—0.71)	285.40 (277.59—294.72)	-0.37 (-0.42—-0.31)
MAT	Nanticoke	0.38 (0.37—0.40)	315.57 (313.72—317.53)	-0.67 (-0.73—-0.62)
MAT	Neuse	0.34 (0.31—0.37)	336.15 (329.95—343.33)	-0.84 (-1.01—-0.70)
MAT	North East	0.52 (0.50—0.54)	299.82 (297.53—302.12)	-0.42 (-0.46—-0.38)
MAT	Pamlico	0.52 (0.41—0.70)	305.74 (292.17—322.63)	-0.38 (-0.46—-0.29)
MAT	Pasquotank	0.45 (0.41—0.49)	315.58 (309.93—321.84)	-0.38 (-0.41—-0.36)
MAT	Patapsco	0.55 (0.41—0.76)	287.80 (259.85—319.59)	-0.36 (-0.48—-0.25)
MAT	Perquimans	0.57 (0.51—0.63)	297.67 (293.12—302.80)	-0.34 (-0.37—-0.31)
MAT	Rappahannock	0.54 (0.52—0.57)	296.54 (294.86—298.28)	-0.36 (-0.37—-0.35)
MAT	Roanoke	0.52 (0.49—0.55)	310.18 (307.41—313.17)	-0.30 (-0.32—-0.29)
MAT	Scuppernong	0.52 (0.50—0.53)	307.94 (305.94—309.94)	-0.37 (-0.38—-0.36)
MAT	Susquehanna	0.57 (0.51—0.63)	279.34 (274.08—285.21)	-0.38 (-0.43—-0.34)
MAT	Westfield	0.68 (0.64—0.72)	277.10 (274.75—279.58)	-0.35 (-0.38—-0.31)
MAT	Wethersfield Cove	0.64 (0.63—0.66)	282.44 (281.34—283.60)	-0.36 (-0.39—-0.33)
MAT	Yeopim	0.49 (0.43—0.56)	304.13 (295.29—314.32)	-0.37 (-0.41—-0.33)
SNE	Charles	0.65 (0.62—0.67)	275.48 (273.39—277.67)	-0.41 (-0.45—-0.38)
SNE	Monument	0.67 (0.65—0.69)	264.05 (262.87—265.30)	-0.36 (-0.39—-0.33)
SNE	Mystic	0.77 (0.75—0.79)	262.53 (261.53—263.49)	-0.28 (-0.31—-0.26)
SNE	Town Brook	0.53 (0.43—0.66)	279.10 (265.17—295.99)	-0.41 (-0.49—-0.34)
MNE	Cocheco	0.65 (0.61—0.69)	285.95 (283.50—288.53)	-0.35 (-0.39—-0.31)
MNE	Exeter	0.61 (0.58—0.64)	293.38 (290.84—296.07)	-0.34 (-0.38—-0.31)
MNE	Lamprey	0.67 (0.58—0.77)	290.16 (284.85—296.31)	-0.34 (-0.39—-0.30)

MNE	Oyster	0.57 (0.55—0.59)	292.61 (290.96—294.32)	-0.41 (-0.45—-0.37)
MNE	Parker	0.77 (0.74—0.79)	272.98 (271.73—274.22)	-0.32 (-0.35—-0.29)
MNE	Pickpocket	0.55 (0.42—0.75)	296.54 (275.29—319.37)	-0.37 (-0.48—-0.28)
MNE	Taylor	0.52 (0.50—0.55)	300.06 (296.67—303.66)	-0.38 (-0.42—-0.35)
MNE	Winnicut	0.58 (0.55—0.62)	284.56 (281.83—287.45)	-0.35 (-0.39—-0.31)
CAN-NNE	ME C1	0.55 (0.43—0.73)	284.47 (264.22—307.55)	-0.42 (-0.52—-0.33)
CAN-NNE	ME C10	0.49 (0.46—0.52)	291.42 (287.84—295.16)	-0.49 (-0.54—-0.44)
CAN-NNE	ME C12	0.55 (0.43—0.72)	290.22 (269.29—313.31)	-0.42 (-0.51—-0.33)
CAN-NNE	ME C15	0.59 (0.46—0.79)	291.33 (270.10—316.61)	-0.38 (-0.47—-0.30)
CAN-NNE	ME C16	0.54 (0.43—0.68)	276.38 (264.15—292.44)	-0.43 (-0.51—-0.35)
CAN-NNE	ME C17	0.54 (0.49—0.61)	288.15 (280.98—296.01)	-0.51 (-0.57—-0.45)
CAN-NNE	ME C18	0.56 (0.50—0.63)	280.73 (273.75—288.89)	-0.44 (-0.50—-0.39)
CAN-NNE	ME C19	0.58 (0.46—0.75)	283.77 (267.10—302.12)	-0.43 (-0.52—-0.35)
CAN-NNE	ME C2	0.53 (0.40—0.71)	289.76 (269.44—312.04)	-0.38 (-0.49—-0.29)
CAN-NNE	ME C3	0.65 (0.58—0.74)	279.09 (274.63—283.88)	-0.35 (-0.40—-0.31)
CAN-NNE	ME C7	0.59 (0.47—0.76)	311.39 (291.82—334.46)	-0.36 (-0.44—-0.29)
CAN-NNE	ME C8	0.60 (0.50—0.73)	279.43 (268.91—293.06)	-0.38 (-0.45—-0.32)
CAN-NNE	ME C9	0.55 (0.42—0.72)	288.34 (264.83—314.81)	-0.42 (-0.53—-0.33)
CAN-NNE	ME N13	0.53 (0.41—0.68)	288.11 (269.19—311.24)	-0.44 (-0.53—-0.36)
CAN-NNE	ME N14	0.51 (0.40—0.68)	281.84 (262.80—303.96)	-0.43 (-0.54—-0.34)
CAN-NNE	ME N16	0.58 (0.45—0.76)	282.24 (267.89—299.13)	-0.43 (-0.52—-0.34)
CAN-NNE	ME N18	0.55 (0.42—0.74)	277.57 (258.37—298.46)	-0.44 (-0.55—-0.33)
CAN-NNE	ME N20	0.55 (0.50—0.62)	281.07 (275.26—287.64)	-0.44 (-0.49—-0.39)
CAN-NNE	ME N25	0.58 (0.52—0.65)	280.16 (274.34—286.50)	-0.39 (-0.44—-0.34)
CAN-NNE	ME N26	0.51 (0.40—0.68)	283.77 (263.36—307.65)	-0.43 (-0.52—-0.34)
CAN-NNE	ME N29	0.49 (0.41—0.60)	252.31 (241.28—265.37)	-0.57 (-0.66—-0.49)
CAN-NNE	ME N30	0.52 (0.41—0.68)	259.58 (247.53—275.30)	-0.52 (-0.63—-0.42)
CAN-NNE	ME N33	0.49 (0.43—0.56)	286.33 (278.13—296.56)	-0.39 (-0.44—-0.34)
CAN-NNE	ME N4	0.57 (0.47—0.70)	284.14 (274.97—295.31)	-0.41 (-0.48—-0.34)
CAN-NNE	ME N6	0.56 (0.43—0.74)	282.66 (265.76—303.03)	-0.38 (-0.47—-0.30)
CAN-NNE	ME N7	0.58 (0.50—0.69)	282.03 (272.21—293.33)	-0.40 (-0.46—-0.34)
CAN-NNE	ME N8	0.61 (0.56—0.67)	276.73 (271.71—282.05)	-0.38 (-0.43—-0.34)

Table S 16. Estimated river-specific parameters from the sex-aggregated von Bertalanffy growth function for blueback herring aged with scales. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals. Regions are organized from south to north top to bottom and include Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE).

Region	River	K	L_∞	t_0
SAT	Cape Fear	0.62 (0.57—0.68)	299.38 (294.24—304.92)	-0.26 (-0.30—-0.23)
SAT	Great Pee Dee	0.95 (0.84—1.11)	270.10 (268.53—271.97)	-0.26 (-0.30—-0.22)
SAT	Santee-Cooper	0.61 (0.59—0.63)	285.01 (283.70—286.33)	-0.38 (-0.41—-0.34)
MAT	Albemarle Sound	0.50 (0.49—0.52)	299.10 (297.40—300.76)	-0.38 (-0.39—-0.38)
MAT	Alligator	0.54 (0.51—0.57)	302.28 (299.28—305.43)	-0.34 (-0.37—-0.31)
MAT	Chickahominy	0.62 (0.59—0.66)	281.84 (279.57—284.38)	-0.33 (-0.34—-0.31)
MAT	Chicopee	0.74 (0.70—0.77)	269.31 (267.25—271.48)	-0.34 (-0.38—-0.31)
MAT	Choptank	0.59 (0.44—0.80)	278.66 (250.01—310.75)	-0.36 (-0.49—-0.26)
MAT	Chowan	0.47 (0.46—0.47)	302.93 (302.11—303.76)	-0.38 (-0.38—-0.38)
MAT	Connecticut	0.95 (0.91—1.00)	267.66 (265.87—269.55)	-0.26 (-0.29—-0.23)
MAT	Farmington	0.66 (0.63—0.68)	276.69 (275.19—278.29)	-0.40 (-0.44—-0.37)
MAT	Hudson	0.51 (0.49—0.52)	287.13 (285.46—288.94)	-0.71 (-0.75—-0.68)
MAT	Little	0.56 (0.46—0.68)	300.80 (291.78—312.22)	-0.34 (-0.40—-0.28)
MAT	Mattabesset	0.65 (0.56—0.76)	276.43 (268.82—285.33)	-0.35 (-0.40—-0.30)
MAT	Nanticoke	0.41 (0.40—0.42)	305.65 (304.30—307.06)	-0.66 (-0.71—-0.61)
MAT	Neuse	0.37 (0.34—0.40)	325.56 (319.95—332.12)	-0.83 (-0.99—-0.69)
MAT	North East	0.56 (0.54—0.58)	290.37 (288.50—292.30)	-0.40 (-0.44—-0.37)
MAT	Pamlico	0.57 (0.44—0.76)	296.09 (283.05—312.48)	-0.36 (-0.45—-0.28)
MAT	Pasquotank	0.49 (0.45—0.53)	305.67 (300.36—311.60)	-0.37 (-0.39—-0.34)
MAT	Patapsco	0.59 (0.44—0.83)	278.75 (251.70—309.37)	-0.34 (-0.47—-0.23)
MAT	Perquimans	0.62 (0.56—0.68)	288.27 (284.00—293.16)	-0.33 (-0.36—-0.30)
MAT	Rappahannock	0.59 (0.56—0.61)	287.21 (285.33—289.20)	-0.34 (-0.36—-0.33)
MAT	Roanoke	0.56 (0.54—0.59)	300.42 (298.01—303.00)	-0.29 (-0.30—-0.28)
MAT	Scuppernong	0.56 (0.54—0.57)	298.25 (296.74—299.80)	-0.36 (-0.37—-0.35)
MAT	Susquehanna	0.61 (0.56—0.68)	270.57 (265.45—276.20)	-0.36 (-0.41—-0.32)
MAT	Westfield	0.74 (0.70—0.78)	268.38 (265.84—270.97)	-0.33 (-0.37—-0.30)
MAT	Wethersfield Cove	0.70 (0.67—0.72)	273.56 (272.03—275.09)	-0.34 (-0.38—-0.31)
MAT	Yeopim	0.53 (0.46—0.61)	294.55 (286.10—304.45)	-0.35 (-0.39—-0.31)
SNE	Charles	0.70 (0.67—0.73)	266.80 (264.83—268.88)	-0.40 (-0.44—-0.36)
SNE	Monument	0.72 (0.70—0.75)	255.74 (254.53—256.99)	-0.34 (-0.38—-0.31)
SNE	Mystic	0.83 (0.81—0.86)	254.27 (253.12—255.44)	-0.27 (-0.30—-0.24)
SNE	Town Brook	0.57 (0.47—0.72)	270.34 (256.80—286.66)	-0.39 (-0.47—-0.32)
MNE	Cocheco	0.71 (0.67—0.75)	276.96 (274.78—279.27)	-0.33 (-0.37—-0.30)
MNE	Exeter	0.66 (0.63—0.70)	284.15 (281.94—286.53)	-0.32 (-0.36—-0.29)
MNE	Lamprey	0.72 (0.63—0.83)	281.03 (275.89—286.95)	-0.33 (-0.38—-0.28)
MNE	Oyster	0.62 (0.60—0.64)	283.42 (282.26—284.69)	-0.39 (-0.43—-0.36)
MNE	Parker	0.83 (0.80—0.86)	264.37 (262.83—266.01)	-0.30 (-0.33—-0.27)

MNE	Pickpocket	0.60 (0.45—0.82)	287.24 (266.61—309.28)	-0.36 (-0.47—-0.26)
MNE	Taylor	0.57 (0.54—0.60)	290.59 (287.48—293.98)	-0.37 (-0.41—-0.33)
MNE	Winnicut	0.63 (0.60—0.67)	275.61 (273.20—278.16)	-0.33 (-0.37—-0.30)
CAN-NNE	ME C1	0.60 (0.46—0.79)	275.50 (256.00—297.86)	-0.40 (-0.50—-0.31)
CAN-NNE	ME C10	0.53 (0.50—0.56)	282.24 (278.98—285.69)	-0.47 (-0.52—-0.43)
CAN-NNE	ME C12	0.59 (0.46—0.78)	281.00 (260.89—303.53)	-0.40 (-0.50—-0.31)
CAN-NNE	ME C15	0.64 (0.50—0.86)	282.25 (261.84—306.64)	-0.36 (-0.45—-0.28)
CAN-NNE	ME C16	0.58 (0.47—0.74)	267.74 (255.91—283.15)	-0.41 (-0.49—-0.33)
CAN-NNE	ME C17	0.59 (0.53—0.66)	279.09 (272.38—286.56)	-0.49 (-0.55—-0.43)
CAN-NNE	ME C18	0.61 (0.54—0.68)	271.90 (265.12—279.58)	-0.42 (-0.48—-0.37)
CAN-NNE	ME C19	0.62 (0.50—0.81)	274.88 (258.61—292.52)	-0.41 (-0.51—-0.33)
CAN-NNE	ME C2	0.57 (0.43—0.77)	280.65 (260.98—302.00)	-0.37 (-0.47—-0.27)
CAN-NNE	ME C3	0.71 (0.63—0.80)	270.29 (266.19—274.90)	-0.33 (-0.38—-0.29)
CAN-NNE	ME C7	0.64 (0.50—0.83)	301.56 (282.59—323.84)	-0.35 (-0.43—-0.27)
CAN-NNE	ME C8	0.65 (0.54—0.79)	270.67 (260.46—283.74)	-0.36 (-0.43—-0.30)
CAN-NNE	ME C9	0.59 (0.46—0.78)	279.30 (256.50—304.87)	-0.41 (-0.51—-0.32)
CAN-NNE	ME N13	0.57 (0.45—0.74)	278.98 (260.72—301.54)	-0.43 (-0.52—-0.35)
CAN-NNE	ME N14	0.56 (0.43—0.73)	273.04 (254.62—294.53)	-0.42 (-0.52—-0.33)
CAN-NNE	ME N16	0.62 (0.49—0.82)	273.35 (259.41—289.68)	-0.41 (-0.51—-0.32)
CAN-NNE	ME N18	0.59 (0.45—0.81)	268.79 (250.23—288.96)	-0.42 (-0.53—-0.32)
CAN-NNE	ME N20	0.60 (0.54—0.67)	272.23 (266.61—278.47)	-0.43 (-0.48—-0.38)
CAN-NNE	ME N25	0.63 (0.56—0.70)	271.32 (265.77—277.50)	-0.37 (-0.42—-0.33)
CAN-NNE	ME N26	0.56 (0.44—0.73)	274.87 (255.07—297.89)	-0.41 (-0.51—-0.32)
CAN-NNE	ME N29	0.53 (0.45—0.64)	244.37 (233.81—257.03)	-0.55 (-0.64—-0.47)
CAN-NNE	ME N30	0.57 (0.44—0.73)	251.43 (239.85—266.64)	-0.50 (-0.61—-0.40)
CAN-NNE	ME N33	0.53 (0.47—0.61)	277.32 (269.44—287.07)	-0.37 (-0.43—-0.32)
CAN-NNE	ME N4	0.62 (0.51—0.75)	275.21 (266.44—286.03)	-0.39 (-0.46—-0.32)
CAN-NNE	ME N6	0.60 (0.47—0.81)	273.79 (257.38—293.50)	-0.37 (-0.45—-0.28)
CAN-NNE	ME N7	0.63 (0.54—0.75)	273.14 (263.71—284.24)	-0.38 (-0.44—-0.32)
CAN-NNE	ME N8	0.66 (0.61—0.73)	268.01 (263.28—273.10)	-0.37 (-0.41—-0.32)

Appendix 4: Statistical Catch-at-Age Models

Update of the Monument River Alewife Escapement-At-Age Model (1980-2022)

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Introduction

A forward-projecting age-structured statistical escapement-at-age (SCA) model for the Monument River alewife stock was constructed in 2011 and is used to estimate age-3 abundance and natural mortality rates during 1980-2022 from total in-river catches, escapement counts, and escapement age composition. The model likelihoods and method for deriving effective samples sizes were changed to reflect current best practices. In addition, instead of estimating "M" values, an M multiplier which is applied to user-specified natural mortality rates is estimated. No changes to the model structure had been made.

Model Structure.

The structure of the population model is aged-based and projects the population numbers-at-age by sex *s* forward through time given model estimates of age-3 numbers and natural mortality rates and field estimates of proportion mature-at-age. The population numbers-at-age ($N_{s,d,y,a}$) matrix has dimensions s x d x y x A-2, where s is number of sexes (2), d is the number of maturity phases (2), y is the number of years and A is the oldest age group (age 8+). The number of year classes in the model was 6, representing ages 3 through 8+.

The cohort dynamics of the model is a hybrid of the Gaspereau River model in Gibson and Myers (2003). The model incorporates the *immature* and *mature* phases by sex of the alewife's life history and assumes the year begins at the start of spawning. Mature individuals of each age move into the Monument River where they are intercepted and removed for harvest, and escapement counts are made upriver of the catchment basin. Biological samples for length, sex, and age are collected from escapement fish. The model allows natural mortality values to be specified for each year, age, sex and maturity phase or allows natural mortality to be estimated for each sex, two periods over the time series, or combinations of the two. If the estimation of natural mortality is chosen, then the resulting estimates are interpreted as including all remaining mortality aside from natural mortality (e.g., bycatch mortality).

Given the above dynamics, population numbers-at-age by sex and maturity phases are calculated through time by using cohort survival models (Table 1). Number of age-3 alewife at the beginning of spawning season (R_y) are directly estimated in the model and these estimates are partitioned into sex-specific (s) (1=female; 2=male) and maturity phase (d)(1=immature*;* 2=mature) estimates of age-3 abundance ($N_{s,d,y,3}$) using the proportion female (f) and mature proportions-at-age (p_a)(derived outside of the model). Number of age-3 alewife (R_y) in the population is modeled as a log-normal deviation (independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years) from average abundance $\bar{R}$ (Table 1). This formulation differs from the original Gibson and Meyers model which linked recruitment via a Beverton-Holt equation.

The initial population abundance-at-age for ages 4-8+ in 1980 for each sex and maturity phase ($N_{s,d,1980,a}$) is calculated by assuming a static stock (Table 1). M is the natural mortality rate in 1980 for sex s, maturity phase d, and age a, and u is the exploitation rate which is assumed known (calculated from catch/(catch+escapement)).

Population abundance-at-age for ages 4-7 ($N_{s,d,y,a}$) and the plus-group ($N_{s,d,y,8+}$) are calculated in the remaining years by using similar cohort equations (Table 1). The program was designed to accept user-inputted M values specified by year, sex, and age or to allow estimation of an M multiplier for two periods (2 estimates) that scales the user-inputted values. The estimates of M multiplier are applied to both immature and mature fish. If M is estimated, then the resulting parameters represent “all mortality other than in-river fishing”.

The annual proportions of fish mature at each age and sex were estimated from age and repeat-spawner frequency data collected in the Monument River by using the Maki et al. (2001) method.

			Age			
Females	3	4	5	6	7	8+
1980-2000	0.0120	0.4690	0.9080	1	1	1
2001-2013	0.0610	0.5130	0.9810	0.999	1	1
2014-2022	0.0510	0.3990	0.8790	1	1	1

Males	3	4	5	6	7	8+
1980-2000	0.071	0.581	1	1	1	1
2001-2013	0.082	0.553	0.973	1	1	1
2014-2022	0.059	0.453	0.882	1	1	1

Two sets of data are used in the estimation of total population abundance and “natural” mortality rates. The first set of data is total removals (numbers per year) of alewife which includes harvested fish and fish taken for transplant to other rivers. For this update, the number of fish taken for determination of sex and species from 1993-2022 were added to the total removals. The second set of data is escapement counts and age structure. Count data were available from 1980-1981, 1984-1987, and 1990-2022. Escapement age data were available only from years 1985-1987, 1993, and 1995-2022. A multiple regression model that predicts well total abundance in the Monument River from lagged autumn monthly cumulative rainfall data was used to fill-in missing escapement data for 1982, 1983, 1988 and 1989 after subtracting removal estimates from the prediction. The equation for escapement numbers-at-age is given in Table 5 and it requires estimates of annual numbers of mature fish at each sex/age and exploitation rates. All predictions are stored in an array of dimensions s x y x $A-2$. Estimated escapement-at-age values are then compared to the observed total escapement and to proportions of escapement numbers-at-age through the predicted total escapement and age composition equations (Table 1).

Estimates of age-specific, base natural mortality rates are now used in the model. These values were calculated by using the Lorenzen (1996) equation and average weights-at-age for males and females.

Female spawning stock biomass (SSB) is calculated from mature female numbers that escaped harvest and mean weight-at-age for mature females (Table 1).

Fishing mortality rates were calculated from the calculated exploitation rates assuming a Type I fishery (Table 1).

For total removals and escapement numbers, lognormal errors are assumed and the generalized concentrated likelihood ($-L_l$)(Parma 2002; Deriso et al. 2007) is calculated (Table 5). CV_y is the coefficient of variation for the observed removal or escapement numbers in year y, n_C and n_E are the number of years, and λ_C and λ_E are the relative weights (Parma 2002; Deriso et al., 2007). Separate CV weights are provided to adjust annual CVs for more detailed weighting of components.

For escapement age composition data, a multinomial error likelihood ($-L_p$) is assumed ($n_{y.s}$ is the effective number of fish of sex s aged in year y and $P_{s,y,a}$ is the observed proportions of escapement numbers-at-age)(Table 1).

The total log-likelihood ($-L_l – L_p$) is used by the auto-differentiation routine in AD Model Builder to search for the “best” age-3 abundance and “natural” mortality parameters that minimize the total log-likelihood. AD Model Builder allows the minimization process to occur in phases. During each phase, a subset of parameters is held fixed and minimization is done over another subset of parameters until eventually all parameters have been included. Average age-3 abundance is minimized in phase 1, abundance deviations are minimized in phase 2, and, if estimated, “natural” mortality is minimized in phase 3.

Model fit for all components was checked by using standardized residual plots and root mean square errors. Equations for standardized residuals (r) for log-normal (total removals and escapement) and multinomial (age composition) errors are given in Table 1 (n is the total number of total removals or escapement values). For escapement age composition data, standardized residuals require the average effective sample size for each sex (Table 1). Equations for root mean square error (RMSE) are given in Table 1.

Data Weighting. Data weighting was accomplished by first running the model with all initial starting values, lambda weights = 1, CV weights of total catch and escapement number = 1. It was discovered that the best CV weights were 1. The effective sample sizes were adjusted once by using the Francis multipliers. The resulting average effective sample sizes were 10.1 and 12.5 for female and male Alewife, respectively.

Reference Points.

Fishing mortality and female spawning stock biomass reference points for management were derived using a simulation model. I conducted spawning biomass per recruit analysis (SSB/R) (Gabriel et al. 1989) to determine the current reproductive potential of alewife because spawning stock-recruitment relationships are not available for most stocks. The general equation used to examine SSB/R at a given fishing mortality is:

$$SSB_F = \sum_{a=1}^{a_{max}} N_a exp^{(-pF*F*sel_a - pM*M_a)} f_a m_a w_a$$

where N_a is abundance at age *a*, *pF* is the proportion of fishing mortality that occurs prior to spawning, *F* is fully-recruited fishing mortality, sel_a is the fishing selectivity at age a, *pM* is the proportion of natural mortality that occurs prior to spawning, M_a is natural mortality at age *a*, f_a is the fraction of females at age *a*, m_a is the proportion of mature females at age *a* and w_a is the average weight (*g*) of female at age *a*. If N_a is unknown, the exponential decay equation with *F*, sel_a and M_a is used to calculate abundance at the beginning of each time period (usually January-1) starting with a value of 1. This would result in SSB/R.

Typically, SSB is calculate over a range of fishing mortality starting at F=0. The resulting SSBs are divided by the SSB at F=0 to represent SSB at any F as a percentage of the unfished spawning stock biomass *(%SSB_F)*. A graph is usually developed to show the declining %SSB as a function increasing F and current F is superimposed on it. Since a spawning stock recruitment relationship is unknown, the SSB versus F curve is not informative because it tells you nothing about the sustainability of the population. In these cases, research has indicated that stocks remain sustainable as long as the current % SSB is 20% or above (with exception, of course).

In SSB/R analyses, fishing mortality encompasses all anthropogenic sources. However, multiple sources can be programmed into the equation to examine contributions of multiple sources that may have different selectivities. I did this for Alewife since fishing mortality can be separated into two spatially-segregated sources, in-river and out-of-river mortality. This is essentially conducting SSB/R analysis in two dimensions.

I developed an SPR model that tracks immature and mature female adults (ages 1-9+) and where they move over a monthly time step. While at-sea, Alewife are exposed to “offshore” fishing mortality which is seasonal in nature and is currently based on data from bycatch sampling (Figure 8). Other sources could be explored in the future, particularly since the Atlantic herring fishery has been limited over the last few years. Offshore selectivity come from the average selectivity of the bottom trawl and mid-water fleets developed in Nelson et al. (2020). Mature adults are allowed to move to freshwater where they can be exposed to “in-river” fishing mortality and all move together on April 1st and stay in the system until June 31 (Figure 8). The model is an equilibrium one, so the abundance at age 1 is starts at 10,000 fish. The model is run for 100 years to obtain equilibrium SPR. For mature fish, total natural mortality is distributed monthly so that 30% of adults die while in the river; the remaining mortality is distributed evenly among month outside of April-June. Estimates of proportion of female mature-at-age, natural mortality-at-age and average weight-at- age used in the Monument River assessment are required used in this SPR approach.

Since there is no in-river harvest, I only ran the SPR for offshore mortality ranging from 0 to 2, by 0.05 increments. The resulting F40% was 0.22 and F20% was 0.41.

To obtain SSB associated with those F values, simulation was used. The same SPR model was initialized with abundance of immature and mature females from the 2021 of the SCA model (values from the terminal tend to be over-estimate; see retrospective analysis) and age-1 female recruits (assumed 0.5 female proportion at age 1) were resampled from a vector of age-3 adjusted numbers (the age-1 numbers were back-calculated from age-3 numbers using natural mortality values of 1.09 and 0.88 for age-1 and age-2, respectively). Using the F at SSB40% and SSB20% for the Monument River at in-river F=0, SSB was projected forward for 100 years and the median of the spawning biomass of 5000 runs in the last year the SSB reference threshold.

Base Configuration and Results.

The model structure determined best in the 2012 assessment was used as the base configuration in this update.

Resulting contributions to total likelihood are listed in Table 2. The converged total likelihood was 816.04. The resulting estimates of recruitment and natural mortality multipliers are given in Table 3. Based on coefficients of variation, most of the recruitment estimates were precise (CVs$\leq$0.20). Graphs depicting the observed and predicted values for total removals and total escapement numbers, and standardized residuals are shown in Figure 1. Plots of observed and predicted catch age composition (proportions) and bubble plots of standardized residuals for each sex, year, and age are shown in Figures 2 and 3. The model fit the observed total catch, escapement numbers and escapement age composition well (Figures 2 and 3).

The abundance estimates of the Monument River alewife by sex, maturity state, year and age are given in Appendix Table 1. Prior to 1989, alewife total abundance (3+) was low and average about 585 thousand fish (Figure 4). Although variable, total abundance increased to 3.7 million fish by 2000. Total abundance declined steadily to 307 thousand fish by 2005 (Figure 4). During 2006-2011, total abundance averaged only 532 thousand fish (Appendix Table 1). Total abundance increased through 2014 to 2.2 million fish, declined to 327 thousand fish through 2016, and increased to 3 million fish in 2018. Since 2020, total abundance has averaged about 596 million fish.

Age-3 abundance followed similar patterns as total abundance (Table 3). Age-3 numbers were low prior to 1989 (average = 412 thousand fish), increased and peaked at about 2 million fish in 1995 (1992 year-class), declined to 478 thousand fish in 1998, increased to over 2.9 million fish in 2000, and declined to 210 thousand fish by 2005 (2002 year-class). From 2006-2011, age-3 numbers varied around an average of 451 thousand fish. Age-3 numbers increased to 2.0 million fish in 2014, but it declined to 186 thousand fish in 2016. Age-3 numbers increased to 2.9 million fish by 2018 and has since declined to average 634,000 fish.

μ and F Mortality Rates. Due to the 2005 moratorium, which is still in effect, there was no harvest taken from the Monument River (μ and F = 0)(Table 4).

Total Mortality. The period estimates of *M* multipliers are 1.67 for 1980-1999 and 2.68 for 2000-2020. The magnitude of "other" mortality in the most recent years can be calculated by multiplying the multiplier value by average natural mortality for ages 3-8+ (0.66).

Spawning Stock Biomass. Estimates of female spawning stock biomass (SSB) for alewife by age are provided in Appendix Table 3. Prior to 1989, female SSB (3+) was low and averaged about 7,996 kilograms (Figure 5). Although variable, female SSB increased steadily to 38 thousand kilograms by 1996 and remained high but variable through 2001. Female SSB declined steadily from about 16 thousand kilograms in 2002 to its lowest value of about 4,524 kilograms in 2006. (Figure 5). During 2007-2012, female SSB averaged only 7,462 kilograms (Figure 5). Since 2013, female SSB fluctuated widely but has increased through 2019. In 2020-2022, SSB has averaged about 11 thousand kilograms.

Retrospective Analysis. Retrospective bias was evident in estimates of age-3 abundance, *M* multipliers, female SSB, and total population abundance (Figure 6). The M multiplier in the second period was slightly underestimated, while the remaining population characteristics tended to be over-estimated in the terminal year.

Reference Points. The SSB thresholds at F40% and F20% were estimated to be 24,531 and 11,607 kilograms, respectively.

Status of the Stock.

Compared to the SSB thresholds (Figure 5), Monument River Alewife SSB exceeded SSB20% frequently, but SSB rarely exceed SSB40%.

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Table 1. Equations describing Alewife population dynamics, likelihood calculations, diagnostics and reference points.

Population Model	**Symbol**	**Equation**
Age-3 numbers	$\hat{R}_y$	$\hat{R}_y = \bar{\hat{R}} \cdot \exp^{\hat{e}_y}$
Sex-specific age-3 numbers	$\hat{N}_{s,d,y,3}$	Female Immature: $\hat{N}_{1,1,y,3} = \hat{R}_y \cdot f \cdot (1 - p_{1,y,3})$ Female Mature: $\hat{N}_{1,2,y,3} = \hat{R}_y \cdot f \cdot p_{1,y,3}$ Male Immature: $\hat{N}_{2,1,y,3} = \hat{R}_y \cdot (1 - f) \cdot (1 - p_{2,y,3})$ Male Mature: $\hat{N}_{2,2,y,3} = \hat{R}_y \cdot (1 - f) \cdot p_{2,y,3}$
1980 abundance-at-age (4-8+)	$\hat{N}_{s,d,1980,a}$	Immature: $\hat{N}_{s,1,1980,a} = \hat{N}_{s,1,1980,a-1} \cdot exp^{-M_{s,1,1980,a-1}} \cdot (1 - p_{s,1980,a})$ Mature: $\hat{N}_{s,2,1980,a} = \hat{N}_{s,2,1980,a-1} \cdot (1 - u_{1980}) \cdot exp^{-M_{s,2,1980,a-1}} +$ $\hat{N}_{s,1,1980,a-1} \cdot exp^{-M_{s,1,1980,a-1}} \cdot p_{s,1980,a}$
Abundance-at-age (4-7)	$\hat{N}_{s,d,y,a}$	Immature: $\hat{N}_{s,1,y,a} = \hat{N}_{s,1,y-1,a-1} \cdot exp^{-M_{s,1,y-1,a-1}} \cdot (1 - p_{s,y,a})$ Mature: $\hat{N}_{s,2,y,a} = \hat{N}_{s,2,y-1,a-1} \cdot (1 - u_{y-1}) \cdot exp^{-M_{s,2,y-1,a-1}} +$ $\hat{N}_{s,1,y-1,a-1} \cdot exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a}$
Plus-group abundance-at-age	$\hat{N}_{s,d,y,8+}$	Immature: $\hat{N}_{s,1,y,8+} = \hat{N}_{s,1,y-1,a-1} \cdot exp^{-M_{s,1,y-1,a-1}} \cdot (1 - p_{s,y,a}) +$ $\hat{N}_{s,1,y-1,8+} \cdot exp^{-M_{s,1,y-1,8+}} \cdot (1 - p_{s,y,a})$ Mature: $\hat{N}_{s,2,y,8+} = \hat{N}_{s,2,y-1,a-1} \cdot (1 - u_{y-1}) \cdot exp^{-M_{s,2,y-1,a-1}} +$ $\hat{N}_{s,1,y-1,a-1} \cdot exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a} +$ $\hat{N}_{s,2,y-1,8+} \cdot (1 - u_{y-1}) \cdot exp^{-M_{s,2,y-1,8+}}$
Predicted removals-at-age	$\hat{C}_{s,y,a}$	$\hat{C}_{s,y,a} = \hat{N}_{s,2,y,a} u_y$
Predicted total removals	$\hat{C}_y$	$\hat{C}_y = \sum_s \sum_a \hat{C}_{s,y,a}$
Predicted escapement-at-age	$\hat{E}_{s,y,a}$	$\hat{E}_{s,y,a} = \hat{N}_{s,2,y,a}(1 - u_y)$
Predicted total escapement	$\hat{E}_y$	$\hat{E}_y = \sum_s \sum_a \hat{E}_{s,y,a}$
Predicted escapement age composition	$\hat{P}_{s,y,a}$	$\hat{P}_{s,y,a} = \frac{\hat{E}_{s,y,a}}{\sum_a \hat{E}_{s,y,a}}$
Female spawning stock biomass	SSB_y	$SSB_y = \sum_a \hat{N}_{1,2,y,a} \cdot (1 - u_y) \cdot w_{1,2,y,a}$
Fishing mortality	$\hat{F}_y$	$\hat{F}_y = -log_e(1 - u_y)$

Table 1 cont.

Negative Log-Likelihood	**Symbol**	**Equation**
Lognormal total removals and escapement	$-L_l$	$-L_l = 0.5 * (n_C + n_E) * ln\left(\frac{RSS_C + RSS_E}{n_C + n_E}\right)$ where $RSS_C = \lambda_C \sum_{y} \left(\frac{log_e(C_y + 1e^{-5}) - log_e(\hat{C}_y + 1e^{-5})}{\delta_c \cdot CV_{c,y}}\right)^2$ $RSS_E = \lambda_E \sum_{y} \left(\frac{log_e(E_y + 1e^{-5}) - log_e(\hat{E}_y + 1e^{-5})}{\delta_E \cdot CV_{E,y}}\right)^2$
Multinomial escapement age composition	$-L_p$	$-L_p = \lambda_p \sum_{y} \sum_{s} - n_{s,y} \sum_{a} (P_{s,y,a} + 1e^{-5}) \cdot \ln(\hat{P}_{s,y,a} + 1e^{-5})$ where λ_p is a user-defined weighting factor.

Table 1 cont.

Diagnostics	**Symbol**	**Equation**
Standardized residuals (lognormal)	$r_{C,y}$ or $r_{E,y}$	$r_{C,y} = \frac{log_e(C_y + 1e^{-5}) - log_e(\hat{C}_y + 1e^{-5})}{\sqrt{log_e(CV_y^2 + 1)}}$ $r_{E,y} = \frac{log_e(E_y + 1e^{-5}) - log_e(\hat{E}_y + 1e^{-5})}{\sqrt{log_e(CV_y^2 + 1)}}$
Standardized residuals (age composition)	$r_{s,y,a}$	$r_{s,y,a} = \frac{P_{s,y,a} - \hat{P}_{s,y,a}}{\sqrt{\frac{\hat{P}_{s,y,a}(1 - \hat{P}_{s,y,a})}{\hat{\bar{n}}_s}}}$
Root mean square error	$RMSE$	Total removals $RMSE_C = \sqrt{\frac{\sum_y r_{C,y}^2}{n}}$ Total escapement $RMSE_E = \sqrt{\frac{\sum_y r_{E,y}^2}{n}}$

Table 2. Likelihood component values for the model fit.

Likelihood Components

	Weight	RSS
Total Escapement	1	23.21
Total Catch	1	42.23
Escape Age Comps	1	826.53
Total Likelihood		816.04
Number of Estimates		46.00
AIC		1724.08
Catch RMSE	1.01737	
Escape. RMSE	0.739884	

Table 3. Estimates of recruitment number and natural mortality multipliers for two time periods.

Year	Age-3 Numbers	SD	CV
1980	373,254	39,511	0.11
1981	582,572	127,803	0.22
1982	273,254	119,990	0.44
1983	781,771	114,826	0.15
1984	437,186	84,823	0.19
1985	387,329	71,888	0.19
1986	489,891	90,057	0.18
1987	376,910	94,044	0.25
1988	13,210	63,605	4.81
1989	416,060	99,432	0.24
1990	1,232,180	191,799	0.16
1991	1,168,770	227,248	0.19
1992	642,863	142,726	0.22
1993	295,290	97,810	0.33
1994	1,709,260	218,864	0.13
1995	2,010,410	315,160	0.16
1996	1,068,540	210,373	0.20
1997	974,708	180,502	0.19
1998	478,241	117,199	0.25
1999	2,298,900	293,481	0.13
2000	2,970,430	446,734	0.15
2001	1,006,880	195,009	0.19
2002	656,832	119,071	0.18
2003	812,347	105,933	0.13
2004	503,701	84,770	0.17
2005	210,772	44,217	0.21
2006	334,467	47,669	0.14
2007	423,608	61,811	0.15
2008	797,099	89,487	0.11
2009	583,017	114,008	0.20
2010	329,759	58,289	0.18
2011	236,986	57,838	0.24
2012	1,191,730	129,309	0.11
2013	1,003,820	150,623	0.15
2014	2,041,570	230,279	0.11
2015	578,719	113,953	0.20
2016	185,930	70,963	0.38
2017	1,091,410	134642	0.12
2018	2,905,230	259149	0.09
2019	1,164,530	236171	0.20
2020	339,271	82055	0.24
2021	386,722	73815.7	0.19
2022	647,075	114289	0.18

Period	M Multiplier	SD	CV
1980-1999	1.666	0.099	0.060
2000-2022	2.678	0.081	0.030

Table 4. In-river exploitation rates (μ) and equivalent fishing mortality rates for the Monument River.

Year	mu	F
1980	0.41	0.52
1981	0.20	0.22
1982	0.40	0.51
1983	0.40	0.51
1984	0.29	0.35
1985	0.21	0.23
1986	0.14	0.16
1987	0.22	0.25
1988	0.19	0.21
1989	0.19	0.21
1990	0.33	0.39
1991	0.14	0.15
1992	0.19	0.22
1993	0.18	0.20
1994	0.28	0.33
1995	0.13	0.14
1996	0.15	0.16
1997	0.17	0.19
1998	0.20	0.22
1999	0.25	0.29
2000	0.04	0.04
2001	0.07	0.07
2002	0.19	0.21
2003	0.09	0.10
2004	0.13	0.14
2005	0.01	0.01
2006	0.00	0.00
2007	0.01	0.01
2008	0.01	0.01
2009	0.00	0.00
2010	0.00	0.00
2011	0.005	0.01
2012	0.002	0.00
2013	0.001	0.00
2014	0.002	0.00
2015	0.001	0.00
2016	0.003	0.00
2017	0.001	0.00
2018	0.001	0.00
2019	0.001	0.00
2020	0.002	0.00
2021	0.004	0.00
2022	0.004	0.00

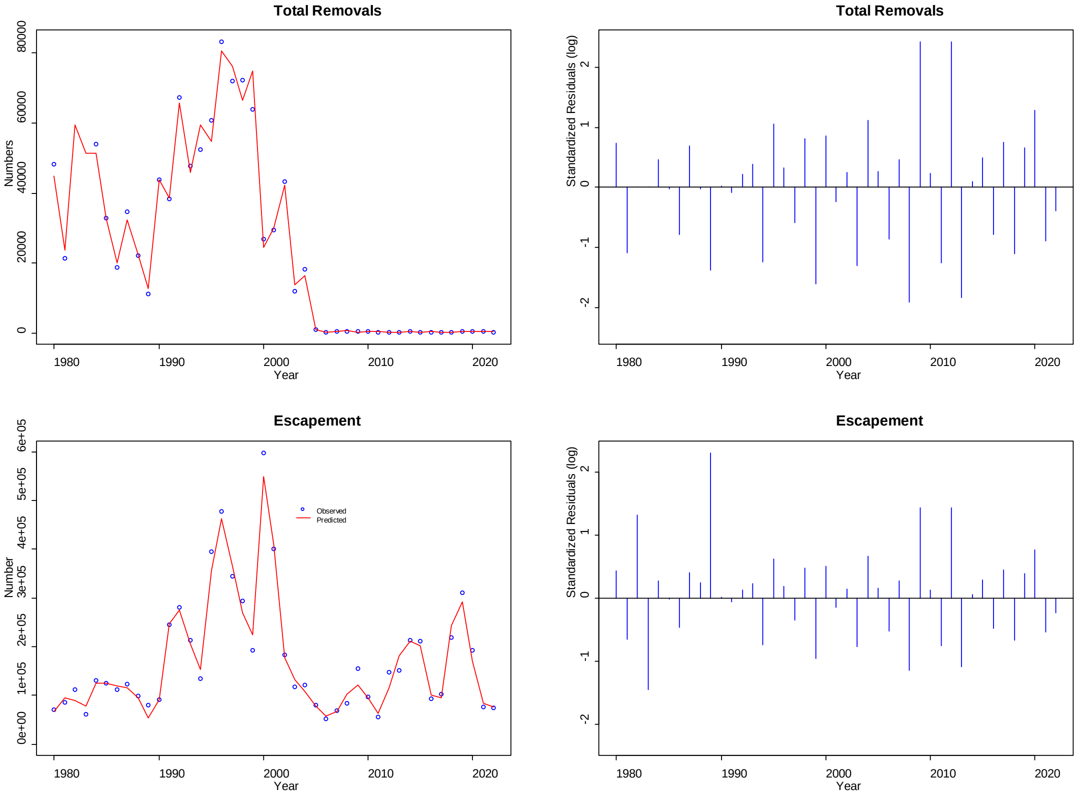

Figure 1. Observed versus predicted and residual plots for total in-river removals and escapement numbers.

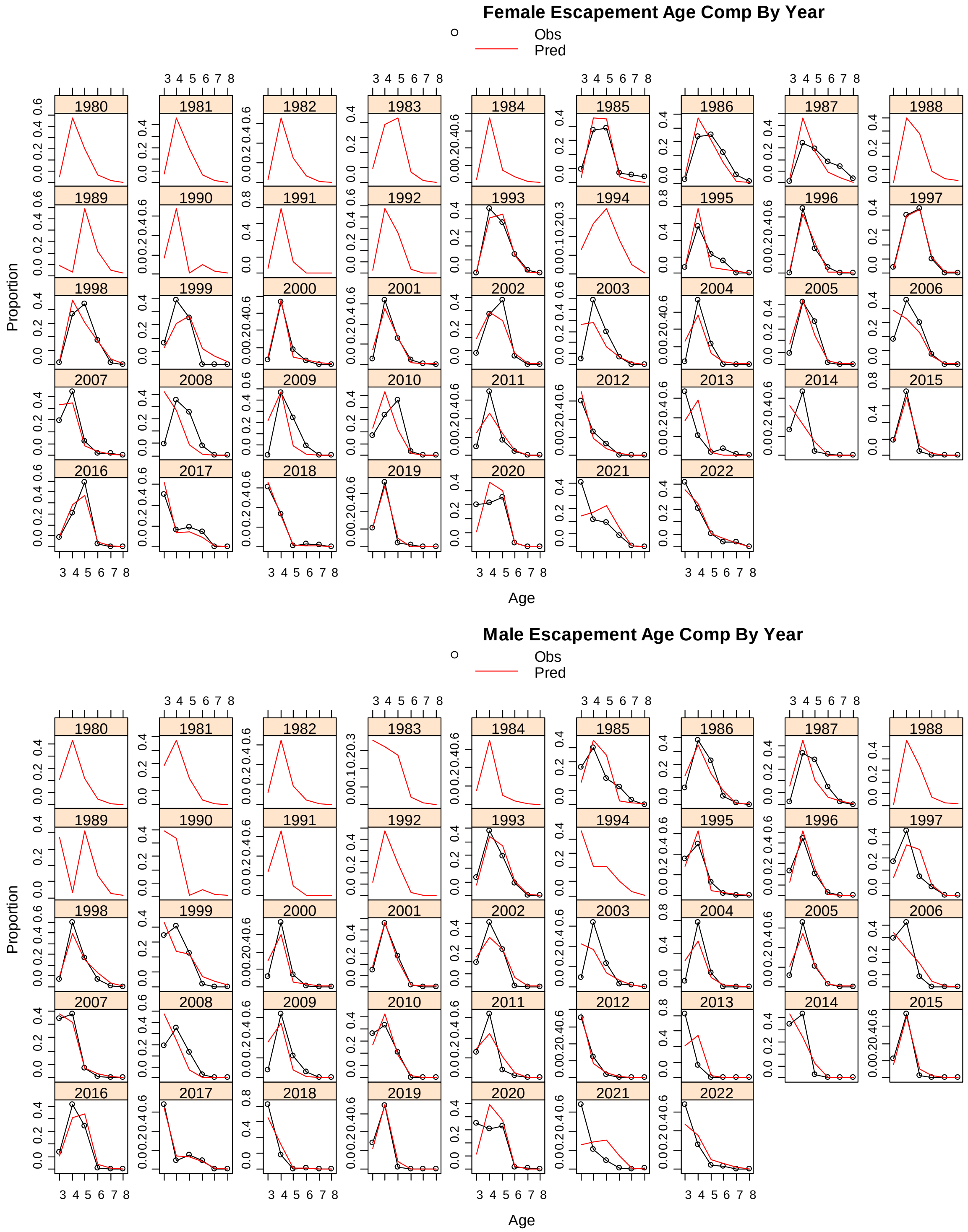

Figure 2. Observed and predicted escapement age composition (proportions) for Monument River alewife by sex, age, and year.

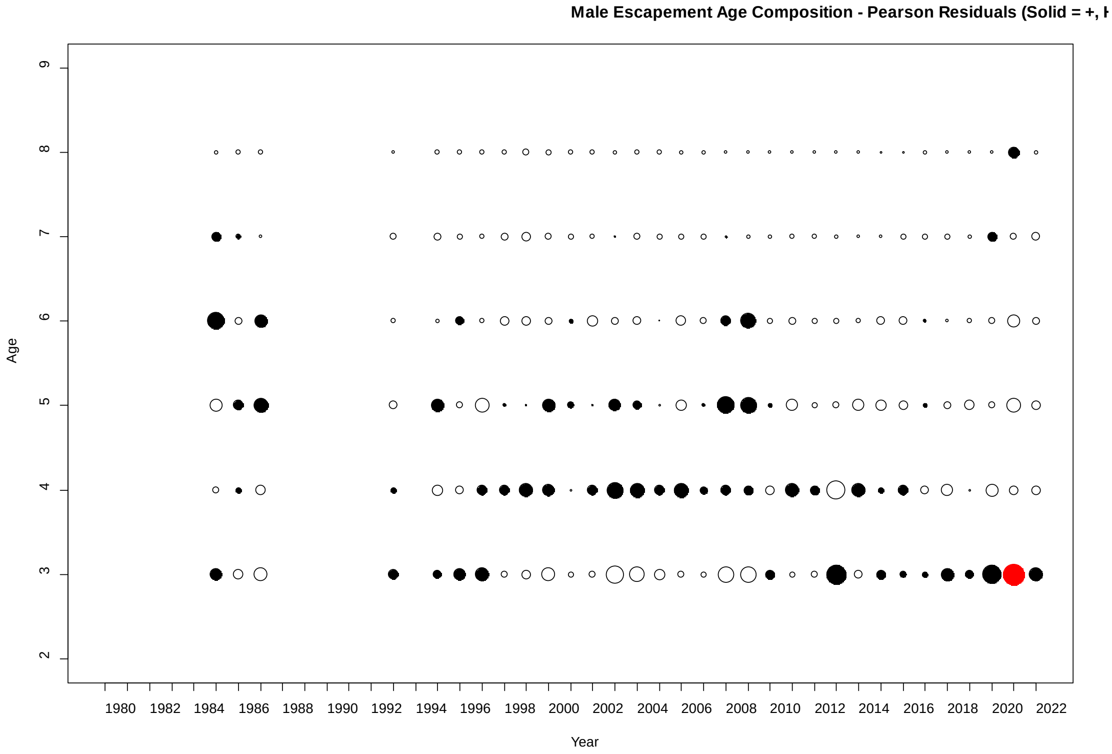

Figure 3. Bubble plots of standardized residuals of catch age composition by sex, year, and age for Monument River.

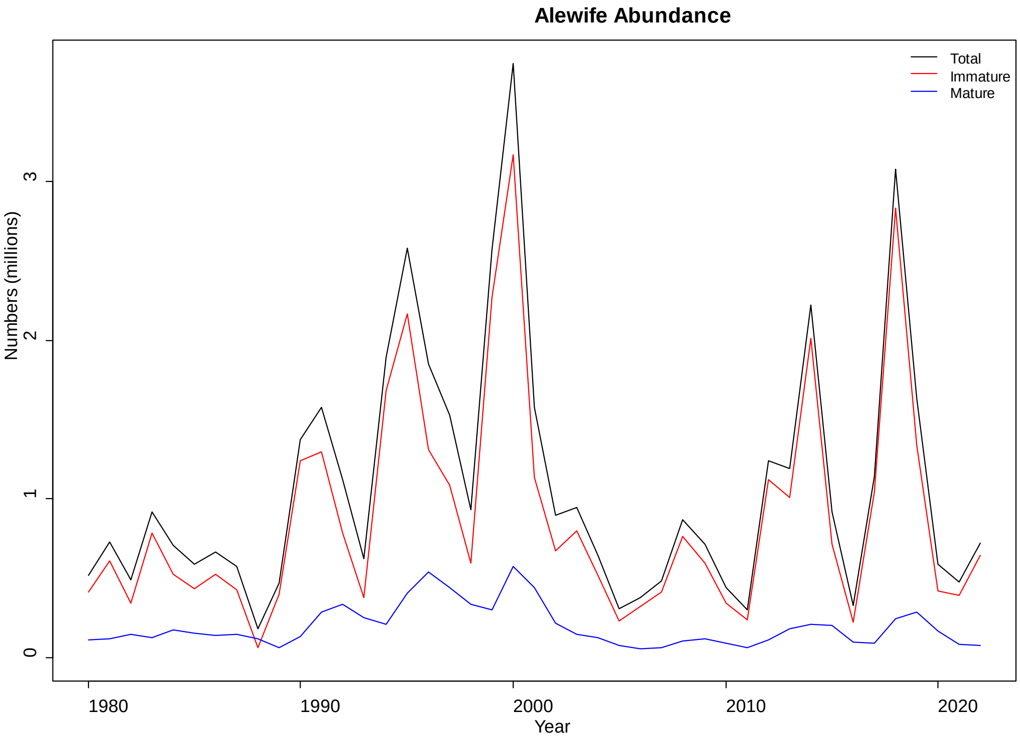

Figure 4. Population abundance estimates for the Monument River alewife stock.

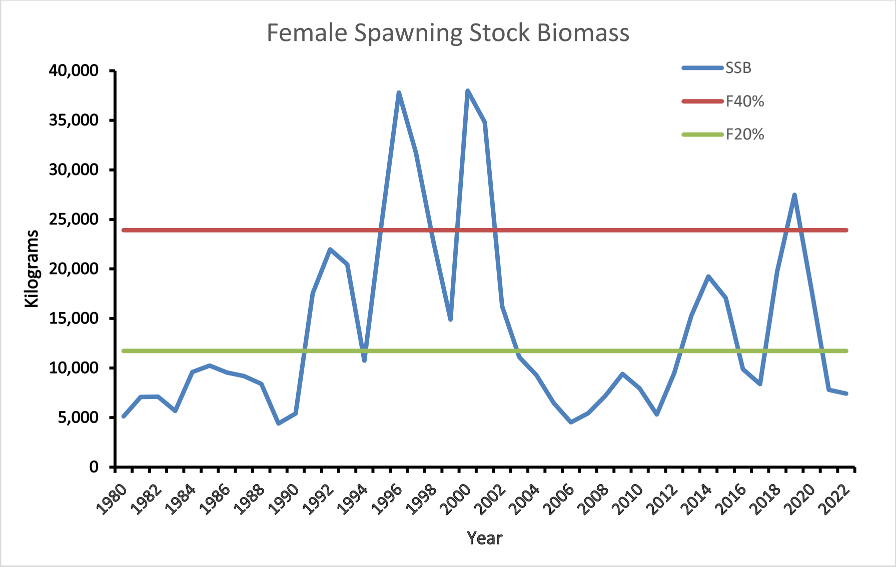

Figure 5. Estimates of female spawning stock biomass (kilograms) for Monument River alewife. SSB thresholds at F40% and F20% (assuming in-river F=0) are shown.

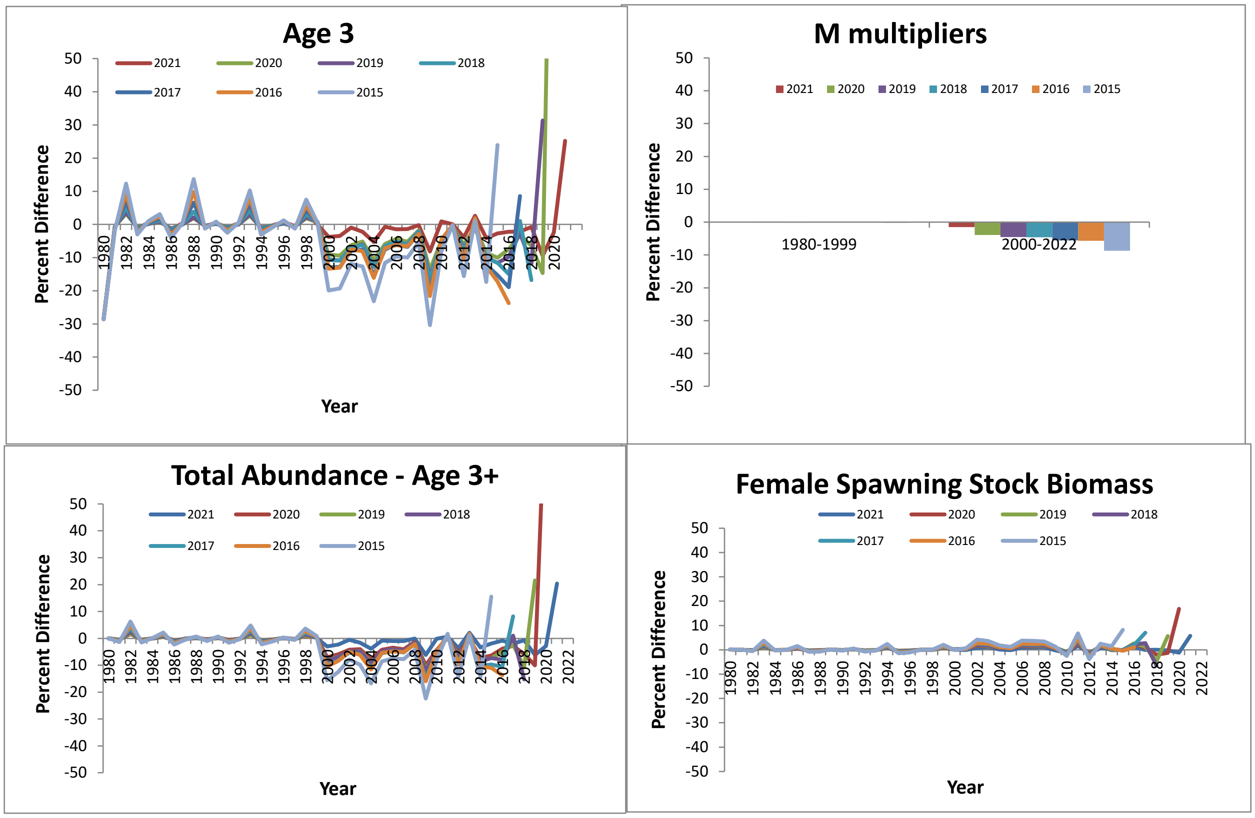

Figure 6. Retrospective analyses for age-3 abundance, M multipliers, and female spawning stock biomass, and total population abundance estimates for the Monument River.

Appendix Table 1.

				Female Immature Age			
Year	Total	3	4	5	6	7	8
1980	215,269	184,387	29,993	889	0	0	0
1981	318,673	287,791	29,993	889	0	0	0
1982	182,688	134,987	46,813	889	0	0	0
1983	409,539	386,195	21,957	1,387	0	0	0
1984	279,440	215,970	62,820	651	0	0	0
1985	228,332	191,341	35,130	1,861	0	0	0
1986	274,171	242,006	31,124	1,041	0	0	0
1987	226,481	186,193	39,365	922	0	0	0
1988	37,979	6,526	30,287	1,166	0	0	0
1989	207,493	205,534	1,061	897	0	0	0
1990	642,159	608,695	33,433	31	0	0	0
1991	677,374	577,372	99,012	991	0	0	0
1992	414,424	317,574	93,917	2,933	0	0	0
1993	200,313	145,873	51,658	2,783	0	0	0
1994	869,634	844,375	23,728	1,530	0	0	0
1995	1,131,192	993,141	137,348	703	0	0	0
1996	693,475	527,859	161,547	4,069	0	0	0
1997	572,155	481,506	85,863	4,786	0	0	0
1998	317,118	236,251	78,323	2,544	0	0	0
1999	1,176,410	1,135,660	38,429	2,320	0	0	0
2000	1,653,258	1,467,390	184,729	1,139	0	0	0
2001	580,074	472,730	106,776	568	0	0	0
2002	343,110	308,383	34,398	328	0	0	0
2003	403,942	381,397	22,440	106	0	0	0
2004	264,309	236,487	27,753	69	0	0	0
2005	116,251	98,958	17,208	85	0	0	0
2006	164,286	157,032	7,201	53	0	0	0
2007	210,333	198,884	11,427	22	0	0	0
2008	388,745	374,238	14,472	35	0	0	0
2009	301,002	273,726	27,232	45	0	0	0
2010	174,824	154,822	19,918	84	0	0	0
2011	122,592	111,265	11,266	61	0	0	0
2012	567,650	559,519	8,096	35	0	0	0
2013	512,031	471,292	40,714	25	0	0	0
2014	1,011,846	968,727	42,321	798	0	0	0
2015	362,422	274,602	86,991	829	0	0	0
2016	114,587	88,224	24,659	1,704	0	0	0
2017	526,279	517,874	7,922	483	0	0	0
2018	1,425,190	1,378,530	46,505	155	0	0	0
2019	677,273	552,571	123,791	911	0	0	0
2020	213,029	160,984	49,620	2,425	0	0	0
2021	198,928	183500	14456	972	0	0	0
2022	323,798	307037	16478	283	0	0	0

Appendix Table 1 cont.

				Female Mature Age			
Year	Total	3	4	5	6	7	8
1980	46,828	2,240	26,898	13,915	3,048	603	125
1981	48,110	3,495	26,898	13,915	3,048	603	151
1982	64,595	1,640	42,205	15,715	4,010	813	212
1983	50,681	4,691	19,695	21,843	3,435	801	215
1984	74,921	2,623	56,347	10,226	4,825	686	213
1985	69,128	2,324	31,597	31,219	2,628	1,138	223
1986	59,227	2,939	28,053	18,323	8,843	692	377
1987	63,049	2,261	35,540	16,836	5,570	2,521	320
1988	54,723	79	27,291	20,445	4,683	1,448	776
1989	27,224	2,496	957	15,975	5,902	1,263	631
1990	44,837	7,393	30,148	560	4,607	1,592	537
1991	113,981	7,013	88,978	16,319	136	1,034	502
1992	147,932	3,857	84,809	53,733	5,029	39	465
1993	114,731	1,772	46,579	49,485	15,403	1,350	142
1994	78,022	10,256	21,401	27,361	14,388	4,190	427
1995	159,207	12,062	123,572	11,898	7,065	3,447	1,163
1996	234,042	6,411	145,886	74,642	3,666	2,038	1,398
1997	195,175	5,848	77,510	87,239	22,515	1,039	1,024
1998	151,719	2,869	70,660	45,761	25,628	6,203	598
1999	111,428	13,793	34,647	41,160	13,071	6,846	1,910
2000	220,370	17,823	166,329	19,605	11,050	3,264	2,298
2001	207,044	30,710	115,025	55,117	3,400	1,807	985
2002	104,746	20,033	40,510	34,311	8,869	541	482
2003	67,758	24,777	26,055	10,761	4,789	1,223	153
2004	58,002	15,363	32,591	7,390	1,685	742	231
2005	37,062	6,429	20,122	8,995	1,109	250	157
2006	26,474	10,201	8,533	5,948	1,531	187	74
2007	30,331	12,920	13,557	2,522	1,023	261	48
2008	46,135	24,312	17,164	3,997	432	174	57
2009	55,939	17,782	32,296	5,061	685	73	42
2010	44,243	10,058	23,633	9,544	870	117	21
2011	29,372	7,228	13,363	6,971	1,636	148	25
2012	51,398	36,348	9,603	3,942	1,195	278	32
2013	82,702	30,616	48,309	2,838	678	204	57
2014	98,987	52,060	32,667	13,608	489	116	48
2015	94,147	14,757	65,517	11,303	2,457	83	30
2016	48,799	4,741	18,573	22,975	2,070	419	21
2017	44,942	27,831	5,966	6,507	4,204	352	81
2018	113,193	74,083	35,027	2,092	1,193	717	80
2019	135,955	29,696	93,241	12,284	384	204	147
2020	81,107	8,651	37,375	32,699	2,252	65	65
2021	40244	9861	10887	13100	5988	384	24
2022	36209	16500	12407	3813	2395	1019	75

Appendix Table 1 cont.

				Male Immature Age			
Year	Total	3	4	5	6	7	8
1980	196,003	173,376	22,627	0	0	0	0
1981	293,232	270,605	22,627	0	0	0	0
1982	162,243	126,926	35,317	0	0	0	0
1983	379,698	363,133	16,565	0	0	0	0
1984	250,466	203,073	47,393	0	0	0	0
1985	206,417	179,914	26,503	0	0	0	0
1986	251,035	227,554	23,481	0	0	0	0
1987	204,773	175,075	29,698	0	0	0	0
1988	28,985	6,136	22,849	0	0	0	0
1989	194,061	193,260	801	0	0	0	0
1990	597,568	572,346	25,222	0	0	0	0
1991	617,590	542,893	74,697	0	0	0	0
1992	369,463	298,610	70,853	0	0	0	0
1993	176,134	137,162	38,972	0	0	0	0
1994	811,853	793,952	17,901	0	0	0	0
1995	1,037,453	933,834	103,619	0	0	0	0
1996	618,212	496,337	121,875	0	0	0	0
1997	517,529	452,752	64,777	0	0	0	0
1998	281,232	222,143	59,089	0	0	0	0
1999	1,096,832	1,067,840	28,992	0	0	0	0
2000	1,519,134	1,379,770	139,364	0	0	0	0
2001	557,405	462,158	94,654	593	0	0	0
2002	333,593	301,486	31,705	403	0	0	0
2003	393,684	372,867	20,682	135	0	0	0
2004	256,866	231,199	25,579	88	0	0	0
2005	112,714	96,744	15,861	109	0	0	0
2006	160,224	153,520	6,637	68	0	0	0
2007	204,996	194,436	10,532	28	0	0	0
2008	379,252	365,869	13,339	45	0	0	0
2009	292,761	267,605	25,099	57	0	0	0
2010	169,825	151,360	18,358	107	0	0	0
2011	119,238	108,776	10,383	78	0	0	0
2012	554,511	547,005	7,462	44	0	0	0
2013	498,309	460,752	37,525	32	0	0	0
2014	999,938	960,561	38,679	698	0	0	0
2015	353,644	272,287	80,637	719	0	0	0
2016	111,838	87,480	22,858	1,500	0	0	0
2017	521,277	513,508	7,344	425	0	0	0
2018	1,410,155	1,366,910	43,108	137	0	0	0
2019	663,465	547,913	114,750	802	0	0	0
2020	207,758	159,627	45,996	2,134	0	0	0
2021	196,209	181,953	13,400	856	0	0	0
2022	319,973	304,449	15,275	249	0	0	0

Appendix Table 1.

Male
Mature
Age

Year	Total	3	4	5	6	7	8
1980	63,855	13,251	33,827	13,530	2,631	512	105
1981	71,307	20,681	33,827	13,530	2,631	512	126
1982	84,010	9,701	54,136	15,755	3,552	691	176
1983	77,980	27,753	24,783	21,473	3,095	698	179
1984	101,387	15,520	70,903	9,956	4,219	608	181
1985	88,314	13,750	40,173	30,912	2,309	978	192
1986	80,723	17,391	35,947	18,460	8,008	598	319
1987	84,075	13,380	45,819	17,185	5,176	2,245	270
1988	62,531	469	34,937	20,734	4,393	1,323	676
1989	39,420	14,770	1,229	16,199	5,499	1,165	557
1990	89,247	43,742	38,701	569	4,297	1,459	480
1991	172,022	41,491	112,759	16,249	126	948	450
1992	191,842	22,822	109,424	54,544	4,601	36	416
1993	136,382	10,483	59,771	50,386	14,402	1,215	125
1994	133,689	60,679	27,490	27,810	13,480	3,853	377
1995	251,363	71,369	157,282	11,935	6,553	3,176	1,048
1996	308,674	37,933	188,257	75,979	3,386	1,859	1,260
1997	246,891	34,602	99,882	89,365	21,183	944	914
1998	185,004	16,978	90,853	46,692	24,213	5,739	529
1999	188,215	81,611	44,444	41,801	12,267	6,361	1,731
2000	352,868	105,450	212,312	19,739	10,266	3,013	2,089
2001	232,935	41,282	132,589	53,408	3,142	1,634	880
2002	115,329	26,930	45,126	33,990	8,374	487	422
2003	78,727	33,306	28,925	10,607	4,632	1,125	132
2004	66,765	20,652	36,280	7,307	1,622	699	205
2005	41,361	8,642	22,377	8,895	1,071	235	142
2006	30,865	13,713	9,519	5,913	1,478	176	67
2007	36,293	17,368	15,129	2,515	992	245	44
2008	56,455	32,681	19,152	3,986	421	164	52
2009	65,761	23,904	36,036	5,047	666	70	39
2010	50,388	13,520	26,372	9,519	847	111	19
2011	33,336	9,716	14,910	6,952	1,593	140	23
2012	64,963	48,861	10,715	3,931	1,163	264	29
2013	98,802	41,157	53,909	2,831	660	193	53
2014	112,904	60,227	38,342	13,706	476	110	44
2015	106,987	17,072	76,006	11,411	2,391	79	28
2016	52,640	5,485	21,547	23,177	2,015	397	19
2017	50,183	32,197	6,921	6,564	4,092	334	75
2018	130,365	85,704	40,635	2,111	1,161	680	74
2019	155,617	34,354	108,169	12,392	373	193	136
2020	88,668	10,009	43,359	32,987	2,192	62	59
2021	43,468	11,408	12,630	13,215	5,829	364	22
2022	40,694	19,089	14,394	3,846	2,331	965	69

Appendix Table 2. Age-specific and total female spawning stock biomass (kilograms).

Female SSB (kg)

		Age					
Year	Total	3	4	5	6	7	8
1980	5,126	206	2,796	1,628	393	84	19
1981	7,081	434	3,774	2,198	530	114	31
1982	7,111	152	4,432	1,857	522	115	32
1983	5,680	436	2,068	2,582	447	113	33
1984	9,592	288	6,983	1,427	742	115	39
1985	10,234	285	4,375	4,866	451	212	45
1986	9,550	390	4,204	3,091	1,643	140	83
1987	9,190	274	4,855	2,589	944	464	64
1988	8,402	10	3,869	3,262	823	277	161
1989	4,408	313	136	2,549	1,037	241	131
1990	5,422	772	3,556	74	674	253	93
1991	17,535	940	13,467	2,780	26	211	111
1992	21,969	482	11,968	8,536	880	7	96
1993	20,456	224	8,068	9,016	2,869	248	30
1994	10,755	1,144	2,695	3,879	2,247	712	79
1995	24,725	1,798	18,951	1,753	1,261	705	258
1996	37,804	846	22,980	12,584	681	410	305
1997	31,702	707	11,609	14,943	4,024	203	217
1998	22,771	281	9,354	7,233	4,585	1,194	123
1999	14,878	1,655	4,054	5,464	2,127	1,212	367
2000	37,994	2,627	28,178	3,753	2,136	737	563
2001	34,804	4,606	18,647	10,270	709	337	235
2002	16,224	2,702	5,987	5,736	1,597	103	100
2003	11,111	3,528	4,395	1,961	929	262	35
2004	9,286	2,217	5,128	1,420	318	152	51
2005	6,461	1,021	3,395	1,722	225	58	40
2006	4,524	1,517	1,439	1,163	342	44	19
2007	5,443	2,030	2,534	542	259	66	12
2008	7,198	3,480	2,815	755	91	44	14
2009	9,416	2,733	5,608	914	133	17	11
2010	7,941	1,631	4,209	1,880	187	27	5
2011	5,305	1,151	2,433	1,345	335	35	6
2012	9,470	6,458	1,831	854	253	66	8
2013	15,261	5,199	9,169	669	161	48	15
2014	19,235	9,302	6,652	3,124	118	27	12
2015	17,076	2,579	11,778	2,145	547	20	8
2016	9,883	912	3,574	4,856	437	99	5
2017	8,386	4,837	1,138	1,358	949	83	21
2018	19,755	12,284	6,543	462	276	169	21
2019	27,474	5,873	18,815	2,601	98	48	38
2020	17,800	1,718	8,204	7,308	537	15	17
2021	7,815	1,768	2,060	2,596	1,294	90	6
2022	7,412	3,057	2,583	915	596	241	19

Statistical catch-at-age model for the Nanticoke River

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1 Model Structure

The model structure was based on the cohort dynamics described in Gibson and Myers (2003). The model tracks abundance at year (*y*), age (*a*), and repeat spawner class (*r*) and fits against observed proportion at age and repeat spawner class, total catch, and a fishery-dependent CPUE index. The model was implemented in ADMB.

Alewife and blueback herring first return to the Nanticoke River at age-3, although the majority of individuals do not mature until age-4, based on repeat spawner marks on their scales. Without data on the at-sea portion of the river herring life cycle, the model treats age-3 as the first age class.

Age-3 recruits (R_y) are estimated by the model directly each year. The total number of age-3 recruits is broken down into numbers at spawning class 1 (immature fish) and spawning class 2 (virgin spawners) based on the proportion of fish that mature at age-3. The proportion of fish that mature at each age ($p_{mat}(a)$) was estimated from the repeat spawner data pooled across years and sexes. The number of age-3 fish in the higher repeat spawner classes is set to zero, as it is assumed no fish mature before age-3.

Immature recruits:

$$NAA_{y,1,1} = R_y\ (1 - p_{mat}(1))$$

First-time spawner recruits:

$$NAA_{y,1,2} = R_y \cdot p_{mat}(1)$$

Recruitment of age-3 river herring is modeled as a log-normal deviation from average recruitment. The model also estimates the initial age and repeat spawning structure of the population. Abundance of ages-4+ from year *y*+1 forward are calculated as:

Immature fish:

$$NAA_{y,a,1} = NAA_{y-1,a-1,1} \cdot e^{-M} \cdot (1 - p_{mat}(a))$$

First-time spawners:

$$NAA_{y,a,2} = NAA_{y-1,a-1,1} \cdot e^{-M} \cdot p_{mat}(a)$$

Mature fish that have previously spawned ($r \geq 3$):

$$NAA_{y,a,r} = NAA_{y-1,a-1,r-1} \cdot e^{-M-F_{y-1}}$$

The oldest age (*A*) and highest repeat spawner class (*RPS*) are treated as a plus group:

$$NAA_{y,A,RPS} = NAA_{y-1,A-1,RPS-1} \cdot e^{-M-F_{y-1}} + NAA_{y-1,A,RPS} \cdot e^{-M-F_{y-1}}$$

The model estimates an annual fishing mortality rate, F_y, and all mature fish are assumed to be equally vulnerable to the fishery, which is primarily prosecuted with fyke and pound nets. Catch is calculated for each age and repeat spawner class by year:

$$\widehat{C_{y,a,r}} = NAA_{y,a,r} \cdot (1 - e^{-Z_{y,a,r}}) \cdot \frac{F_{y,a,r}}{Z_{y,a,r}}$$

Total catch is summed across age and repeat spawner class to obtain predicted annual total catch, and the catch at age and repeat spawner class is divided by total annual catch to obtain the predicted proportion of catch at age and repeat spawner class:

To tune the model, a fishery dependent CPUE (fish per net-day) from the fyke net fishery was used. Catchability was estimated by the model on a log scale, and the predicted index was calculated as the catchability times the abundance of mature fish:

$$\hat{I}_y = q \cdot N_{total,mature}$$

Lognormal errors were assumed for the total catch data and the index data:

$$-\ln(L) = \ln(\sigma) + 0.5 \cdot n_{years} \cdot \sum_y \frac{(\ln(obs) - \ln(pred))^2}{\sigma^2}$$

Multinomial errors were assumed for the proportion at age and repeat spawn class:

$$-\ln(L) = \ln(\sigma) + 0.5 \cdot n_{years} \cdot \sum_y \left(\frac{(\ln(obs) - \ln\,(pred))^2}{\sigma^2} \right)$$

Effective sample size was the annual number of sampling trips over which the biological samples were obtained. ADMB's delta-method was used to estimate standard deviation for parameters of interest.

2 Data Used

Total catch of river herring in Maryland is not reported by species. Since the runs of alewife and blueback herring peak at different times, the species composition of the fisheries dependent sampling by month was multiplied by the reported landings by month to obtain landings by species by month, and then summed across month to obtain total annual landings by species (Figure 1). For month and year combinations with low sample size, the average species composition across years for that month was used. The directed fishery was closed in 2012, but monitoring of the gear continued using the same protocols. The research removals – fish killed to obtain age samples – were used as total catch from 2012-2021.

Proportion of catch at age and repeat spawner class was obtained from the same biological sampling of the fishery; see Section 2.1.10 in the main assessment report for more details on the sampling protocols. Age 7 was the final age in the model, and 4 was the maximum number of repeat spawner classes, plus an additional class to represent immature fish which was not included in the likelihood function.

A fishery-dependent CPUE of the geometric mean of fish per net-day from the fyke net fishery was used as a tuning index (Figure 2); see Section 2.1.10 in the main assessment report for more details. Monitoring continued after the moratorium using the same methods, so the index time series was preserved. The index was assigned a higher CV than the total catch estimates, to reflect the fact that the index was more variable over time and less precise than the catch, which are assumed to be well-reported over the time period of the model.

The Lorenzen estimate of *M* for the MAT stock-region for each species (see Section 4.4 in the main assessment report) was used as the estimate of *M* for both mature and immature fish.

3 Reference Points

The stochastic SPR reference point (Section 4.4 in the main assessment report) for the alewife and blueback herring MAT stock-regions were used as the reference points for *F*.

4 Results and Conclusions

The catch was fit very well, due to the low CV; standardized residuals were higher for the index for both species, but did not show any patterning (Figure 3).

The base model estimated total age-3+ abundance at 4.77 million alewife and 2.91 million blueback herring at the start of the model in 1991. Both species declined from that point, to 180,000 alewife and 130,000 blueback herring in 2021 (Table 1-Table 2, Figure 4). About 60% of age-3+ individuals were immature in 2021. Spawning stock biomass showed a similar trend, starting out at 207mt for alewife and 282mt for blueback herring in 1991 and ending at 15.6mt for alewife and 9.0mt for blueback herring (Table 1-Table 2, Figure 5). Alewife started out at a higher abundance but lower SSB than blueback herring because 84% of the initial abundance of alewife was immature fish, compared to 54% immature blueback herring at that point and the time-series average of 60% immature fish. Abundance and spawning stock biomass of alewife had a brief uptick in 2000 (Figure 4-Figure 5), driven by strong recruitment of age-3 fish in 1999 (Figure 6), but continued the declining trend after that.

In-river fishing mortality increased from the start of the time series for both species, with alewife peaking at 0.38 yr^{-1} in 1996 and blueback herring peaking at 1.14 yr^{-1} in 2004 (Table 1-Table 2,

Figure 7). In-river *F* dropped to negligible levels with the implementation of the moratorium in 2012 (Table 1-Table 2, Figure 7).

With the closure of the fishery, the utility of this model is limited. Sensitivity runs indicate population scale is affected by the scale of the removals, and with no directed fishery, the main source of removals is likely now bycatch in other fisheries, and other factors like climate effects and predation, which cannot be captured with certainty with the data that exist for this system.

References

Gibson, A. J. F. and R. A. Myers. 2003. A statistical, age-structured, life-history-based stock assessment model for anadromous Alosa. Am. Fish. Soc. Sym. 35: 275-283.

Table 1. Abundance, recruitment, SSB, and F for alewife in the Nanticoke River.

	Alewife				
	Immature Abundance	Mature Abundance	Age-3 Recruitment	SSB	In-River F
Year	(millions of fish)	(millions of fish)	(millions of fish)	mt	
1991	3.99	0.77	0.88	206.6	0.153
1992	1.59	0.66	0.30	161.4	0.255
1993	0.98	0.39	0.53	96.8	0.211
1994	0.77	0.36	0.60	86.4	0.209
1995	0.44	0.34	0.30	79.0	0.381
1996	1.23	0.33	1.24	71.7	0.322
1997	0.83	0.51	0.62	112.0	0.249
1998	0.36	0.42	0.16	95.3	0.243
1999	3.04	0.54	3.24	114.4	0.159
2000	1.40	1.16	0.83	252.7	0.058
2001	0.61	0.89	0.25	205.0	0.117
2002	0.58	0.54	0.40	142.4	0.054
2003	0.81	0.45	0.69	119.7	0.156
2004	0.44	0.37	0.29	85.5	0.137
2005	0.24	0.26	0.13	62.5	0.080
2006	0.46	0.21	0.43	51.6	0.085
2007	0.19	0.22	0.09	52.9	0.076
2008	0.10	0.14	0.05	33.3	0.064
2009	0.09	0.09	0.06	22.7	0.166
2010	0.05	0.06	0.03	15.4	0.082
2011	0.05	0.03	0.04	8.1	0.006
2012	0.10	0.04	0.10	8.4	0.016
2013	0.18	0.06	0.18	13.4	0.003
2014	0.26	0.10	0.25	22.1	0.012
2015	0.17	0.13	0.12	29.8	0.000
2016	0.09	0.11	0.05	26.9	0.013
2017	0.09	0.08	0.07	20.7	0.009
2018	0.11	0.07	0.10	17.0	0.004
2019	0.11	0.07	0.09	15.4	0.021
2020	0.10	0.07	0.08	15.3	0.000
2021	0.11	0.07	0.10	15.6	0.004

Table 2. Abundance, recruitment, SSB, and F for blueback herring in the Nanticoke River.

	Blueback herring				
	Immature Abundance	Mature Abundance	Age-3 Recruitment	SSB	In-River F
Year	(millions of fish)	(millions of fish)	(millions of fish)	mt	
1991	1.58	1.32	0.40	282.9	0.130
1992	1.28	0.67	0.88	136.3	0.160
1993	1.09	0.56	0.87	102.7	0.265
1994	1.80	0.64	1.75	108.3	0.223
1995	1.88	0.89	1.67	148.5	0.210
1996	0.74	0.85	0.32	148.7	0.240
1997	0.68	0.52	0.50	95.3	0.400
1998	0.41	0.33	0.25	62.2	0.291
1999	0.33	0.22	0.24	40.1	0.290
2000	0.59	0.20	0.57	34.4	0.782
2001	0.32	0.22	0.21	36.3	0.365
2002	0.63	0.21	0.61	35.0	0.375
2003	0.25	0.24	0.12	41.1	0.433
2004	0.15	0.13	0.09	24.3	1.144
2005	0.14	0.06	0.10	10.0	0.293
2006	0.13	0.06	0.10	10.3	0.272
2007	0.26	0.08	0.26	12.7	0.240
2008	0.08	0.10	0.03	17.0	0.069
2009	0.06	0.06	0.04	11.8	0.352
2010	0.09	0.04	0.08	7.9	0.050
2011	0.06	0.05	0.04	8.4	0.003
2012	0.05	0.04	0.04	6.5	0.012
2013	0.13	0.04	0.14	7.6	0.003
2014	0.12	0.07	0.10	11.3	0.013
2015	0.07	0.06	0.05	11.2	0.000
2016	0.05	0.05	0.03	9.2	0.007
2017	0.04	0.04	0.03	7.3	0.003
2018	0.08	0.03	0.07	6.1	0.004
2019	0.12	0.05	0.11	7.8	0.015
2020	0.07	0.06	0.05	9.8	0.000
2021	0.08	0.05	0.07	9.0	0.001

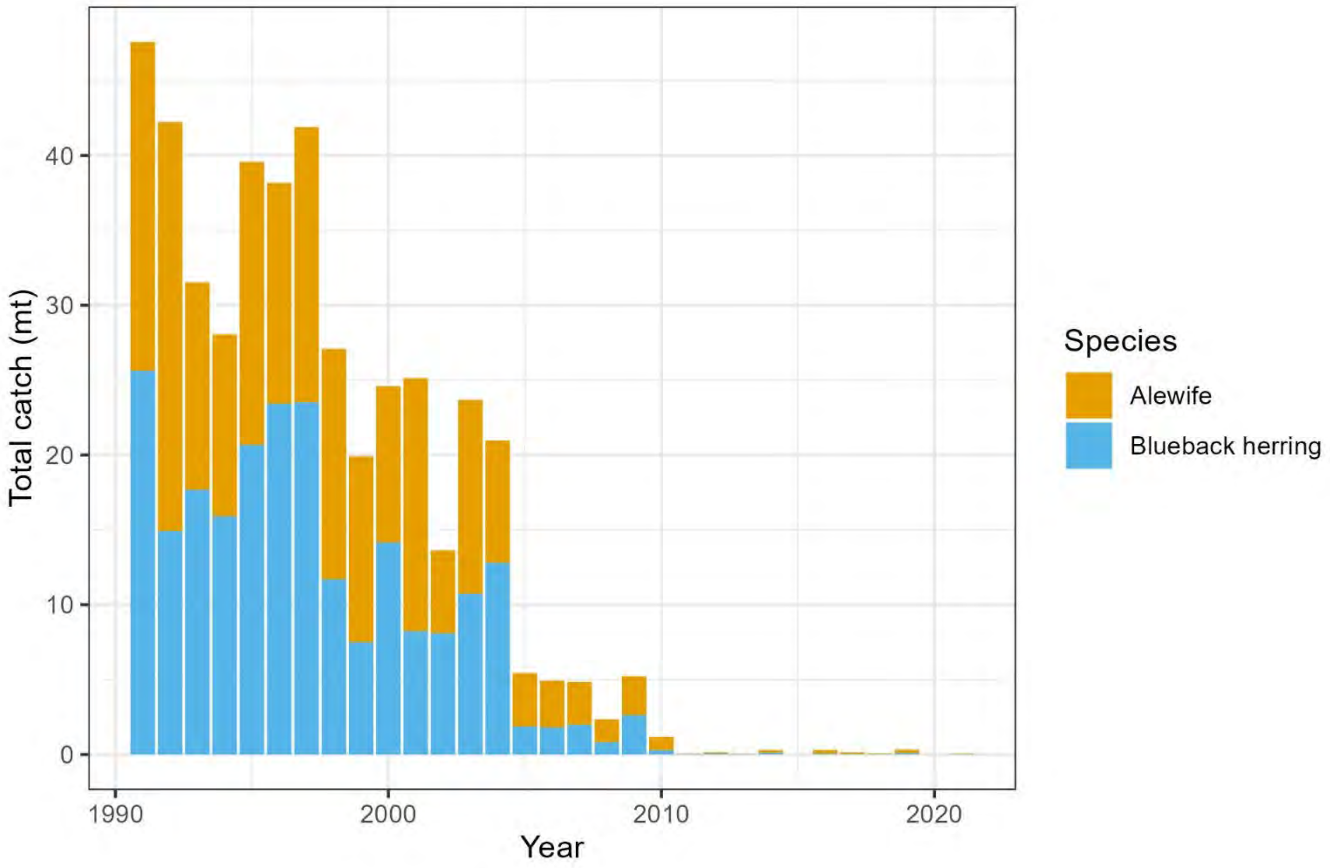

Figure 1. Total catch of river herring in metric tons from the Nanticoke River by species.

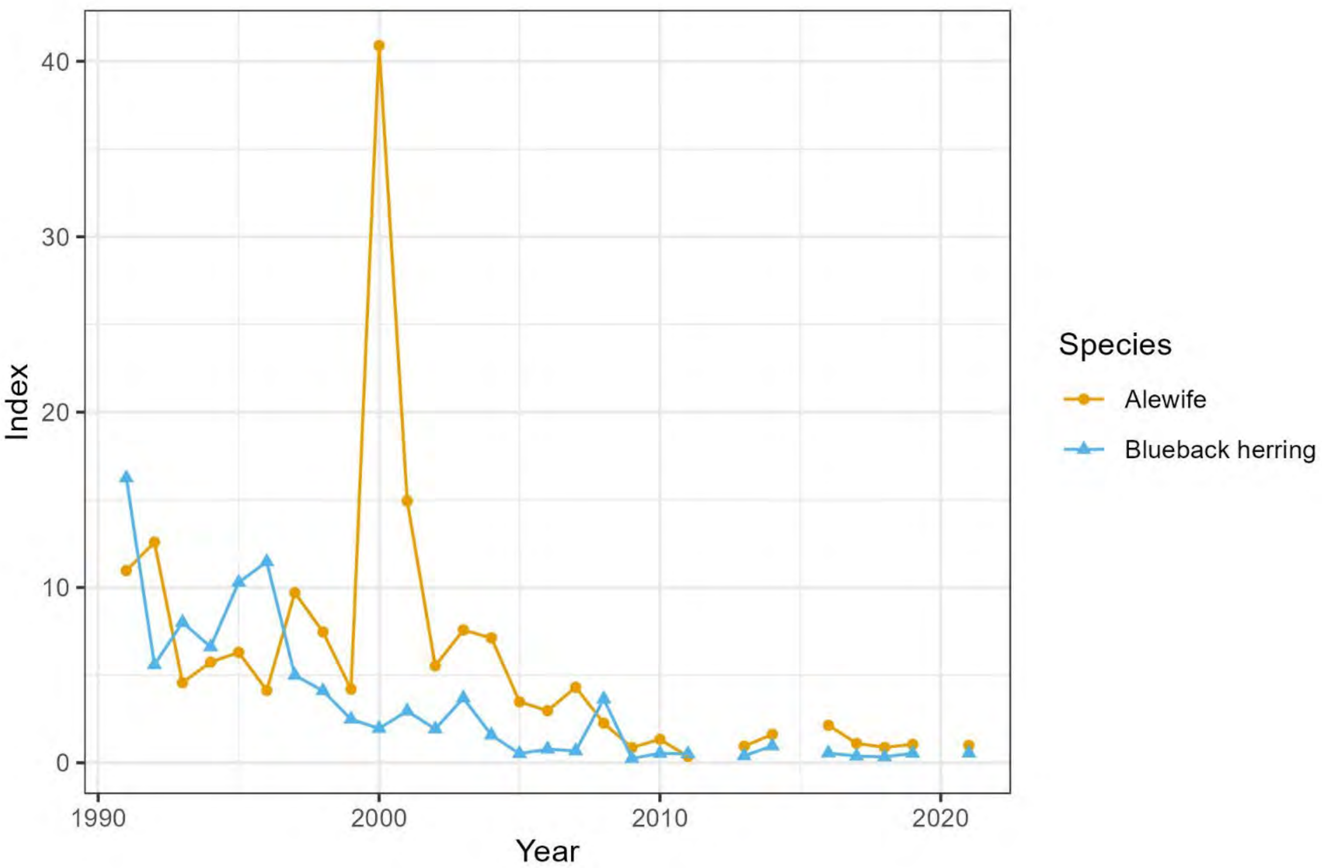

Figure 2. Fishery-independent indices of abundance by species for the Nanticoke River.

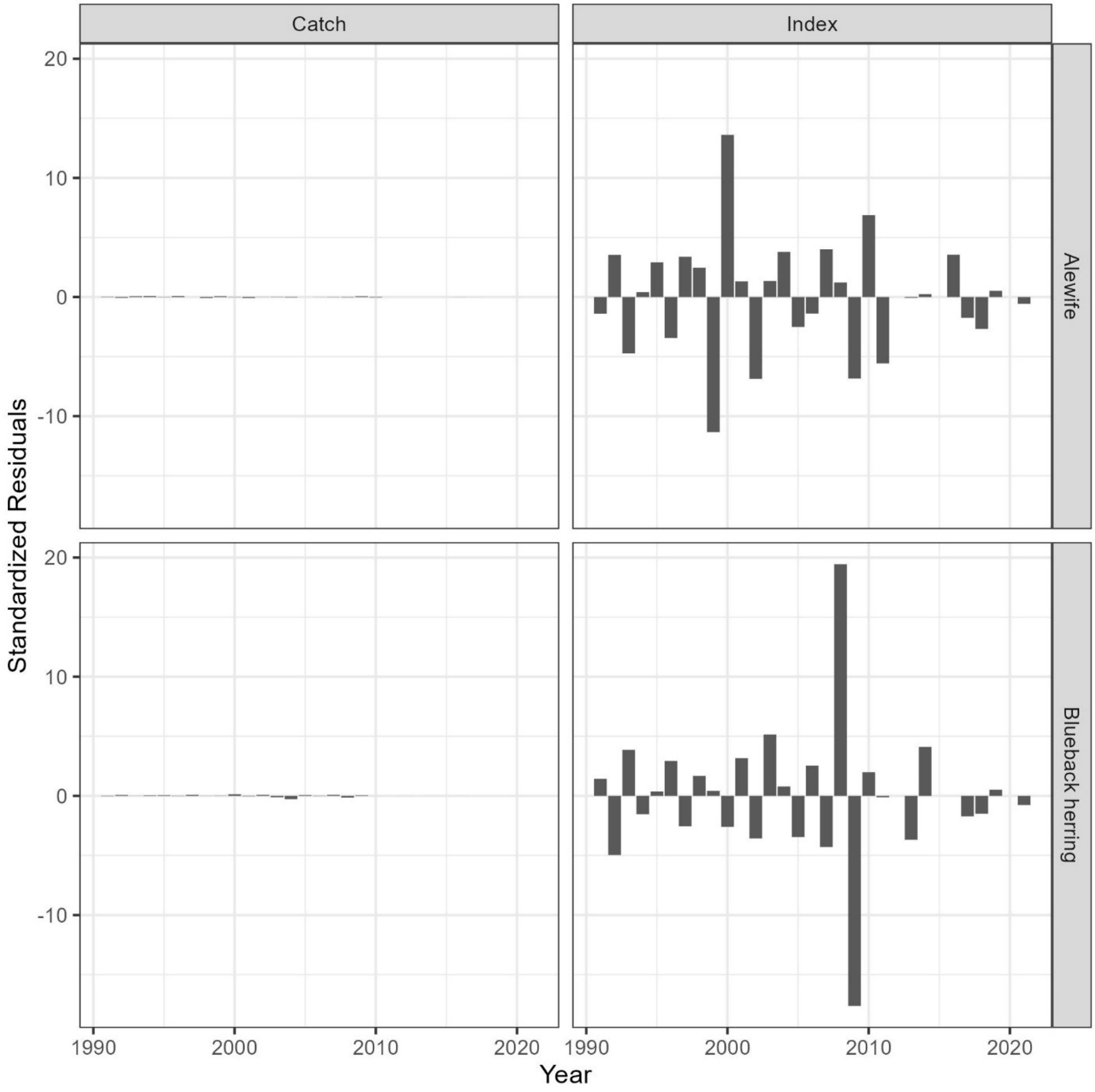

Figure 3. Standardized residuals by species for total catch (left) and indices (right).

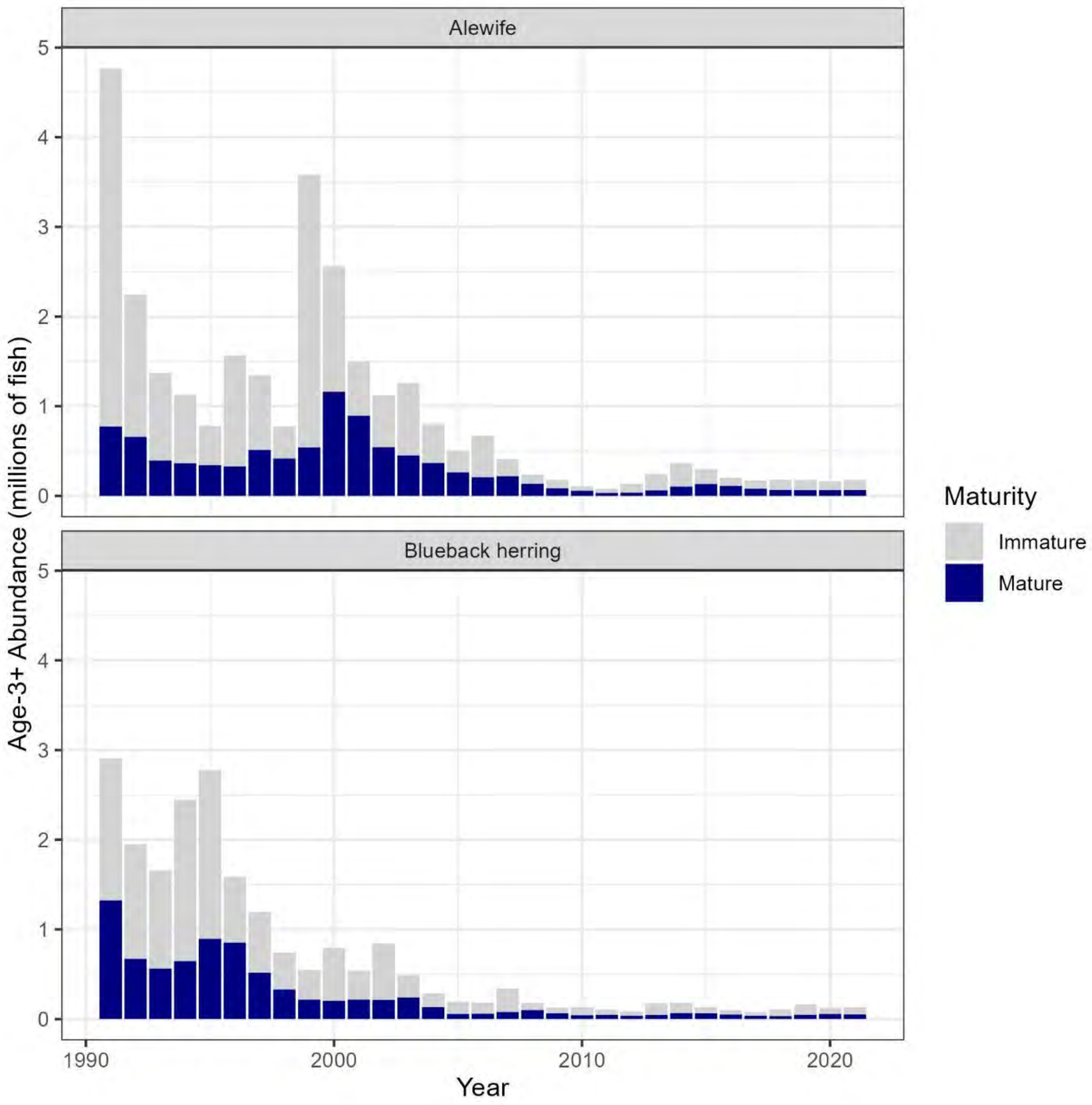

Figure 4. Total age-3+ abundance of river herring in the Nanticoke River by species and maturity stage.

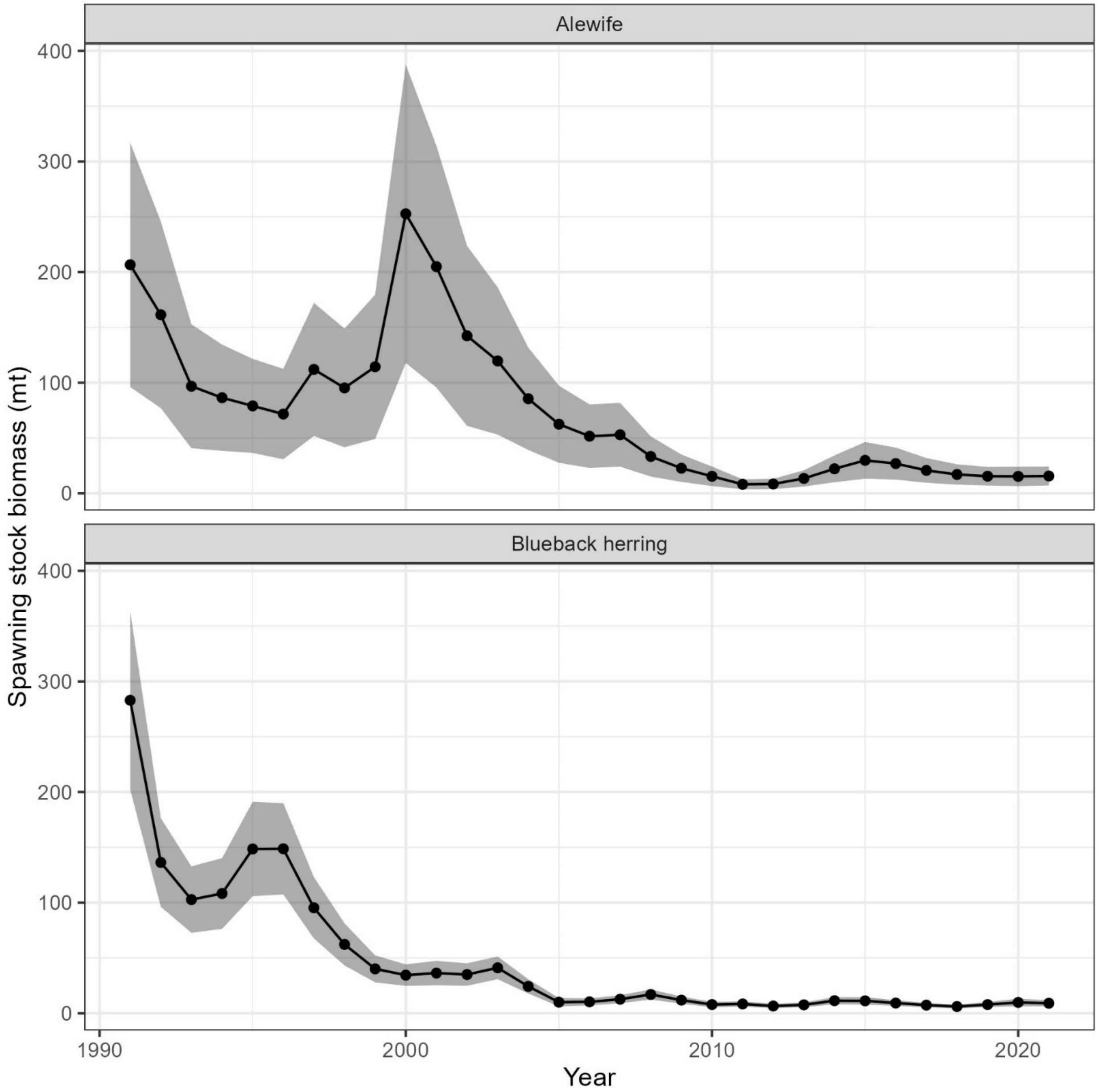

Figure 5. Spawning stock biomass of river herring by species for the Nanticoke River.

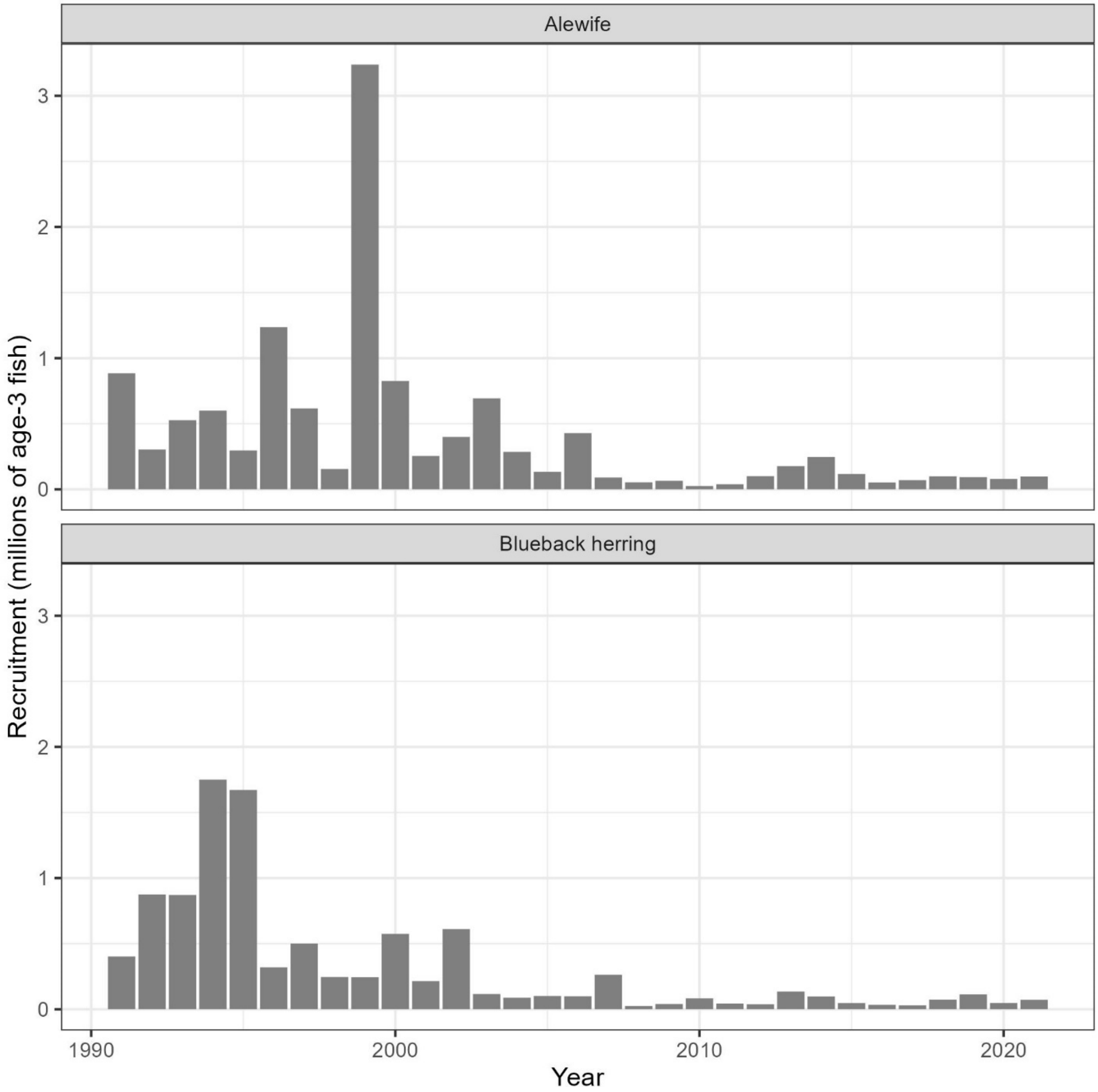

Figure 6. Recruitment (millions of age-3 fish) of river herring by species for the Nanticoke River.

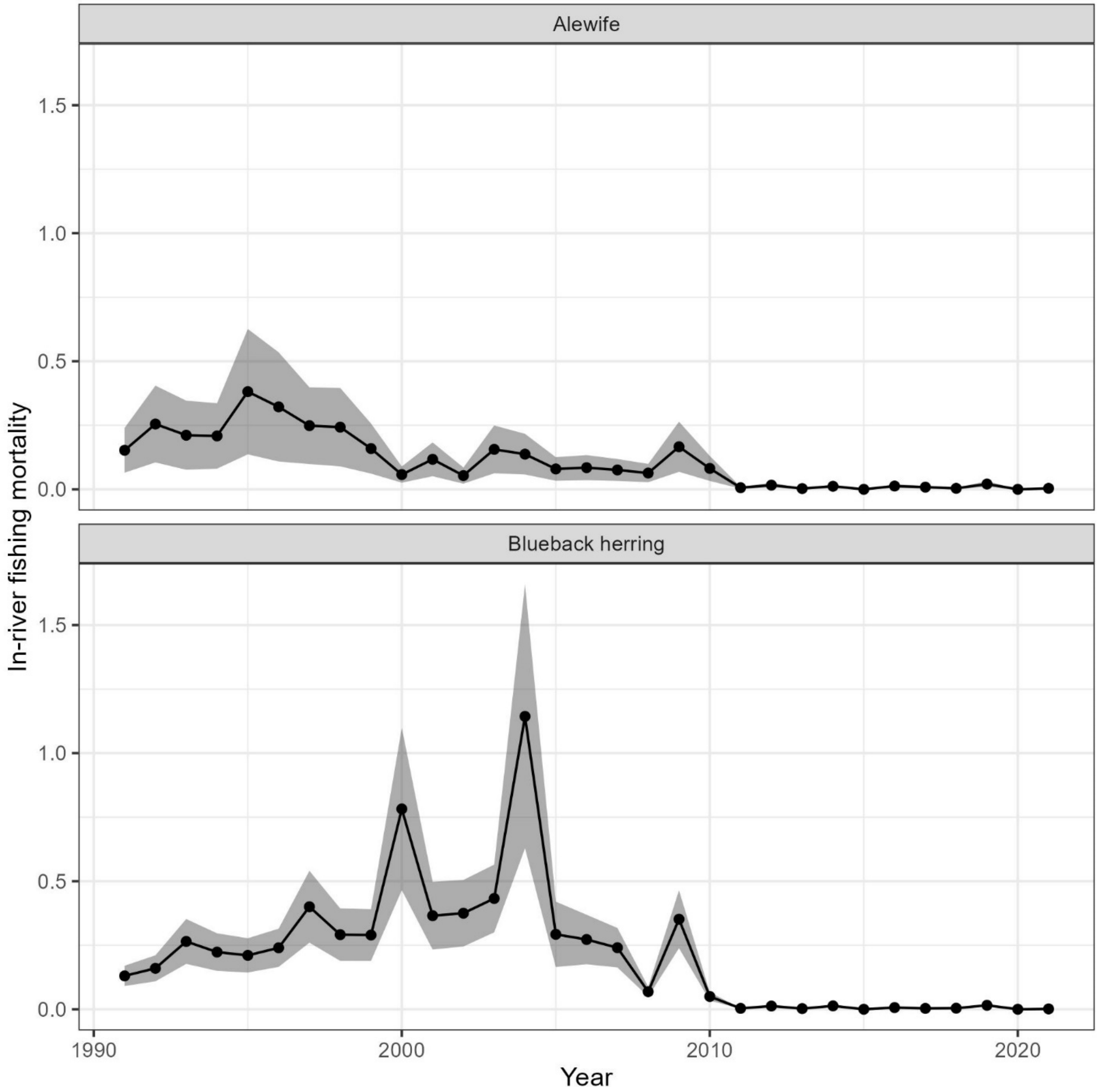

Figure 7. In-river fishing mortality on river herring by species for the Nanticoke River.

Update of the Statistical Catch-at-Age Model for the Chowan River

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A forward-projecting age-structured statistical catch-at-age (SCA) model for the Chowan River blueback herring stock was applied to total in-river catches, catch age compositions, and the fisheries-independent young-of-year (YOY) index and gillnet adult index to estimate age-3 abundance and mortality rates. To incorporate the gillnet index, model code was added which represents a change in the base model structure. This assessment updates data covering the time period from 1972 to 2021. This SCA model requires removal data, but there are none from a fishery because of the 2015 moratorium. Therefore, the number of samples collected for biology in each year was added as a source of removals.

MODEL STRUCTURE

The population model is aged-based and projects the population numbers-at-age by sex *s* forward through time given model estimates of age-3 numbers and mortality rates, assumed known values of natural mortality for immature and mature fish by age, and proportion mature-at-age. The population numbers-at-age ($N_{s,d,y,a}$) matrix has dimensions *s* x *d* x *y* x *A-2*, where *s* is number of sexes, *d* is the number of maturity phases, *y* is the number of years, and *A* is the oldest age group (age 8+). There were six year-classes in the model, representing ages 3 through 8+.

The cohort dynamics of the model is a hybrid of the Margaree River model in Gibson and Myers (2003a). The model incorporates the immature and mature phases by sex and assumes the year begins at the start of spawning. Mature individuals of each age move into the Chowan River where they are intercepted and removed for harvest. The model assumes harvest occurs before the fish reach the spawning grounds. Biological samples for sex, and age and repeat-spawning data are collected from fishery landings. The model allows different natural mortality values for each year, age, sex, and maturity phase.

Given the above dynamics, population numbers-at-age by sex and maturity phases are calculated through time by using the cohort survival models shown in Figure 16.9. The number of age-3 bluebacks at the beginning of spawning season (R_y) are directly estimated in the model, and these estimates are partitioned into sex- (1=female; 2=male) and maturity phase- (1=immature*;* 2=mature) specific estimates of age-3 abundance using sex ratio and mature proportions-at-age (derived outside of the model):

Female

Immature: $$\hat{N}_{1,1,y,3} = \hat{R}_y \cdot f \cdot (1 - p_{1,y,3})$$

Mature: $$\hat{N}_{1,2,y,3} = \hat{R}_y \cdot f \cdot p_{1,y,3}$$

Male

Immature: $$\hat{N}_{2,1,y,3} = \hat{R}_y \cdot (1 - f) \cdot (1 - p_{2,y,3})$$

Mature: $$\hat{N}_{2,2,y,3} = \hat{R}_y \cdot (1 - f) \cdot p_{2,y,3}$$

where *f* is the female sex ratio (proportion) and *p* is the proportion mature by sex s, year *y*, and age *a*. Recruitment of age-3 bluebacks (R_y) is modeled as a log-normal deviation from average recruitment:

$$\hat{R}_y = \hat{\bar{R}} \cdot \exp^{\hat{e}_y}$$

where $\overline{R}$ is the average recruitment parameter and e_y are independent and identically distributed normal random errors with mean zero and constant variance and are constrained to sum to zero over all years. This formulation differs from the original Gibson and Meyers model, which linked recruitment via a Beverton-Holt equation to log-normal deviations.

The initial population abundance-at-age for ages 4 to 8+ in 1972 for each sex and maturity phase is calculated by assuming a static stock:

Immature: $$\hat{N}_{s,1,1972,a} = \hat{N}_{s,1,1972,a-1} \cdot \exp^{-M_{s,1,1972,a-1}} \cdot (1 - p_{s,1972,a})$$

Mature: $$\hat{N}_{s,2,1972,a} = \hat{N}_{s,2,1972,a-1} \cdot (1 - \hat{u}_{1972}) \cdot \exp^{-M_{s,2,1972,a-1}} + \hat{N}_{s,1,1972,a-1} \cdot \exp^{-M_{s,1,1972,a-1}} \cdot p_{s,1972,a}$$

where *M* is the sex-, maturity phase-, year-, and age-specific instantaneous natural mortality rate, and *u* is the year-specific exploitation rate. Population abundance-at-age for ages 4 through 7 in the remaining years is calculated by:

Immature: $$\hat{N}_{s,1,y,a} = \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot (1 - p_{s,y,a})$$

Mature: $$\hat{N}_{s,2,y,a} = \hat{N}_{s,2,y-1,a-1} \cdot (1 - \hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} + \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a}$$

The population abundance of the plus group (8+) is calculated as:

Mature: $$\hat{N}_{s,2,y,8+} = \hat{N}_{s,2,y-1,a-1} \cdot (1 - \hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} + \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a} + \hat{N}_{s,2,y-1,8+} \cdot (1 - \hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,8+}}$$

Exploitation rates for each year (u_y) are estimated as individual parameters in the model.

Input values for age- and sex-specific *M* were calculated using the Lorenzen (1996) equation that relates body weight (in grams) to natural mortality. The grand mean of average weight-at-age of blueback herring from the pound net fishery during 1972 through 1980 was used to derive *M*. Natural mortality rate was assumed constant with time and among maturity phases for the base model runs. The *M* estimates for each sex and age were:

			Age			
	3	4	5	6	7	8
Female	0.71	0.66	0.64	0.62	0.60	0.59
Male	0.72	0.70	0.67	0.64	0.62	0.61

The annual proportions of fish mature at each age and sex were calculated from repeat-spawner frequency data provided by the NCDMF. When data were missing in some years and ages, averaged values from surrounding cells were used to fill in missing data (Appendix Table 16.1).

Total removals of blueback herring are one set of data from which age-3 abundances and exploitation rates are estimated. Total catch in numbers was provided by NCDMF (Appendix Table 16.2). Total catch for 2007 to 2015 was estimated by using pound net catch proportions provided in 2008, average blueback landings to alewife landings ratio from years prior to 2007, and annual mean weight by species. Given estimates of annual numbers of mature for fish at each sex and age, predicted removals-at-age is computed by:

$$\hat{C}_{y,s,a} = \hat{N}_{y,s,m,a}\hat{u}_y$$

where $C_{y,s,a}$ is the predicted in-river removals of sex (*s)* of age (*a)* during year (*y)*. All predictions are stored in an array of dimensions *s* x *y* x *A-2*. Predicted catch-at-age data are then compared to the observed total catch and observed proportions of catch numbers-at-age data (sample numbers at age are provided in Appendix Table 16.3) through the equations:

Predicted Total Catch: $$\hat{C}_y = \sum_s \sum_a \hat{C}_{y,s,a}$$

Predicted Proportions of Catch Numbers-At-Age: $$\hat{P}_{y,s,a} = \frac{\hat{C}_{y,s,a}}{\sum_a \hat{C}_{y,s,a}}$$

The North Carolina YOY seine survey index for blueback herring was incorporated into the model by linking it to the recruitment estimates:

$$\hat{I}_y = \hat{q} \cdot \hat{R}_{y+3}$$

where $\hat{I}_y$ is the predicted index of survey in year *y*, and *q* is the catchability coefficient. Based on the lagged year comparison, YOY indices from 1972 to 2018 (Appendix Table 16.4) were used to tune recruitment estimates for 1975 to 2021. Based on preliminary examination of the model fit, it was deemed that two qs (1972-2005 and 2006-2021) would help provide a better model fit.

The North Carolina gillnet survey index for blueback herring was incorporated into the model by linking it to the January-1 mature fish abundance (TM):

$$\hat{G}_y = \hat{q} \cdot \widehat{TM}_y$$

where G_y is the predicted index of survey in year *y*, and *q* is the catchability coefficient.

Female spawning stock biomass (SSB) in year *y* was calculated as:

$$SSB_y = \sum_a \hat{N}_{1,2,y,a} \cdot (1 - \hat{u}_y) \cdot w_{1,2,y,a}$$

where $w_{1,2,y,a}$ is the mean weight-at-age for mature females in year *y* and age *a*. Calculated mean weights-at-age are provided in Appendix Table 16.5.

Fishing mortality rates were calculated from the estimated exploitation rates assuming a Type I fishery:

$$\hat{F}_y = -\log_e(1-\hat{u}_y)$$

Standard errors of fishing mortality rates were derived using the delta method provided in AD Model Builder.

Lognormal errors were assumed for the total catch data, YOY index, and gillnet index. The concentrated likelihood was weighted for variation in each observation. The generalized concentrated negative log-likelihood (-L_l; Parma 2002; Deriso et al. 2007) is:

$$-L_l = 0.5 * \sum_i n_i * \ln\left(\frac{\sum_i RSS_i}{\sum_i n_i}\right)$$

where n_i is the total number of observations and RSS_i is the weighted residual sum-of-squares from dataset *i*. Equations for the weighted residual sum-of-squares of total removals (*C*), YOY index (*I*), and gillnet index (*G*) are:

$$RSS_C = \lambda_C \sum_y \left(\frac{log_e(C_y + 1e^{-5}) - log_e(\hat{C}_y + 1e^{-5})}{CV_y}\right)^2$$

$$RSS_I = \lambda_E \sum_y \left(\frac{log_e(I_y + 1e^{-5}) - log_e(\hat{I}_y + 1e5)}{CV_y}\right)^2$$

$$RSS_G = \lambda_E \sum_y \left(\frac{log_e(G_y + 1e^{-5}) - log_e(\hat{G}_y + 1e5)}{CV_y}\right)^2$$

where CV_y is the coefficient of variation for the observed catch or index estimate in year *y*, and λ_C and λ_E are the relative weights (Parma 2002; Deriso et al. 2007).

For catch age composition data, a multinomial error distribution is assumed and the negative log-likelihood is calculated using the general equation:

$$-L_p = \lambda_p \sum_y \sum_s -n_{y,s} \sum_a (P_{y,s,a} + 1e^{-5}) \cdot \ln(\hat{P}_{y,s,a} + 1e^{-5})$$

where $n_{y.s}$ is the effective number of fish of sex *s* aged in year *y*, and $P_{y,s,a}$ is the observed proportions of catch-at-age.

Effective sample size for the catch age composition was determined via the Francis method (Francis 2011).

The total log-likelihood of the model is:

$$f = -L_l - L_p$$

The total log-likelihood was estimated by the auto-differentiation routine in AD Model Builder to search for the “best” age-3 abundance estimates that minimize the total log-likelihood. AD Model Builder allows the minimization process to occur in phases. During each phase, a subset of parameters is held fixed and minimization is done over another subset of parameters until eventually all parameters have been included. In this model, the following parameters were solved over two phases:

Phase
1 average recruitment (log scale) and exploitation rates
2 catchability coefficient(s) (log scale)
3 recruitment deviations

Model fit for all components was checked by using standardized residual plots and root mean square errors. Standardized residuals (*r*) for lognormal (total catch and YOY index) were calculated as:

Total Catch:

$$r_{C,y} = \frac{\log_e(C_y + 1e^{-5}) - \log_e(\hat{C}_y + 1e^{-5})}{\sqrt{\log_e(CV_y^2 + 1)}}$$

YOY Index:

$$r_{I,y} = \frac{\log_e(I_y + 1e^{-5}) - \log_e(\hat{I}_y + 1e^{-5})}{\sqrt{\log_e(CV_y^2 + 1)}}$$

Gillnet Index:

$$r_{G,y} = \frac{log_e(G_y + 1e^{-5}) - log_e(\widehat{G_y} + 1e^{-5})}{\sqrt{log_e(CV_y^2 + 1)}}0$$

The root mean square errors for total catch, YOY index, and Gillnet index were calculated as:

Total Catch

$$RMSE_C = \sqrt{\frac{\Sigma_y r_{C,y}^2}{n}}$$

YOY Index

$$RMSE_I = \sqrt{\frac{\Sigma_y r_{I,y}^2}{n}}$$

Gillnet Index

$$RMSE_G = \sqrt{\frac{\Sigma_y r_{G,y}^2}{n}}$$

where *n* is the total observation for the total catch, YOY index or Gillnet index.

For catch age composition data, standardized residuals were derived as:

$$r_{y,s,a} = \frac{P_{y,s,a} - \hat{P}_{y,s,a}}{\sqrt{\frac{\hat{P}_{y,s,a}(1 - \hat{P}_{y,s,a})}{\hat{\hat{n}}_s}}}$$

where n_s is the average effective sample size for sex *s* and type of data.

REFERENCE POINT DERIVATION

Reference points for management were derived using three analytical approaches. First, yield-per-recruit (YPR) analyses were conducted to derive $F_{0.10}$ (F where slope between two adjacent YPR values is 10% of the slope at the origin) and F_{MAX} (F at maximum yield) reference values. Second, spawning biomass-per-recruit (SPR) analysis was conducted to derive the $F_{40\%}$ and $F_{20\%}$ reference points (fishing mortality rates that reduce the spawning biomass to 40% and 20% of the maximum unfished biomass, respectively). Third, recruitment and spawning stock biomass estimates in conjunction with SPR and YPR (production model method in Gibson and Myers 2003b) were used to derive values for F_{MED} (level of fishing mortality where recruitment has been sufficient to balance losses to fishing mortality in half the observed years), $\mathrm{F}_{\mathrm{COL}}$ (the fishing mortality that drives the population to extinction), F_{MSY} (the fishing rates that produces maximum sustainable yield), $\mathrm{SSB}_{\mathrm{MSY}}$ (the spawning stock biomass at MSY), and $\mathrm{SSB}_{20\%}$ (minimum threshold population size).

The YPR and SPR analyses follow the model adapted by Gibson and Myers (2003c) for alewife. For a given F, YPR is calculated as:

$$YPR_F = \sum_{a=3}^{\max a} SS_a w_a (1 - e^{-F})$$

where SS_a is given by:

$$\begin{aligned}
SS_3 &= p_3 \\
SS_4 &= SS_3 e^{-M_{m,3}-F} + (1-p_3) e^{-M_{i,3}} p_4 \\
SS_5 &= SS_4 e^{-M_{m,4}-F} + (1-p_3)(1-p_4) e^{-M_{i,3}-M_{i,4}} p_5 \\
SS_6 &= SS_5 e^{-M_{m,5}-F} + (1-p_3)(1-p_4)(1-p_5) e^{-M_{i,3}-M_{i,4}-M_{i,5}} p_6 \\
SS_7 &= SS_6 e^{-M_{m,6}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6) e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}} p_7 \\
SS_8 &= SS_7 e^{-M_{m,7}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7) e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}} p_8
\end{aligned}$$

Where a is the age of the fish, p_a is the proportion mature at that age, $M_{m,a}$ and $M_{i,a}$ are the instantaneous natural mortality rates for mature and immature fish of age a, and w_a is the female weight at age.

Since a plus group was used in the model, one additional SS_a was calculated to match the maximum observed age (9) for female blueback:

$$SS_9 = SS_8 e^{-M_{m,8}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7)(1-p_8) e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}-M_{i,8}} p_8$$

Similarly, SPR is calculated as:

$$SPR_F = \sum_{a=3}^{\max a} SS_a w_a e^{-F}$$

YPR and SPR were calculated for a set of Fs that ranged from 0 to 5 with an increment of 0.01. F_{MAX} was found by selecting the fishing mortality where $\mathrm{YPR}_{\mathrm{F}}$ takes its largest value, and $F_{0.10}$ was found by selecting the fishing mortality where the marginal gain in yield was 10% that at F = 0. The $\mathrm{SPR}_{x\%}$ reference points were found by selecting the fishing mortality rate where $\mathrm{SPR}_{\mathrm{F}}$ was x% that of $\mathrm{SPR}_{F=0}$. Data from 1976 were used to calculate SPR and YPR values to develop historical estimates of population quantities before the decline in abundance and changes in age structure.

F_{MED} was calculated by finding the fishing mortality rate that produced a SPR replacement line with a slope that equals the median survival ratio (median of $R_y/SSB_{y\text{-}3}$) from the spawner-recruitment (S-R) biomass estimates. The remaining quantities were produced using a production model based on the Beverton-Holt spawner-recruit model. A Beverton-Holt spawner-recruit model was fit externally to the age-3 recruitment numbers (R_y) and corresponding spawning stocking biomass ($SSB_{y\text{-}3}$). The model is:

$$R_y = \frac{aSSB_{y-3}}{1+(aSSB_{y-3}/R_0)}\,\mathrm{e}^{\epsilon}$$

Here, a is the slope at the origin of the spawner-recruit relationship (the maximum rate at which spawners can produce recruits at low population sizes) and R_0 is the asymptotic recruitment level which is the carrying capacity expressed as the number of fish that survive to age-3 (Gibson and Myers 2003b, 2003c). The linearized form of the model:

$$\log_e(R_y) = \log_e(a) + \log_e(SSB_{y-3}) - \log_e(1 + aSSB_{y-3}/R_0) + \varepsilon$$

was fitted to the spawner-recruitment data using non-linear least-squares regression. Only estimates of recruitment from 1978–2005 and SSB from 1975–2002 were used to estimate the S-R relationship to eliminate the influence and possible bias of the static stock abundance estimates during the first year (1972) and the retrospective bias near the terminal (see below). For a given level of F, the equilibrium spawning biomass (SSB*) is calculated using the relationship:

$$SSB^* = \frac{(\hat{a}SPR_F - 1)\hat{R}_0}{\hat{a}}$$

The corresponding equilibrium number of recruits (R*) is found by substituting SSB* in the spawner-recruit model:

$$R^* = \frac{\hat{a}SSB^*}{1+(\hat{a}SSB^*/\hat{R}_0)}$$

The equilibrium catch (C*) is R* multiplied by the yield-per-recruit for the given value of F:

$$C^* = R^* \cdot YPR_F$$

F_{MSY} is found by finding the fishing mortality rate that produces the maximum C*, and SSB_{MSY} is the value of SSB* corresponding to this fishing mortality rate. F_{COL} is the value of F where $1/SPR_{F=0} = a$. The minimum threshold population size ($\text{SSB}_{20\%}$) was calculated as 20% of the equilibrium spawner abundance in the absence of fishing:

$$SSB_{20\%} = 0.2\frac{(\hat{a}SPR_{F=0} - 1)\hat{R}_0}{\hat{a}}$$

MODEL RESULTS

The current assessment uses age-3 female sex ratio (0.5), the initial effective sample sizes for females and males started at 25, and updated age-specific natural mortality rates. Initial CVs were set at 0.30 for the total catch and the gillnet index, and 1 for the YOY index. All lambda weights were initially set to 1. The final configuration based on analyses of RMSEs and residual patterns was: the likelihood weight for the gill net index was increased to 1.2 and effective sample sizes for female and male age compositions were 10.3 and 11.8, respectively, based on the Francis method.

Resulting contributions to total likelihood are listed in Table 16.5. The converged total likelihood was 1550.75. A total of 104 parameters was estimated in the model. The resulting estimates of recruitment, exploitation rates, and catchability coefficients are given in Table 16.6. The model fit the observed total catch, YOY index, gill net index (Figure 16.10), and catch age composition of each sex fairly well (Figure 16.11). Exceptions for the age compositions were that the proportions of age-3 fish from 2010 to 2015 were greatly under-estimated by the model and produced very large standardized residuals (Figure 16.12). This was due to age-3 fish comprising higher proportions of sample than were observed prior to 2010. Parameter estimates for years prior to 2006 were fairly precise (CV<0.30; Table 16.6), but precision of the estimates became less near the terminal year.

Exploitation and Fishing Mortality Rates

Exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.098 in 1979 to as high as 0.84 in 1986 (Table 16.6; Figure 16.13). Exploitation averaged about 0.22 prior to 1985, increased to an average of 0.67 during 1985–1988, and averaged 0.33 between 1989 and 2000. Since the moratorium (2015), exploitation rates have been close to zero. Corresponding fishing mortality rates are listed in Table 16.7 and are plotted in Figure 16.13. Fishing mortality averaged about 0.26 prior to 1985, increased to an average of 1.18 during 1985–1988, and averaged 0.45 between 1989 and 2000. Since the moratorium, fishing mortality has been close to zero.

Population Abundance

The abundance estimates of the Chowan River blueback herring stock by sex, maturity phase, year, and age are given in Table 16.8, and total abundance by maturity state and year is given in Table 16.9. Blueback herring total abundance (age 3+) declined steadily from 173 million fish in 1976 to 75 million fish in 1980 (Table 16.9; Figure 16.13). Total abundance increased through 1983 to 112 million fish but then declined precipitously to 5.6 million fish in 1995 (Figure 16.14). After a slight increase occurred through 1997, total abundance declined to the lowest value of the time series (2.99 million fish) in 2010. Total abundance has been increasing slowly since 2011. The total population estimate for 2021 was 13.7 million fish. Age-3 abundance peaked at 101 million fish in 1975, declined to 34.0 million fish in 1980, increased to 68 million through 1983, and then declined precipitously to its lowest value of 1.44 million fish in 2006 (Table 16.6; Figure 16.13). Since then, the model estimated that age-3 fish abundance increased steadily through 2020 to 10.3 million fish before decreasing to 4.2 million fish in 2021.

Spawning Stock Biomass

Estimates of female spawning stock biomass for blueback herring are provided in Table 16.10. Female SSB fluctuated but declined steadily from the peak of 6.6 million kilograms in 1972 to a low of 0.17

million kilograms in 1986 (Figure 16.13). Female SSB increased slightly to 0.5 million through 1990, but then it declined slowly to its lowest level of 93 thousand kilograms in 2012. The model estimated that female SSB, while still low, has been increasing since 2013 (Table 16.10; Figure 16.13).

Retrospective Analysis

Small to large retrospective bias was evident in estimates of age-3 abundance, exploitation rate, female SSB, and total population abundance (Figure 16.15). For age-3 abundance and total population abundance, the bias patterns for terminal year estimates changed over time from being under-estimated to being over-estimated. The largest absolute percent difference observed for age-3 recruits was 85.7%, and for total abundance, 48.9%. For exploitation rates, percent differences were small (<|20|%), but the retrospective pattern indicated under-estimation during early years and slight over-estimation in recent years. For female SSSB, percent differences were also small (<|18|%), but the retrospective patterns indicated slight over-estimation during early years and slight under-estimation in recent years. The Mohn's rhos were 0.10, -0.072, 0.06, and 0.093 for age-3 abundance, exploitation rate, female SSB and total population, respectively, indicating the average retrospective biases were low.

BENCHMARKS

The fit of the Beverton-Holt stock-recruitment equation to the age-3 abundance and female SSB is shown in Figure 16.16. A plot of the residuals indicated reasonable model fit (Figure 16.16). The estimates of *a* and R_0 are 23.469 (SE = 3.842) and 38,467,435 fish (SE = 14,375,168), respectively. The estimate of *a* was precise (CV=0.16), but the estimate of R_0 was only moderately precise (CV=0.37) (Figure 16.16). Reference points generated from YPR, SPR, and the production model are shown in Table 16.11 and Figure 16.17. For YPR analysis, the fishing mortality rate that maximized the yield-per-recruit, F_{max}, was greater than 5, and $F_{0.1}$ was 1.03. The fishing mortality that reduced the female spawning biomass to 40% and 20% of the level without fishing was 0.53 and 1.04, respectively.

From the spawner-recruit data and production model, F_{MED} was estimated to be 0.51 (Table 16.11; Figure 16.18). The fishing mortality rate that produces maximum sustainable yield, F_{MSY}, was 0.4 and corresponding spawning stock bass, SSB_{MSY}, was 1,868,696 kilograms. SSB_{MSY} was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (1,116,142 kilograms). Current female spawning stock biomass is only 38% of SSB_{MSY}. The fishing mortality rate that drives the population to extinction, F_{COL}, was 0.94. The relationships between the reference points from the production model are shown with the S-R data in Figure 16.18. The estimates of F_{MSY} and F_{COL} are considerably lower than those estimated for alewife ($F_{MSY} > 1.0$; $F_{COL} > 1.82$) in three Canadian rivers by Gibson and Myers (2003b). Historical fishing mortality rate estimates exceeded most reference points several times over the time series, particularly after 1985.

SENSITIVITY ANALYSES

Sensitivity analyses were conducted to determine the influence of assumed-known input values on the resulting estimates of age-3 abundance, exploitation rates, female SSB a, and total population abundance. The sensitivity of the base model to changes in the age-3 female sex ratio, proportion mature-at-age, and natural mortality rates were examined. The following changes in input parameters were made: female sex ratio: $\underline{+}$20% change; sex-specific mature proportions-at-age: used average for the times series; natural mortality: +20% change in all age-specific values. In addition, changes in the total catch (10% and 30%) were made to determine potential effects of missing recreational catch and bycatch. In all scenarios, we show graphically results from 1990 through 2021 to observe the impact in recent years.

Changing the female sex ratio by +20% had little impact (<+5%) on the estimates of age-3 abundance, exploitation rates and total population abundance (Figure 16.19), The +20% change had about an equivalent impact (+20-25% change) on the female SSB estimates (Figure 16.19). Use of the times-series average mature proportions-at-age for each sex had a large effect on model output. In a few years, estimates of age-3 abundance, exploitation rates, female SSB, and total population abundance changed by as much as 50% (Figure 16.20). These changes were the result of the worsening agreement between predicted and observed catch age composition. A 20 % increase in natural mortality increased the age-3 abundance by an average of 65%, decreased exploitation by an average of 26%, increased female SSB by an average of 39%, and increased total population by an average of 51%. Decreasing natural mortality by 20% had less of an impact. The estimates of age-3 abundance, female SSB and total population abundance decreased by 39.5%, 29.0%, and 33.5% on average, while exploitation rates increased by an average of 38.7% (Figure 16.21). Increases in total catch by 10% and 30% from 1990 to 22021 produced larger estimates of age-3 abundance, female SSB, and total population abundance, but smaller estimates of exploitation rates (Figure 16.22).

CONCLUSIONS AND RECOMMENDATIONS

Based on the 2021 fishing mortality rate and female spawning stock biomass estimates, the Chowan River blueback herring population is overfished (2021 SSB=720,142 versus SSB_{MSY}=1.86 million kilograms), but over-fishing is not occurring (F=0.000 versus F_{MSY}=0.40). Estimates of fishing mortality have been close to zero since the moratorium (Table 16.7, Figure 16.13). The forward-projecting statistical catch-at-age model estimated that both age-3 and adult abundances (Figure 16.13) have been increasing since 2011. Female SSB has been increasing since 2011, but still remains at approximately 38% of the target of 1.88 million kilograms (Table 16.10; Figure 16.13). The factors leading to this recommendation of stock status remain largely unchanged since the 2017 stock assessment, despite a fishing pressure that is negligible. Therefore, although the stock is not currently experiencing overfishing, it remains overfished since the spawning stock biomass remains less than 38% of the amount necessary to replace itself in the complete absence of fishing.

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Table 16.5. Likelihood components with respective contributions in base model run.

Likelihood Components

	Weight	RSS
YOY Index	1	32.3562
Total Catch	1	2.28442
Catch Age Comps	1	1576.42
GN Index	1.2	47.317
Total Likelihood		1550.75
Number of Estimate		104
AIC		3309.49

Catch RMSE	0.218437
Index RMSE	1.0185
GN RMSE	1.19163

Table 16.6. Parameter estimates and associated standard deviations of base model configuration.

Year	Age-3 Numbers	SD	CV
1972	74,311,800	1.60E+07	0.21
1973	49,424,000	1.64E+07	0.33
1974	86,644,800	2.66E+07	0.31
1975	101,592,000	2.68E+07	0.26
1976	97,438,200	2.66E+07	0.27
1977	76,411,800	2.20E+07	0.29
1978	44,763,000	1.36E+07	0.30
1979	35,288,200	1.12E+07	0.32
1980	34,257,900	1.10E+07	0.32
1981	53,359,800	1.38E+07	0.26
1982	61,649,400	1.45E+07	0.24
1983	68,797,600	1.39E+07	0.20
1984	23,377,500	6.33E+06	0.27
1985	13,935,900	3.73E+06	0.27
1986	10,726,300	2.65E+06	0.25
1987	10,684,500	2.46E+06	0.23
1988	6,968,460	1.84E+06	0.26
1989	7,226,420	1.77E+06	0.25
1990	8,453,850	1.69E+06	0.20
1991	7,984,570	1.44E+06	0.18
1992	1,482,510	5.04E+05	0.34
1993	3,820,760	8.54E+05	0.22
1994	4,009,820	8.73E+05	0.22
1995	3,039,490	8.65E+05	0.28
1996	6,185,340	1.43E+06	0.23
1997	6,095,290	1.41E+06	0.23
1998	4,520,230	1.18E+06	0.26
1999	5,018,590	1.26E+06	0.25
2000	4,252,870	1.09E+06	0.26
2001	2,878,090	8.10E+05	0.28
2002	2,625,890	7.82E+05	0.30
2003	2,100,390	6.14E+05	0.29
2004	2,879,390	7.15E+05	0.25
2005	2,932,710	7.13E+05	0.24
2006	1,440,740	4.19E+05	0.29
2007	1,771,710	4.54E+05	0.26
2008	1,637,490	4.38E+05	0.27
2009	1,304,640	366896	0.28
2010	1,529,200	408238	0.27
2011	2,848,920	7.86E+05	0.28
2012	4,553,480	1.40E+06	0.31
2013	4,052,250	1.23E+06	0.30
2014	5,845,720	1.61E+06	0.28
2015	5,703,960	1.59E+06	0.28
2016	5,701,710	1.63E+06	0.29
2017	6,173,390	1.76E+06	0.29
2018	9,388,620	2.67E+06	0.28
2019	10,349,400	3.72E+06	0.36
2020	10,306,500	4.38E+06	0.43
2021	4,252,680	3.59E+06	0.84

Year	u	SD	CV
1972	0.215	0.059	0.27
1973	0.271	0.089	0.33
1974	0.303	0.107	0.35
1975	0.124	0.045	0.36
1976	0.175	0.057	0.33
1977	0.367	0.122	0.33
1978	0.180	0.062	0.34
1979	0.098	0.035	0.35
1980	0.228	0.078	0.34
1981	0.200	0.073	0.36
1982	0.377	0.111	0.29
1983	0.141	0.043	0.30
1984	0.193	0.052	0.27
1985	0.664	0.099	0.15
1986	0.845	0.085	0.10
1987	0.576	0.141	0.25
1988	0.605	0.130	0.22
1989	0.355	0.107	0.30
1990	0.215	0.060	0.28
1991	0.347	0.082	0.23
1992	0.418	0.082	0.20
1993	0.761	0.116	0.15
1994	0.395	0.085	0.22
1995	0.337	0.088	0.26
1996	0.396	0.105	0.26
1997	0.105	0.031	0.30
1998	0.259	0.071	0.27
1999	0.270	0.078	0.29
2000	0.128	0.042	0.33
2001	0.121	0.041	0.34
2002	0.051	0.017	0.33
2003	0.064	0.021	0.33
2004	0.040	0.013	0.32
2005	0.167	0.054	0.32
2006	0.066	0.022	0.33
2007	0.001	0.000	0.32
2008	0.001	0.000	0.32
2009	0.001	0.000	0.32
2010	0.002	0.001	0.32
2011	0.002	0.000	0.32
2012	0.001	0.000	0.32
2013	0.001	0.000	0.32
2014	0.001	0.000	0.33
2015	0.000	0.000	0.33
2016	0.000	0.000	0.32
2017	0.000	0.000	0.32
2018	0.000	0.000	0.33
2019	0.000	0.000	0.34
2020	0.000	0.000	0.36
2021	0.000	0.000	0.39

q	Parm	SD	CV
I1	1.40E-07	2.53E-08	0.1802
I2	3.27E-08	1.02E-08	0.3122
G1	1.29E-06	2.28E-07	0.1770

Table 16.7 Derived fishing mortality values for Chowan River blueback herring.

Year	F	SD	CV
1972	0.243	0.075	0.31
1973	0.316	0.123	0.39
1974	0.361	0.154	0.43
1975	0.133	0.051	0.39
1976	0.192	0.070	0.36
1977	0.457	0.192	0.42
1978	0.199	0.075	0.38
1979	0.104	0.039	0.37
1980	0.259	0.101	0.39
1981	0.224	0.091	0.41
1982	0.474	0.178	0.38
1983	0.152	0.050	0.33
1984	0.215	0.064	0.30
1985	1.092	0.295	0.27
1986	1.864	0.551	0.30
1987	0.858	0.334	0.39
1988	0.928	0.330	0.36
1989	0.439	0.167	0.38
1990	0.242	0.076	0.31
1991	0.427	0.125	0.29
1992	0.542	0.140	0.26
1993	1.432	0.485	0.34
1994	0.503	0.141	0.28
1995	0.412	0.133	0.32
1996	0.503	0.173	0.34
1997	0.111	0.035	0.32
1998	0.299	0.095	0.32
1999	0.314	0.107	0.34
2000	0.137	0.049	0.35
2001	0.129	0.047	0.36
2002	0.052	0.018	0.34
2003	0.066	0.023	0.34
2004	0.041	0.013	0.33
2005	0.183	0.065	0.35
2006	0.068	0.023	0.34
2007	0.001	0.000	0.32
2008	0.001	0.000	0.32
2009	0.001	0.000	0.32
2010	0.002	0.001	0.32
2011	0.002	0.000	0.32
2012	0.001	0.000	0.32
2013	0.001	0.000	0.32
2014	0.001	0.000	0.33
2015	0.000	0.000	0.33
2016	0.000	0.000	0.32
2017	0.000	0.000	0.32
2018	0.000	0.000	0.33
2019	0.000	0.000	0.34
2020	0.000	0.000	0.36
2021	0.000	0.000	0.39

Table 16.8 Estimates of population abundance by sex, maturity state, year, and age.

				Female Immature Age			
Year	Total	3	4	5	6	7	8
1972	22,782,397	20,807,300	1,953,890	21,207	0	0	0
1973	27,992,375	24,415,500	3,539,510	37,365	0	0	0
1974	46,202,617	43,322,400	2,808,870	71,347	0	0	0
1975	51,275,740	49,678,300	1,597,440	0	0	0	0
1976	54,094,460	47,939,600	6,154,860	0	0	0	0
1977	54,231,668	38,205,900	16,003,500	22,268	0	0	0
1978	31,162,674	22,157,700	8,922,260	82,714	0	0	0
1979	19,462,092	16,832,500	2,592,700	36,892	0	0	0
1980	21,750,709	16,974,800	4,708,810	67,002	97	0	0
1981	33,467,907	26,679,900	6,459,450	328,557	0	0	0
1982	35,054,990	30,516,500	4,538,490	0	0	0	0
1983	37,236,560	33,710,800	3,525,760	0	0	0	0
1984	16,435,100	11,197,800	5,237,300	0	0	0	0
1985	11,344,690	6,967,940	4,376,750	0	0	0	0
1986	7,735,597	5,363,170	2,322,660	49,767	0	0	0
1987	6,007,220	5,080,490	912,324	14,406	0	0	0
1988	4,063,718	3,484,230	579,488	0	0	0	0
1989	3,848,728	3,530,110	318,618	0	0	0	0
1990	3,575,780	3,419,580	156,200	0	0	0	0
1991	3,588,891	3,353,520	235,371	0	0	0	0
1992	1,177,877	699,743	478,134	0	0	0	0
1993	2,058,986	1,864,530	188,525	5,931	0	0	0
1994	2,295,507	1,940,750	354,757	0	0	0	0
1995	1,820,443	1,489,350	331,093	0	0	0	0
1996	3,608,654	3,092,670	512,561	3,423	0	0	0
1997	3,491,863	2,968,410	520,009	3,444	0	0	0
1998	2,935,312	2,260,110	672,783	2,419	0	0	0
1999	3,059,600	2,509,290	548,919	1,391	0	0	0
2000	2,603,836	2,126,440	466,331	11,065	0	0	0
2001	2,054,206	1,433,290	619,952	964	0	0	0
2002	1,802,694	1,312,950	489,744	0	0	0	0
2003	1,583,980	1,050,200	531,249	2,531	0	0	0
2004	1,569,237	1,379,230	190,007	0	0	0	0
2005	1,398,943	1,318,250	80,693	0	0	0	0
2006	814,347	720,371	93,976	0	0	0	0
2007	921,393	773,351	148,042	0	0	0	0
2008	944,910	818,746	124,710	1,454	0	0	0
2009	763,418	652,319	111,099	0	0	0	0
2010	716,295	649,908	66,387	0	0	0	0
2011	1,694,002	1,424,460	268,719	823	0	0	0
2012	2,830,518	2,276,740	549,056	4,722	0	0	0
2013	2,905,211	2,026,130	850,703	28,378	0	0	0
2014	3,578,070	2,922,860	619,595	35,615	0	0	0
2015	3,673,487	2,851,980	814,782	6,725	0	0	0
2016	3,426,313	2,808,090	608,537	9,686	0	0	0
2017	3,400,933	2,895,320	505,293	315	5	0	0
2018	4,635,168	4,417,340	199,286	18,543	0	0	0
2019	5,370,496	4,771,090	599,406	0	0	0	0
2020	5,740,789	5,034,740	706,049	0	0	0	0
2021	2,875,946	2,105,080	759,918	10,948	0	0	0

				Female Mature Age			
Year	Total	3	4	5	6	7	8
1972	42,427,227	16,348,600	14,581,500	6,901,050	2,865,890	1,209,460	520,727
1973	24,773,411	296,544	12,995,900	6,884,890	2,865,890	1,209,460	520,727
1974	20,234,699	0	9,301,190	6,657,270	2,667,620	1,124,480	484,139
1975	29,535,607	1,117,510	19,701,800	4,802,080	2,484,030	1,000,100	430,087
1976	33,143,111	779,506	18,750,400	9,744,350	2,217,750	1,170,380	480,725
1977	24,797,379	0	7,882,080	11,158,800	4,241,450	984,826	530,223
1978	26,378,238	223,815	9,861,440	10,768,400	3,737,550	1,444,790	342,243
1979	24,951,884	811,628	8,391,200	8,752,730	4,698,170	1,648,170	649,986
1980	16,538,186	154,160	3,926,530	5,183,130	4,180,300	2,278,570	815,496
1981	10,462,501	0	1,944,600	3,671,740	2,144,980	1,735,900	965,281
1982	16,434,515	308,247	8,578,540	4,142,180	1,721,240	922,588	761,720
1983	19,618,252	687,976	11,571,800	5,106,600	1,360,030	576,564	315,282
1984	22,294,617	490,928	11,627,100	6,962,000	2,313,950	628,719	271,920
1985	13,119,836	0	1,323,260	7,553,640	2,960,720	1,003,930	278,286
1986	5,600,767	0	1,103,090	2,441,860	1,336,500	534,438	184,879
1987	3,643,689	261,771	1,724,450	1,274,500	225,956	111,518	45,494
1988	3,192,331	0	1,972,870	849,438	292,536	51,538	25,950
1989	2,430,677	83,104	1,394,380	702,688	177,099	62,223	11,184
1990	3,364,657	807,343	1,605,700	629,305	238,874	61,420	22,016
1991	3,515,717	638,766	1,757,320	731,960	260,385	100,835	26,451
1992	2,511,033	41,510	1,375,580	714,482	251,915	91,426	36,120
1993	1,195,117	45,849	167,370	654,746	219,140	78,826	29,186
1994	873,661	64,157	567,312	118,103	85,596	28,159	10,334
1995	1,108,123	30,395	642,145	360,715	37,668	27,852	9,348
1996	766,801	0	229,571	387,634	126,039	13,428	10,129
1997	1,583,716	79,239	1,000,490	333,195	125,354	40,983	4,454
1998	1,790,439	0	821,495	729,317	159,115	60,374	20,138
1999	1,597,846	0	562,253	661,151	286,410	63,464	24,567
2000	1,645,519	0	767,349	484,875	255,336	112,522	25,437
2001	1,419,186	5,756	425,498	585,727	228,668	119,715	53,822
2002	1,168,771	0	217,410	513,660	271,885	108,086	57,730
2003	923,711	0	114,254	357,250	257,080	138,824	56,303
2004	1,094,976	60,467	326,316	329,841	177,627	129,424	71,301
2005	1,361,164	148,102	625,943	260,155	167,006	91,754	68,205
2006	1,156,939	0	614,778	311,150	114,249	74,824	41,939
2007	912,907	112,504	206,125	345,313	153,220	57,396	38,349
2008	788,113	0	310,778	181,527	181,960	82,369	31,479
2009	755,645	0	291,433	224,904	96,378	97,776	45,155
2010	800,912	114,690	254,322	207,950	118,513	51,812	53,625
2011	473,338	0	107,100	164,724	109,474	63,651	28,389
2012	521,539	0	151,271	189,434	87,157	58,799	34,878
2013	783,548	0	268,643	333,522	102,294	46,846	32,243
2014	1,190,756	0	376,538	542,826	190,708	54,991	25,692
2015	1,567,718	0	622,224	507,997	304,816	102,521	30,160
2016	2,060,933	42,763	793,622	732,980	271,365	163,947	56,256
2017	2,439,529	191,375	896,312	724,352	391,558	145,965	89,967
2018	2,973,835	276,964	1,318,260	705,828	382,069	210,616	80,098
2019	3,599,280	403,628	1,708,500	784,212	381,882	205,492	115,566
2020	3,880,950	118,525	1,838,050	1,192,740	413,463	205,408	112,764
2021	4,062,795	21,263	1,773,650	1,303,890	628,870	222,401	112,721

Table 16.8. Continued.

				Male Immature Age			
Year	Total	3	4	5	6	7	8
1972	22,966,854	21,587,600	1,376,520	2,734	0	0	0
1973	23,478,980	22,018,400	1,460,580	0	0	0	0
1974	43,603,200	42,499,300	1,103,900	0	0	0	0
1975	49,513,530	46,782,900	2,730,630	0	0	0	0
1976	48,295,520	45,016,400	3,279,120	0	0	0	0
1977	52,361,000	38,205,900	14,155,100	0	0	0	0
1978	28,020,577	20,971,500	6,936,610	112,467	0	0	0
1979	17,624,750	16,532,500	1,092,250	0	0	0	0
1980	19,724,955	16,735,000	2,977,480	12,475	0	0	0
1981	31,292,377	26,439,800	4,797,870	54,707	0	0	0
1982	31,673,430	28,636,200	3,037,230	0	0	0	0
1983	32,086,870	30,511,800	1,575,070	0	0	0	0
1984	12,738,970	9,783,490	2,955,480	0	0	0	0
1985	9,282,030	6,696,190	2,585,840	0	0	0	0
1986	6,063,471	5,116,470	935,444	11,557	0	0	0
1987	5,277,126	4,968,310	308,816	0	0	0	0
1988	2,763,598	2,630,590	133,008	0	0	0	0
1989	2,887,907	2,811,080	76,827	0	0	0	0
1990	2,290,259	2,265,630	24,629	0	0	0	0
1991	2,634,547	2,555,060	79,402	86	0	0	0
1992	709,346	669,351	39,798	197	0	0	0
1993	1,900,087	1,820,590	79,497	0	0	0	0
1994	1,417,536	1,349,300	68,236	0	0	0	0
1995	1,599,050	1,460,470	138,580	0	0	0	0
1996	2,566,197	2,505,060	61,137	0	0	0	0
1997	1,963,316	1,862,110	101,206	0	0	0	0
1998	2,209,560	2,025,060	183,997	503	0	0	0
1999	2,596,386	2,363,760	232,626	0	0	0	0
2000	2,127,004	2,077,530	49,474	0	0	0	0
2001	1,505,909	1,408,830	97,079	0	0	0	0
2002	1,329,319	1,284,060	45,259	0	0	0	0
2003	1,011,432	971,431	40,001	0	0	0	0
2004	1,025,780	1,009,230	16,550	0	0	0	0
2005	1,151,620	1,143,760	7,860	0	0	0	0
2006	633,539	597,908	35,631	0	0	0	0
2007	689,042	678,565	10,477	0	0	0	0
2008	845,291	752,427	92,812	52	0	0	0
2009	751,906	634,707	117,199	0	0	0	0
2010	628,348	582,624	45,724	0	0	0	0
2011	1,246,939	1,240,700	6,239	0	0	0	0
2012	2,649,356	2,276,740	372,616	0	0	0	0
2013	2,877,622	2,026,130	841,130	10,362	0	0	0
2014	3,441,612	2,922,860	518,752	0	0	0	0
2015	3,142,212	2,851,980	290,232	0	0	0	0
2016	2,948,142	2,637,040	310,958	144	0	0	0
2017	3,352,709	2,852,110	500,599	0	0	0	0
2018	4,206,272	4,023,020	183,252	0	0	0	0
2019	4,763,279	4,553,750	209,529	0	0	0	0
2020	4,914,133	4,473,040	441,093	0	0	0	0
2021	2,793,021	2,111,460	668,419	13,142	0	0	0

				Male Mature Age			
Year	Total	3	4	5	6	7	8
1972	41,379,568	15,568,300	15,076,200	6,554,100	2,632,460	1,088,950	459,558
1973	28,423,508	2,693,610	14,992,100	6,556,830	2,632,460	1,088,950	459,558
1974	21,435,413	823,125	10,569,900	6,155,460	2,447,220	1,012,440	427,268
1975	29,928,296	4,012,870	18,235,200	4,206,210	2,195,150	899,300	379,566
1976	37,515,845	3,702,650	21,203,400	9,287,140	1,885,150	1,013,790	423,715
1977	24,758,349	0	9,244,550	10,320,100	3,922,960	820,551	450,188
1978	27,827,179	1,410,040	11,660,200	9,823,640	3,343,950	1,309,840	279,509
1979	25,182,287	1,111,580	9,678,290	8,191,150	4,178,260	1,445,400	577,607
1980	17,280,643	393,965	5,557,560	4,862,920	3,778,890	1,986,300	701,008
1981	11,580,360	240,119	3,495,940	3,554,190	1,927,210	1,538,100	824,801
1982	18,841,213	2,188,550	9,925,850	3,770,600	1,482,150	812,506	661,557
1983	23,451,799	3,887,070	13,027,000	4,577,480	1,201,440	486,644	272,165
1984	24,550,933	1,905,270	13,522,100	6,341,300	2,012,890	544,406	224,967
1985	13,788,553	271,750	2,924,250	6,883,290	2,617,050	856,017	236,196
1986	6,174,314	246,706	2,368,330	1,759,810	1,181,900	463,049	154,519
1987	3,502,057	373,958	2,200,260	646,947	145,590	96,665	38,637
1988	4,027,719	853,636	2,362,500	616,621	140,364	32,550	22,048
1989	2,860,911	802,132	1,367,910	529,922	124,759	29,264	6,923
1990	4,260,134	1,961,290	1,595,380	476,084	174,820	42,411	10,149
1991	4,124,972	1,437,220	1,772,530	633,819	191,166	72,335	17,903
1992	2,649,075	71,902	1,660,500	613,748	211,735	65,793	25,398
1993	1,124,164	89,788	266,669	499,398	182,781	64,942	20,587
1994	1,647,504	655,605	828,380	71,109	61,043	23,022	8,345
1995	1,102,168	59,270	711,222	282,706	22,010	19,469	7,491
1996	1,669,825	587,608	668,870	302,855	95,862	7,690	6,940
1997	2,834,420	1,185,530	1,291,030	231,131	93,675	30,554	2,501
1998	2,262,665	235,052	1,239,040	623,744	105,890	44,223	14,716
1999	1,826,972	145,539	837,908	547,577	236,910	41,399	17,639
2000	1,933,266	48,908	1,152,830	419,398	204,634	91,232	16,264
2001	1,812,513	30,220	934,911	523,518	187,046	94,044	42,774
2002	1,504,940	28,885	653,414	456,142	235,386	86,661	44,452
2003	1,391,188	78,765	598,364	330,456	221,546	117,808	44,249
2004	1,547,474	430,469	492,176	297,943	158,251	109,326	59,309
2005	1,533,083	322,598	684,583	242,906	146,397	80,126	56,473
2006	1,265,083	122,463	651,875	287,034	103,521	64,291	35,899
2007	1,083,960	207,290	336,224	320,003	137,167	50,977	32,299
2008	839,958	66,318	338,312	172,004	163,640	72,279	27,405
2009	725,781	17,613	281,292	213,903	87,945	86,190	38,839
2010	853,617	181,974	271,788	197,793	109,385	46,342	46,335
2011	890,522	183,755	365,788	157,455	101,050	57,585	24,889
2012	669,637	0	320,603	184,460	80,445	53,200	30,929
2013	766,115	0	267,078	333,748	94,311	42,383	28,595
2014	1,266,147	0	467,469	550,230	175,968	49,696	22,784
2015	2,022,877	0	1,132,480	489,588	281,369	92,725	26,716
2016	2,446,020	213,814	1,077,250	706,259	250,485	148,339	49,873
2017	2,384,242	234,589	887,052	689,309	361,436	132,066	79,790
2018	3,293,800	671,286	1,319,190	689,039	352,687	190,562	71,036
2019	4,083,241	620,966	2,075,370	745,963	352,518	185,933	102,491
2020	4,559,983	680,231	2,077,680	1,134,530	381,673	185,859	100,010
2021	3,974,064	14,884	1,839,920	1,237,550	580,500	201,236	99,973

Table 16.9 Total population abundance (number of fish 3+) estimate for the Chowan River blueback herring stock by maturity state.

Year	Immature	Mature	Total
1972	45,749,252	83,806,795	129,556,047
1973	51,471,355	53,196,919	104,668,274
1974	89,805,817	41,670,112	131,475,929
1975	100,789,270	59,463,903	160,253,173
1976	102,389,980	70,658,956	173,048,936
1977	106,592,668	49,555,728	156,148,396
1978	59,183,251	54,205,417	113,388,668
1979	37,086,842	50,134,171	87,221,013
1980	41,475,664	33,818,829	75,294,493
1981	64,760,284	22,042,861	86,803,145
1982	66,728,420	35,275,728	102,004,148
1983	69,323,430	43,070,051	112,393,481
1984	29,174,070	46,845,550	76,019,620
1985	20,626,720	26,908,389	47,535,109
1986	13,799,068	11,775,081	25,574,149
1987	11,284,346	7,145,746	18,430,092
1988	6,827,316	7,220,050	14,047,366
1989	6,736,635	5,291,588	12,028,223
1990	5,866,039	7,624,792	13,490,831
1991	6,223,438	7,640,689	13,864,127
1992	1,887,223	5,160,108	7,047,331
1993	3,959,073	2,319,281	6,278,354
1994	3,713,043	2,521,165	6,234,207
1995	3,419,493	2,210,291	5,629,784
1996	6,174,850	2,436,626	8,611,476
1997	5,455,179	4,418,136	9,873,315
1998	5,144,871	4,053,103	9,197,975
1999	5,655,986	3,424,817	9,080,803
2000	4,730,840	3,578,785	8,309,625
2001	3,560,115	3,231,699	6,791,814
2002	3,132,013	2,673,711	5,805,724
2003	2,595,413	2,314,899	4,910,312
2004	2,595,017	2,642,450	5,237,467
2005	2,550,563	2,894,247	5,444,809
2006	1,447,886	2,422,022	3,869,908
2007	1,610,435	1,996,867	3,607,302
2008	1,790,201	1,628,071	3,418,272
2009	1,515,324	1,481,427	2,996,751
2010	1,344,643	1,654,530	2,999,172
2011	2,940,942	1,363,860	4,304,802
2012	5,479,874	1,191,176	6,671,050
2013	5,782,833	1,549,663	7,332,496
2014	7,019,682	2,456,903	9,476,584
2015	6,815,699	3,590,595	10,406,294
2016	6,374,455	4,506,952	10,881,407
2017	6,753,642	4,823,771	11,577,413
2018	8,841,440	6,267,636	15,109,076
2019	10,133,775	7,682,521	17,816,296
2020	10,654,922	8,440,933	19,095,855
2021	5,668,967	8,036,859	13,705,826

Table 16.10 Estimates of female spawning stock biomass (kilograms) for the Chowan River blueback herring stock

		Female SSB (kg)					
		Age					
Year	Total	3	4	5	6	7	8
1972	6,680,569	2,385,550	2,345,040	1,131,500	499,123	199,253	120,103
1973	3,703,964	31,579	1,772,570	1,054,560	495,408	238,183	111,664
1974	2,937,865	0	1,212,160	974,309	440,608	211,591	99,197
1975	5,115,874	142,901	3,226,850	883,244	515,628	236,503	110,748
1976	5,488,972	93,947	2,894,420	1,689,200	433,881	260,855	116,669
1977	3,320,786	0	933,329	1,483,850	636,524	168,374	98,709
1978	4,520,582	26,787	1,511,680	1,853,730	726,128	319,775	82,482
1979	4,756,009	106,833	1,414,690	1,657,140	1,003,860	401,201	172,285
1980	2,849,071	17,374	566,785	840,193	764,757	474,891	185,071
1981	2,011,460	0	310,961	666,414	440,761	366,417	226,907
1982	2,167,936	24,952	1,025,610	575,178	260,445	155,110	126,641
1983	3,406,644	79,814	1,829,750	974,216	303,873	132,291	86,700
1984	3,299,375	52,660	1,584,780	1,044,380	416,170	136,909	64,476
1985	837,343	0	74,596	451,168	206,644	77,481	27,454
1986	175,436	0	27,718	74,614	44,778	19,895	8,431
1987	273,544	14,096	119,180	102,132	20,502	11,963	5,671
1988	211,743	0	118,570	60,791	24,984	4,381	3,017
1989	292,996	7,501	150,126	95,587	26,831	10,831	2,120
1990	498,892	103,264	240,658	91,356	46,486	12,049	5,079
1991	406,951	56,285	180,080	103,672	40,449	21,390	5,076
1992	261,226	3,380	128,822	77,716	30,772	14,359	6,177
1993	48,824	1,095	5,997	26,432	9,108	4,142	2,050
1994	75,982	4,657	43,923	10,073	12,426	3,066	1,838
1995	118,928	2,417	65,530	38,723	4,992	5,445	1,821
1996	92,164	0	26,088	45,456	16,913	1,907	1,800
1997	269,658	7,804	146,903	73,684	28,170	11,925	1,173
1998	216,376	0	89,538	88,683	22,887	10,878	4,390
1999	200,570	0	64,468	85,464	36,186	9,177	5,275
2000	244,112	0	100,988	74,378	40,948	21,281	6,518
2001	245,959	607	58,324	98,300	46,213	28,612	13,904
2002	218,817	0	32,192	91,171	56,774	22,570	16,110
2003	153,869	0	13,259	56,503	45,231	23,385	15,491
2004	180,209	6,968	43,868	47,509	32,407	29,329	20,129
2005	185,782	14,802	72,985	36,834	26,427	18,034	16,701
2006	182,278	0	86,120	46,493	21,659	16,491	11,515
2007	175,637	15,403	36,254	66,256	32,920	13,537	11,267
2008	136,684	0	42,840	29,012	36,170	19,418	9,244
2009	130,967	0	39,609	35,961	19,070	23,060	13,267
2010	135,258	14,886	35,548	33,219	23,664	12,415	15,526
2011	95,830	0	19,248	31,249	21,861	15,252	8,220
2012	93,219	0	21,160	32,177	15,675	14,100	10,106
2013	151,651	0	48,323	63,326	19,423	11,236	9,344
2014	220,558	0	71,494	92,219	36,210	13,189	7,446
2015	279,042	0	93,318	91,425	60,953	24,601	8,745
2016	360,099	5,644	121,412	134,122	51,012	31,147	16,763
2017	372,910	22,963	115,612	114,435	68,124	31,087	20,690
2018	515,182	34,891	200,336	119,967	77,163	58,961	23,865
2019	627,329	50,851	263,079	150,552	78,277	50,134	34,435
2020	745,322	15,881	297,738	244,491	93,021	60,590	33,601
2021	720,142	2,679	280,219	245,115	120,735	37,806	33,589

Table 16.11. Reference points derived from YPR, SPR and production model methods.

	Basis	Estimate
Yield Per Recruit	F0.1	1.03
	Fmax	5
Spawner Per Recruit	F40%	0.53
	F20%	1.04
Production Model	Fmed	0.51
	Fcol	0.94
	Fmsy	0.4
	SSBmsy	1868696
	SSB20%	1116142

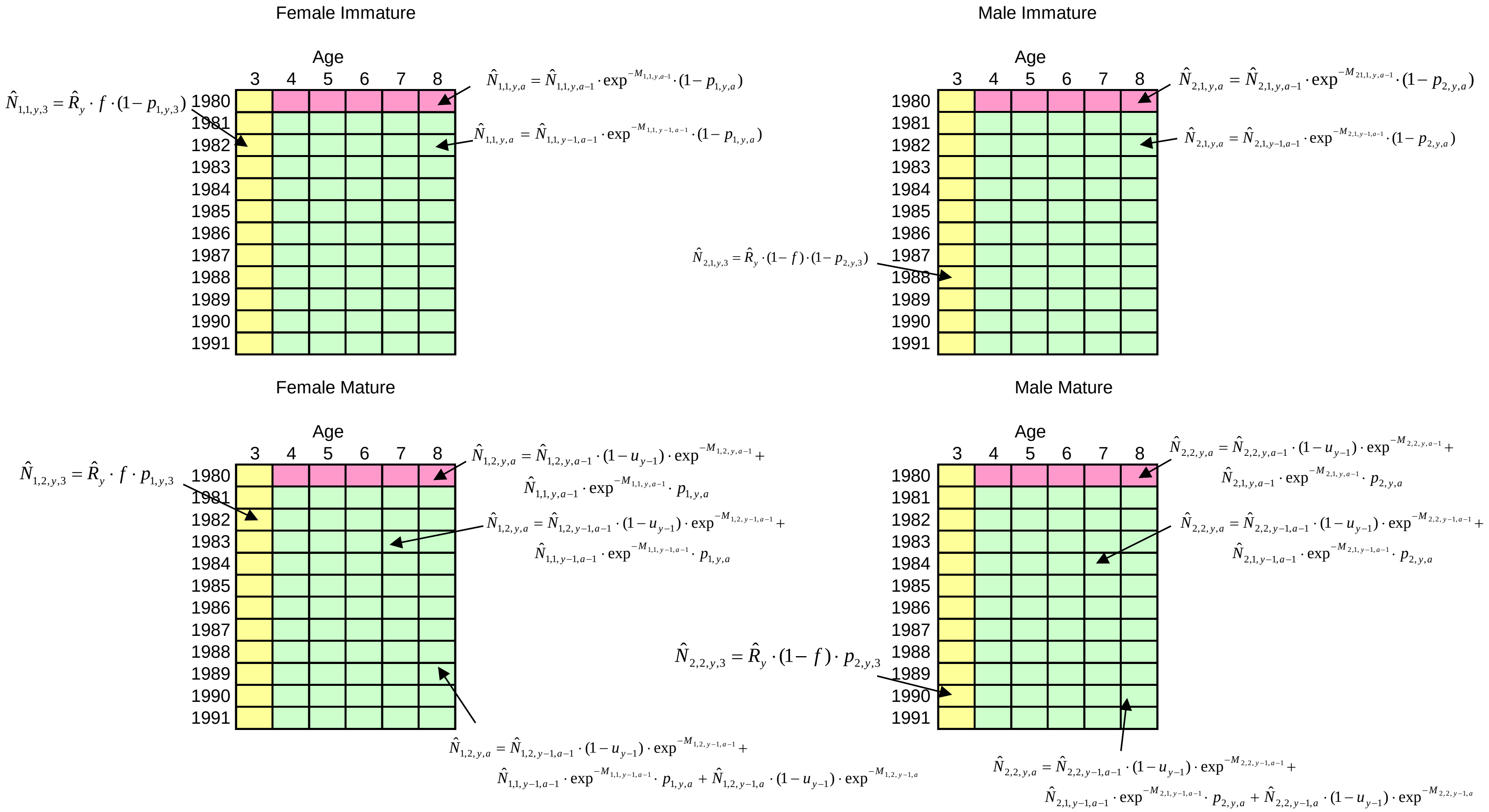


Figure 16.9 Diagram of blueback herring cohort population dynamics .

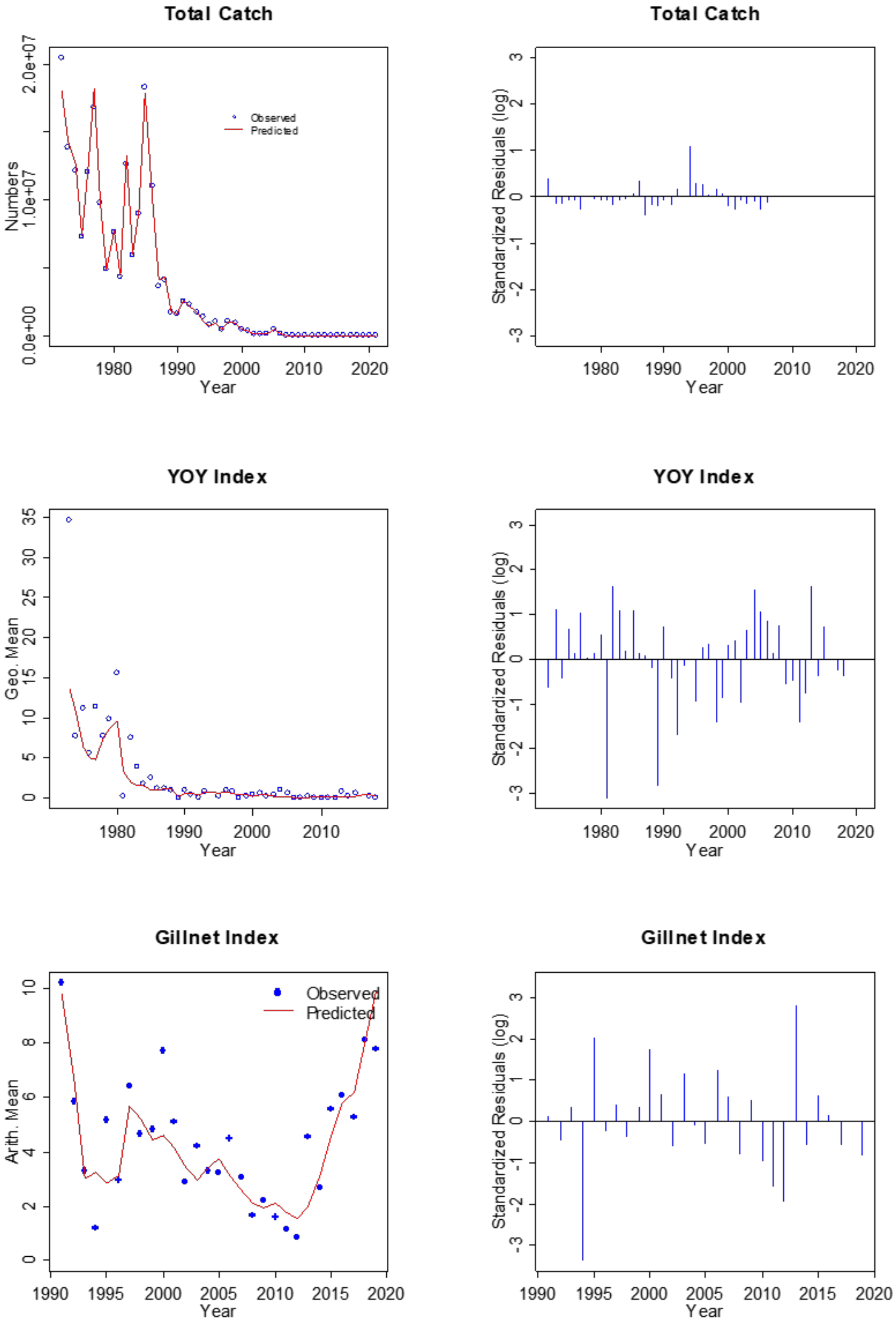
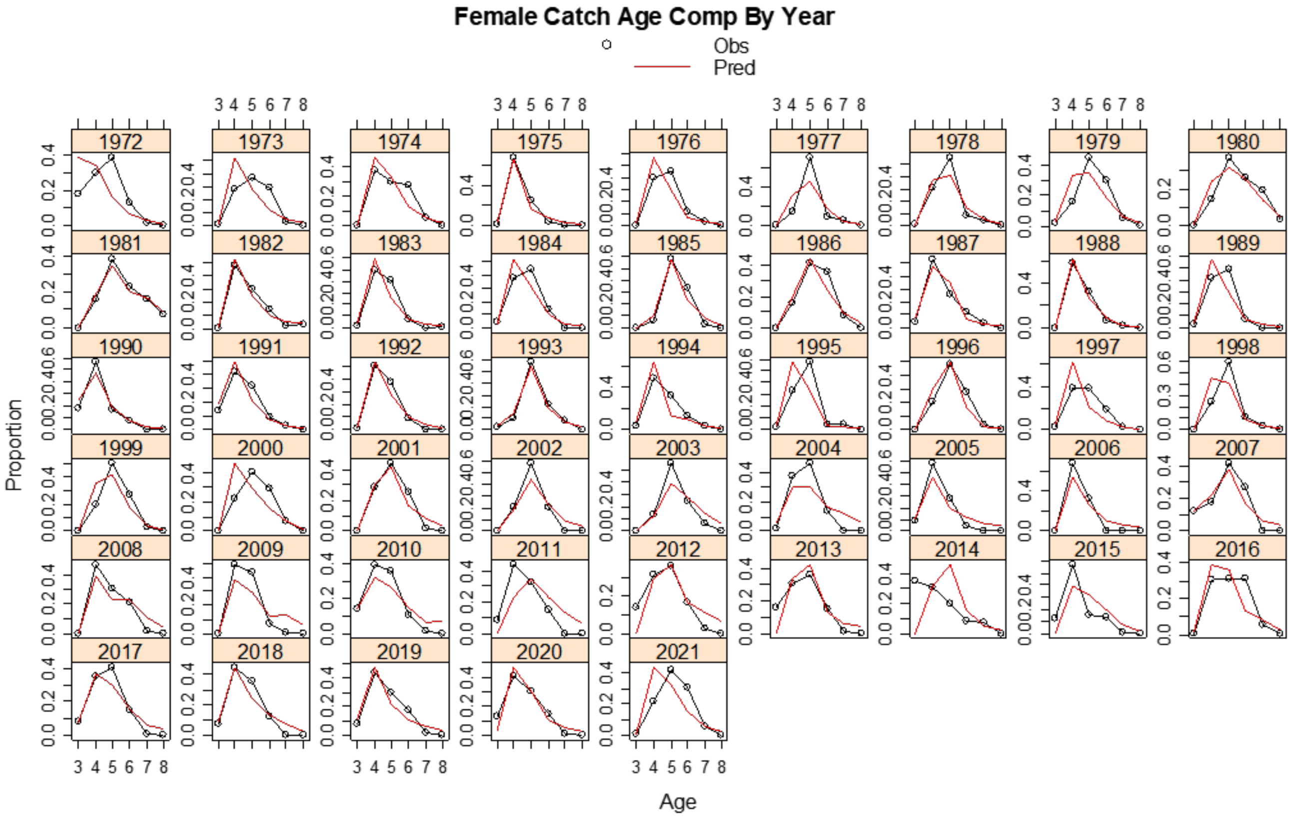


Figure 16.10. Comparison of total catch, YOY index and Gillnet index observed and predicted values and standardized residuals for Chowan River blueback herring.



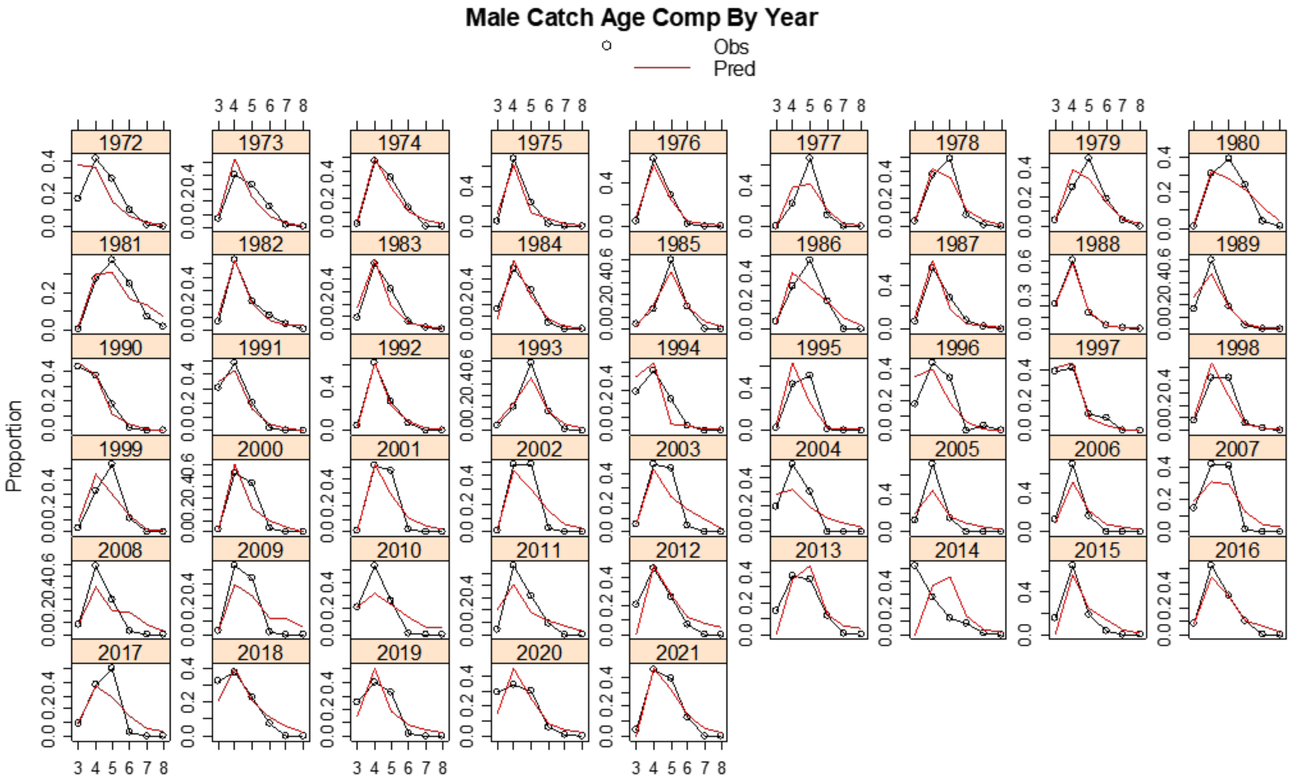
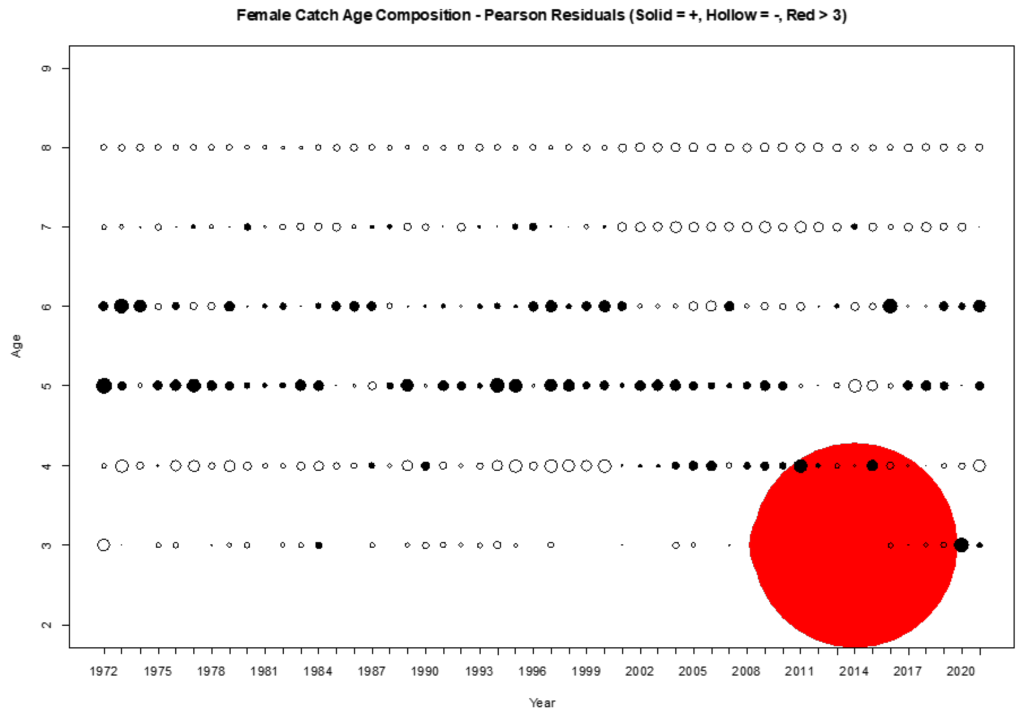


Figure 16.11. Observed and predicted catch age composition (proportions) for Chowan River blueback herring by sex, age, and year.



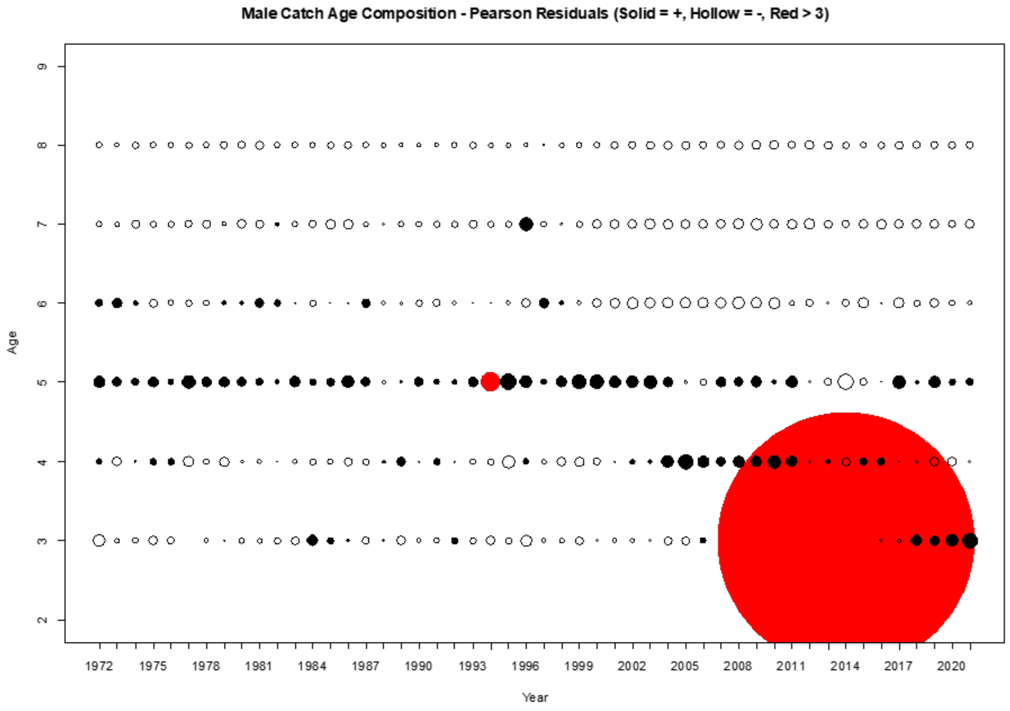


Figure 16.12. Bubble plots of standardized residuals of catch age composition by sex, year, age.

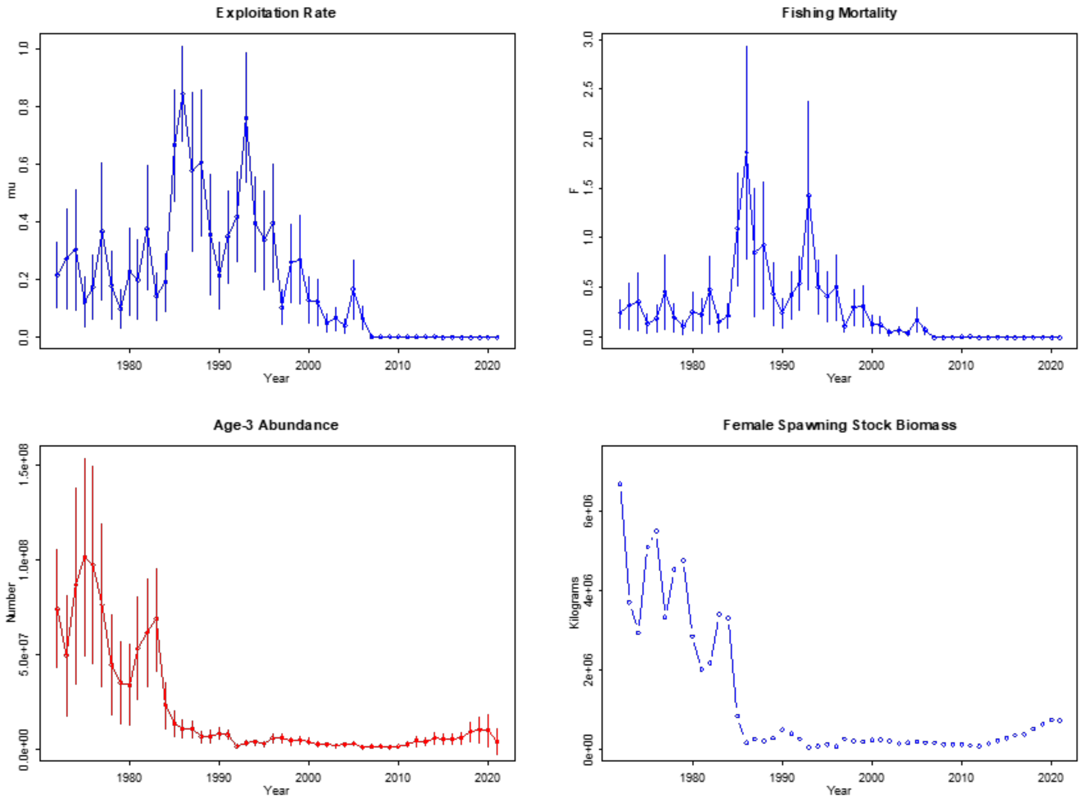


Figure 16.13. Estimates of exploitation rates, derived fishing mortality rates, recruitment (age-3 numbers), and estimates of female spawning stock biomass (in kilograms) for Chowan River blueback herring. Vertical lines, where present, represent 95% confidence intervals.

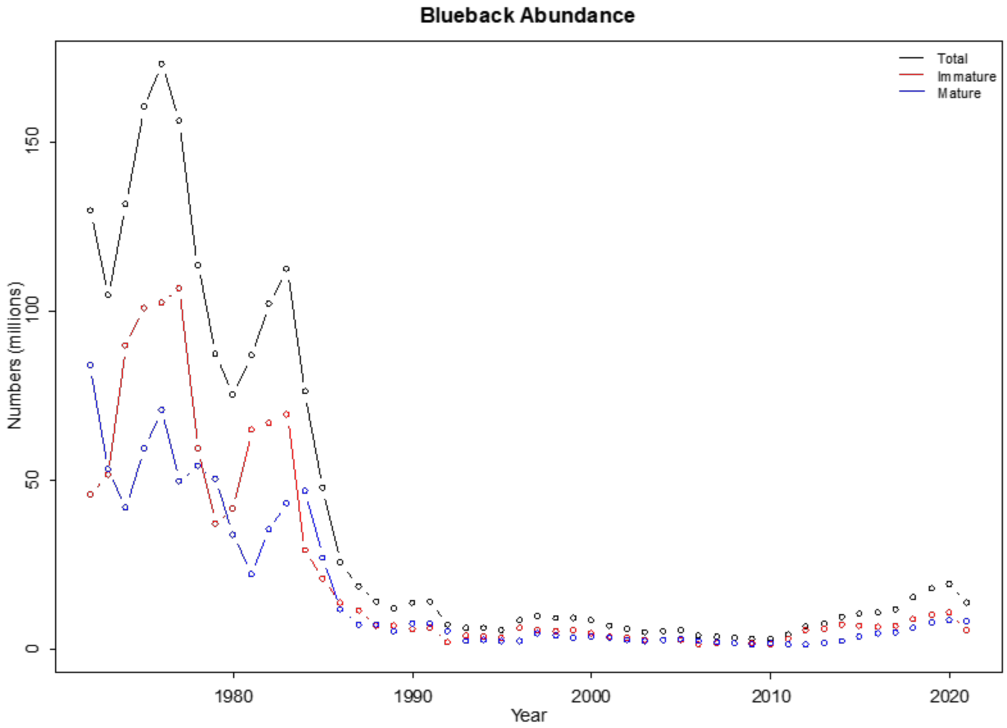


Figure 16.14. Population abundance (3+) estimates of the Chowan River blueback stock. Abundances are shown for immature and mature fish (sexes combined) and the total population.

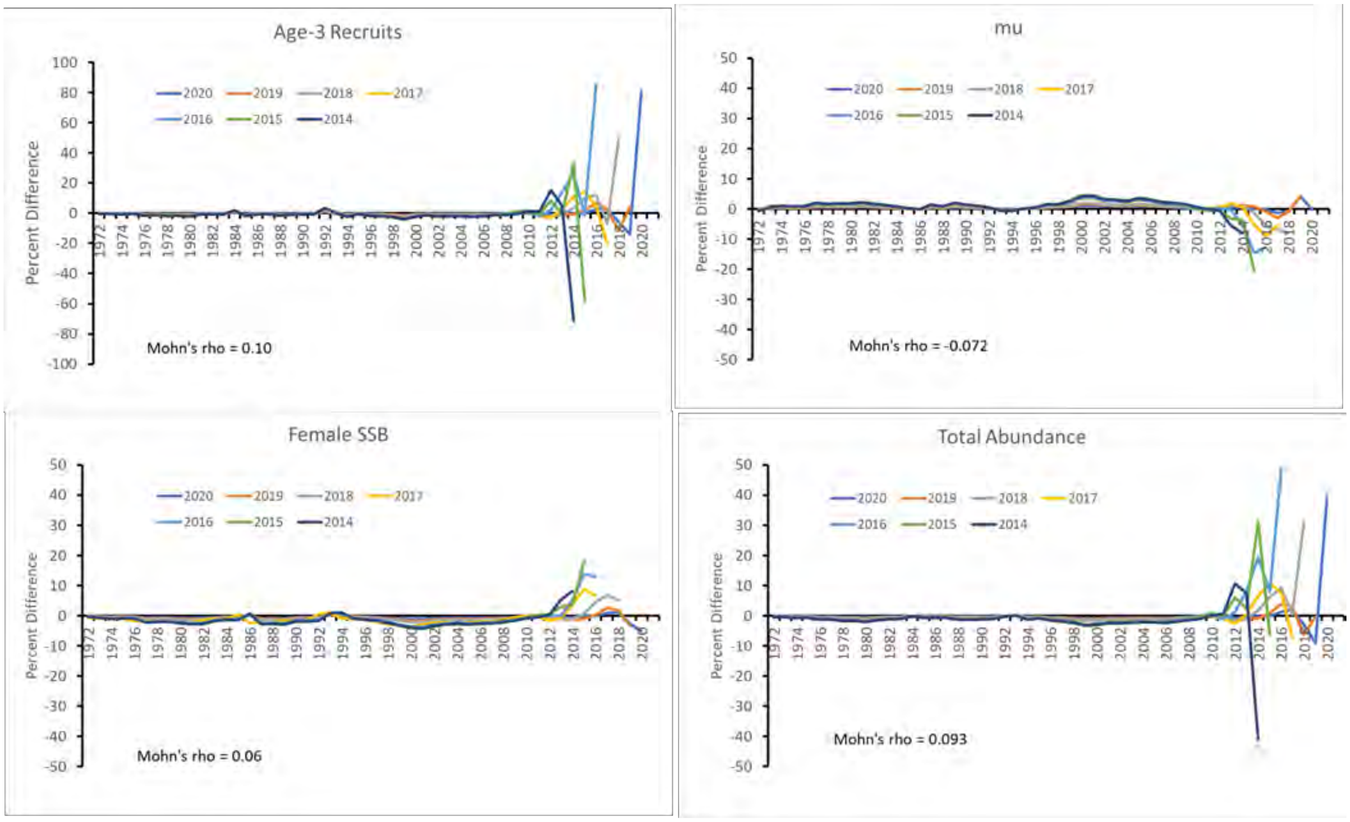
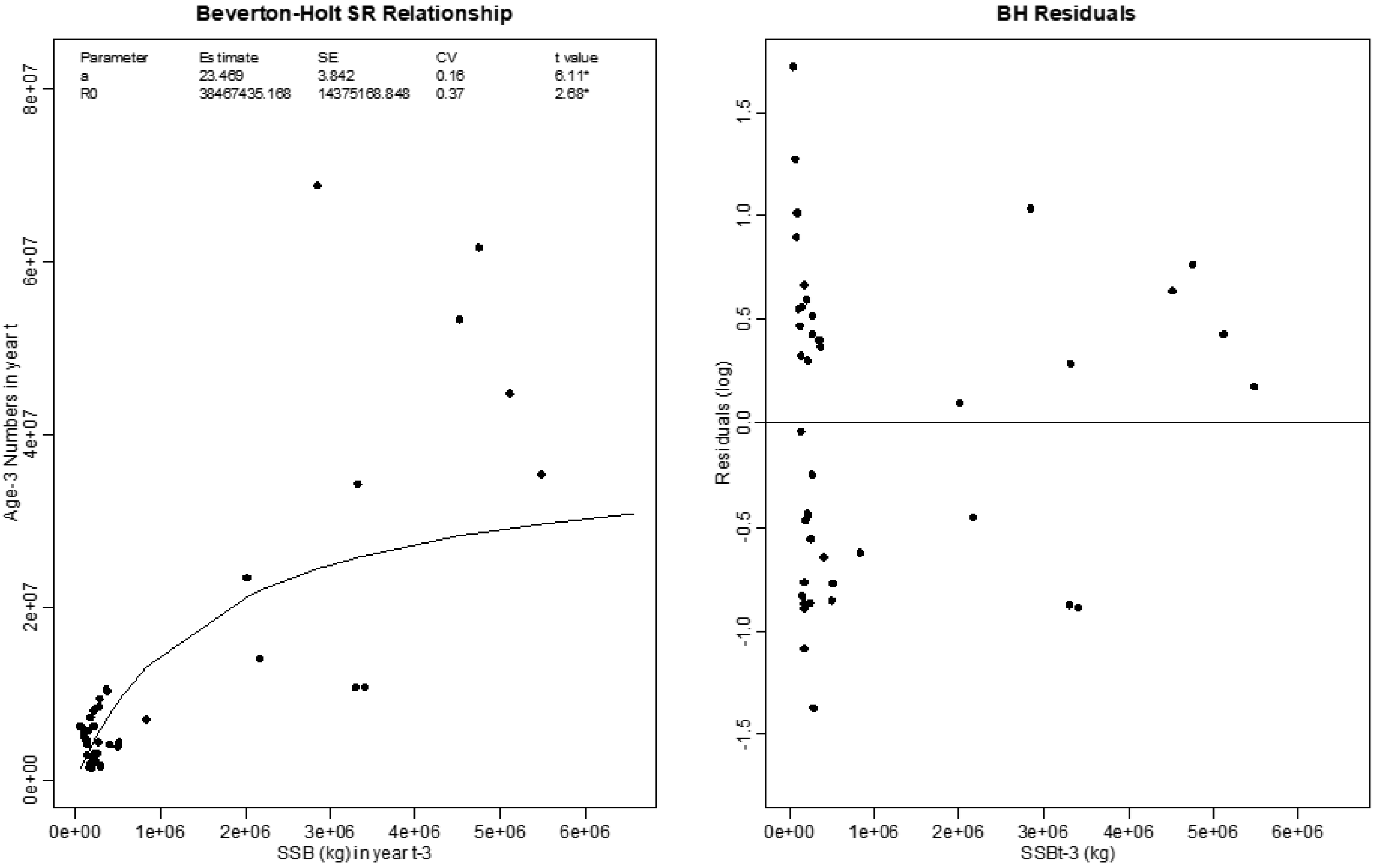


Figure 16.15. Retrospective analyses for age-3 abundance, exploitation rate, female spawning stock biomass, and total population abundance.



Parameter	Estimate	SE	CV	t value
a	23.469	3.842	0.16	6.11*
R0	38467435.168	14375168.848	0.37	2.68*

Figure 16.16. Fit of the Beverton-Holt stock-recruitment relationship to the age-3 abundance and female spawning stock biomass. Estimates of parameters *a* and R_0 from the Beverton-Holt equation are provided in the first graph, and residuals for the model fit are shown in the second graph.

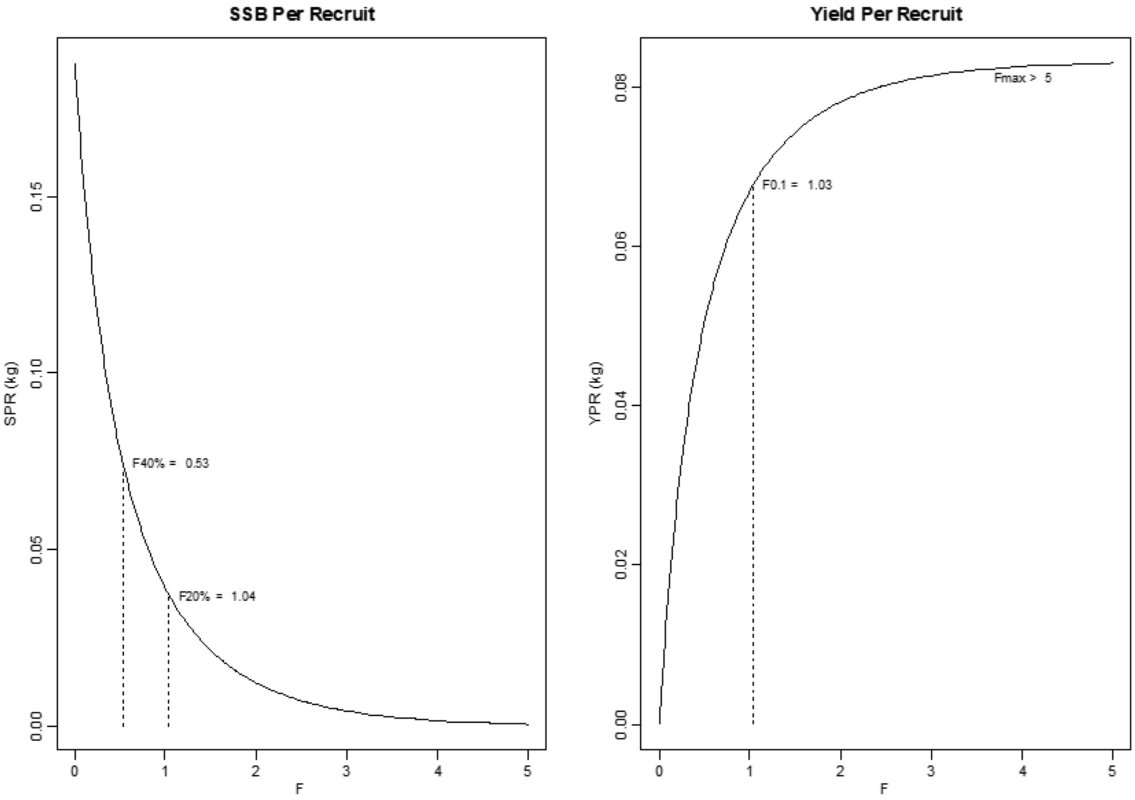


Figure 16.17. Results of spawning biomass per recruit and yield-per-recruit and analyses for the Chowan River blueback herring stock.

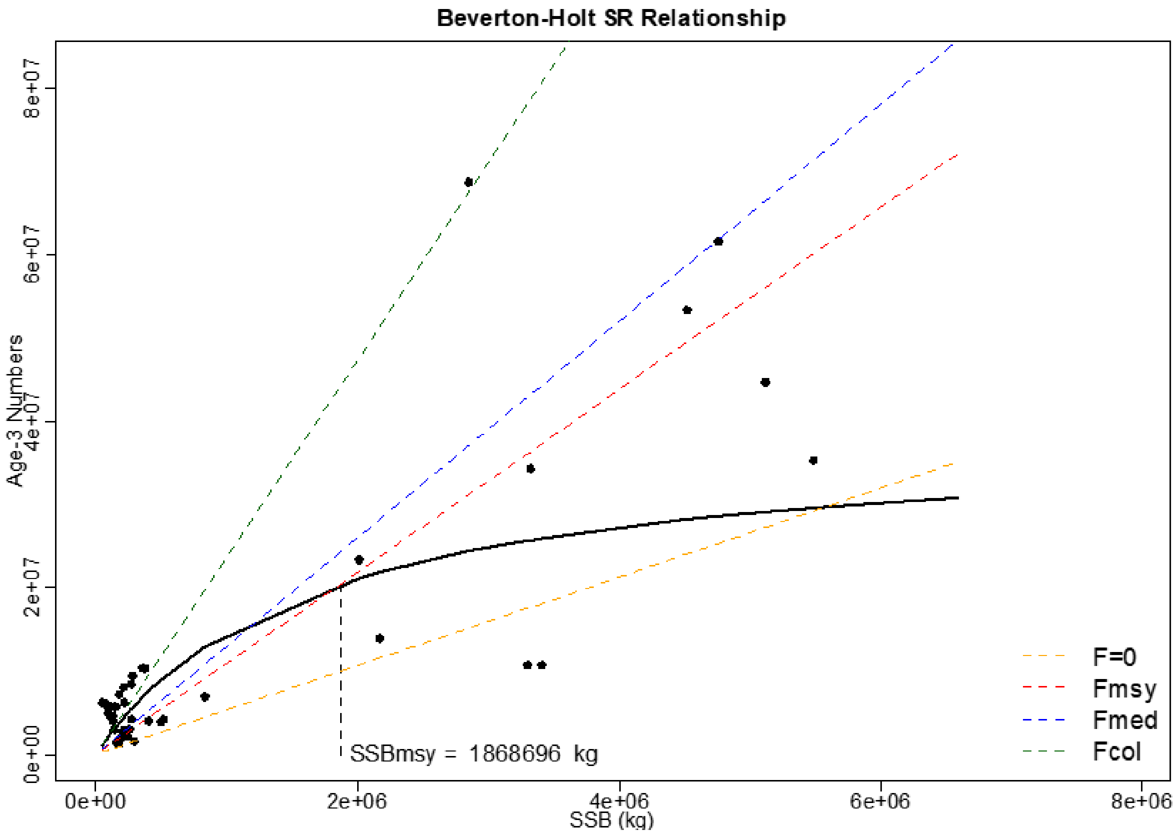


Figure 160.18. Beverton-Holt spawner-recruit model and production model reference points (see text) for the Chowan River blueback herring stock. Also shown is the replacement line in absence of fishing mortality (F=0).

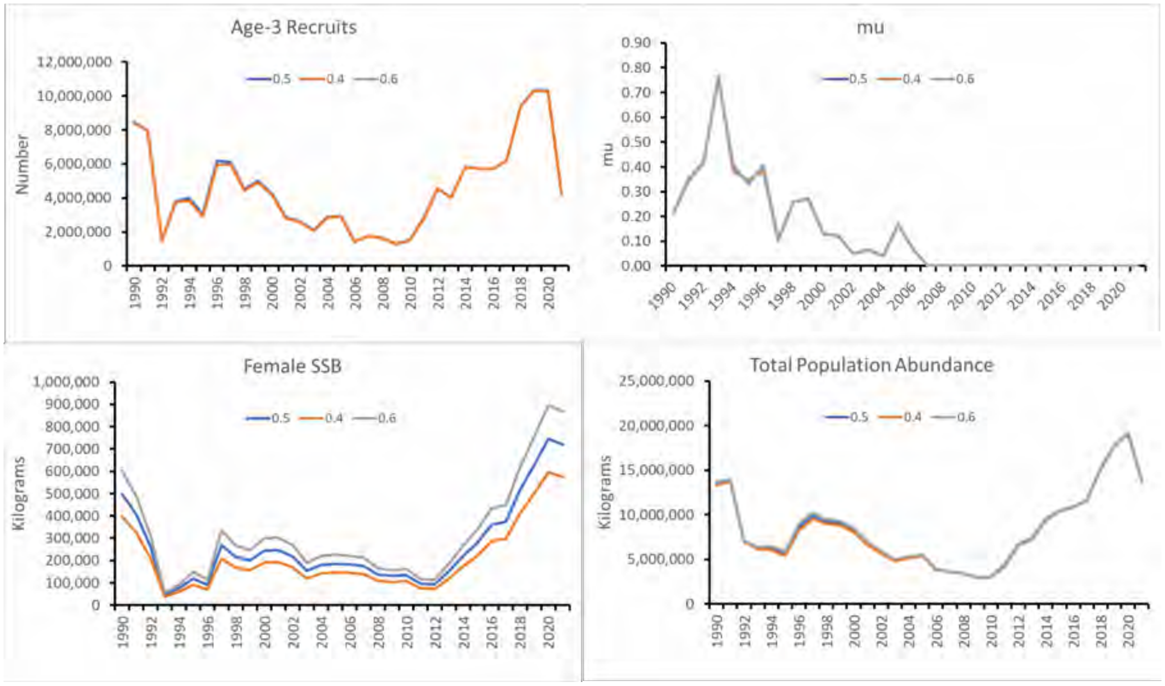


Figure 16.19. Results of sensitivity analysis of input age-3 sex ratio. Base model ratio = 0.5.

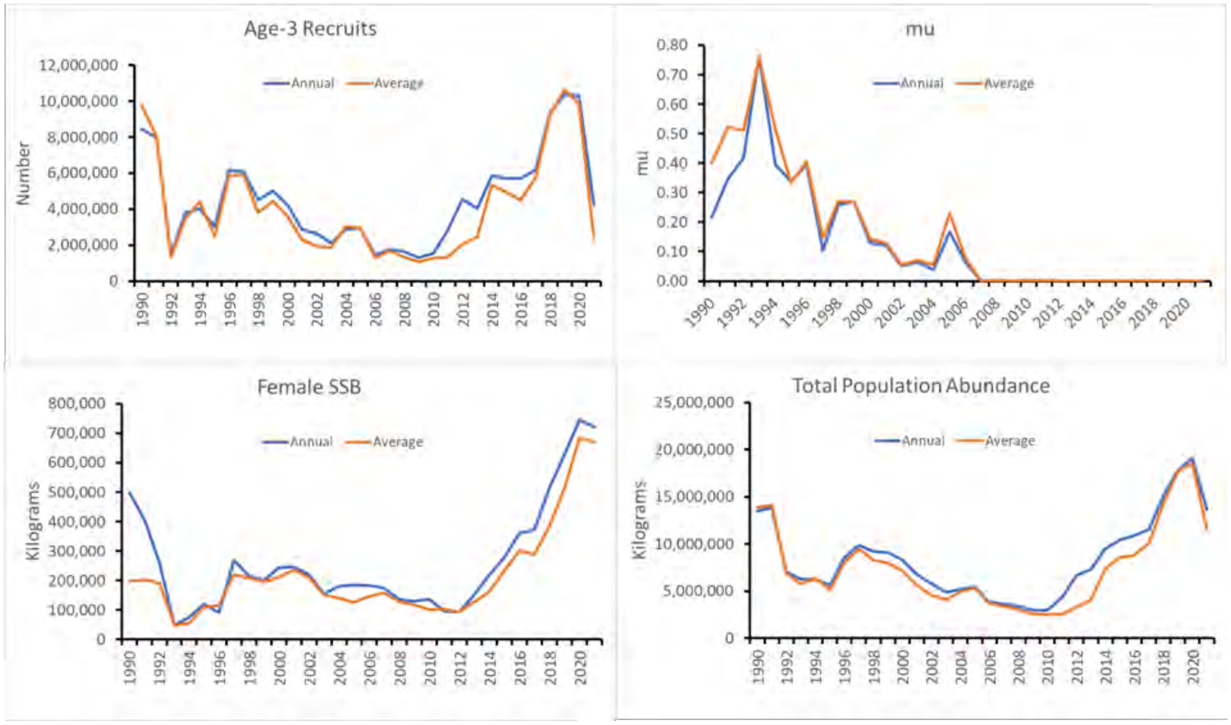


Figure 16.20. Results of sensitivity analysis of female and male proportions mature-at-age using annual estimates (base model) or time-series averages.

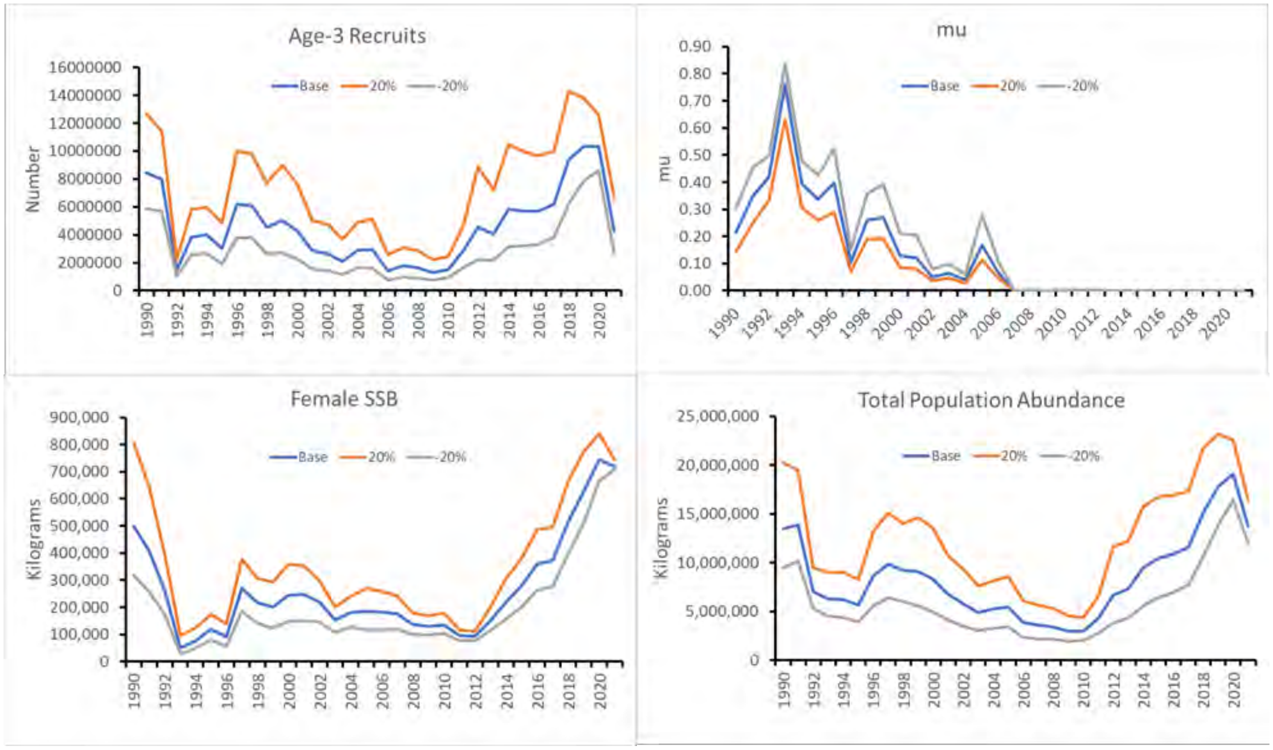


Figure 16.21. Results of sensitivity analysis of changing input sex- and age-specific natural mortality by ±20%.

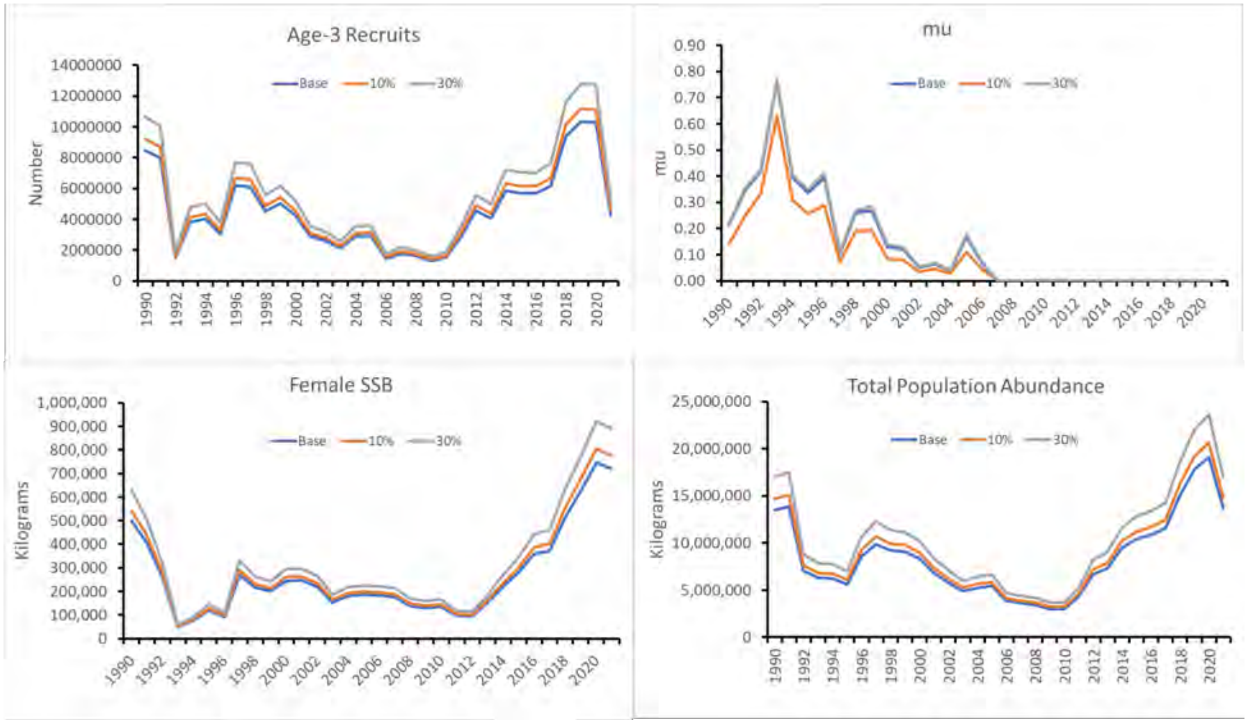


Figure 16.22. Results of sensitivity analysis of total catch. Total catch for 1990-2021 was increased by 10% and 30%.

Appendix Table 16.1. Estimates of proportion mature-at-age for female and male blueback herring in the Chowan river by year.

Female

Year	3	4	5	6	7	8
1972	0.440	0.809	0.979	1.000	1.000	1.000
1973	0.012	0.654	0.963	1.000	1.000	1.000
1974	0.000	0.766	0.961	1.000	1.000	1.000
1975	0.022	0.925	1.000	1.000	1.000	1.000
1976	0.016	0.748	1.000	1.000	1.000	1.000
1977	0.000	0.321	0.993	1.000	1.000	1.000
1978	0.010	0.525	0.990	1.000	1.000	1.000
1979	0.046	0.762	0.992	1.000	1.000	1.000
1980	0.009	0.431	0.950	0.995	1.000	1.000
1981	0.000	0.226	0.865	1.000	1.000	1.000
1982	0.010	0.654	1.000	1.000	1.000	1.000
1983	0.020	0.765	1.000	1.000	1.000	1.000
1984	0.042	0.684	1.000	1.000	1.000	1.000
1985	0.000	0.205	1.000	1.000	1.000	1.000
1986	0.000	0.322	0.978	1.000	1.000	1.000
1987	0.049	0.654	0.988	1.000	1.000	1.000
1988	0.000	0.768	1.000	1.000	1.000	1.000
1989	0.023	0.814	1.000	1.000	1.000	1.000
1990	0.191	0.910	1.000	1.000	1.000	1.000
1991	0.160	0.860	1.000	1.000	1.000	1.000
1992	0.056	0.710	1.000	1.000	1.000	1.000
1993	0.024	0.452	0.976	1.000	1.000	1.000
1994	0.032	0.613	1.000	1.000	1.000	1.000
1995	0.020	0.653	1.000	1.000	1.000	1.000
1996	0.000	0.300	0.980	1.000	1.000	1.000
1997	0.026	0.658	0.987	1.000	1.000	1.000
1998	0.000	0.539	0.991	1.000	1.000	1.000
1999	0.000	0.506	0.996	1.000	1.000	1.000
2000	0.000	0.622	0.961	1.000	1.000	1.000
2001	0.004	0.407	0.996	1.000	1.000	1.000
2002	0.000	0.305	1.000	1.000	1.000	1.000
2003	0.000	0.177	0.990	1.000	1.000	1.000
2004	0.042	0.632	1.000	1.000	1.000	1.000
2005	0.101	0.881	1.000	1.000	1.000	1.000
2006	0.000	0.855	1.000	1.000	1.000	1.000
2007	0.127	0.582	1.000	1.000	1.000	1.000
2008	0.000	0.672	0.981	1.000	1.000	1.000
2009	0.000	0.724	1.000	1.000	1.000	1.000
2010	0.150	0.793	1.000	1.000	1.000	1.000
2011	0.000	0.159	0.976	1.000	1.000	1.000
2012	0.000	0.216	0.966	1.000	1.000	1.000
2013	0.000	0.240	0.900	1.000	1.000	1.000
2014	0.000	0.378	0.919	1.000	1.000	1.000
2015	0.000	0.433	0.979	1.000	1.000	1.000
2016	0.015	0.566	0.977	1.000	1.000	1.000
2017	0.062	0.634	0.999	0.999	1.000	1.000
2018	0.059	0.860	0.929	1.001	1.000	1.000
2019	0.078	0.724	1.000	1.000	1.000	1.000
2020	0.023	0.699	1.000	1.000	1.000	1.000
2021	0.010	0.693	0.970	1.000	1.000	1.000

Male

Year	3	4	5	6	7	8
1972	0.419	0.869	0.996	1.000	1.000	1.000
1973	0.109	0.861	1.000	1.000	1.000	1.000
1974	0.019	0.897	1.000	1.000	1.000	1.000
1975	0.079	0.868	1.000	1.000	1.000	1.000
1976	0.076	0.856	1.000	1.000	1.000	1.000
1977	0.000	0.354	1.000	1.000	1.000	1.000
1978	0.063	0.627	0.984	1.000	1.000	1.000
1979	0.063	0.893	1.000	1.000	1.000	1.000
1980	0.023	0.630	0.977	1.000	1.000	1.000
1981	0.009	0.411	0.963	1.000	1.000	1.000
1982	0.071	0.764	1.000	1.000	1.000	1.000
1983	0.113	0.887	1.000	1.000	1.000	1.000
1984	0.163	0.801	1.000	1.000	1.000	1.000
1985	0.039	0.457	1.000	1.000	1.000	1.000
1986	0.046	0.713	0.991	1.000	1.000	1.000
1987	0.070	0.876	1.000	1.000	1.000	1.000
1988	0.245	0.945	1.000	1.000	1.000	1.000
1989	0.222	0.940	1.000	1.000	1.000	1.000
1990	0.464	0.982	1.000	1.000	1.000	1.000
1991	0.360	0.928	0.993	1.000	1.000	1.000
1992	0.097	0.968	0.995	1.000	1.000	1.000
1993	0.047	0.756	1.000	1.000	1.000	1.000
1994	0.327	0.923	1.000	1.000	1.000	1.000
1995	0.039	0.789	1.000	1.000	1.000	1.000
1996	0.190	0.914	1.000	1.000	1.000	1.000
1997	0.389	0.917	1.000	1.000	1.000	1.000
1998	0.104	0.797	0.990	1.000	1.000	1.000
1999	0.058	0.764	1.000	1.000	1.000	1.000
2000	0.023	0.957	1.000	1.000	1.000	1.000
2001	0.021	0.904	1.000	1.000	1.000	1.000
2002	0.022	0.934	1.000	1.000	1.000	1.000
2003	0.075	0.936	1.000	1.000	1.000	1.000
2004	0.299	0.965	1.000	1.000	1.000	1.000
2005	0.220	0.984	1.000	1.000	1.000	1.000
2006	0.170	0.936	1.000	1.000	1.000	1.000
2007	0.234	0.964	1.000	1.000	1.000	1.000
2008	0.081	0.719	0.990	1.000	1.000	1.000
2009	0.027	0.680	1.000	1.000	1.000	1.000
2010	0.238	0.852	1.000	1.000	1.000	1.000
2011	0.129	0.978	1.000	1.000	1.000	1.000
2012	0.000	0.383	1.000	1.000	1.000	1.000
2013	0.000	0.241	0.944	1.000	1.000	1.000
2014	0.000	0.474	1.000	1.000	1.000	1.000
2015	0.000	0.796	1.000	1.000	1.000	1.000
2016	0.075	0.776	0.999	0.999	1.000	1.000
2017	0.076	0.610	1.000	1.000	1.000	1.000
2018	0.143	0.868	1.000	1.000	1.000	1.000
2019	0.120	0.893	1.000	1.000	1.000	1.000
2020	0.132	0.801	1.000	1.000	1.000	1.000
2021	0.007	0.693	0.940	1.001	1.000	1.000

Appendix Table 16.2. Estimates of total removals (in numbers) for blueback herring in the Chowan River used in the base model run.

Year	Numbers
1972	20,443,867
1973	13,918,880
1974	12,141,597
1975	7,286,423
1976	12,121,822
1977	16,831,692
1978	9,762,107
1979	4,921,229
1980	7,617,940
1981	4,360,204
1982	12,658,422
1983	5,955,402
1984	9,023,870
1985	18,364,344
1986	10,997,451
1987	3,664,782
1988	4,162,095
1989	1,772,115
1990	1,612,157
1991	2,545,614
1992	2,281,605
1993	1,763,114
1994	1,380,804
1995	814,048
1996	1,043,026
1997	468,830
1998	1,105,760
1999	948,791
2000	436,067
2001	363,260
2002	133,659
2003	143,201
2004	102,534
2005	447,376
2006	153,862
2007	1,325
2008	1,808
2009	970
2010	2,658
2011	2,125
2012	991
2013	1,051
2014	1,644
2015	589
2016	456
2017	528
2018	1,232
2019	858
2020	733
2021	525

Appendix Table 16.3. Number of Chowan River blueback samples from pound nets aged by sex, year, and age.

Female

Year	3	4	5	6	7	8
1972	25	42	54	18	2	0
1973	1	23	30	24	3	0
1974	0	29	23	21	4	0
1975	2	63	23	4	1	0
1976	1	49	55	14	4	0
1977	0	20	98	14	7	1
1978	1	31	55	8	4	0
1979	3	21	58	39	8	1
1980	0	32	80	57	41	8
1981	0	50	122	73	50	23
1982	1	49	31	15	3	4
1983	2	50	42	7	0	1
1984	4	36	42	13	0	0
1985	0	5	48	28	2	0
1986	0	14	37	32	7	0
1987	4	43	21	10	3	0
1988	0	48	27	5	2	0
1989	1	18	21	3	0	0
1990	16	51	15	7	0	0
1991	14	42	32	9	3	0
1992	1	55	41	10	0	0
1993	1	4	25	9	3	0
1994	1	15	10	4	1	0
1995	1	16	28	2	2	0
1996	0	10	24	14	2	0
1997	2	29	29	14	2	0
1998	0	131	321	60	17	0
1999	0	50	125	67	7	0
2000	0	58	102	74	19	1
2001	1	72	111	64	5	0
2002	0	29	82	29	1	0
2003	0	13	53	24	6	0
2004	2	36	44	13	0	0
2005	15	98	47	8	0	0
2006	0	37	18	0	0	0
2007	7	10	23	15	0	0
2008	0	148	98	66	5	0
2009	0	105	93	15	1	0
2010	30	83	76	22	2	0
2011	7	35	26	12	0	0
2012	12	27	31	14	2	0
2013	16	30	36	15	1	0
2014	25	22	14	6	5	0
2015	12	54	15	13	1	0
2016	1	34	35	35	6	1
2017	10	44	51	19	1	0
2018	9	52	41	14	0	0
2019	11	61	42	25	2	0
2020	17	53	40	19	1	0
2021	1	20	38	28	5	0

Male

Year	3	4	5	6	7	8
1972	46	112	78	28	3	0
1973	16	93	76	38	5	2
1974	3	74	55	22	1	0
1975	6	77	27	3	1	0
1976	12	147	69	7	1	0
1977	0	39	115	20	1	0
1978	5	47	62	11	1	0
1979	12	66	116	48	11	0
1980	2	66	85	53	9	2
1981	3	97	131	87	25	7
1982	10	74	31	16	7	2
1983	19	108	65	11	1	0
1984	23	68	44	6	0	0
1985	5	22	76	24	0	0
1986	5	32	51	20	0	0
1987	8	73	36	10	2	0
1988	36	99	23	4	1	0
1989	20	70	23	4	0	0
1990	48	41	20	2	0	0
1991	42	68	27	2	0	0
1992	9	116	49	12	1	0
1993	4	17	50	14	1	0
1994	15	23	12	2	0	0
1995	2	33	40	1	0	0
1996	10	26	20	0	2	0
1997	14	15	4	3	0	0
1998	30	163	163	23	6	0
1999	9	101	167	35	1	0
2000	15	383	316	24	1	0
2001	3	170	155	7	0	0
2002	2	86	87	6	0	0
2003	9	80	76	8	0	0
2004	27	73	43	1	0	0
2005	16	89	18	0	0	0
2006	12	66	16	0	0	0
2007	25	70	69	3	0	0
2008	49	358	181	20	0	0
2009	7	174	142	5	0	0
2010	123	310	149	6	0	0
2011	3	51	29	8	0	0
2012	20	44	25	6	0	0
2013	17	42	39	13	1	0
2014	65	35	15	10	1	0
2015	13	57	16	3	0	0
2016	9	59	33	12	0	0
2017	11	47	63	4	0	0
2018	51	59	35	11	0	0
2019	34	54	44	3	0	0
2020	36	42	37	7	1	0
2021	5	58	50	16	0	0

Appendix Table 16.4. Young-of-the-year blueback herring seine and adult gillnet indices by year. -1 = not used. The YOY 1994 and 2016 values were not used because the model could not reconcile zero YOY fish. The gillnet 2020 and 2021 were missing due to COVID restrictions.

YOY seine Index

Year	Geo Mean
1972	8.63
1973	34.52
1974	7.70
1975	11.08
1976	5.52
1977	11.32
1978	7.76
1979	9.90
1980	15.57
1981	0.25
1982	7.58
1983	3.80
1984	1.75
1985	2.47
1986	1.16
1987	1.25
1988	0.95
1989	0.02
1990	0.99
1991	0.40
1992	0.10
1993	0.79
1994	-1.00
1995	0.29
1996	0.90
1997	0.81
1998	0.13
1999	0.18
2000	0.38
2001	0.58
2002	0.19
2003	0.36
2004	0.90
2005	0.56
2006	0.09
2007	0.06
2008	0.17
2009	0.10
2010	0.09
2011	0.06
2012	0.10
2013	0.72
2014	0.15
2015	0.56
2016	-1.00
2017	0.27
2018	0.10
2019	2.56
2020	0.19
2021	0.22

Gillnet Index

Year	Arth Mean
1972	-1.00
1973	-1.00
1974	-1.00
1975	-1.00
1976	-1.00
1977	-1.00
1978	-1.00
1979	-1.00
1980	-1.00
1981	-1.00
1982	-1.00
1983	-1.00
1984	-1.00
1985	-1.00
1986	-1.00
1987	-1.00
1988	-1.00
1989	-1.00
1990	-1.00
1991	10.21
1992	5.83
1993	3.29
1994	1.21
1995	5.17
1996	2.96
1997	6.41
1998	4.67
1999	4.85
2000	7.69
2001	5.09
2002	2.89
2003	4.19
2004	3.32
2005	3.21
2006	4.49
2007	3.06
2008	1.67
2009	2.24
2010	1.60
2011	1.11
2012	0.86
2013	4.52
2014	2.68
2015	5.58
2016	6.09
2017	5.26
2018	8.10
2019	7.77
2020	-1.00
2021	-1.00

Appendix Table 16.5. Female weights-at-age (kg). Color indicates that values were estimated from observed values from other years.

Year	3	4	5	6	7	8
1972	0.19	0.20	0.21	0.22	0.21	0.29
1973	0.15	0.19	0.21	0.24	0.27	0.29
1974	0.15	0.19	0.21	0.24	0.27	0.29
1975	0.15	0.19	0.21	0.24	0.27	0.29
1976	0.15	0.19	0.21	0.24	0.27	0.29
1977	0.15	0.19	0.21	0.24	0.27	0.29
1978	0.15	0.19	0.21	0.24	0.27	0.29
1979	0.15	0.19	0.21	0.24	0.27	0.29
1980	0.15	0.19	0.21	0.24	0.27	0.29
1981	0.15	0.20	0.23	0.26	0.26	0.29
1982	0.13	0.19	0.22	0.24	0.27	0.27
1983	0.14	0.18	0.22	0.26	0.27	0.32
1984	0.13	0.17	0.19	0.22	0.27	0.29
1985	0.13	0.17	0.18	0.21	0.23	0.29
1986	0.13	0.16	0.20	0.22	0.24	0.29
1987	0.13	0.16	0.19	0.21	0.25	0.29
1988	0.13	0.15	0.18	0.22	0.22	0.29
1989	0.14	0.17	0.21	0.24	0.27	0.29
1990	0.16	0.19	0.18	0.25	0.25	0.29
1991	0.13	0.16	0.22	0.24	0.33	0.29
1992	0.14	0.16	0.19	0.21	0.27	0.29
1993	0.10	0.15	0.17	0.17	0.22	0.29
1994	0.12	0.13	0.14	0.24	0.18	0.29
1995	0.12	0.15	0.16	0.20	0.30	0.29
1996	0.13	0.19	0.19	0.22	0.24	0.29
1997	0.11	0.16	0.25	0.25	0.33	0.29
1998	0.12	0.15	0.16	0.19	0.24	0.29
1999	0.13	0.16	0.18	0.17	0.20	0.29
2000	0.13	0.15	0.18	0.18	0.22	0.29
2001	0.12	0.16	0.19	0.23	0.27	0.29
2002	0.13	0.16	0.19	0.22	0.22	0.29
2003	0.13	0.12	0.17	0.19	0.18	0.29
2004	0.12	0.14	0.15	0.19	0.24	0.29
2005	0.12	0.14	0.17	0.19	0.24	0.29
2006	0.13	0.15	0.16	0.20	0.24	0.29
2007	0.14	0.18	0.19	0.22	0.24	0.29
2008	0.13	0.14	0.16	0.20	0.24	0.29
2009	0.13	0.14	0.16	0.20	0.24	0.29
2010	0.13	0.14	0.16	0.2	0.24	0.29
2011	0.14	0.18	0.19	0.2	0.24	0.29
2012	0.13	0.14	0.17	0.18	0.24	0.29
2013	0.17	0.18	0.19	0.19	0.24	0.29
2014	0.16	0.19	0.17	0.19	0.24	0.29
2015	0.14	0.15	0.18	0.2	0.24	0.29
2016	0.13	0.15	0.18	0.19	0.19	0.30
2017	0.12	0.13	0.16	0.17	0.21	0.23
2018	0.13	0.15	0.17	0.20	0.28	0.30
2019	0.13	0.15	0.19	0.21	0.24	0.30
2020	0.13	0.16	0.21	0.23	0.30	0.30
2021	0.13	0.16	0.19	0.19	0.17	0.30

Appendix 5: Analyses Completed at the Review Workshop

Comparing the Results of the New Method to Calculate the Standard Error for the Poisson-GLM *Z* Estimates

The adjustment for overdispersion as implemented in the *fishmethods* package can result in infinite standard errors in situations where the degrees of freedom is equal to the number of age classes where the predicted value is greater than or equal to one. In this case, the denominator of the adjustment factor becomes zero and the adjusted standard error is infinite.

An alternative method of adjusting for overdispersion which would not become infinite was explored. The new adjustment looked at the ratio of the deviance of the Z estimate to the degrees of freedom; if the ratio was greater than one, it was assumed overdispersion was present and the square root of that ratio was used to adjust the SE. If the ratio was less than one, no adjustment to the SE was made. Although the final adjusted SE was always equal to or greater than the unadjusted SE from the Poisson GLM, the adjustment factor from this new method was generally lower than the adjustment factor implemented in *fishmethods*, resulting in SEs that were lower than the original estimates.

This translated to 28 rivers having a higher probability of being above $Z_{40\%SPR}$ and 29 having a lower probability compared to the original SE methods, with 7 having the same probability. Four of the five rivers that had infinite SEs in the original method generally had slightly lower probabilities, going from 1 to 0.97-0.99, although the Nemasket River remained at 100% probability of being above $Z_{40\%SPR}$ even with a finite SE. One, ME C10, went from having 49.6% probability of being above $Z_{40\%SPR}$ to having a 51.4% probability of being above the reference point. None of the other rivers went from being less than 50% to greater than 50% or vice-versa.

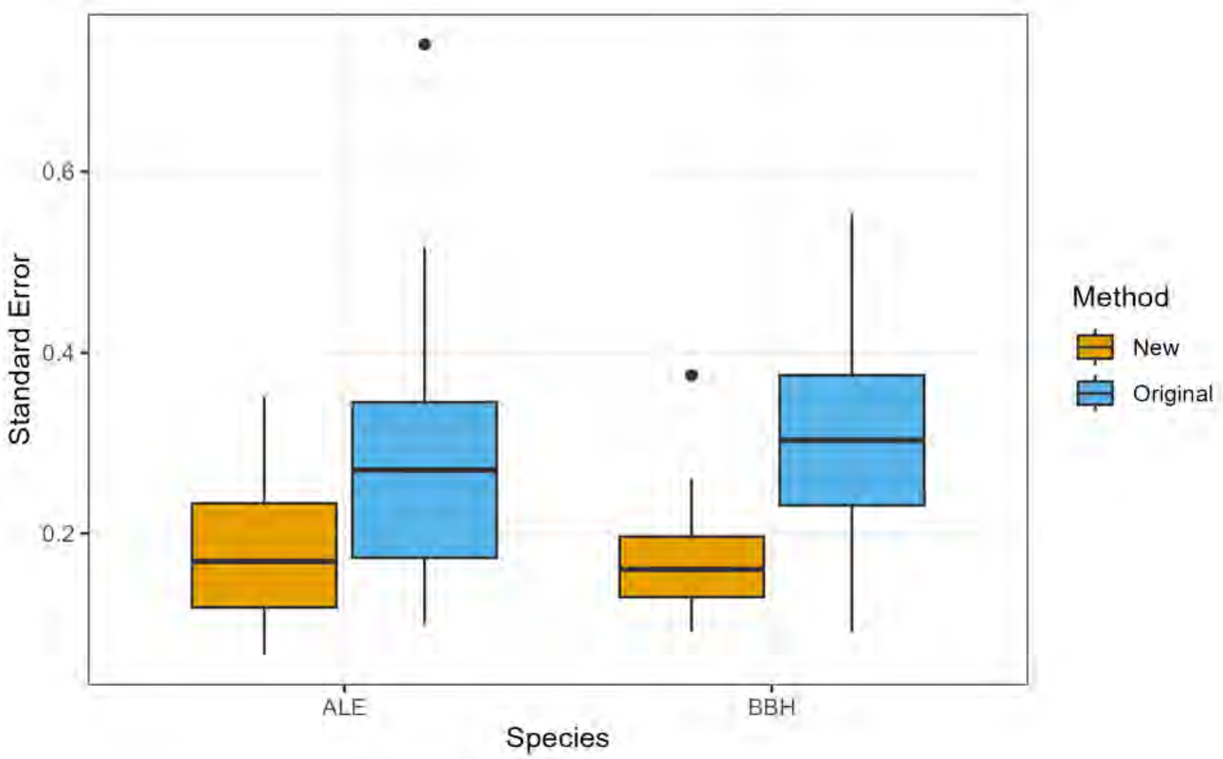


Figure 1. Distribution of standard error of Z estimates in the terminal year for the new method and the original method by species.

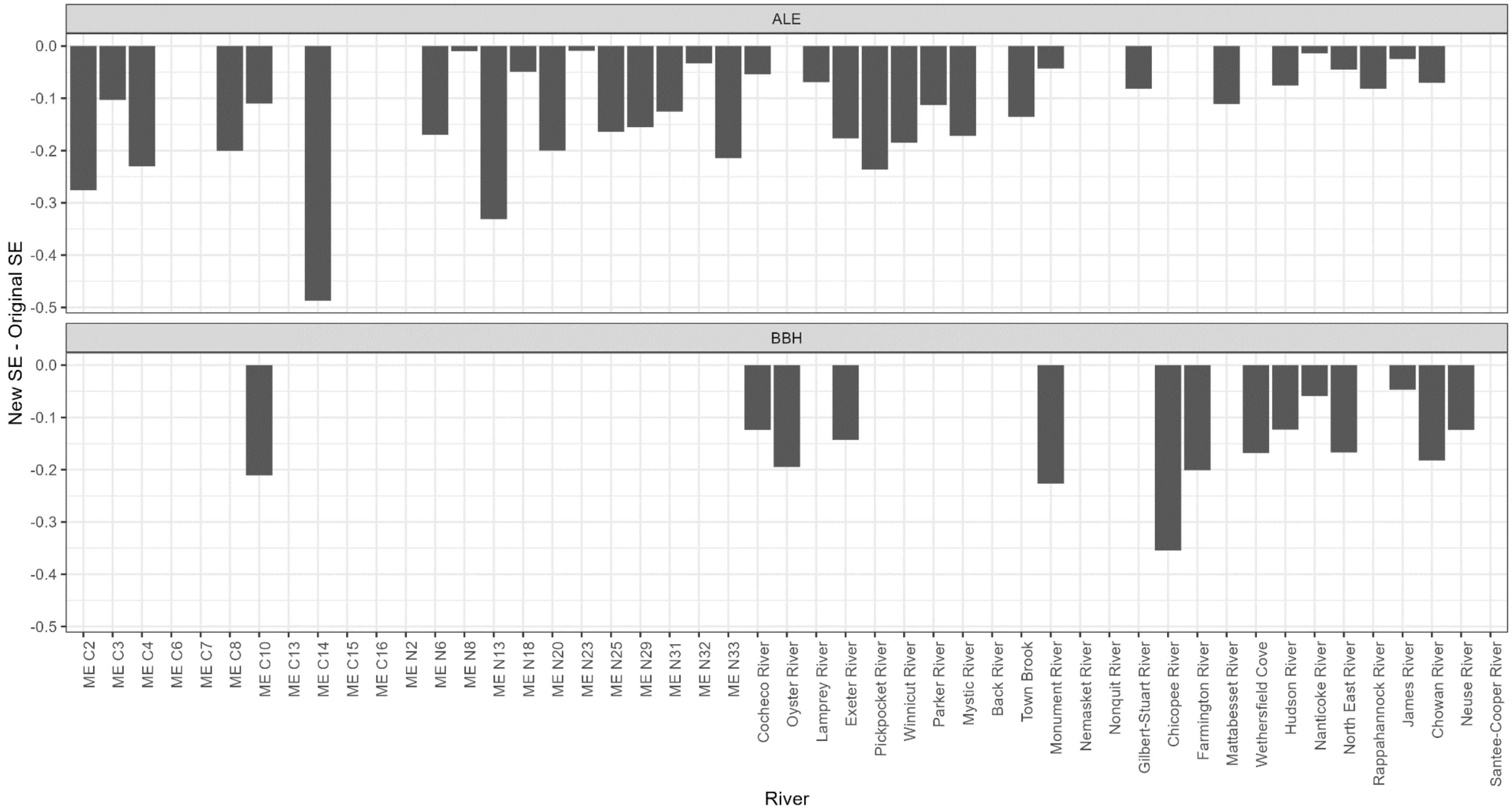


Figure 2. Difference in the standard error estimates for the new method compared to the original method by river. A negative value means the new value is smaller. Rivers are arranged north to south.

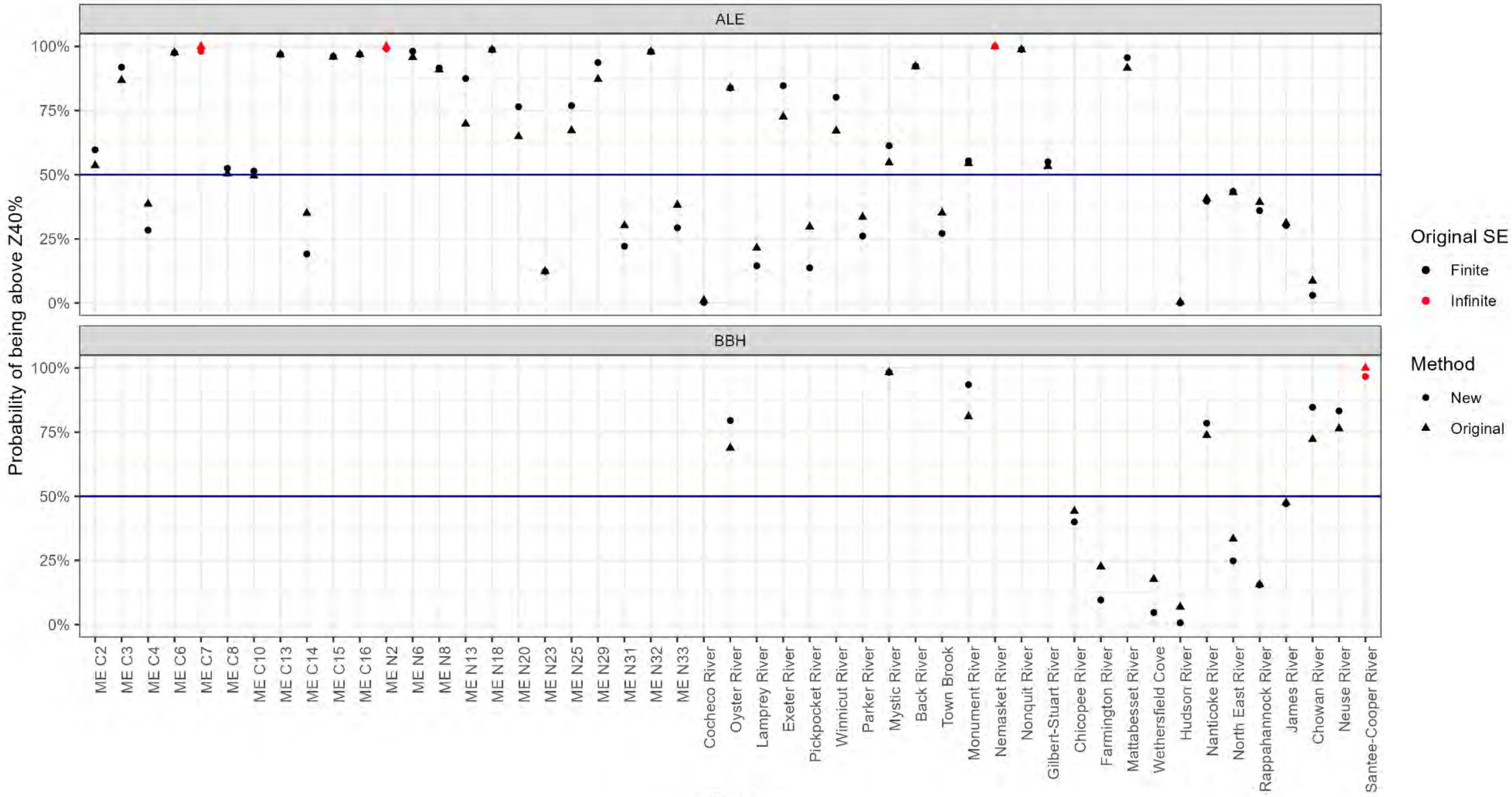


Figure 3. The probability of the terminal year Z being above the Z40% reference point using the new SEs and the original standard errors for each river. Rivers that had an infinite standard error using the original method are highlighted in red. Horizontal blue line indicates 50% probability. Rivers are arranged north to south.

Appendix 6: Survey Metadata Table

This table was not part of the original report, but was provided to the Review Panel at the workshop at their request. The “Survey ID” column corresponds to the survey numbers where used in figures.

Table 1. List of surveys used to assess river herring trends by species and waterbody.

Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
29	ME DMR Merrymeeting Bay Juvenile Alosine Survey	CAN-NNE	Merrymeeting Bay	YOY	Blueback	Delta mean	1982	2021
172	ME DMR Merrymeeting Bay Juvenile Alosine Survey	NNE	Merrymeeting Bay	YOY	Alewife	Delta mean	1982	2021
174	NH Juvenile Finfish Seine Survey	NNE	Great Bay and other	YOY	Alewife	Delta mean	1997	2021
170	NH Juvenile Finfish Seine Survey	MNE	Great Bay and other	YOY	Blueback	Delta mean	1997	2021
196	RI DEM Coastal Pond Survey	SNE	Narrow River	YOY	Alewife	Delta mean	1994	2022
32	NC DMF P135 Independent Gillnet Survey	MAT	Albermarle Sound	Adult	Alewife	Stratified arithmetic mean	1991	2019
34	NC DMF P135 Independent Gillnet Survey	MAT	Albermarle Sound	Adult	Blueback	Stratified arithmetic mean	1991	2019
35	NC DMF P100 Albemarle Sound Juvenile Seine Survey	MAT	Albermarle Sound	YOY	Blueback	Delta mean	1972	2021
37	NC DMF P100 Albemarle Sound Juvenile Seine Survey	MAT	Albermarle Sound	YOY	Alewife	Delta mean	1972	2021
39	NC DMF P100 Albemarle Sound Juvenile Trawl Survey	MAT	Albermarle Sound	Adult	Alewife	Delta mean	1982	2021
41	NC DMF P100 Albemarle Sound Juvenile Trawl Survey	MAT	Albermarle Sound	Adult	Blueback	Delta mean	1982	2021
43	NC DMF P150 River Herring Spawning Stock Survey	MAT	Chowan River	Adult	Blueback	Delta mean	2012	2021
45	VIMS River Herring Juvenile Surface Trawl Survey	MAT	Chickahominy River	YOY	Alewife	Delta mean	2014	2022
52	VIMS River Herring Juvenile Surface Trawl Survey	MAT	Chickahominy River	YOY	Blueback	Standardized	2014	2022

Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
57	MD DNR Estuarine Juvenile Finfish Survey	MAT	Head of Chesapeake Bay	YOY	Alewife	Delta mean	1959	2021
61	MD DNR Estuarine Juvenile Finfish Survey	MAT	Head of Chesapeake Bay	YOY	Blueback	Delta mean	1959	2021
65	VDGIF Electrofishing Survey	MAT	James River	Adult	Alewife	Arithmetic Mean - TC Provided	2000	2020
69	VIMS River Herring Adult Relative Abundance Monitoring Program	MAT	James River	Adult	Alewife	Standardized	2015	2021
73	VIMS River Herring Adult Relative Abundance Monitoring Program	MAT	James River	Adult	Blueback	Standardized	2015	2021
74	VIMS Juvenile Striped Bass Seine Survey	MAT	James River	YOY	Blueback	Delta mean	1967	2022
80	DE Juvenile Seine Survey	MAT	Nanticoke River	Juvenile	Alewife	Geometric mean	1999	2021
81	DE Juvenile Seine Survey	MAT	Nanticoke River	Juvenile	Blueback	Geometric mean	1999	2021
82	MD DNR Estuarine Juvenile Finfish Survey	MAT	Nanticoke River	YOY	Alewife	Delta mean	1959	2021
85	MD DNR Estuarine Juvenile Finfish Survey	MAT	Nanticoke River	YOY	Blueback	Delta mean	1959	2021
89	MD DNR Commercial Fyke Net Survey	MAT	Nanticoke River	Adult	Alewife	Geometric Mean - TC Provided	1990	2021
91	MD DNR Commercial Fyke Net Survey	MAT	Nanticoke River	Adult	Blueback	Geometric mean - TC Provided	1989	2021
93	MD DNR North East River Gillnet Survey	MAT	North East River	Adult	Alewife	Delta mean	2015	2021
96	MD DNR North East River Gillnet Survey	MAT	North East River	Adult	Blueback	Delta mean	2015	2021

Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
101	MD DNR Estuarine Juvenile Finfish Survey	MAT	Potomac River	YOY	Alewife	Delta mean	1959	2021
103	MD DNR Estuarine Juvenile Finfish Survey	MAT	Potomac River	YOY	Blueback	Delta mean	1959	2021
107	VA DWR Pushnet YOY Survey	MAT	Rappahannock River	YOY	Blueback	Delta mean	2005	2021
111	VDGIF Electrofishing Survey	MAT	Rappahannock River	Adult	Alewife	Arithmetic Mean - TC Provided	2000	2020
112	VDGIF Electrofishing Survey	MAT	Rappahannock River	Adult	Blueback	Arithmetic Mean - TC Provided	2000	2020
113	VIMS Juvenile Striped Bass Seine Survey	MAT	Rappahannock River	YOY	Blueback	Delta mean	1967	2022
117	NCWRC Chowan River Electrofishing Survey	MAT	Chowan River	Adult	Alewife	Delta mean	2006	2022
119	NCWRC Chowan River Electrofishing Survey	MAT	Chowan River	Adult	Blueback	Delta mean	2006	2022
121	Connecticut River Juvenile Seine Survey	MAT	Connecticut River	YOY	Blueback	Delta mean	1979	2021
122	USFWS Connecticut River Electrofishing Survey	MAT	Connecticut River	Adult	Blueback	Delta mean	2013	2022
125	DE 16ft Trawl Survey	MAT	Delaware Bay	Age-1	Alewife	Delta mean	1991	2021
127	DE 30ft Trawl Survey	MAT	Delaware Bay	Age-1	Alewife	Delta mean	1990	2021
130	DE 30ft Trawl Survey	MAT	Delaware Bay	Age-1	Blueback	Delta mean	1992	2021
133	NJ Juvenile Striped Bass Seine Survey	MAT	Delaware River	YOY	Alewife	Delta mean	1987	2021
137	NJ Juvenile Striped Bass Seine Survey	MAT	Delaware River	YOY	Blueback	Delta mean	1987	2021
148	NY DEC River Herring Spawning Stock Survey	MAT	Hudson River	Adult	Alewife	Delta mean	2012	2022

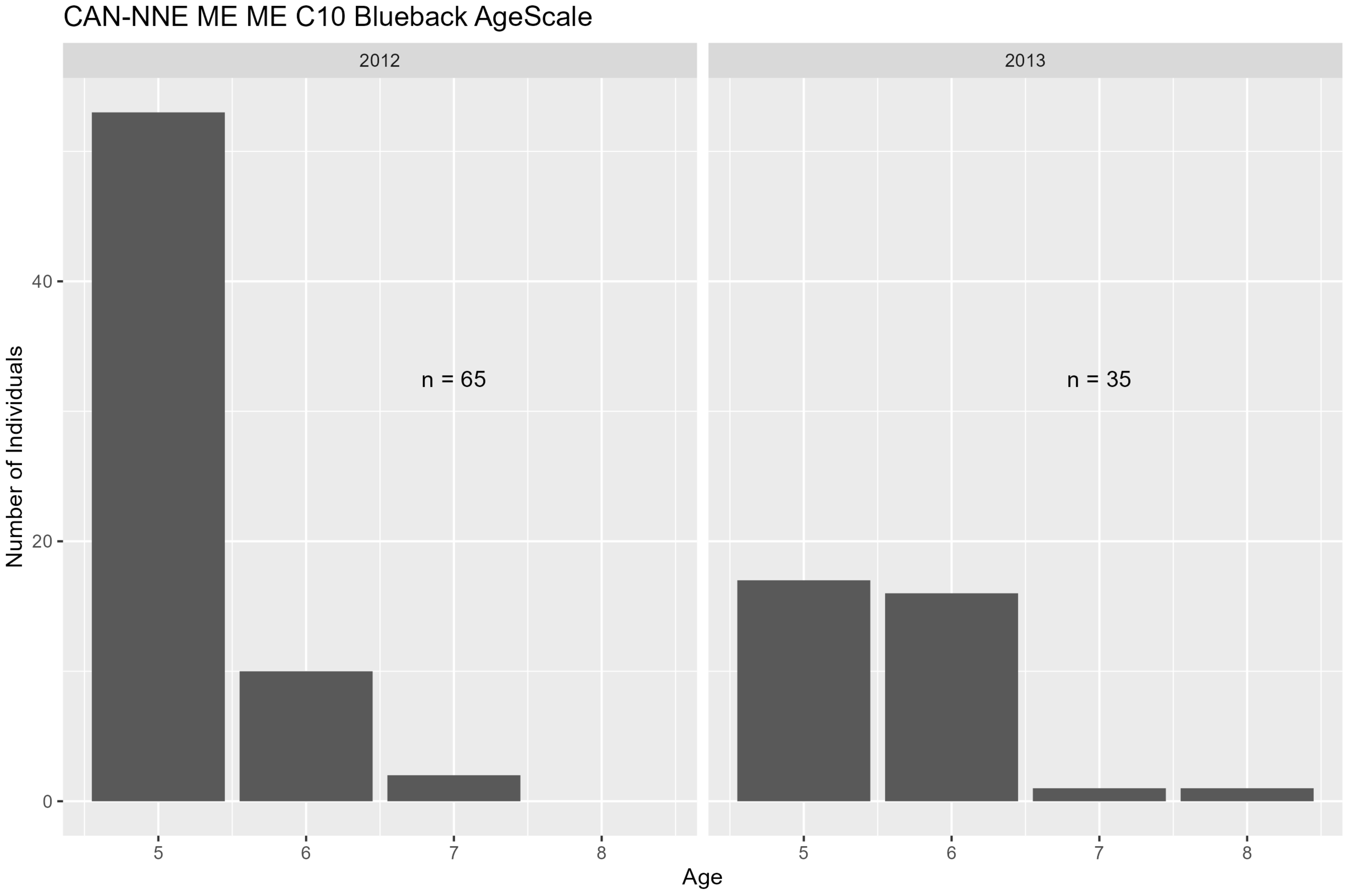
Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
150	NY DEC River Herring Spawning Stock Survey	MAT	Hudson River	Adult	Blueback	Delta mean	2012	2022
152	NY DEC Juvenile Beach Seine Survey	MAT	Hudson River	YOY	Alewife	Delta mean	1980	2022
154	NY DEC Juvenile Beach Seine Survey	MAT	Hudson River	YOY	Blueback	Delta mean	1980	2022
156	VDGIF Electrofishing Survey	MAT	Appomattox River	Adult	Alewife	Arithmetic Mean - TC Provided	1995	2018
157	VDGIF Electrofishing Survey	MAT	Appomattox River	Adult	Blueback	Arithmetic Mean - TC Provided	1995	2016
158	VDGIF Electrofishing Survey	MAT	Chickahominy River	Adult	Alewife	Arithmetic Mean - TC Provided	2000	2020
159	VDGIF Electrofishing Survey	MAT	Chickahominy River	Adult	Blueback	Arithmetic Mean - TC Provided	2000	2020
160	NCWRC Neuse River Electofishing Survey	MAT	Neuse River	Adult	Blueback	Delta mean	2004	2021
162	NJ Ocean Trawl Survey	MAT	Atlantic Ocean	Juvenile & Adult	Alewife	Delta mean	1989	2020
165	NJ Ocean Trawl Survey	MAT	Atlantic Ocean	Juvenile & Adult	Blueback	Delta mean	1989	2020
168	VDGIF Electrofishing Survey	MAT	Mattaponi River	Adult	Alewife	Arithmetic Mean - TC Provided	2000	2014
169	VDGIF Electrofishing Survey	MAT	Mattaponi River	Adult	Blueback	Arithmetic Mean - TC Provided	2000	2012
191	MD DNR Estuarine Juvenile Finfish Survey	MAT	Choptank River	YOY	Alewife	Delta mean	1959	2021
192	MD DNR Estuarine Juvenile Finfish Survey	MAT	Choptank River	YOY	Blueback	Delta mean	1959	2021
204	NCWRC Cape Fear River Electofishing Survey	SAT	Town Creek/Rice's Creek	Adult	Blueback	Delta mean	2006	2021

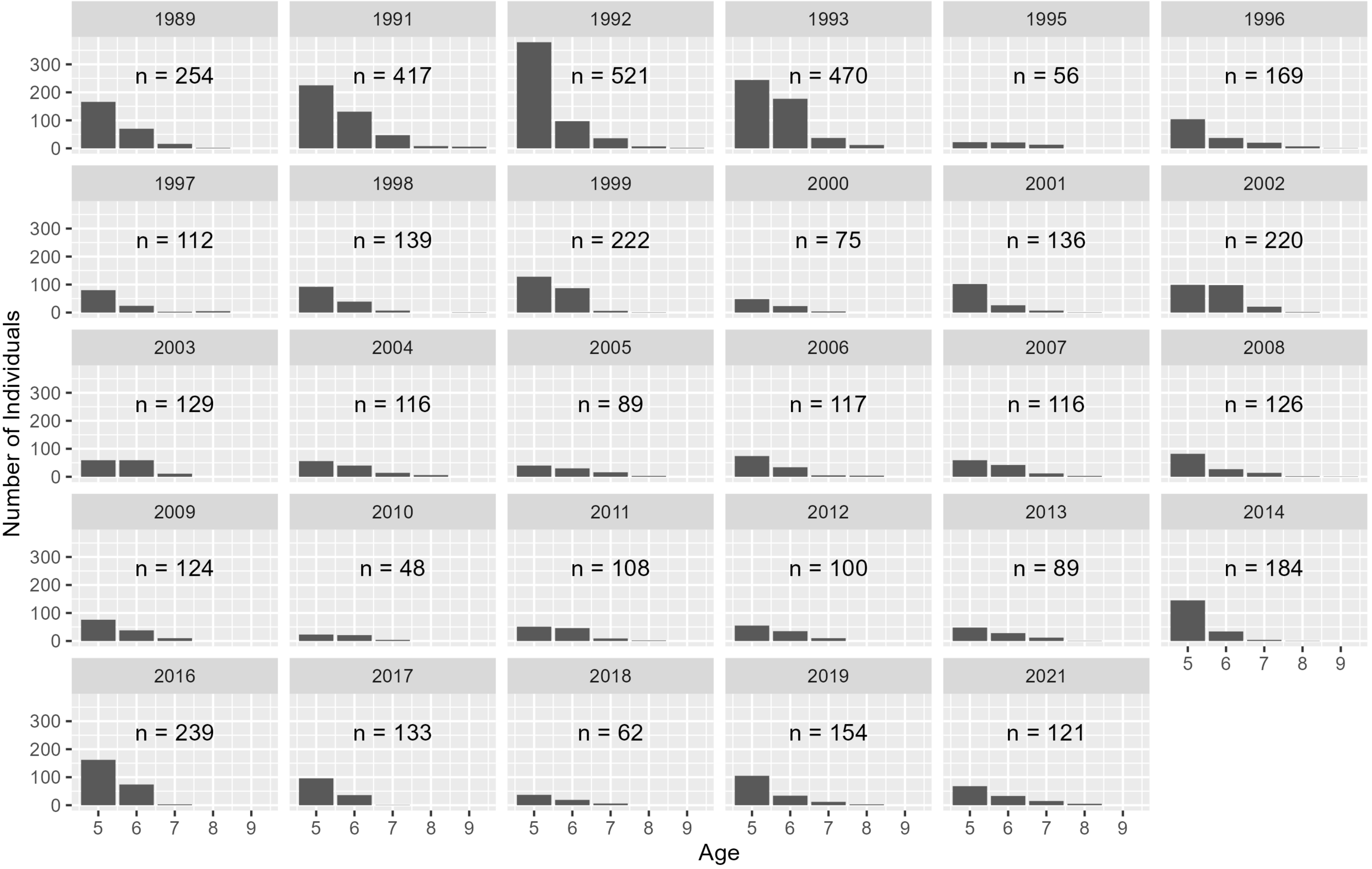
Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
198	FL FWC St. Johns Electofishing Survey	SAT	St. Johns River	Adult	Blueback	Delta mean	2008	2021
201	FL FWC St. Johns Pushnet Survey	SAT	St. Johns River	YOY	Blueback	Delta mean	2006	2021
1	ME-NH Fall Inshore Trawl Survey	Mixed Stock	Gulf of Maine	Juvenile & Adult	Alewife	Stratified arithmetic mean	2000	2021
3	ME-NH Fall Inshore Trawl Survey	Mixed Stock	Gulf of Maine	Juvenile & Adult	Blueback	Stratified arithmetic mean	2000	2021
5	ME-NH Spring Inshore Trawl Survey	Mixed Stock	Gulf of Maine	Juvenile & Adult	Alewife	Stratified arithmetic mean	2001	2021
7	ME-NH Spring Inshore Trawl Survey	Mixed Stock	Gulf of Maine	Juvenile & Adult	Blueback	Stratified arithmetic mean	2001	2021
9	NEFSC Fall Bottom Trawl Survey (Albatross)	Mixed Stock	Atlantic Ocean	Adult	Alewife	Stratified arithmetic mean	1975	2008
10	NEFSC Fall Bottom Trawl Survey (Albatross)	Mixed Stock	Atlantic Ocean	Adult	Blueback	Stratified arithmetic mean	1975	2008
11	NEFSC Fall Bottom Trawl Survey (Bigelow)	Mixed Stock	Atlantic Ocean	Adult	Alewife	Stratified arithmetic mean	2009	2022
12	NEFSC Fall Bottom Trawl Survey (Bigelow)	Mixed Stock	Atlantic Ocean	Adult	Blueback	Stratified arithmetic mean	2009	2022
13	NEFSC Spring Bottom Trawl Survey (Albatross)	Mixed Stock	Atlantic Ocean	Adult	Alewife	Stratified arithmetic mean	1976	2008
14	NEFSC Spring Bottom Trawl Survey (Albatross)	Mixed Stock	Atlantic Ocean	Adult	Blueback	Stratified arithmetic mean	1976	2008
15	NEFSC Spring Bottom Trawl Survey (Bigelow)	Mixed Stock	Atlantic Ocean	Adult	Alewife	Stratified arithmetic mean	2009	2022
16	NEFSC Spring Bottom Trawl Survey (Bigelow)	Mixed Stock	Atlantic Ocean	Adult	Blueback	Stratified arithmetic mean	2009	2022
17	NEAMP Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Alewife	Stratified arithmetic mean	2008	2022
18	NEAMP Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Blueback	Stratified arithmetic mean	2008	2022

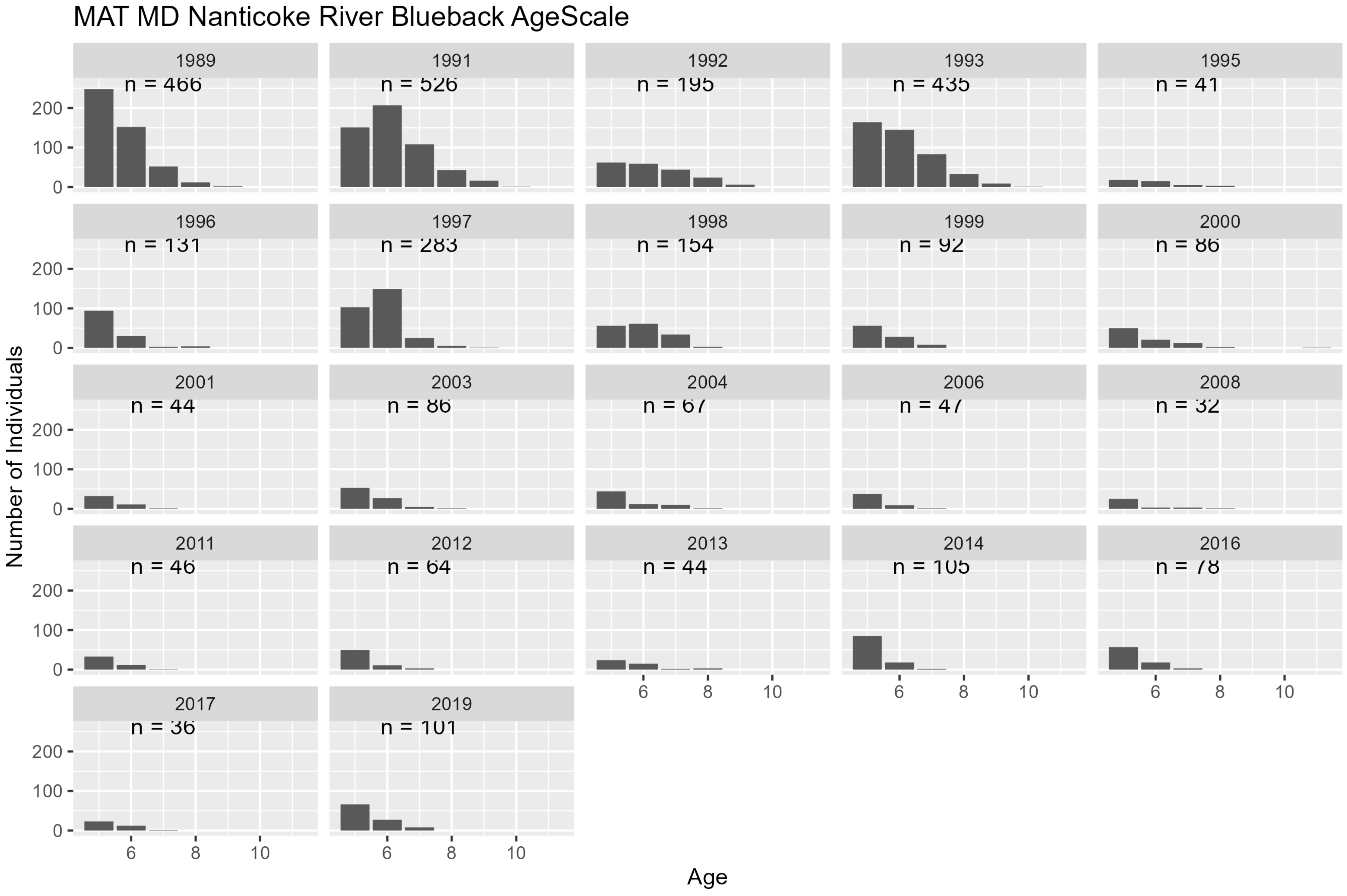
Survey ID	Survey Name	Stock-Region	Waterbody	Life Stage	Species	Index Calculation Method	First Year	Last Year
21	NEFSC Summer Shrimp Survey	Mixed Stock	Atlantic Ocean	Adult	Alewife	Stratified arithmetic mean	1983	2022
22	CT DEEP Long Island Sound Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Alewife	Stratified arithmetic mean	1984	2021
23	CT DEEP Long Island Sound Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Blueback	Stratified arithmetic mean	1984	2021
24	RI DMF Spring Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Alewife	Delta mean	2012	2022
25	RI DMF Spring Trawl Survey	Mixed Stock	Atlantic Ocean	Juvenile & Adult	Blueback	Delta mean	2012	2022
27	MA DMF Coastal Trawl Survey	Mixed Stock	Atlantic Ocean	Age-1	Alewife	Stratified arithmetic mean	1978	2021

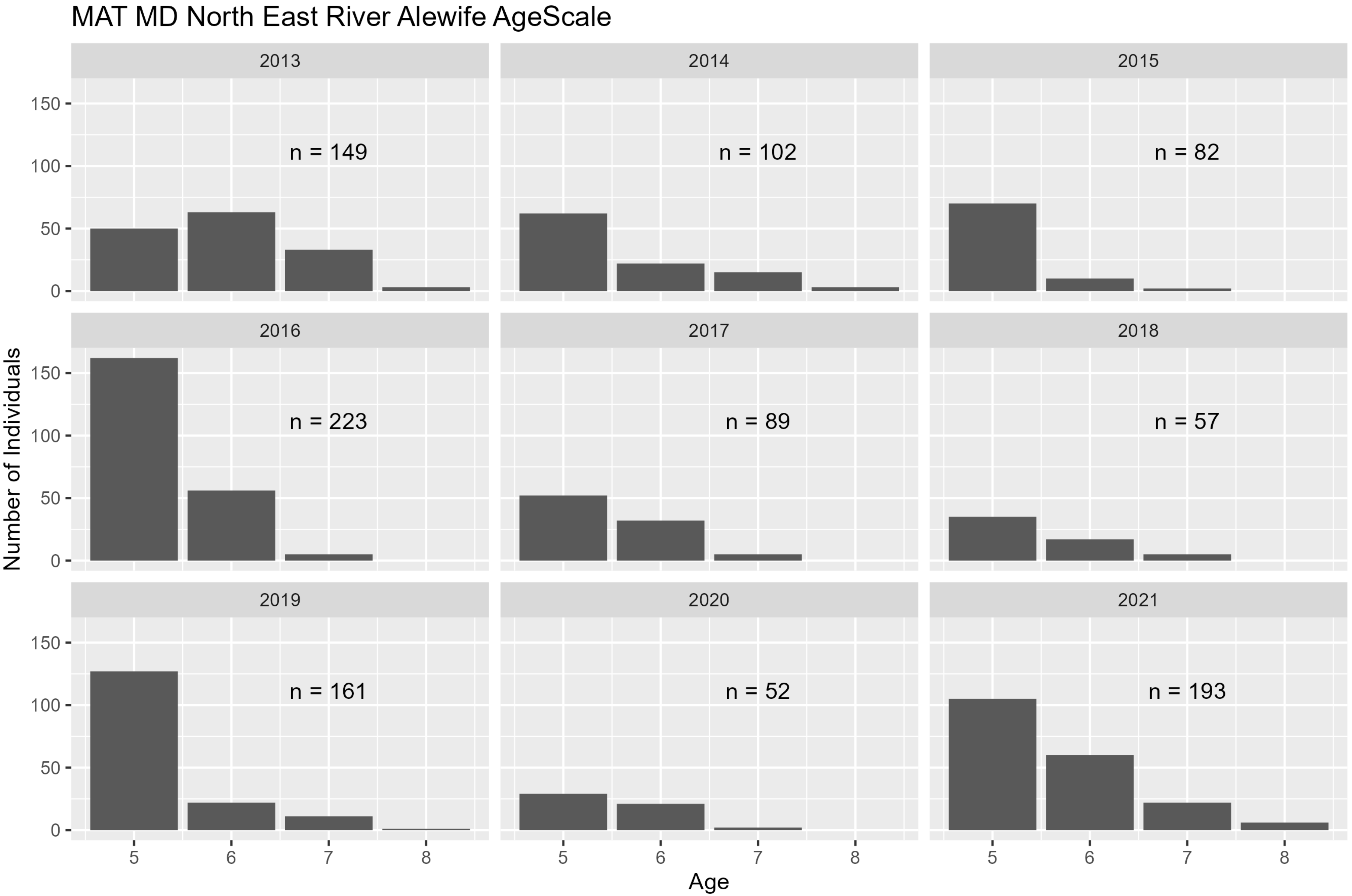
Appendix 7: Sample Size Figures

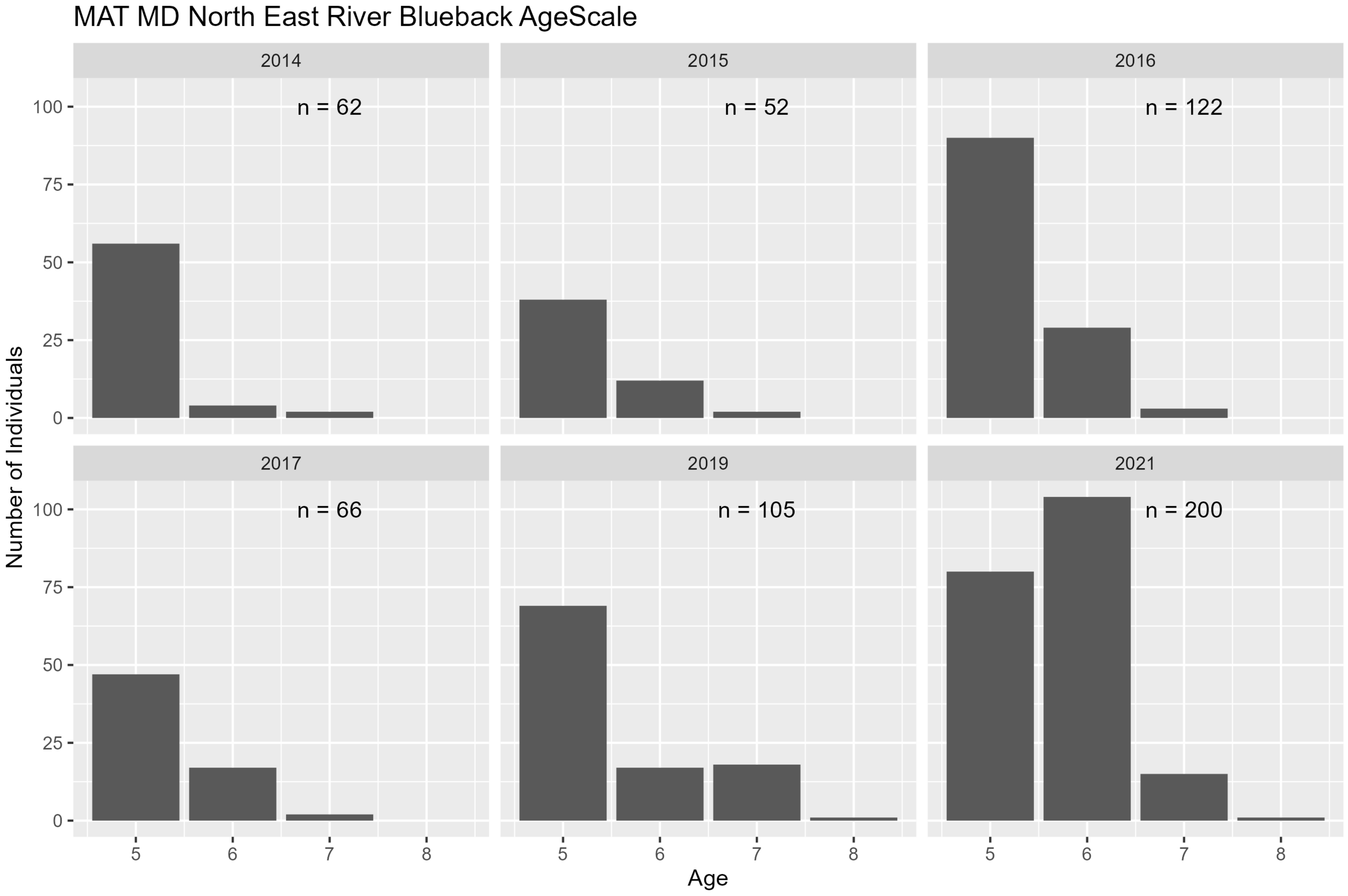
These figures showing the sample size of the catch curve and maturity curve analyses were not part of the original report, but qwew provided to the Review Panel at the workshop at their request.

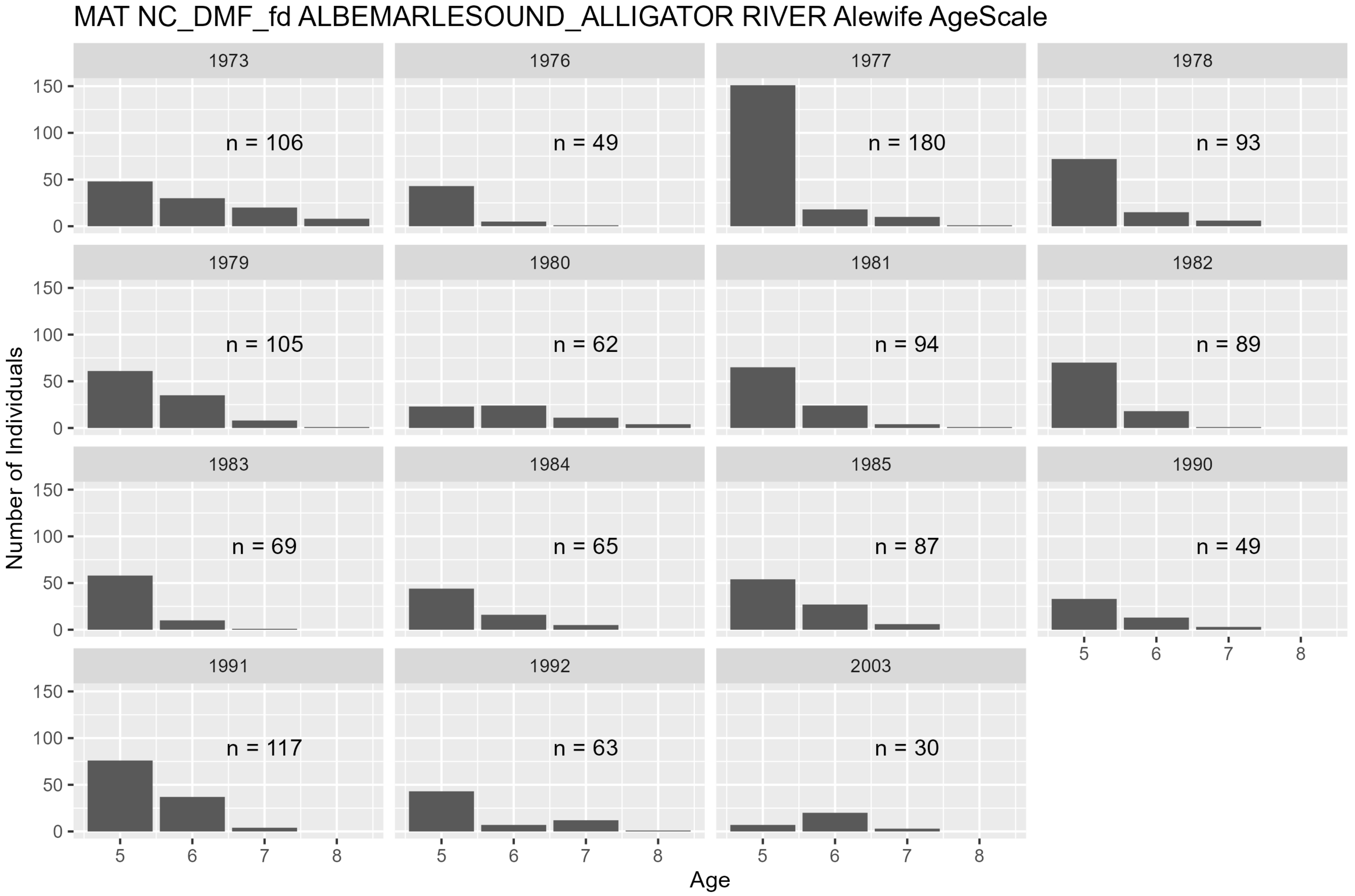

CAN-NNE ME ME C10 Blueback AgeScale
2012
2013
n = 65
n = 35
Number of Individuals
0
20
40
5
6
7
8
5
6
7
8
Age


MAT MD Nanticoke River Alewife AgeScale

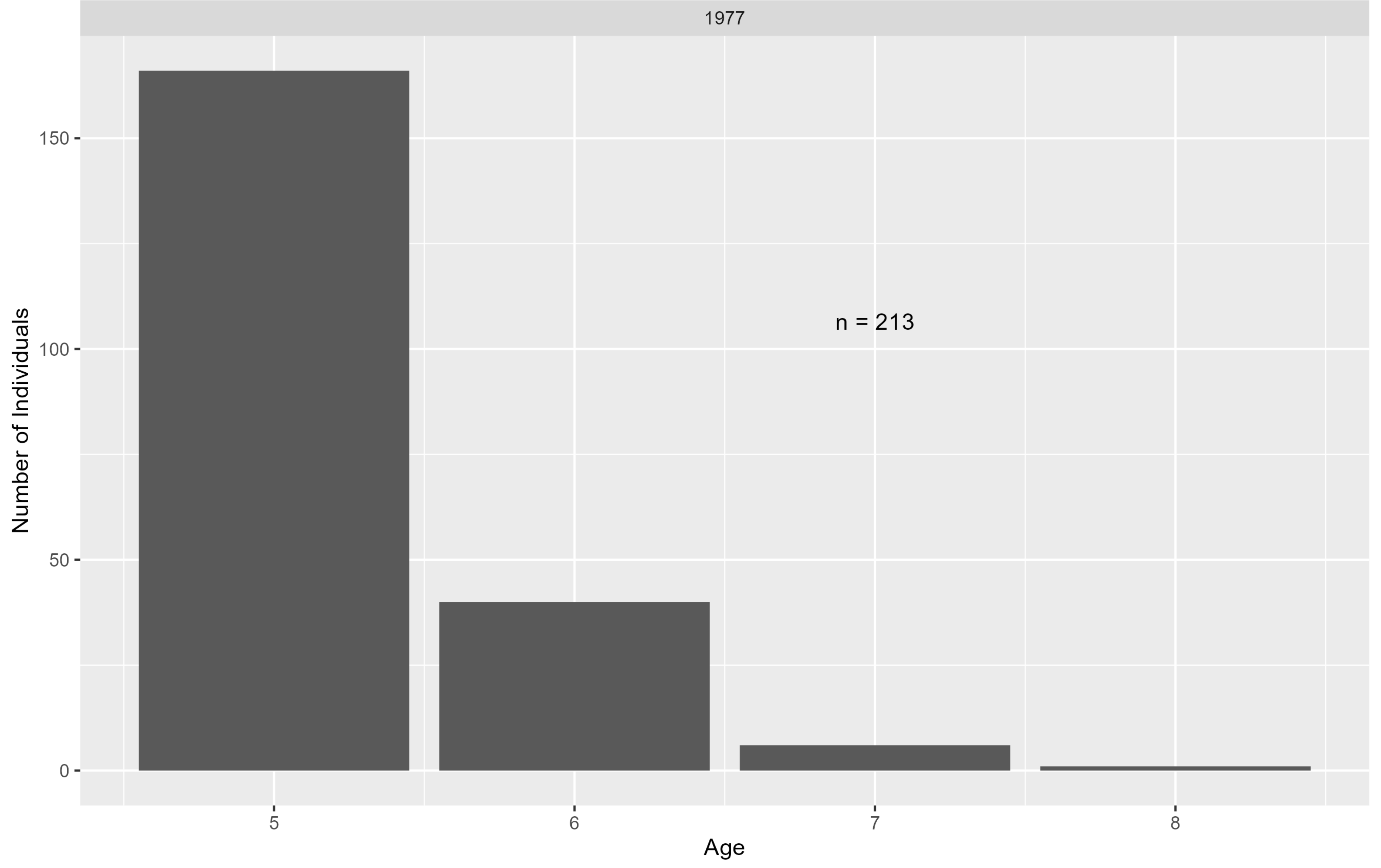

MAT MD Nanticoke River Blueback AgeScale
1989
n = 466
1991
n = 526
1992
n = 195
1993
n = 435
1995
n = 41
1996
n = 131
1997
n = 283
1998
n = 154
1999
n = 92
2000
n = 86
2001
n = 44
2003
n = 86
2004
n = 67
2006
n = 47
2008
n = 32
2011
n = 46
2012
n = 64
2013
n = 44
2014
n = 105
2016
n = 78
2017
n = 36
2019
n = 101
0
100
200
6
8
10
Number of Individuals
Age

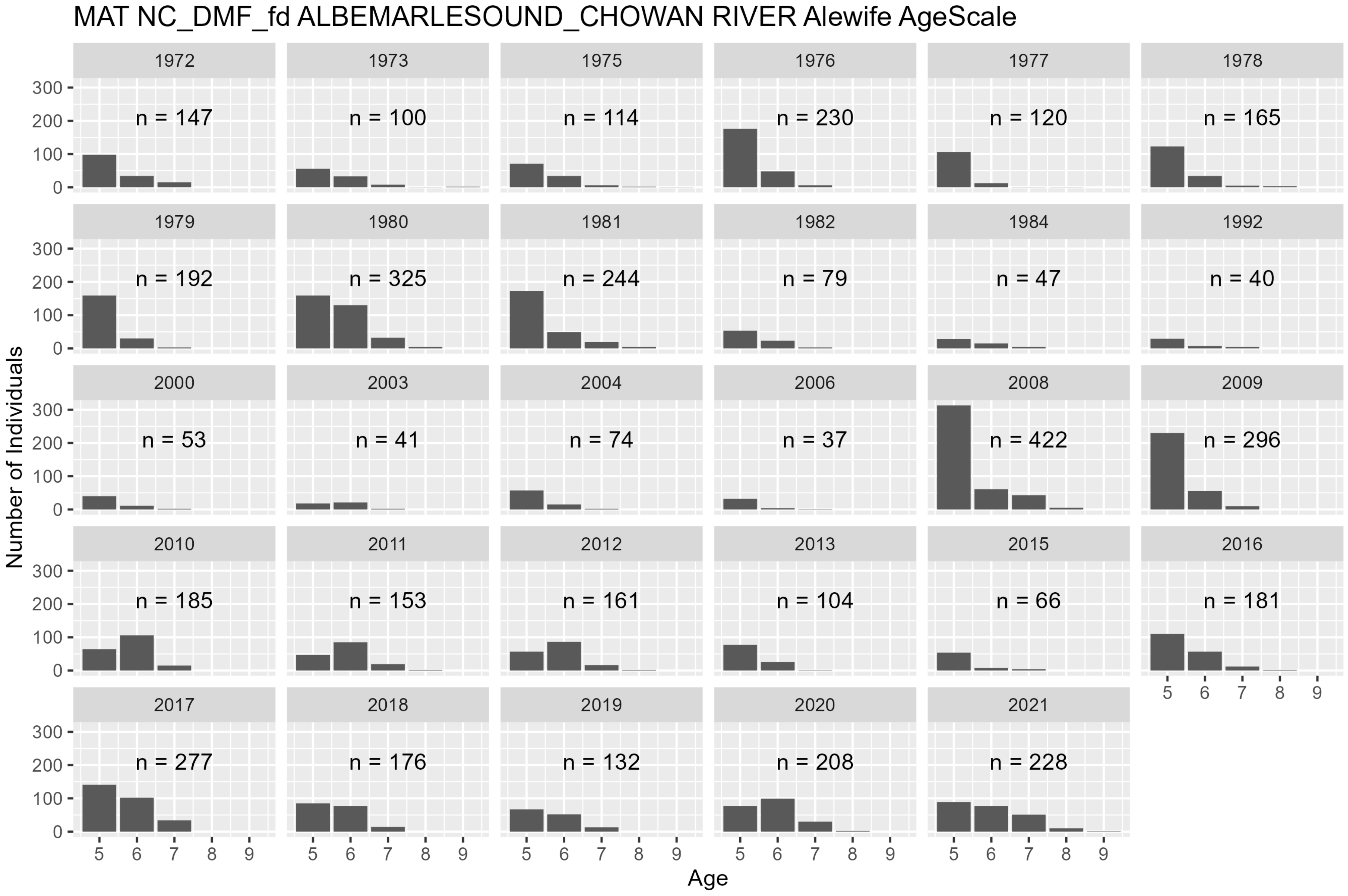

MAT MD North East River Alewife AgeScale
2013
n = 149
2014
n = 102
2015
n = 82
2016
n = 223
2017
n = 89
2018
n = 57
2019
n = 161
2020
n = 52
2021
n = 193
150
100
50
0
5
6
7
8
Number of Individuals
Age


MAT MD North East River Blueback AgeScale
2014
n = 62
2015
n = 52
2016
n = 122
2017
n = 66
2019
n = 105
2021
n = 200
Number of Individuals
0
25
50
75
100
Age
5
6
7
8

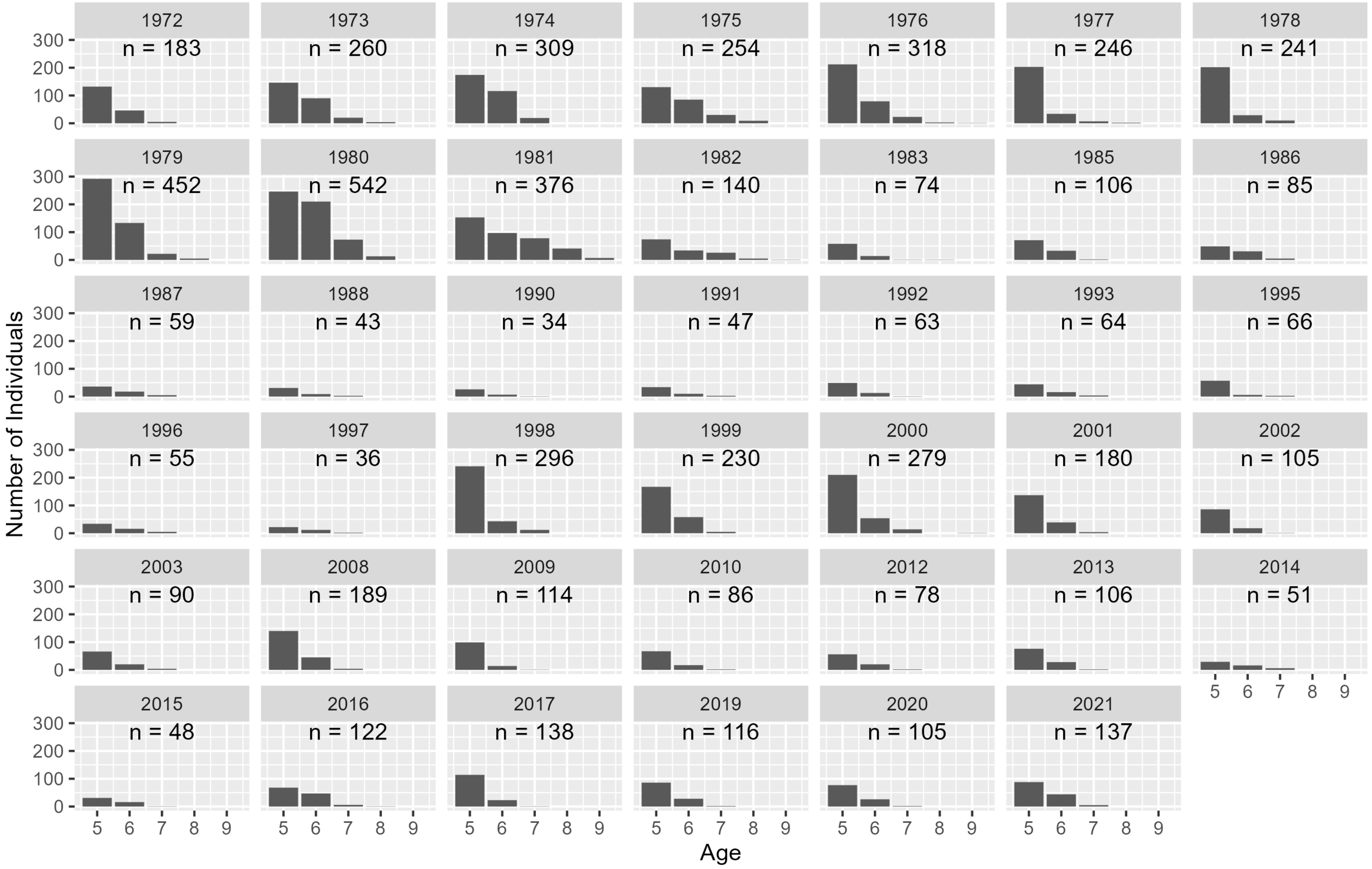

MAT NC_DMF_fd ALBEMARLESOUND_ALLIGATOR RIVER Alewife AgeScale
1973
n = 106
1976
n = 49
1977
n = 180
1978
n = 93
1979
n = 105
1980
n = 62
1981
n = 94
1982
n = 89
1983
n = 69
1984
n = 65
1985
n = 87
1990
n = 49
1991
n = 117
1992
n = 63
2003
n = 30
Number of Individuals
0
50
100
150
Age
5
6
7
8

MAT NC_DMF_fd ALBEMARLESOUND_ALLIGATOR RIVER Blueback AgeScale

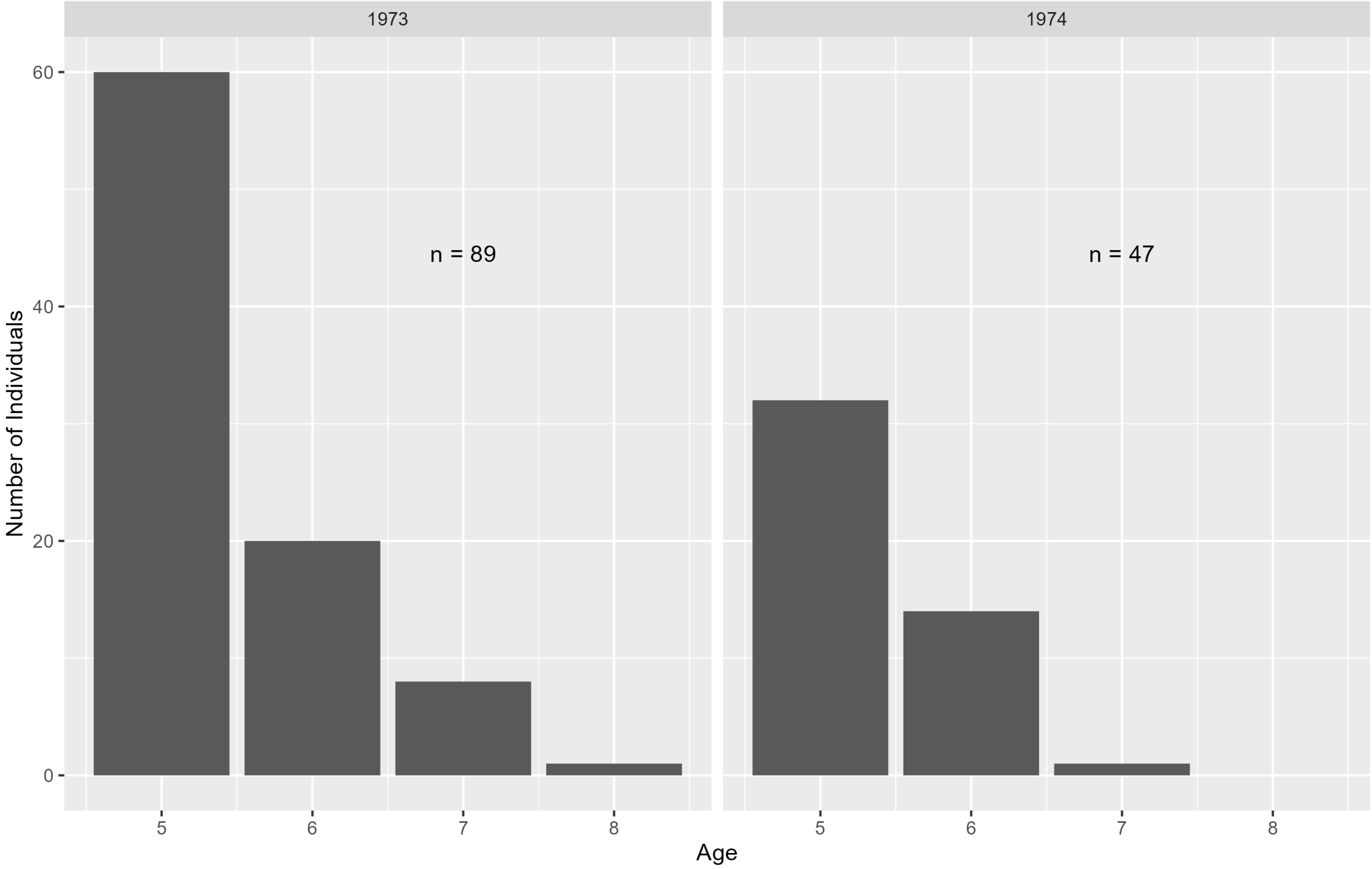



MAT NC_DMF_fd ALBEMARLESOUND_CHOWAN RIVER Alewife AgeScale
Number of Individuals
Age
1972 n = 147
1973 n = 100
1975 n = 114
1976 n = 230
1977 n = 120
1978 n = 165
1979 n = 192
1980 n = 325
1981 n = 244
1982 n = 79
1984 n = 47
1992 n = 40
2000 n = 53
2003 n = 41
2004 n = 74
2006 n = 37
2008 n = 422
2009 n = 296
2010 n = 185
2011 n = 153
2012 n = 161
2013 n = 104
2015 n = 66
2016 n = 181
2017 n = 277
2018 n = 176
2019 n = 132
2020 n = 208
2021 n = 228
0
100
200
300
5
6
7
8
9

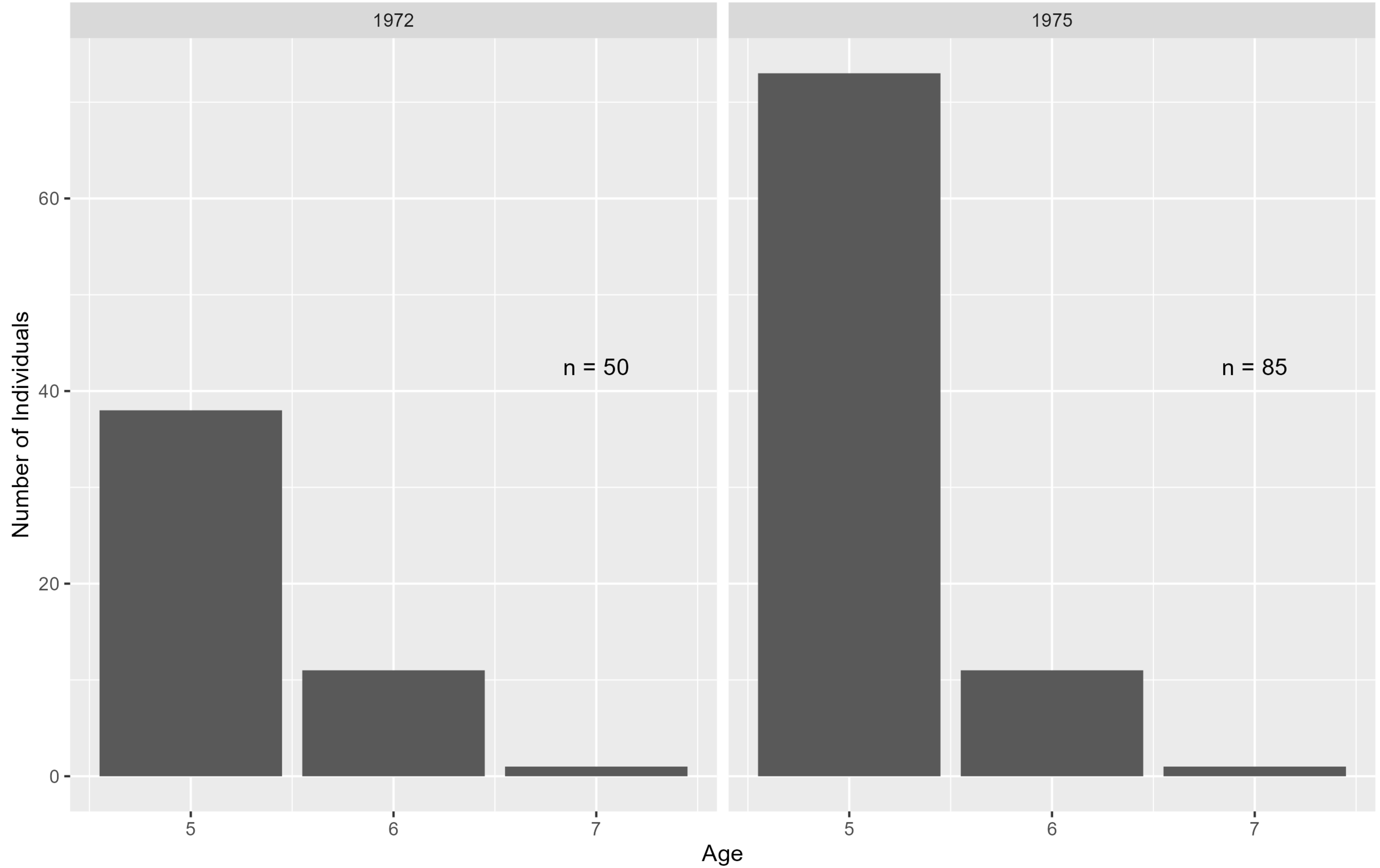
MAT NC_DMF_fd ALBEMARLESOUND_CHOWAN RIVER Blueback AgeScale

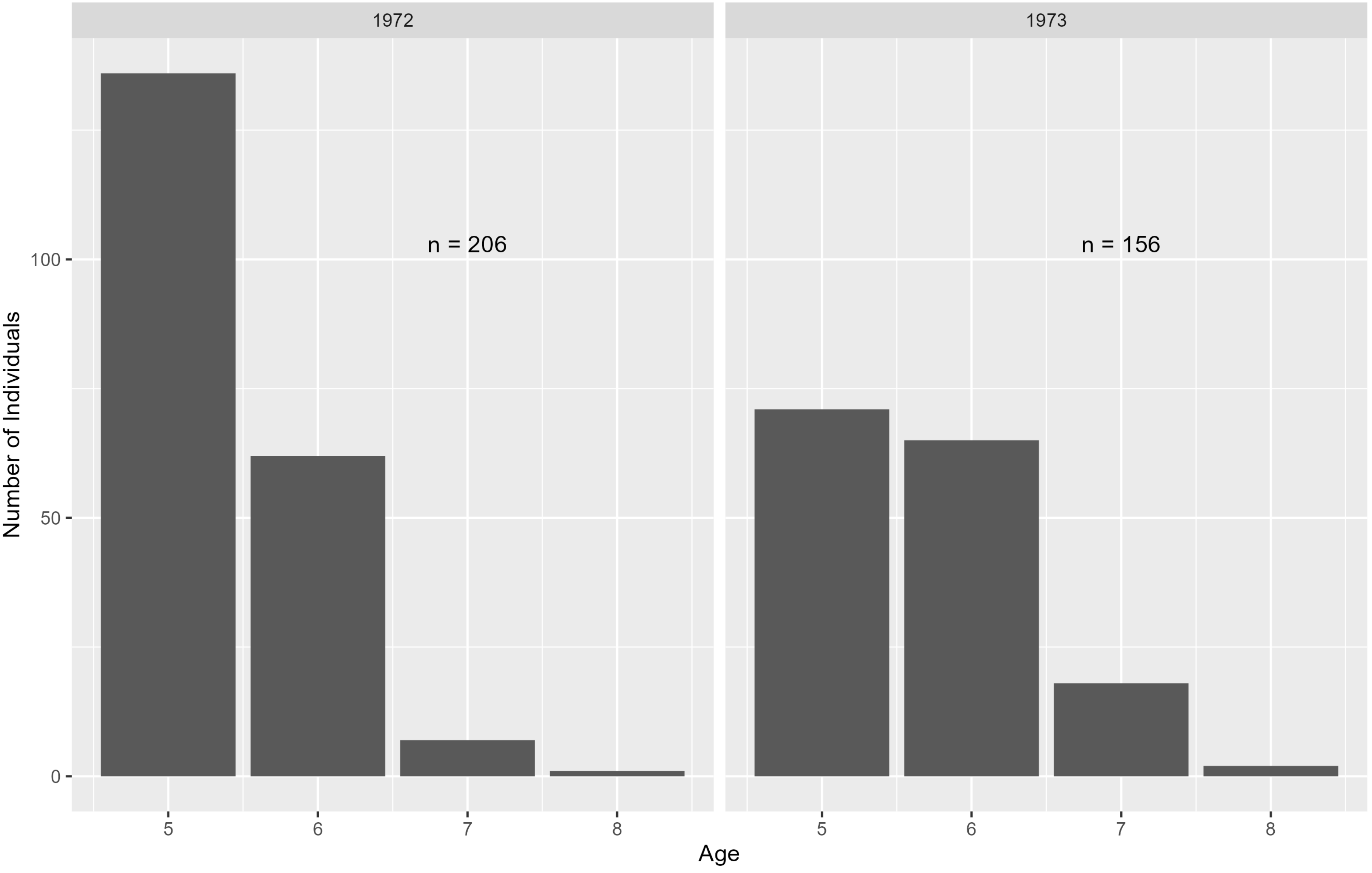


MAT NC_DMF_fd ALBEMARLESOUND_PASQUOTANK RIVER Blueback AgeScale



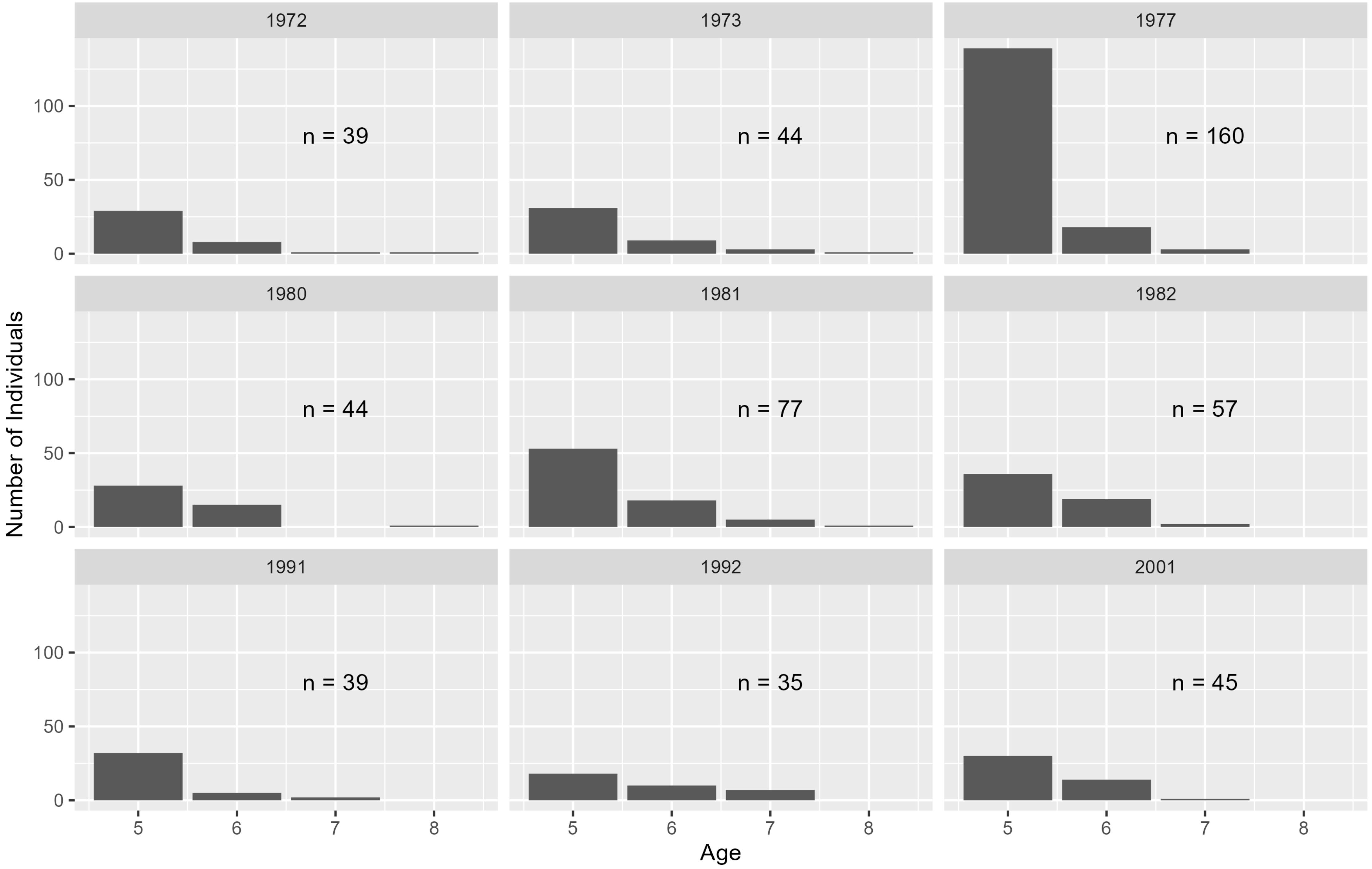
MAT NC_DMF_fd ALBEMARLESOUND_PERQUIMANS RIVER Blueback AgeScale

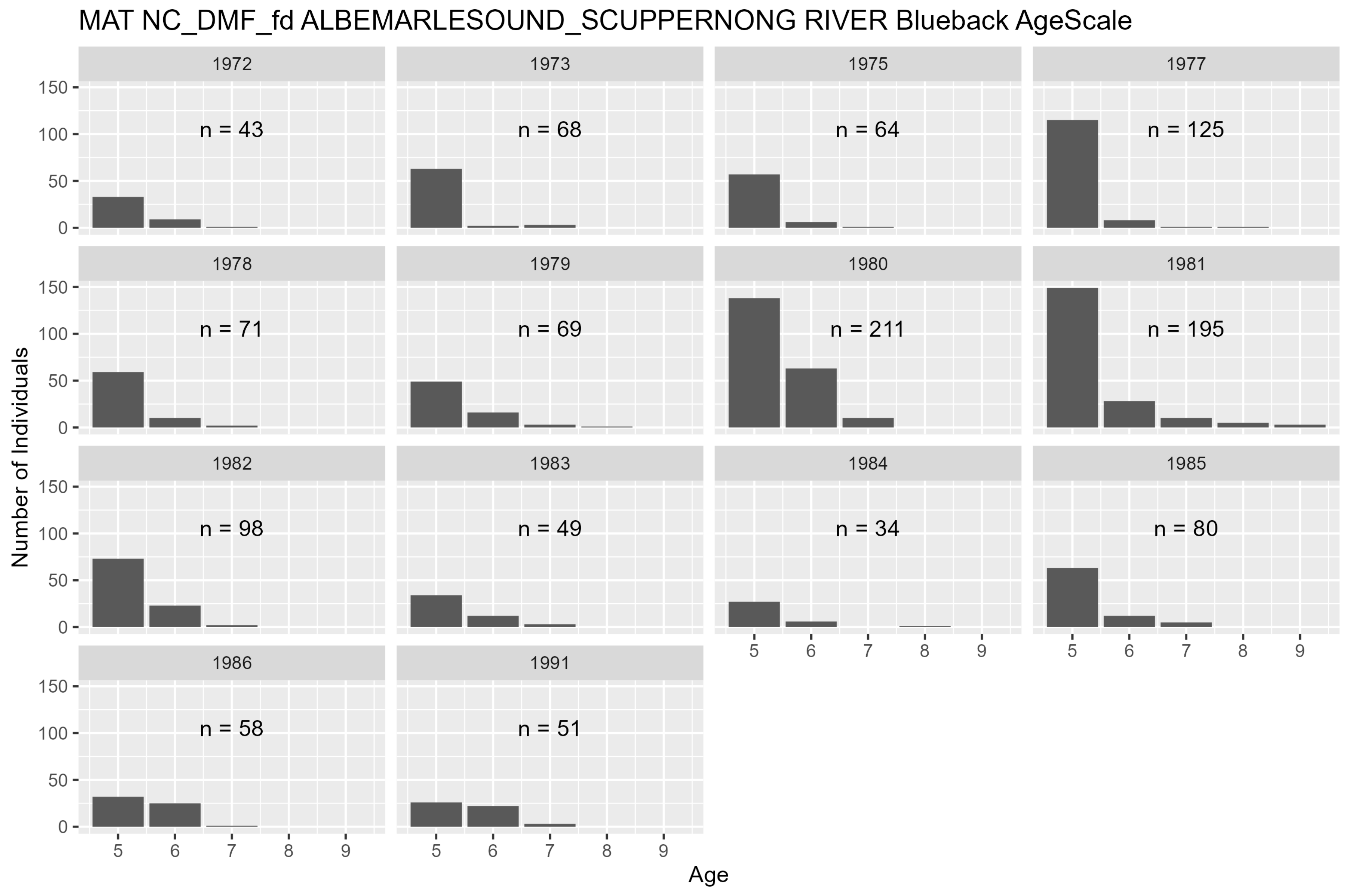


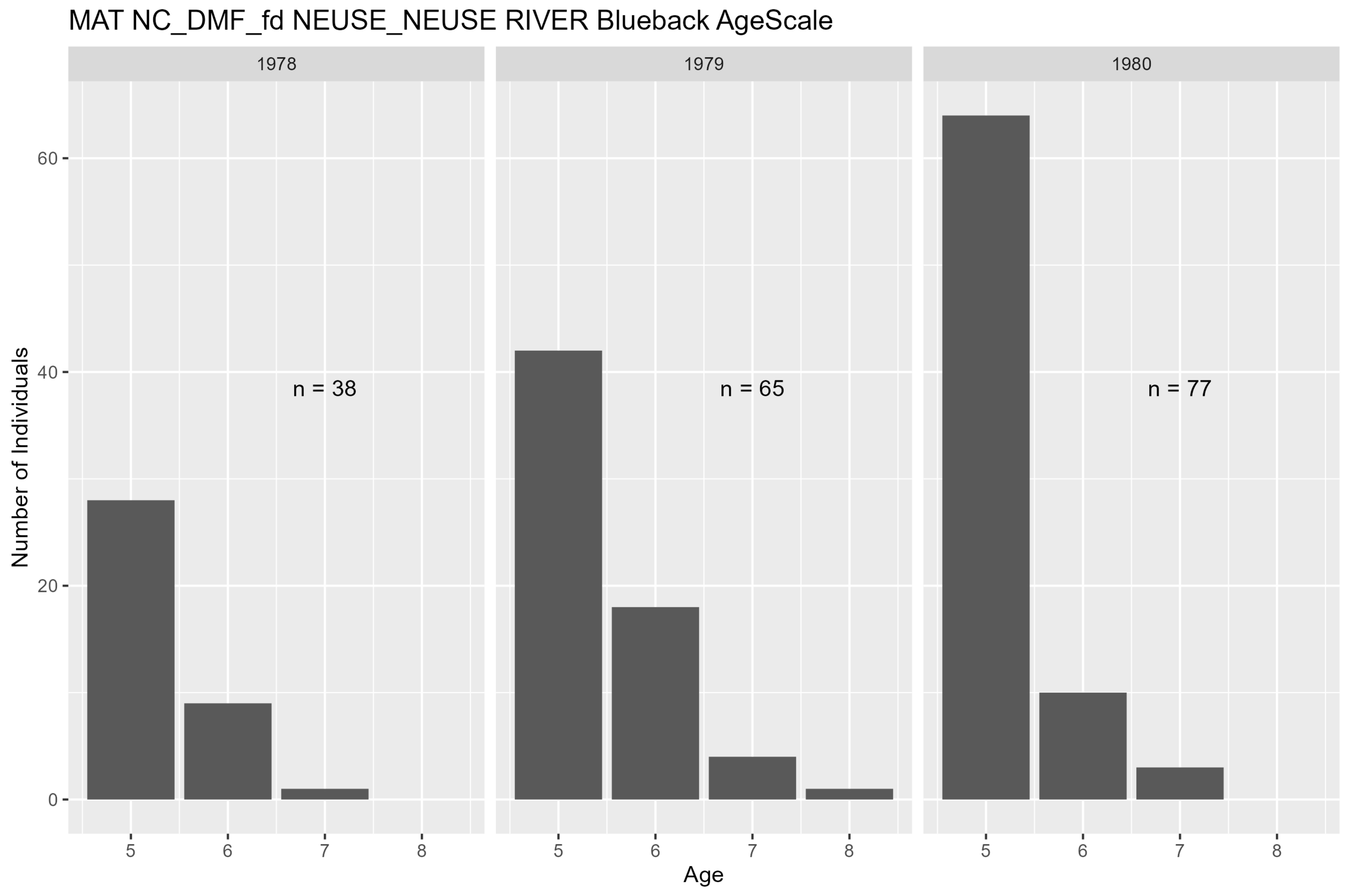


MAT NC_DMF_fd ALBEMARLESOUND_ROANOKE RIVER Blueback AgeScale

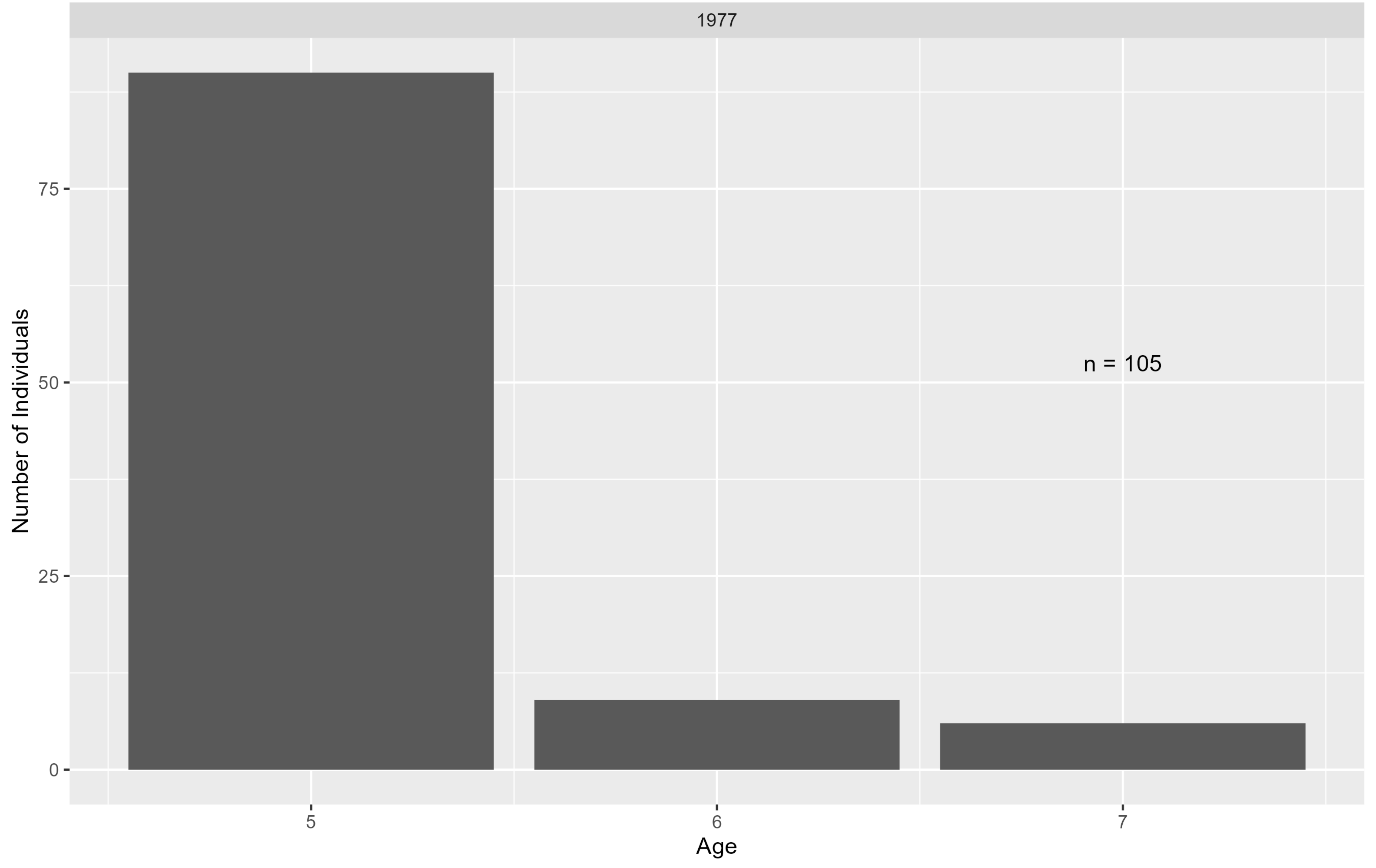
MAT NC_DMF_fd ALBEMARLESOUND_SCUPPERNONG RIVER Alewife AgeScale



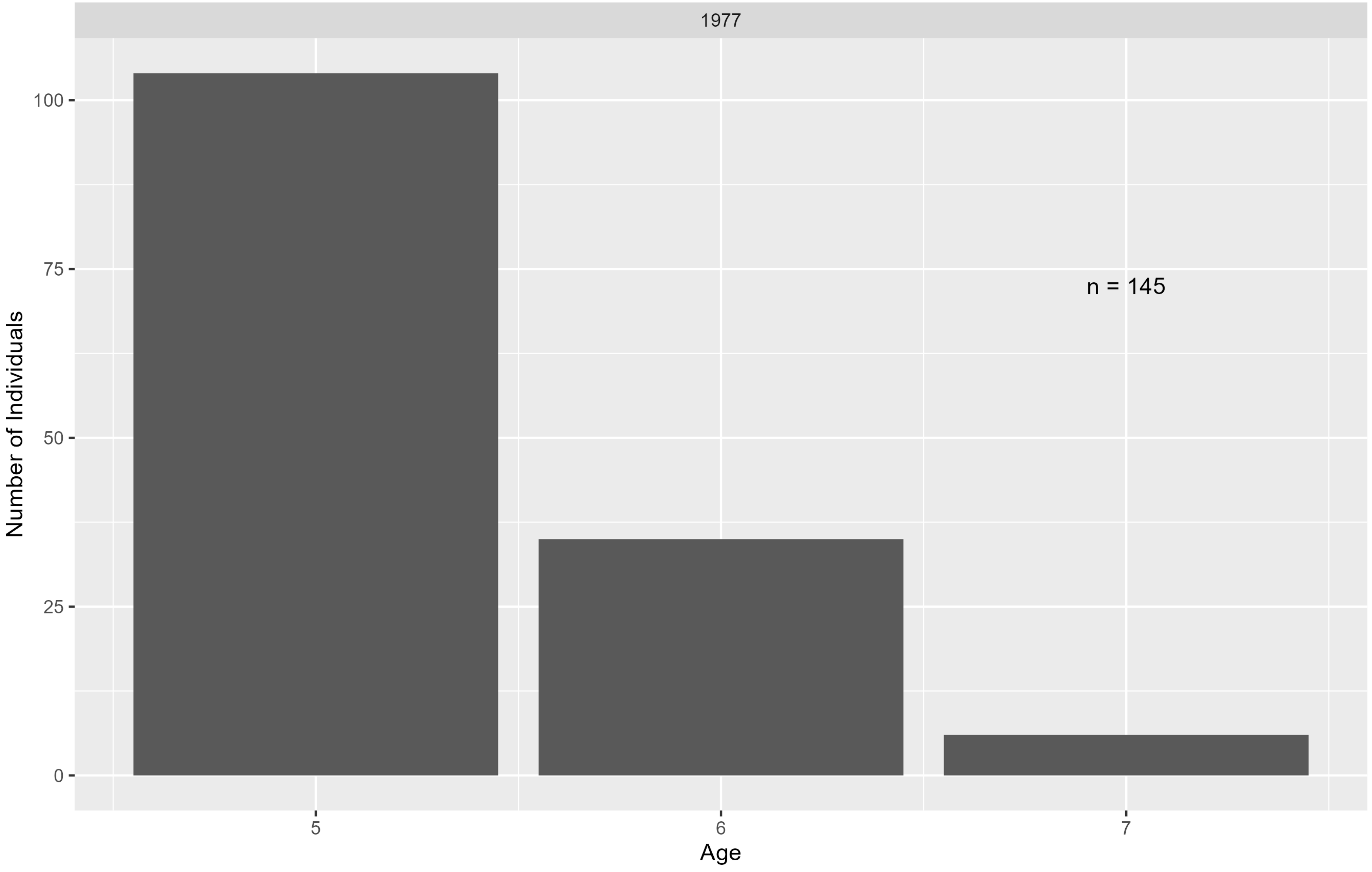
MAT NC_DMF_fd ALBEMARLESOUND_SCUPPERNONG RIVER Blueback AgeScale
1972
n = 43
1973
n = 68
1975
n = 64
1977
n = 125
1978
n = 71
1979
n = 69
1980
n = 211
1981
n = 195
1982
n = 98
1983
n = 49
1984
n = 34
1985
n = 80
1986
n = 58
1991
n = 51
Number of Individuals
0
50
100
150
Age
5
6
7
8
9


MAT NC_DMF_fd NEUSE_NEUSE RIVER Blueback AgeScale
1978
1979
1980
n = 38
n = 65
n = 77
Number of Individuals
0
20
40
60
5
6
7
8
Age

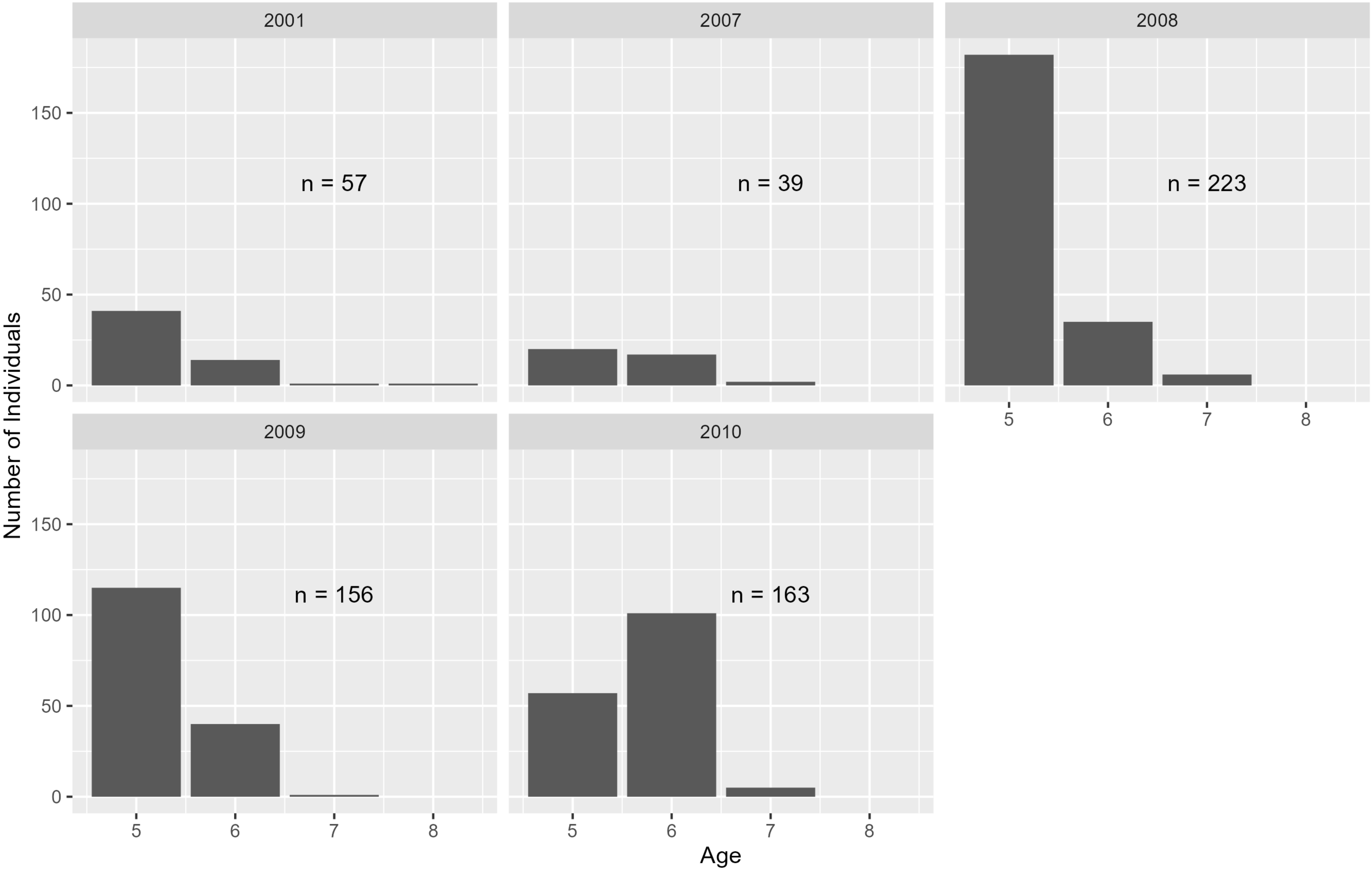
MAT NC_DMF_fi ALBEMARLESOUND_ALLIGATOR RIVER Alewife AgeScale

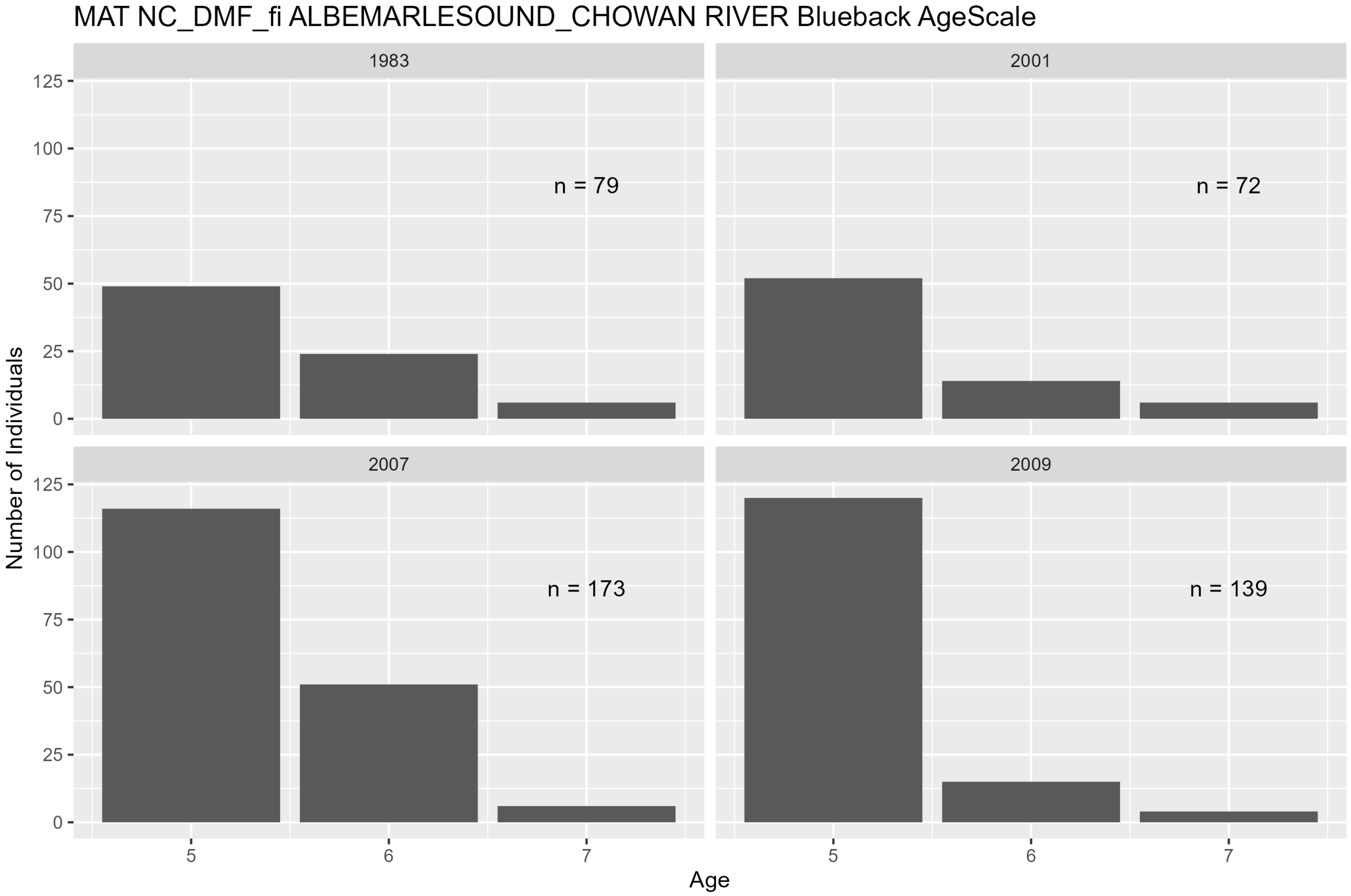


MAT NC_DMF_fi ALBEMARLESOUND_ALLIGATOR RIVER Blueback AgeScale

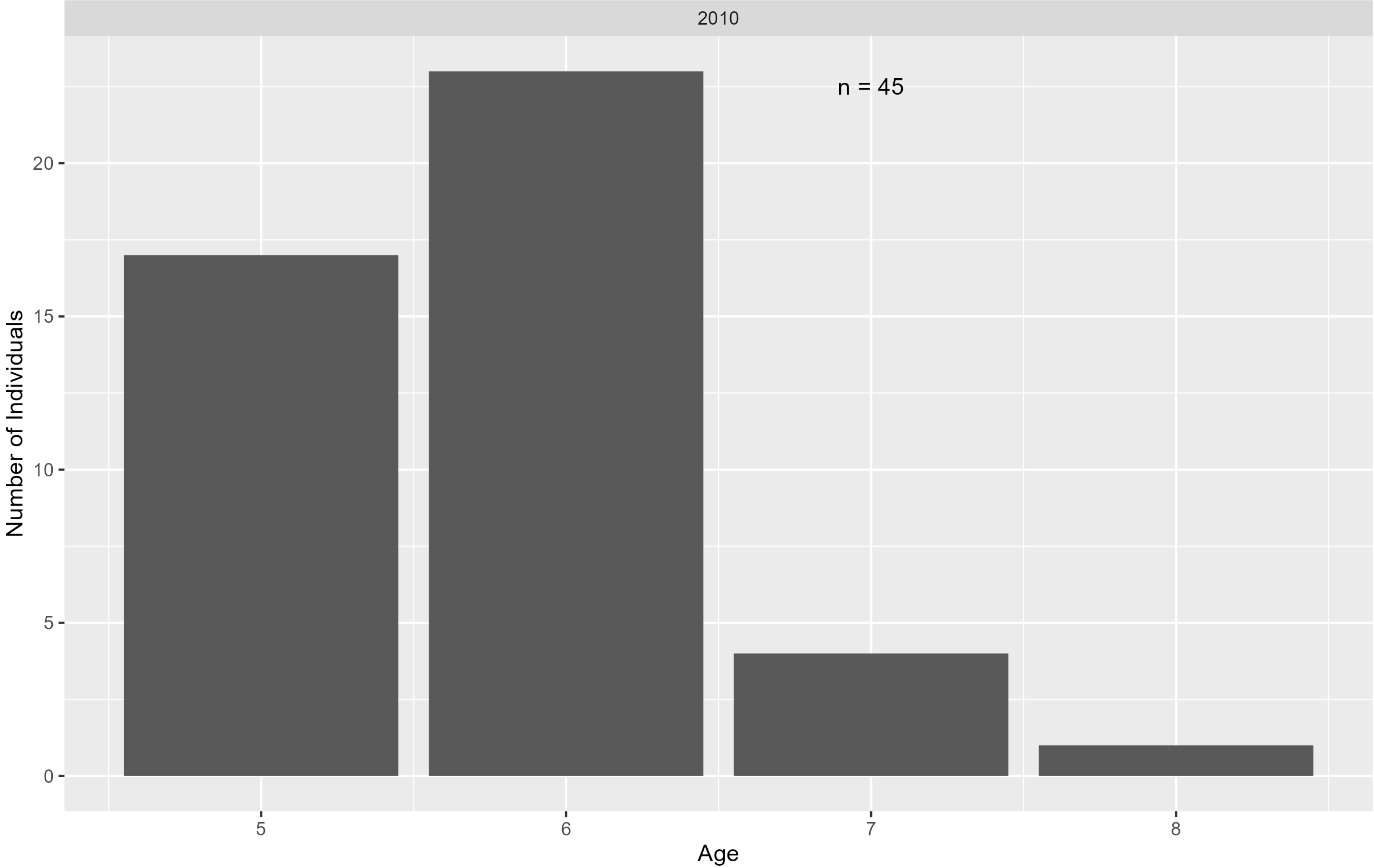


MAT NC_DMF_fi ALBEMARLESOUND_CHOWAN RIVER Alewife AgeScale

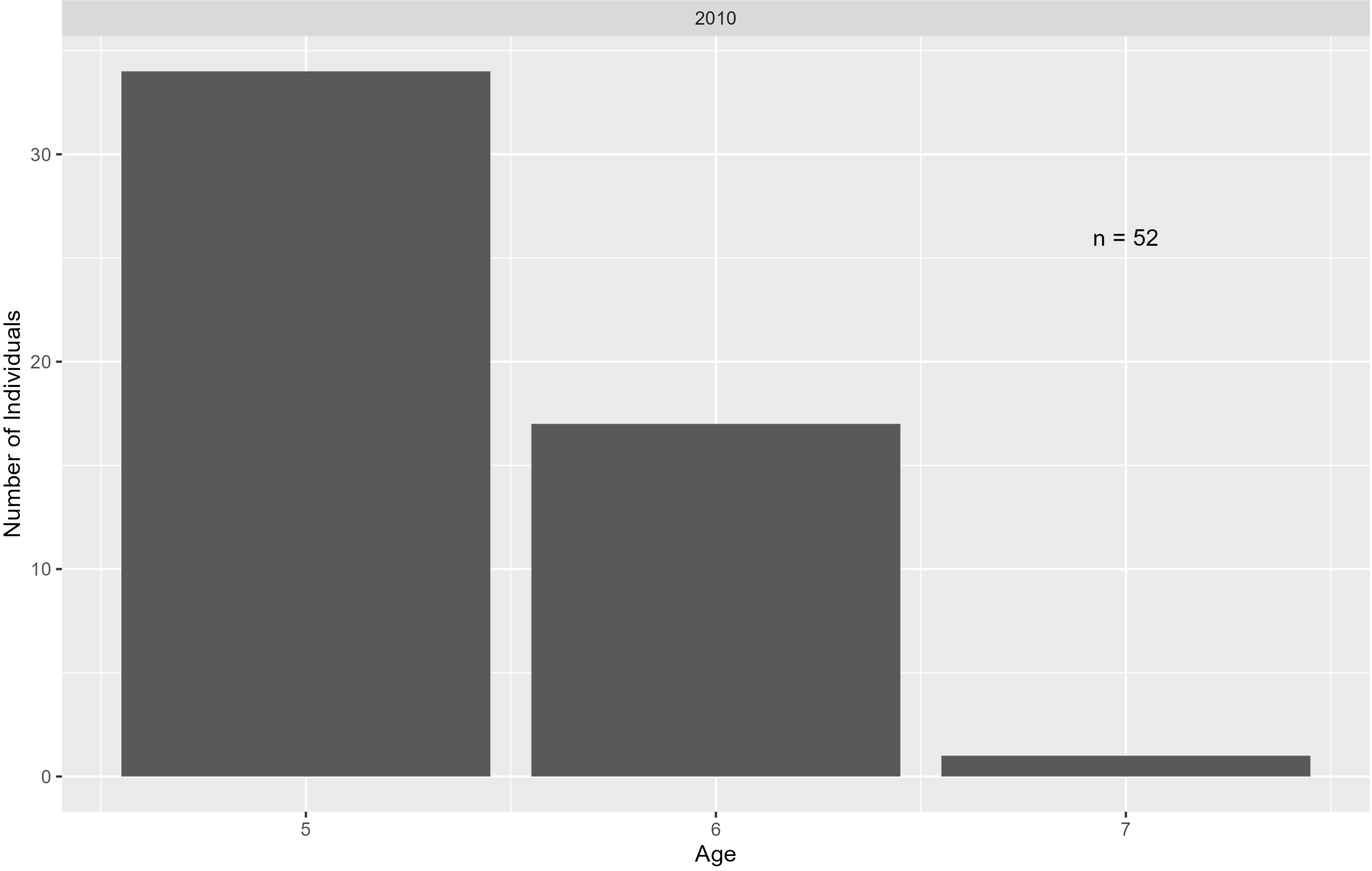



MAT NC_DMF_fi ALBEMARLESOUND_CHOWAN RIVER Blueback AgeScale
1983
2001
2007
2009
n = 79
n = 72
n = 173
n = 139
Number of Individuals
0
25
50
75
100
125
Age
5
6
7

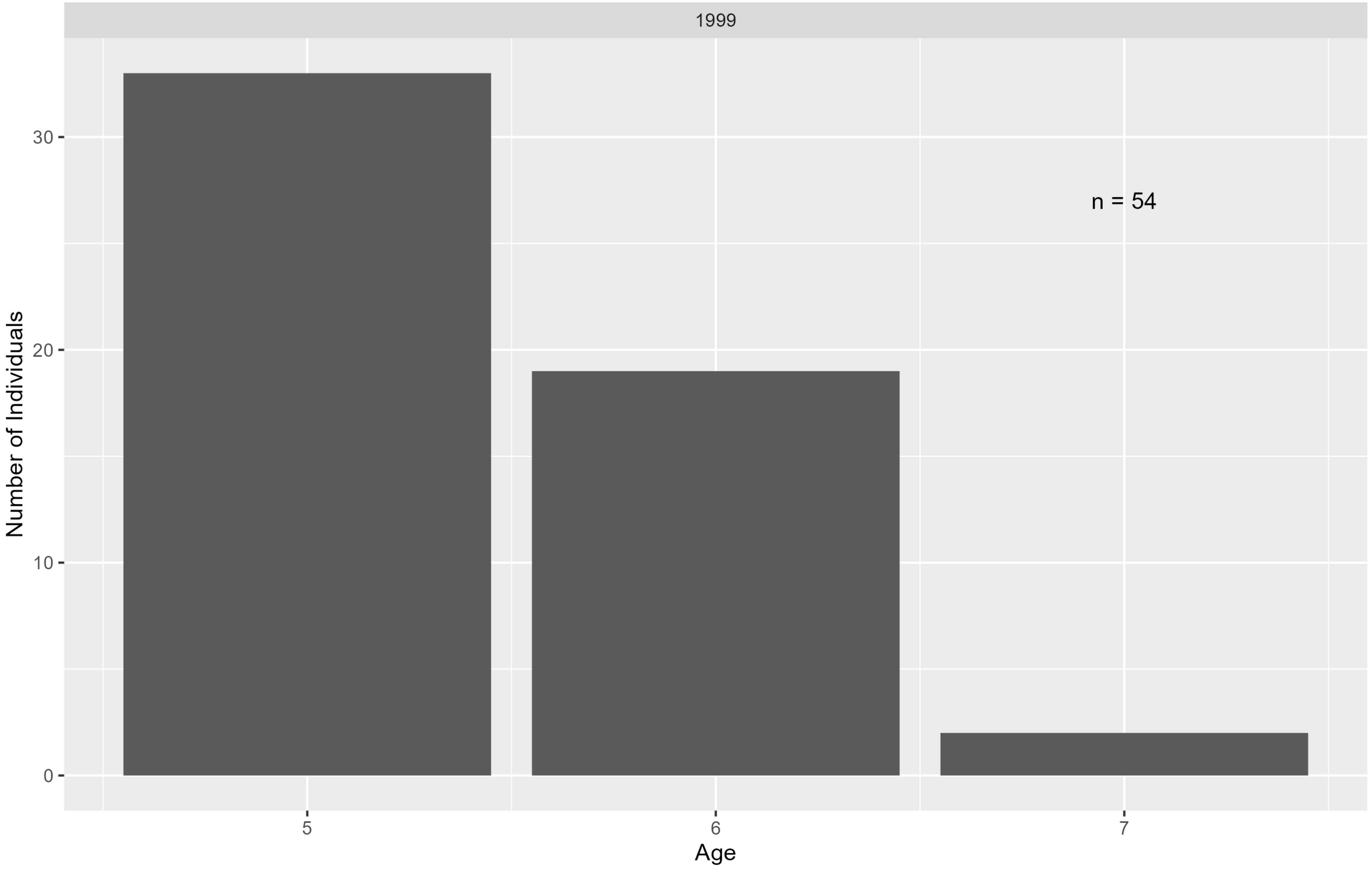
MAT NC_DMF_fi ALBEMARLESOUND_LITTLE RIVER Alewife AgeScale



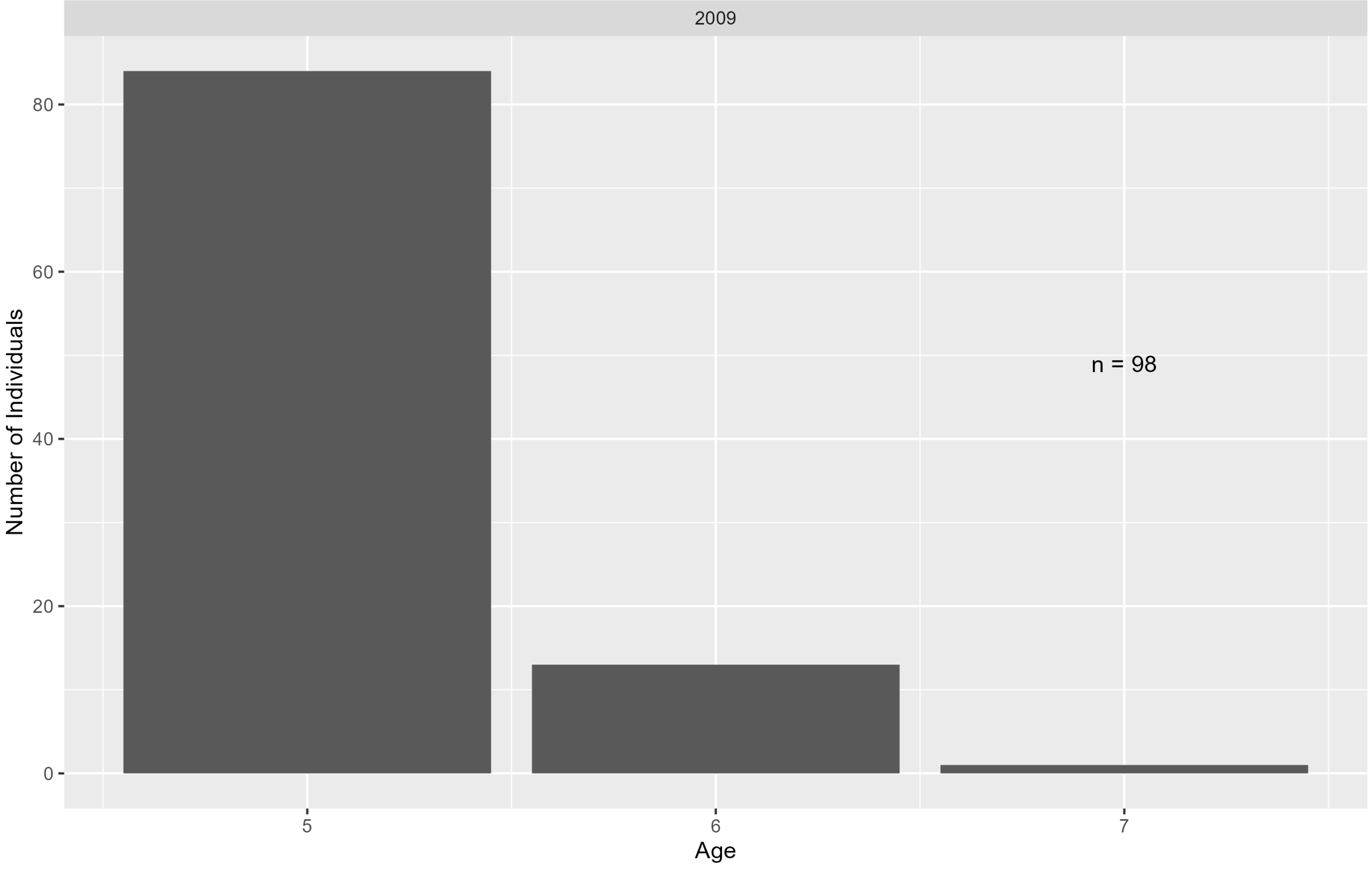
MAT NC_DMF_fi ALBEMARLESOUND_PERQUIMANS RIVER Alewife AgeScale



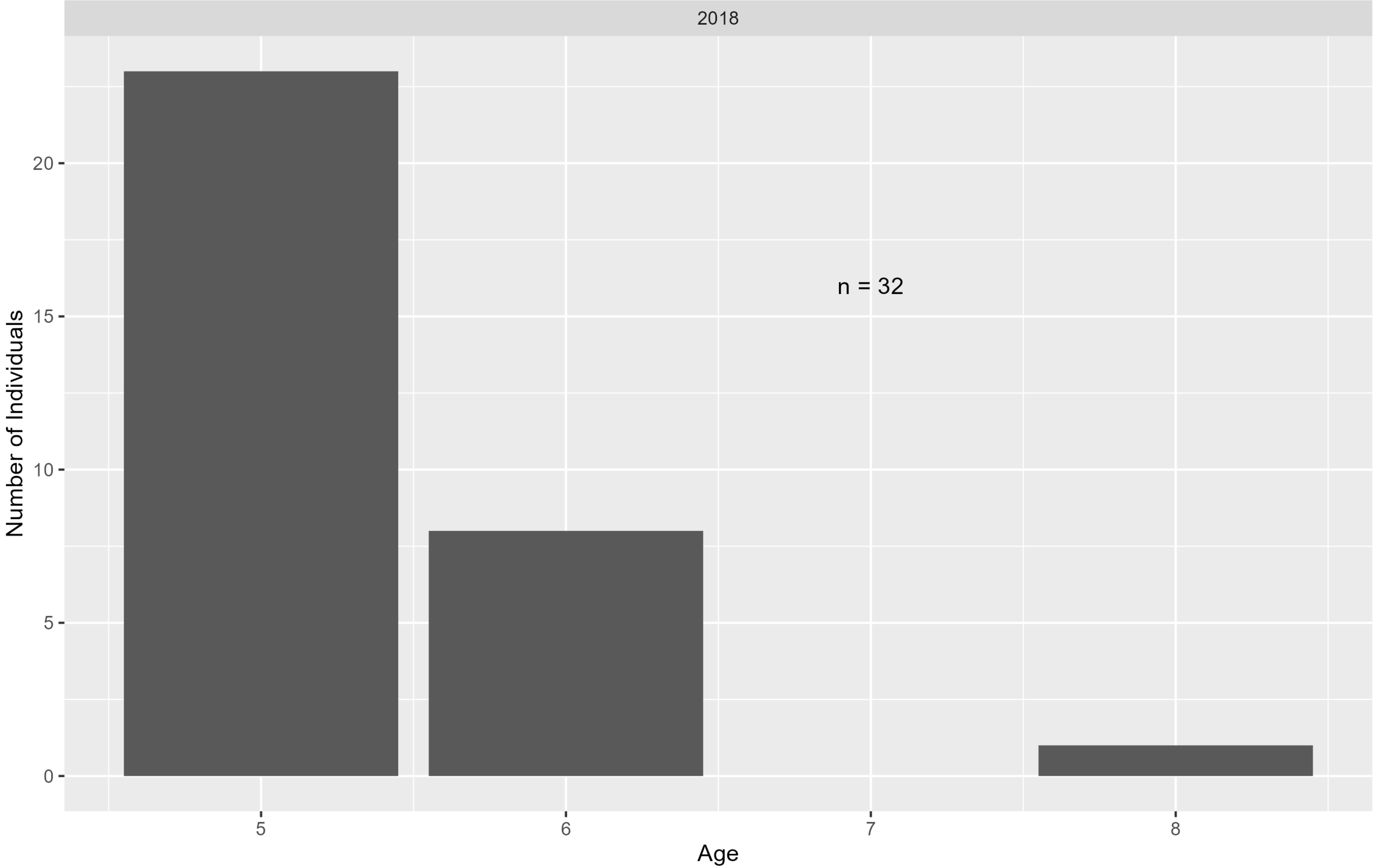
MAT NC_DMF_fi ALBEMARLESOUND_ROANOKE RIVER Blueback AgeScale

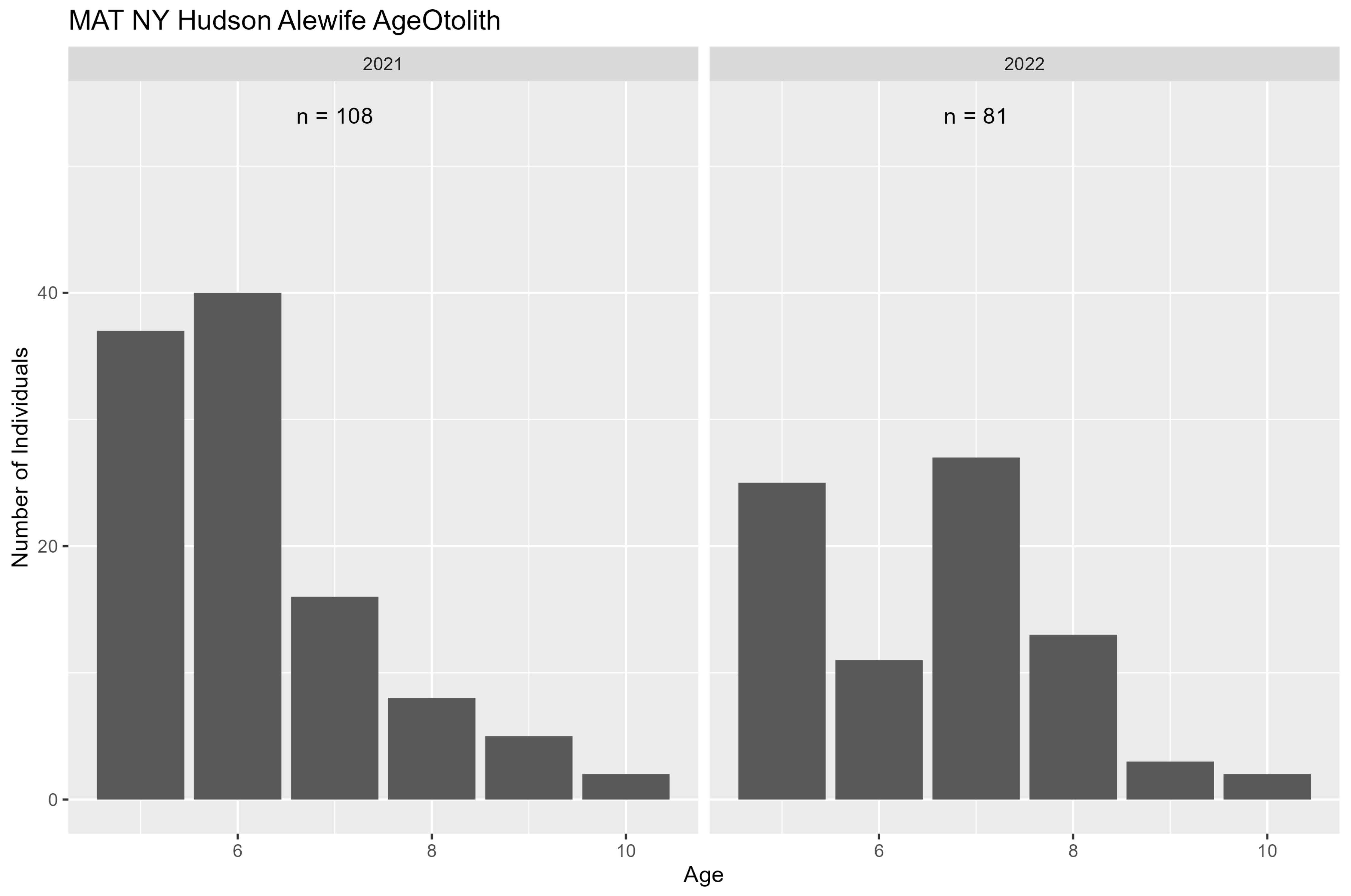


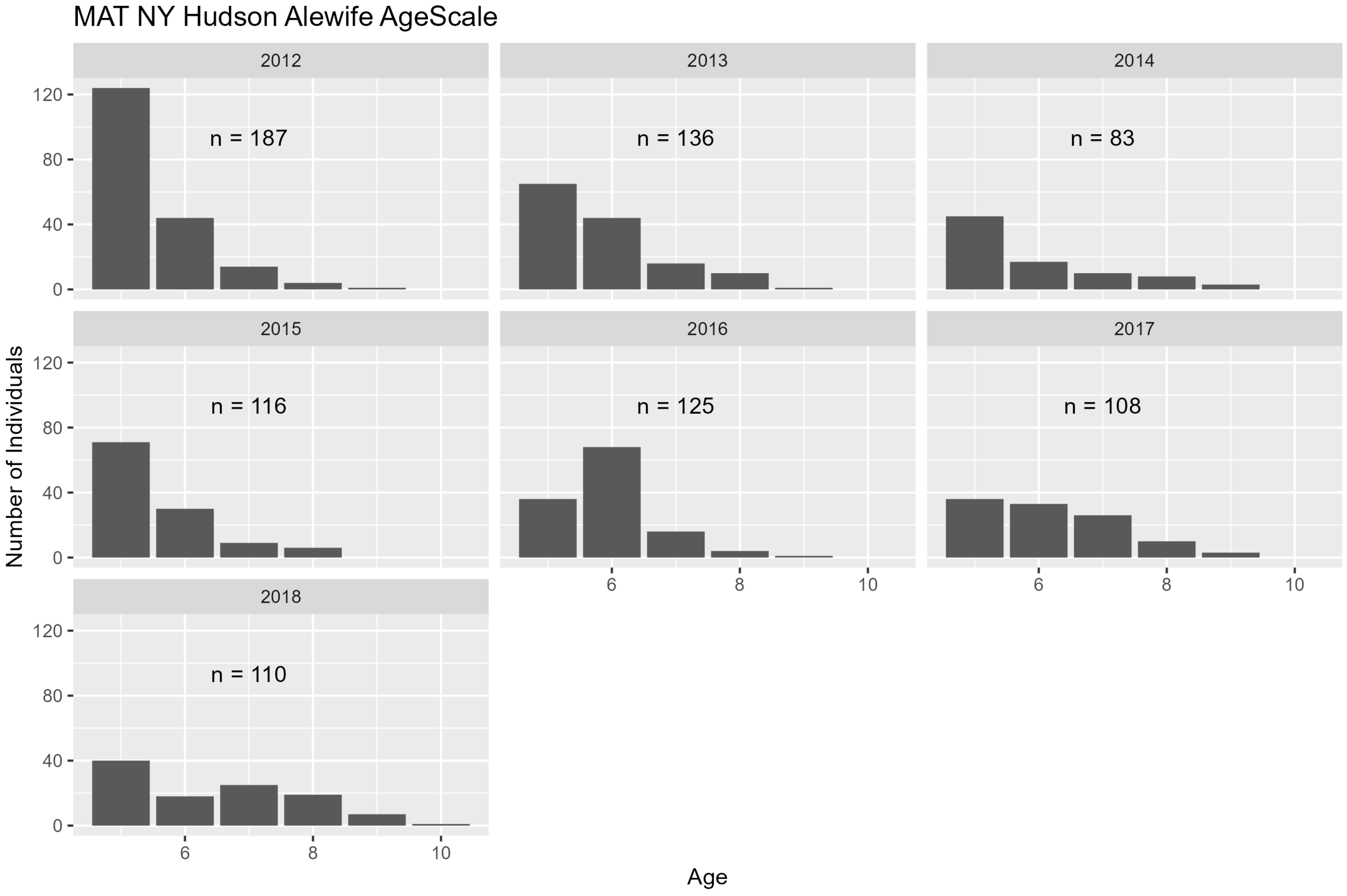
MAT NC_DMF_fi ALBEMARLESOUND_SCUPPERNONG RIVER Alewife AgeScale



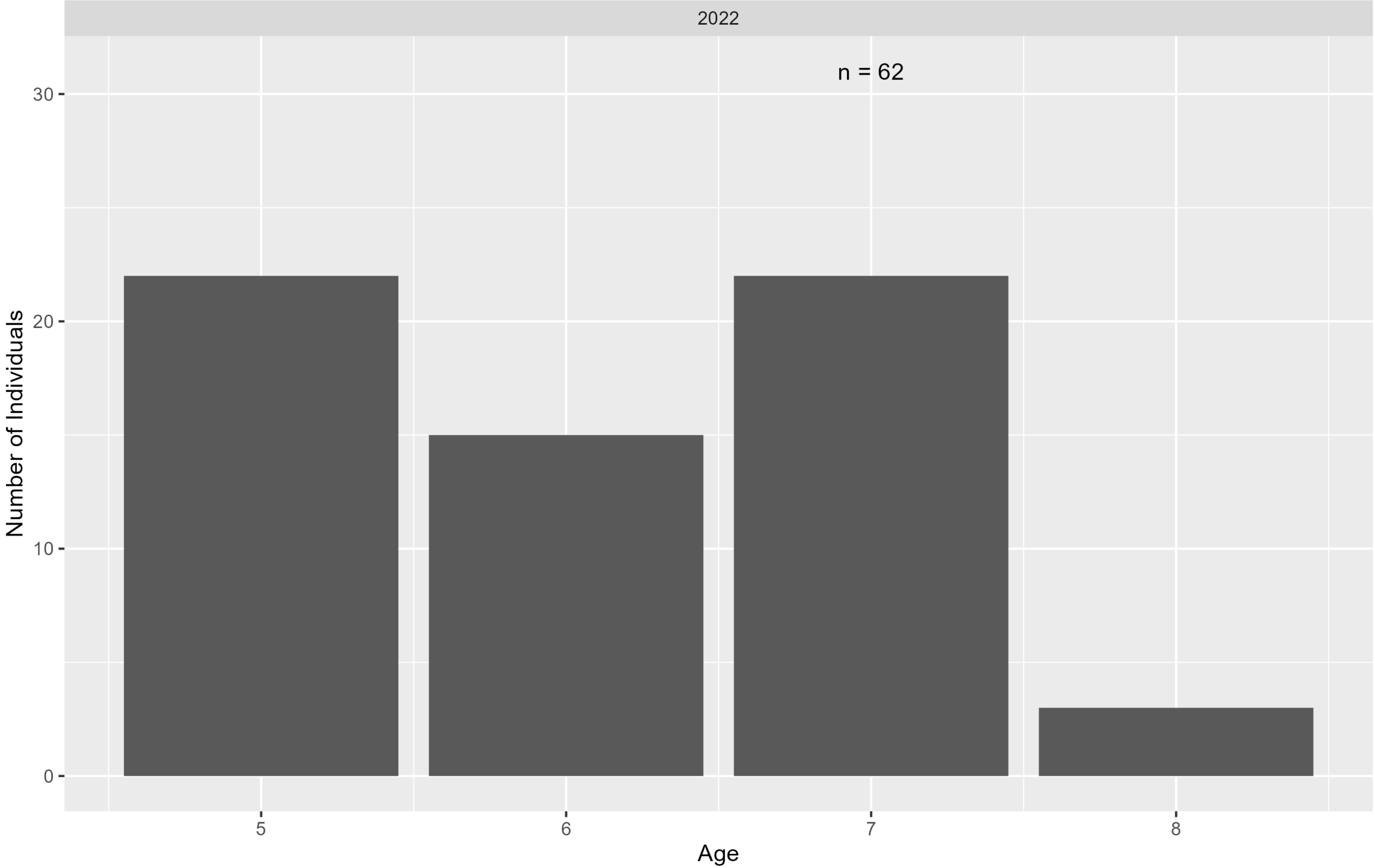
MAT NC_WRC Neuse River Blueback AgeOtolith

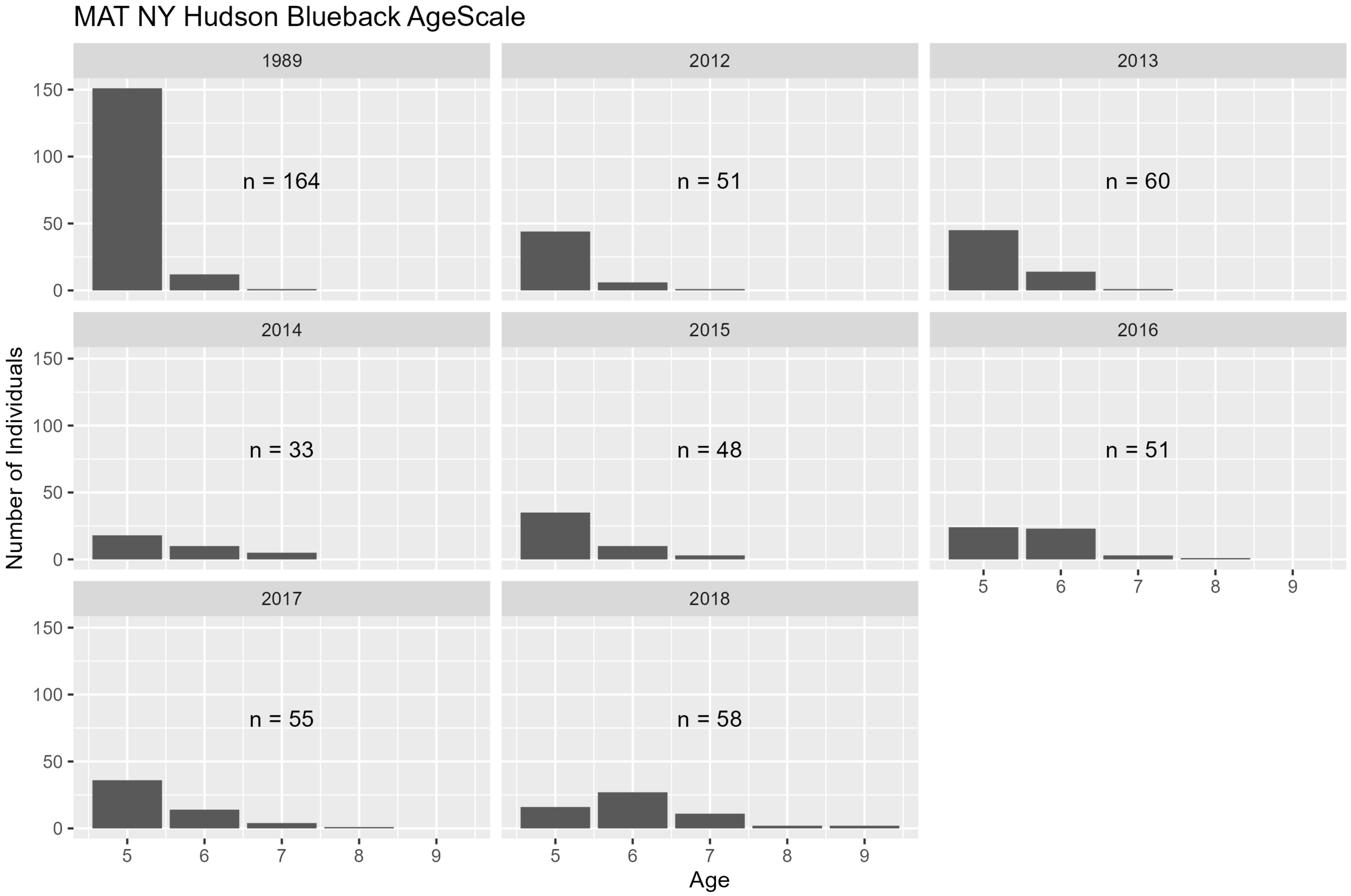



MAT NY Hudson Alewife AgeOtolith
2021
2022
n = 108
n = 81
Number of Individuals
0
20
40
6
8
10
6
8
10
Age


MAT NY Hudson Alewife AgeScale
2012
n = 187
2013
n = 136
2014
n = 83
2015
n = 116
2016
n = 125
2017
n = 108
2018
n = 110
Number of Individuals
0
40
80
120
Age
6
8
10

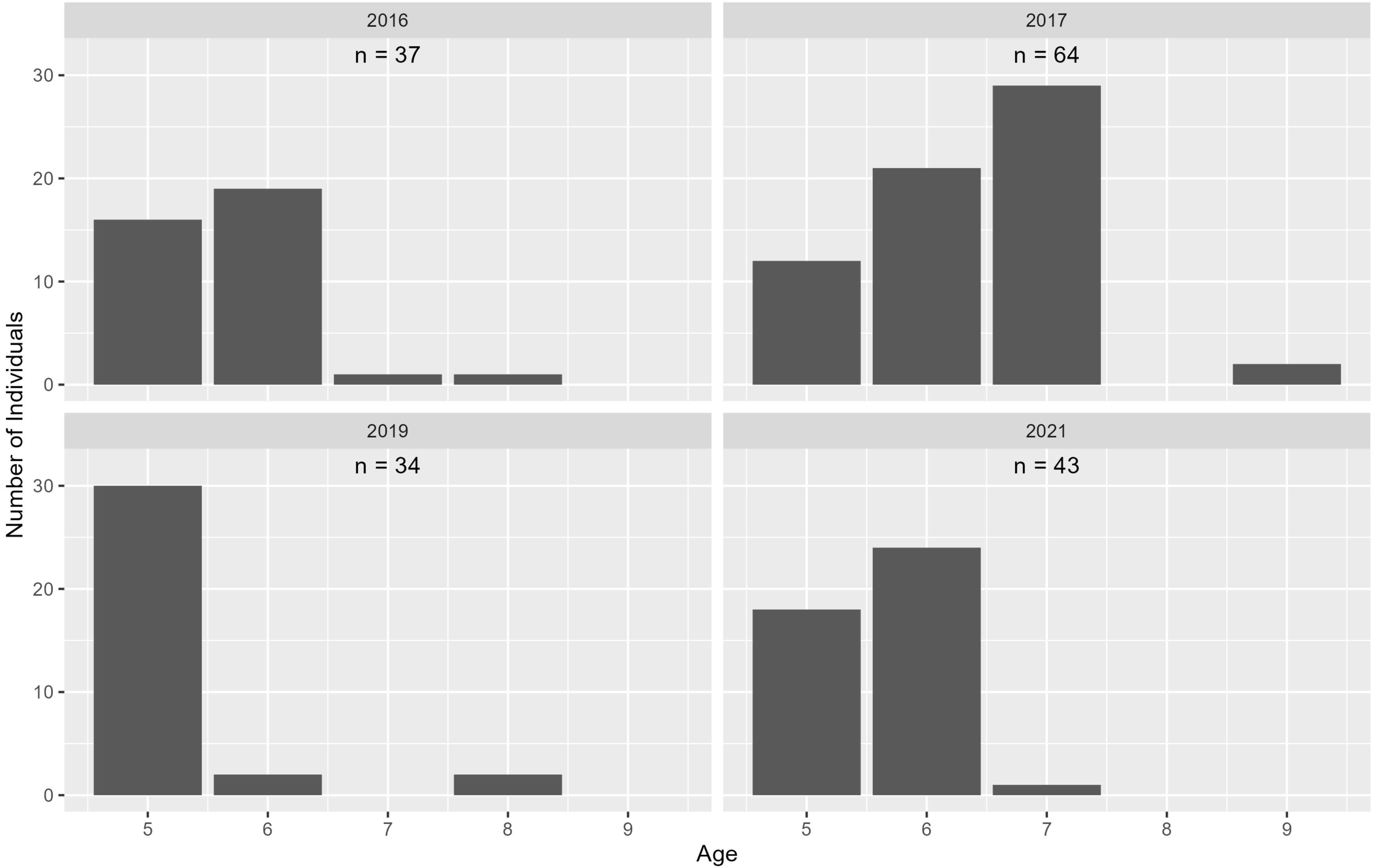
MAT NY Hudson Blueback AgeOtolith



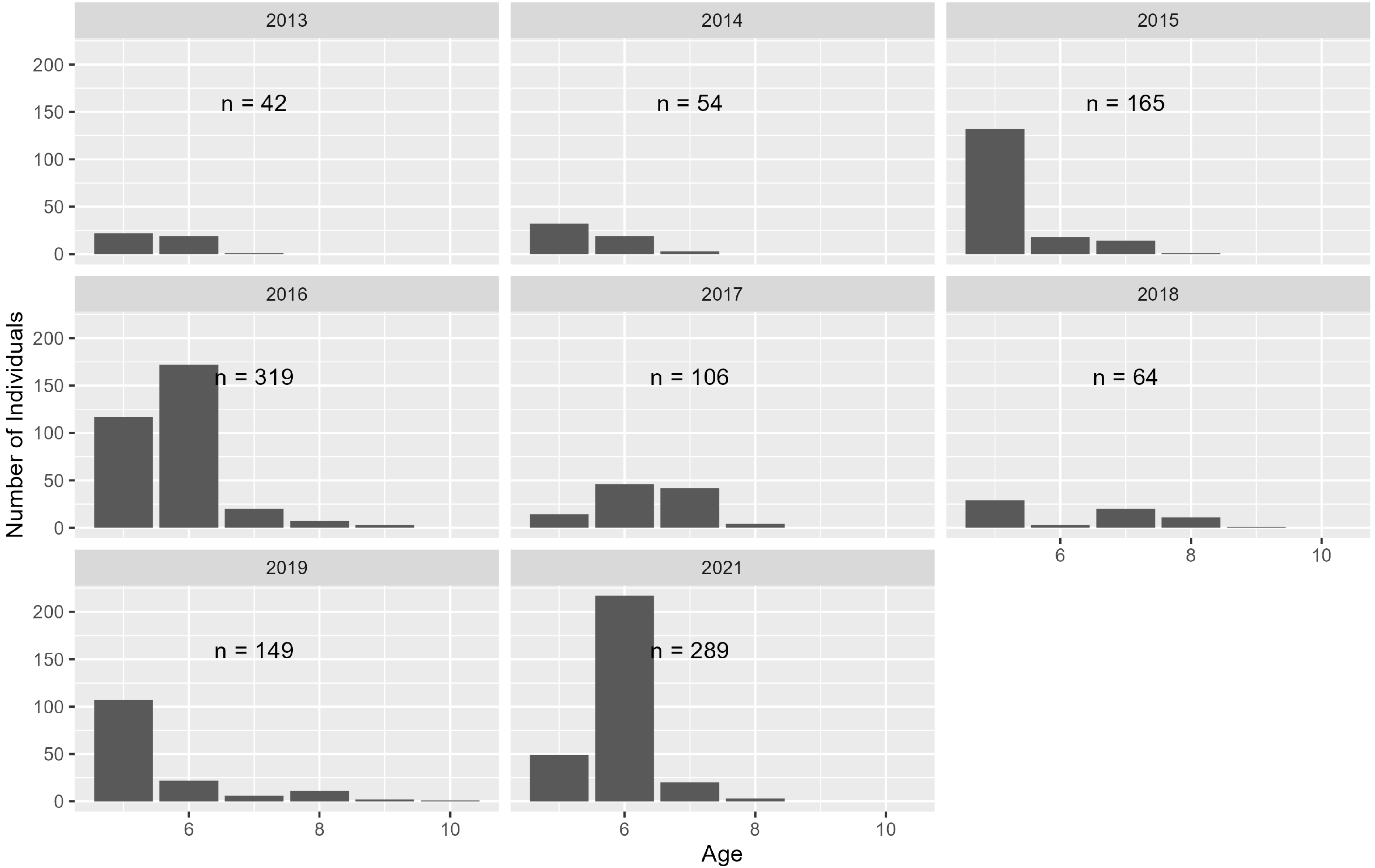


MAT NY Hudson Blueback AgeScale
1989
n = 164
2012
n = 51
2013
n = 60
2014
n = 33
2015
n = 48
2016
n = 51
2017
n = 55
2018
n = 58
Number of Individuals
0
50
100
150
Age
5
6
7
8
9

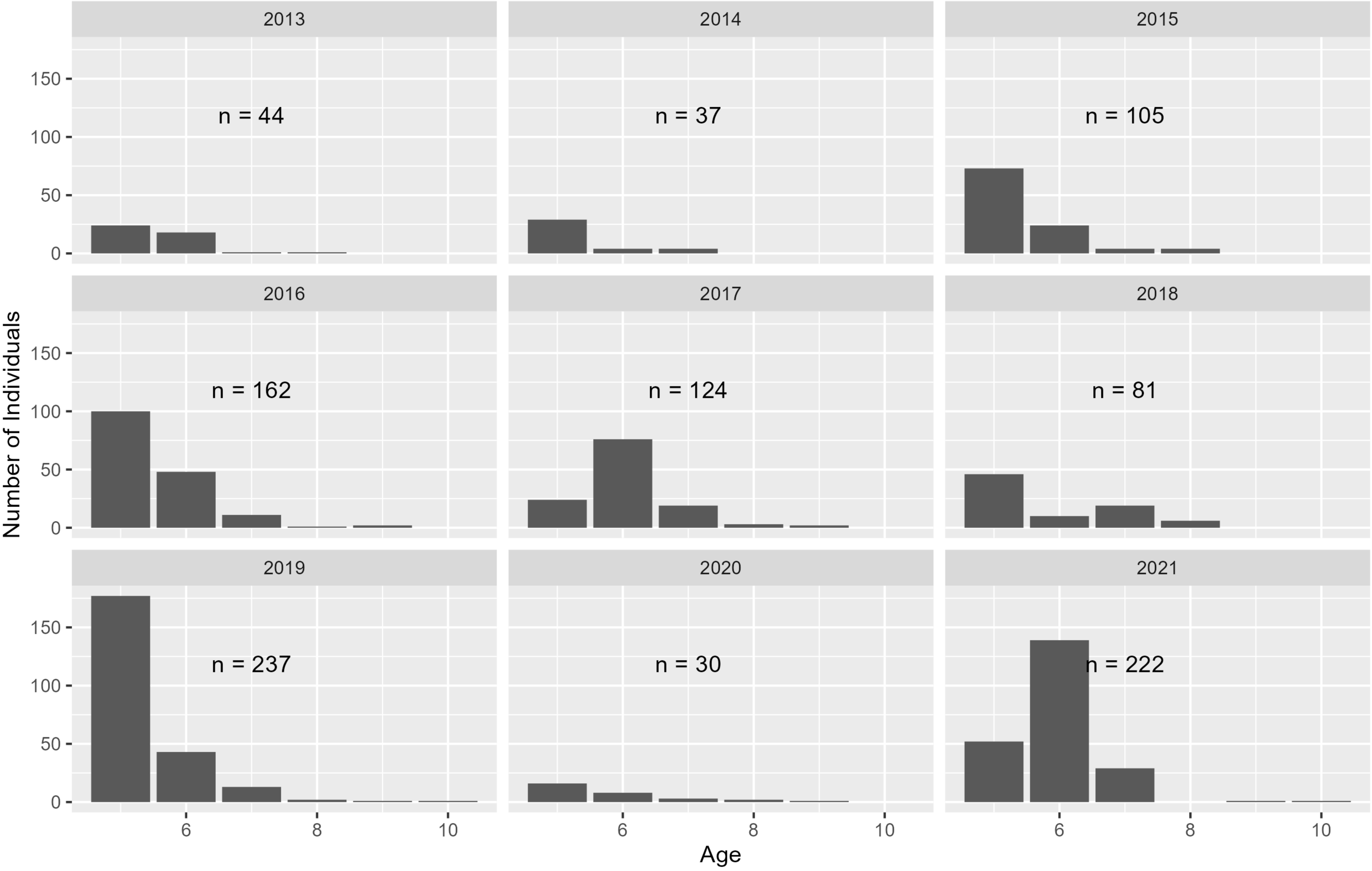
MAT USFWS Chicopee River Blueback AgeOtolith



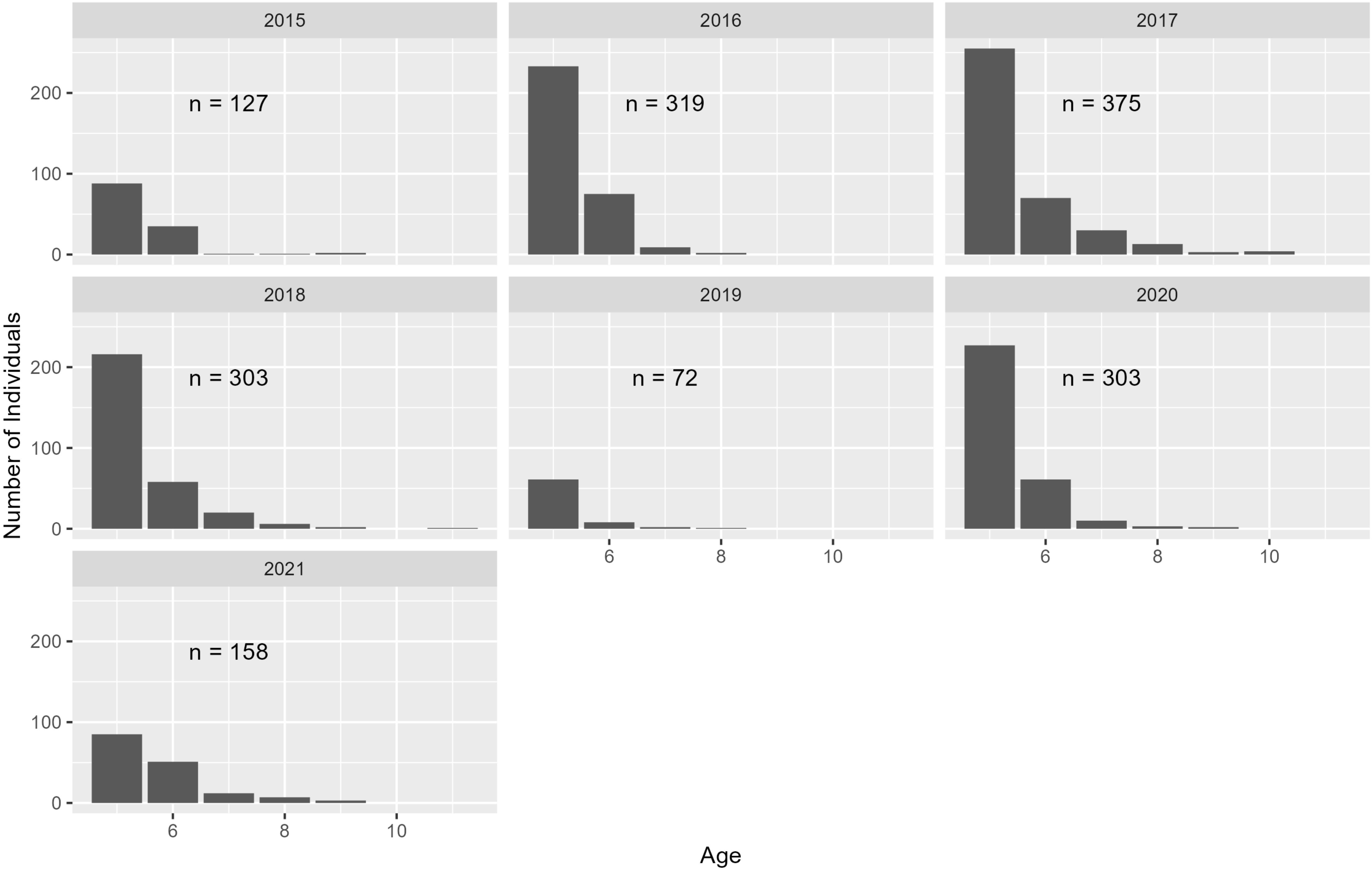
MAT USFWS Farmington River Blueback AgeOtolith

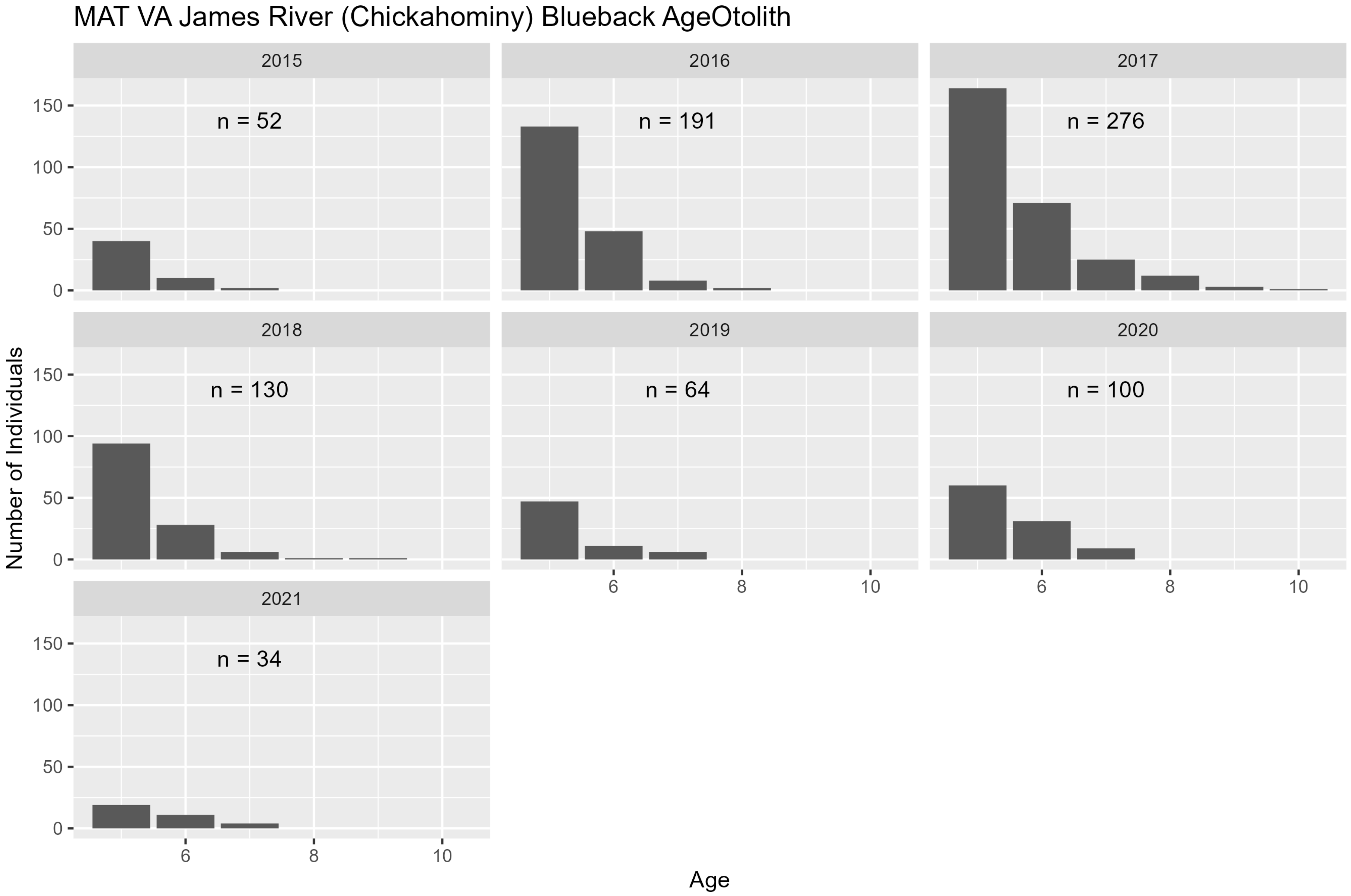


MAT USFWS Wethersfield Cove Blueback AgeOtolith

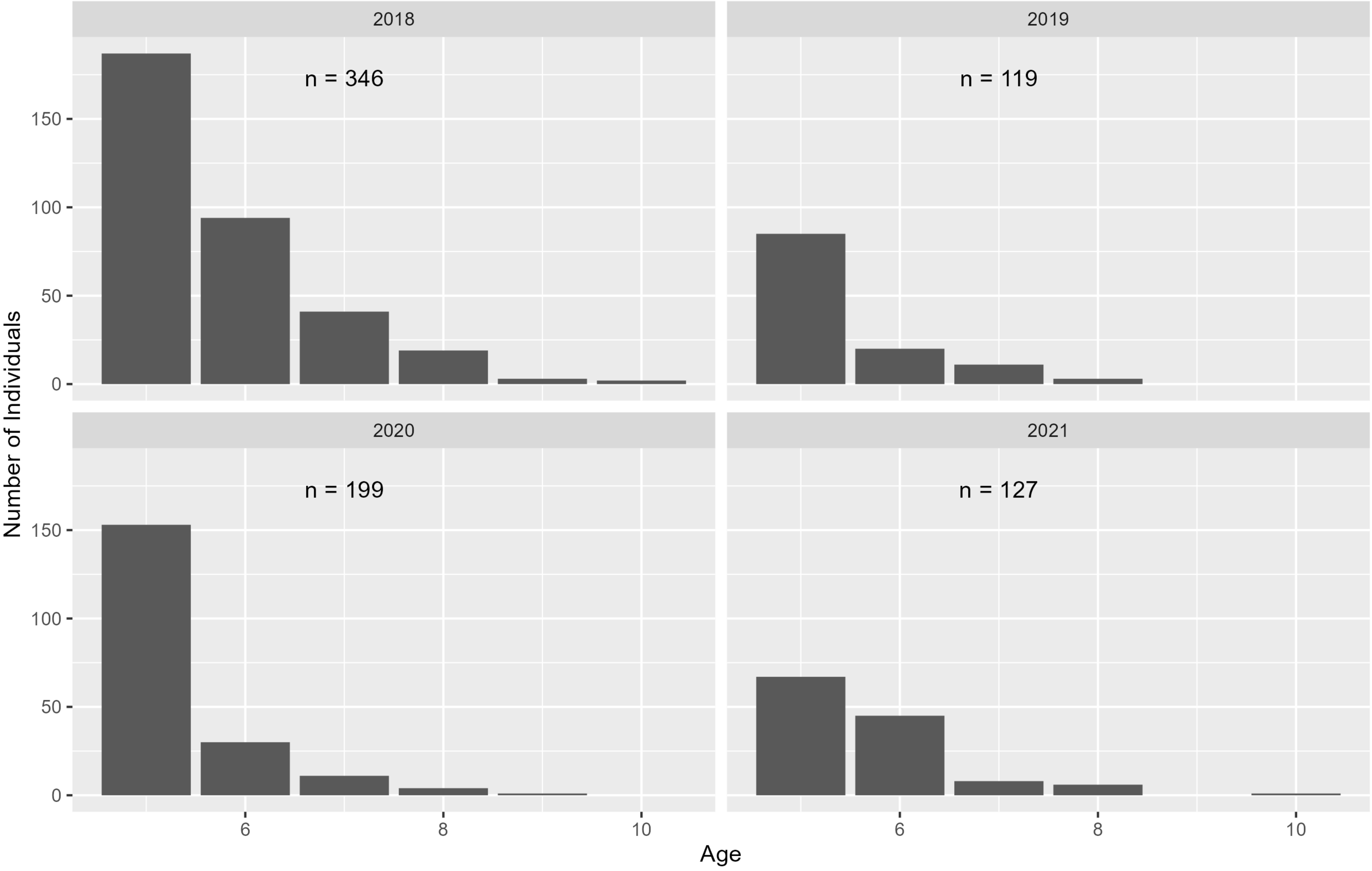


MAT VA James (Chickahominy) Alewife AgeOtolith

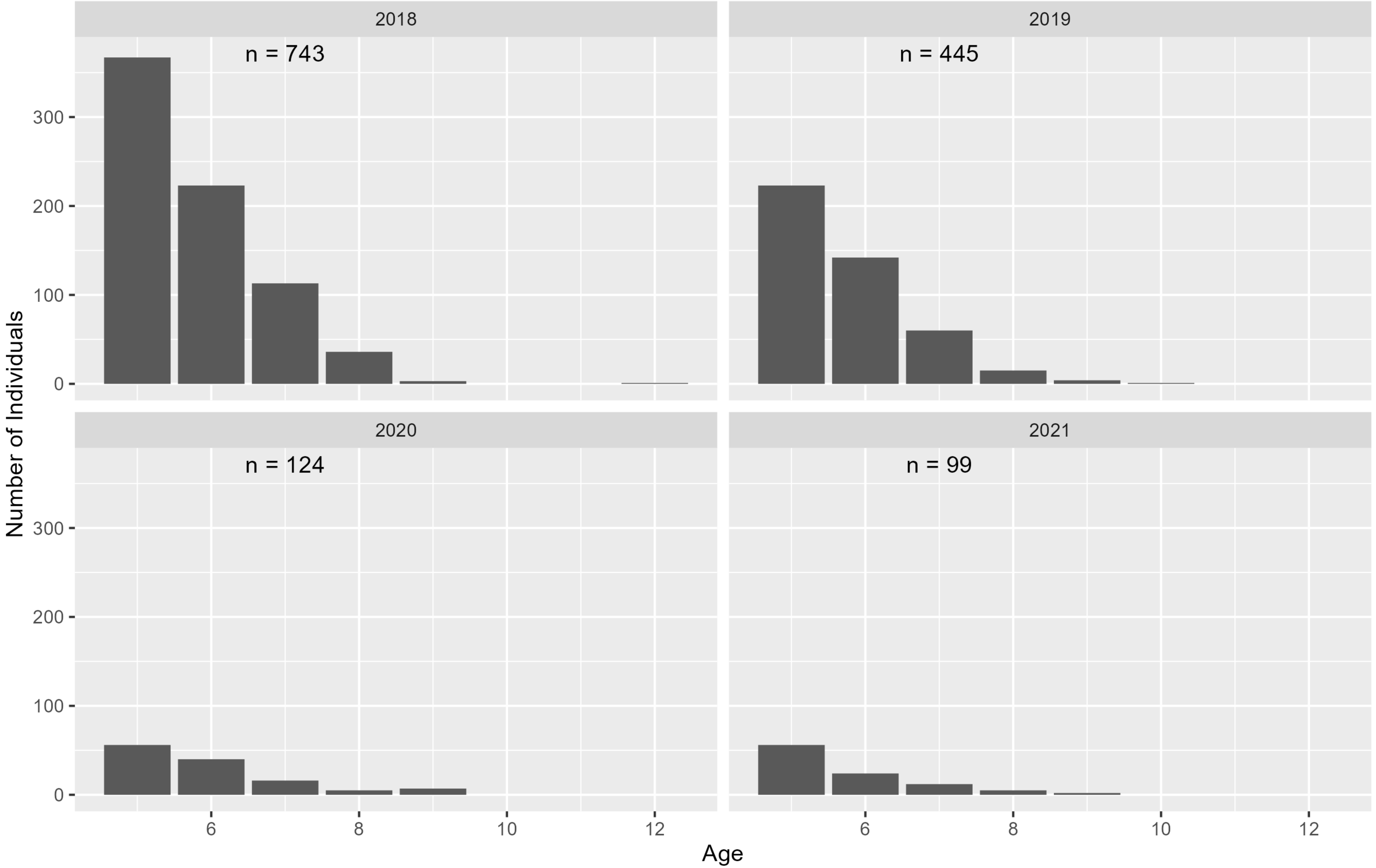


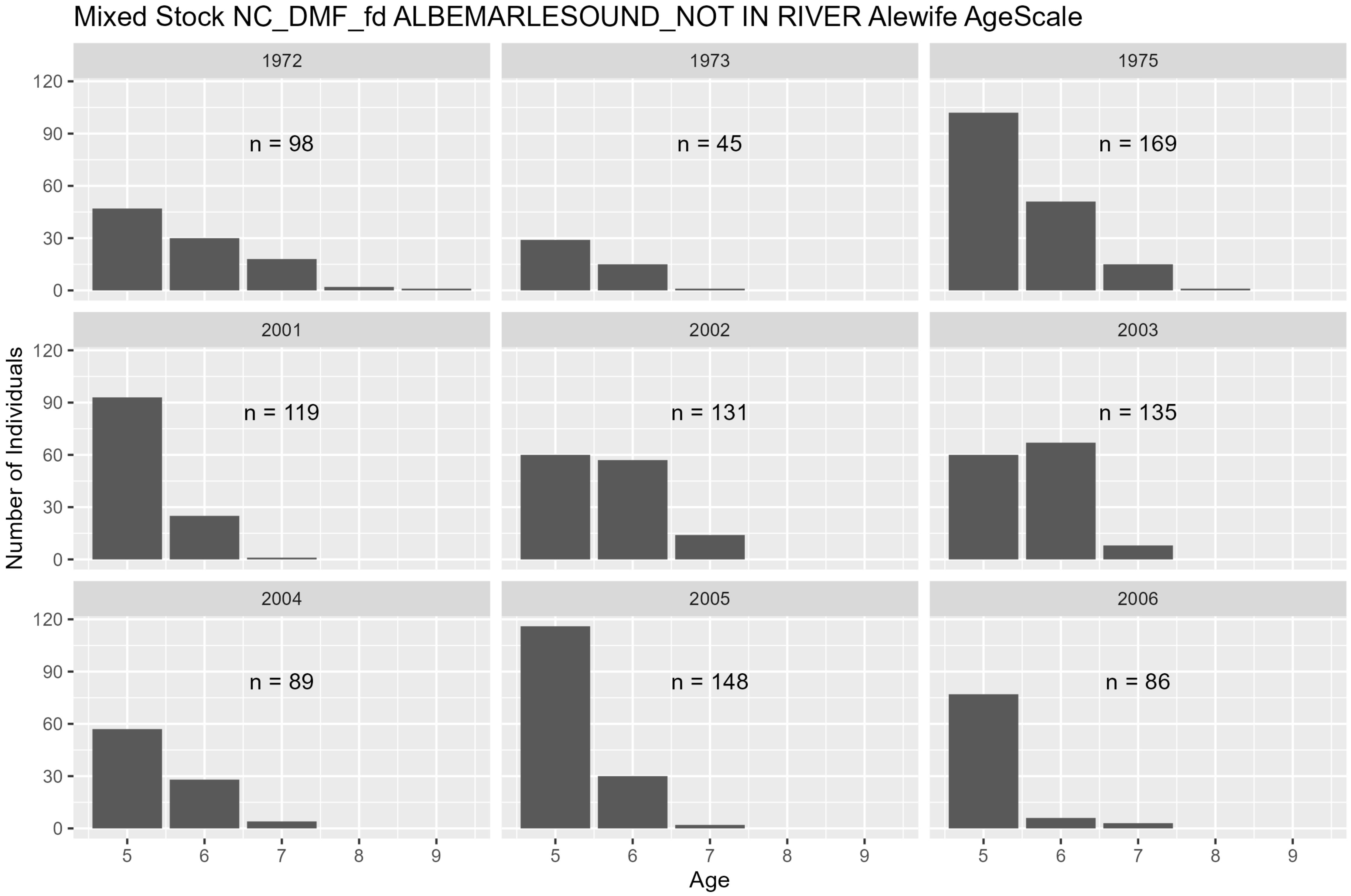

MAT VA James River (Chickahominy) Blueback AgeOtolith
2015
n = 52
2016
n = 191
2017
n = 276
2018
n = 130
2019
n = 64
2020
n = 100
2021
n = 34
Number of Individuals
0
50
100
150
6
8
10
Age

MAT VA Rappahannock River Alewife AgeOtolith

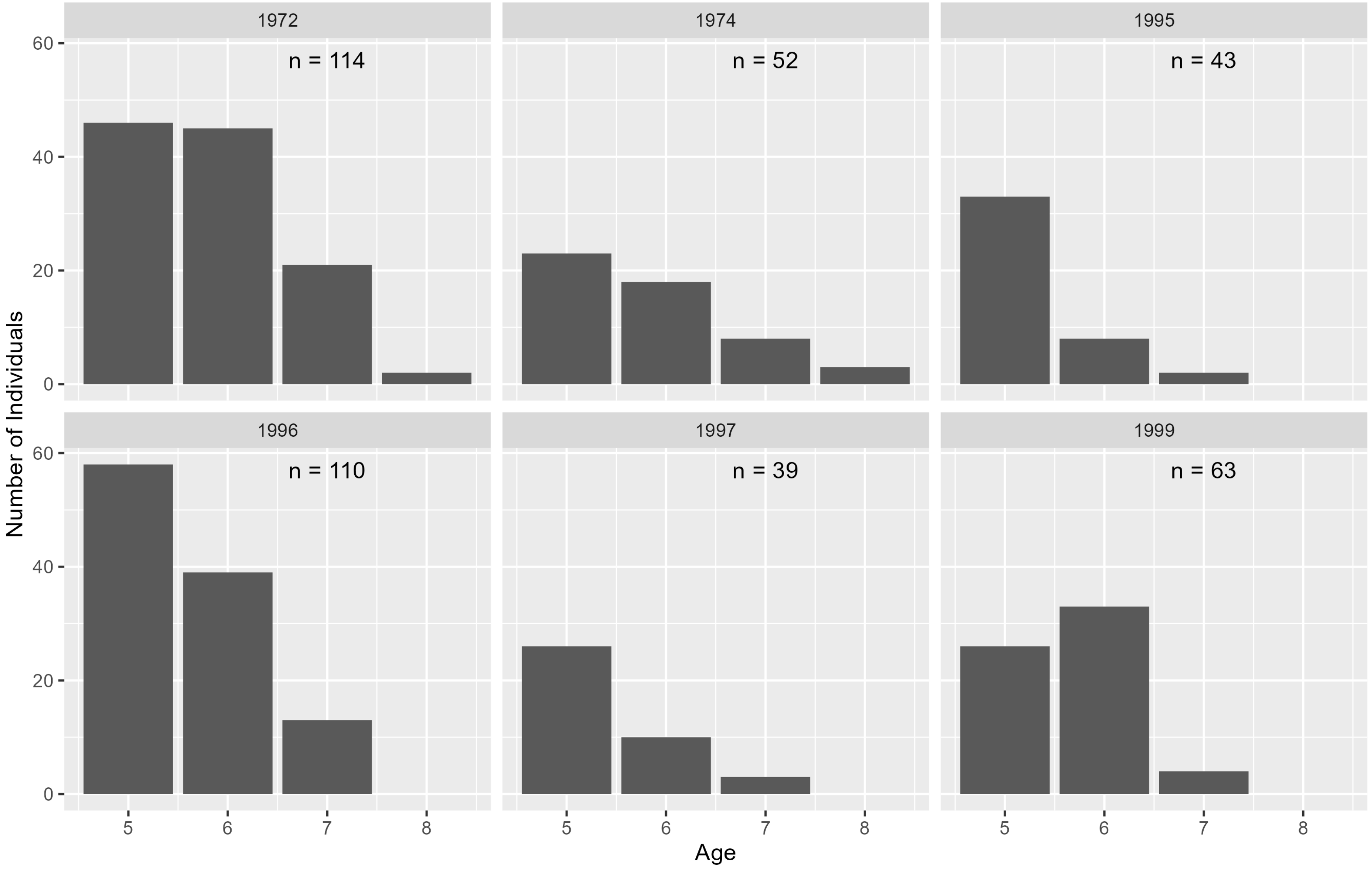


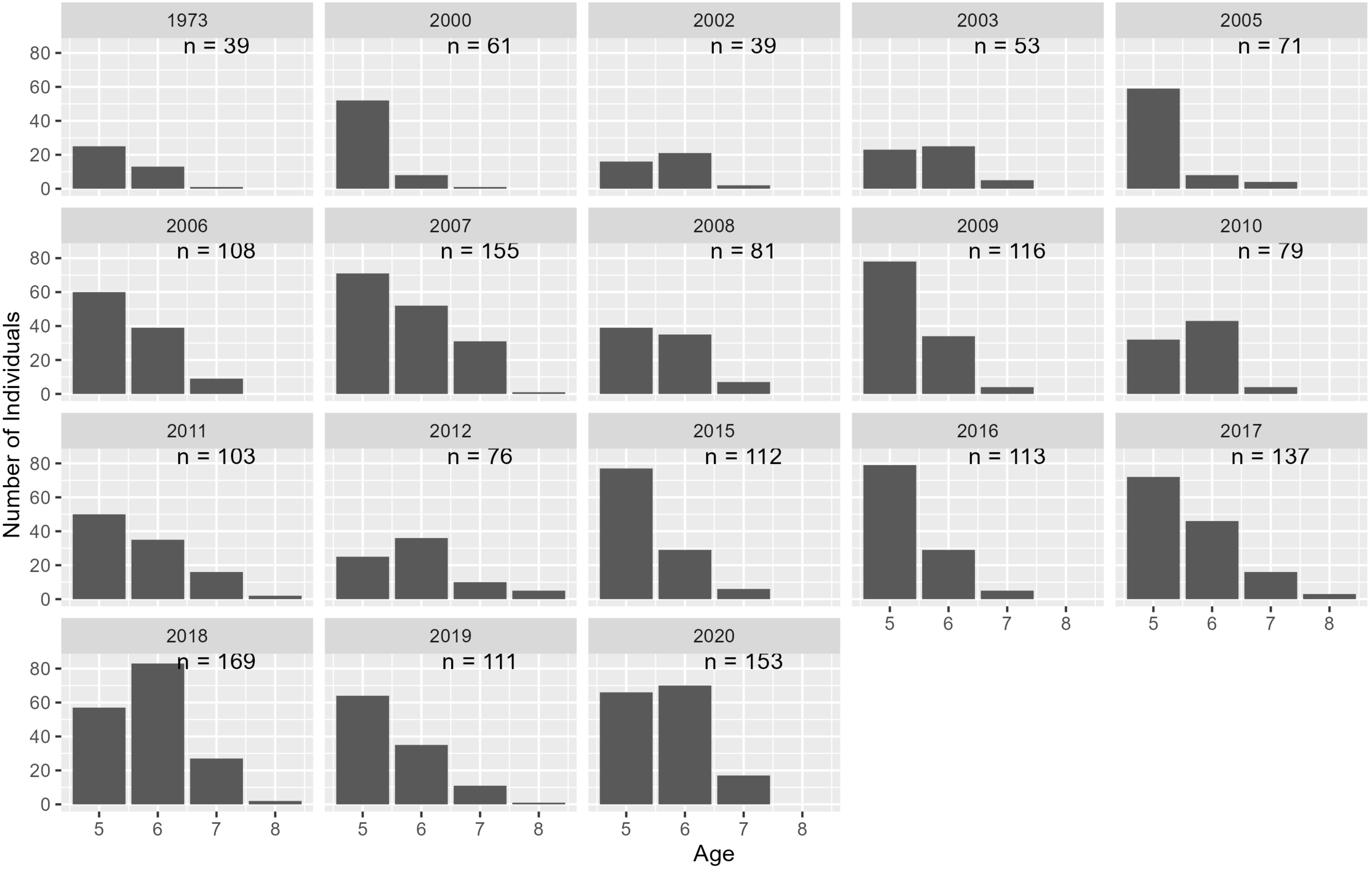
MAT VA Rappahannock River Blueback AgeOtolith




Mixed Stock NC_DMF_fd ALBEMARLESOUND_NOT IN RIVER Alewife AgeScale
1972
n = 98
1973
n = 45
1975
n = 169
2001
n = 119
2002
n = 131
2003
n = 135
2004
n = 89
2005
n = 148
2006
n = 86
Number of Individuals
0
30
60
90
120
Age
5
6
7
8
9

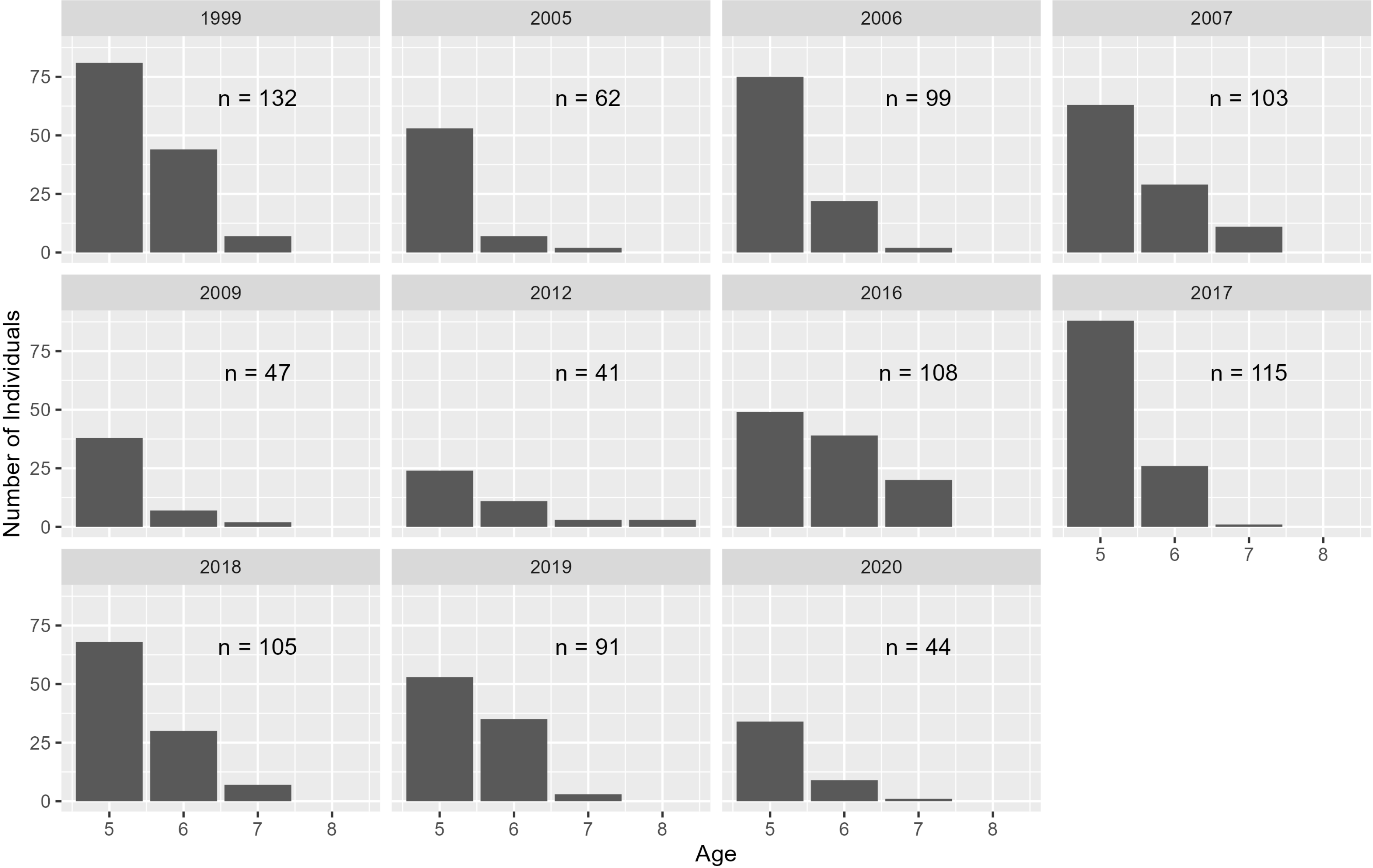
Mixed Stock NC_DMF_fd ALBEMARLESOUND_NOT IN RIVER Blueback AgeScale

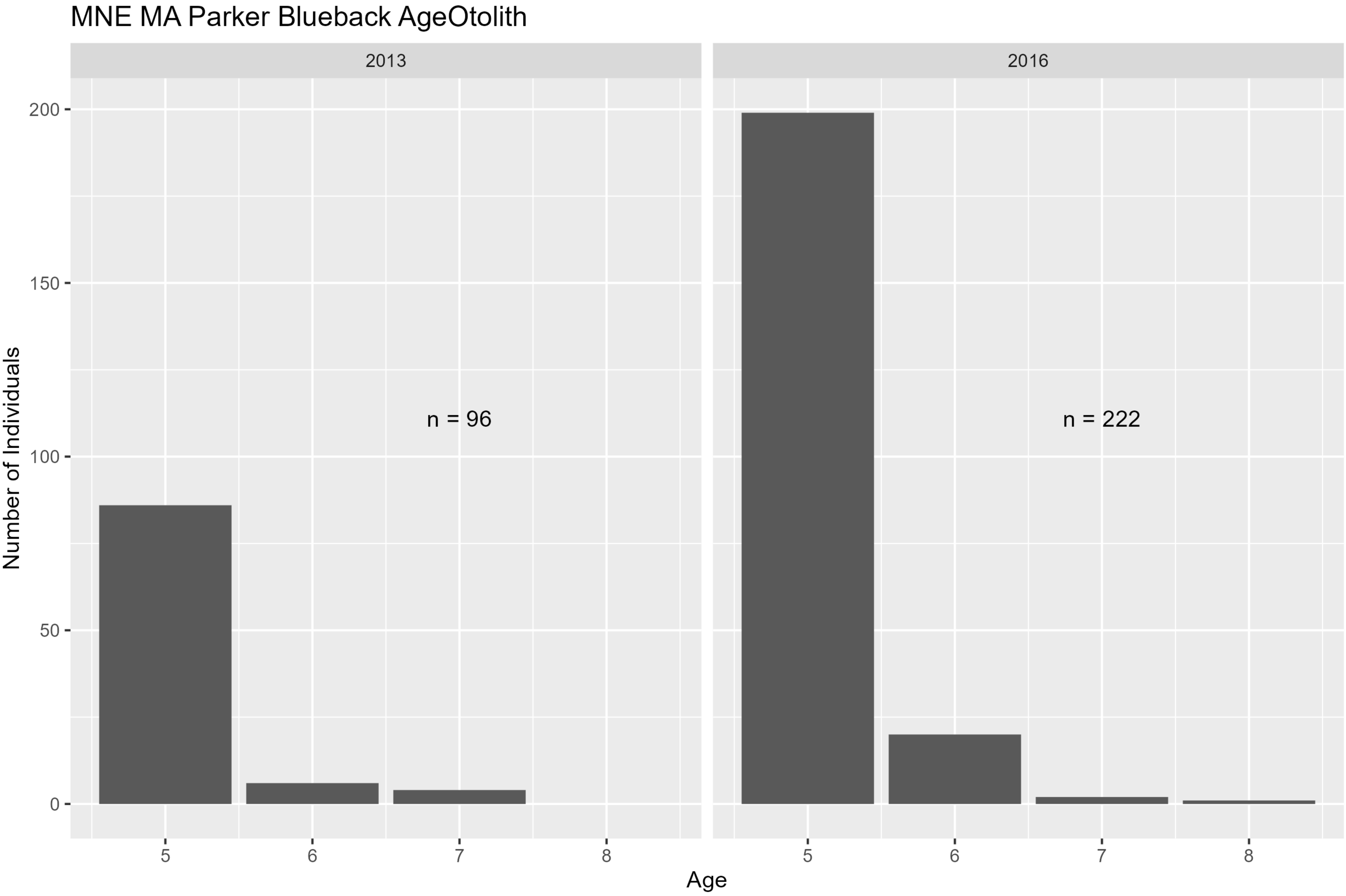




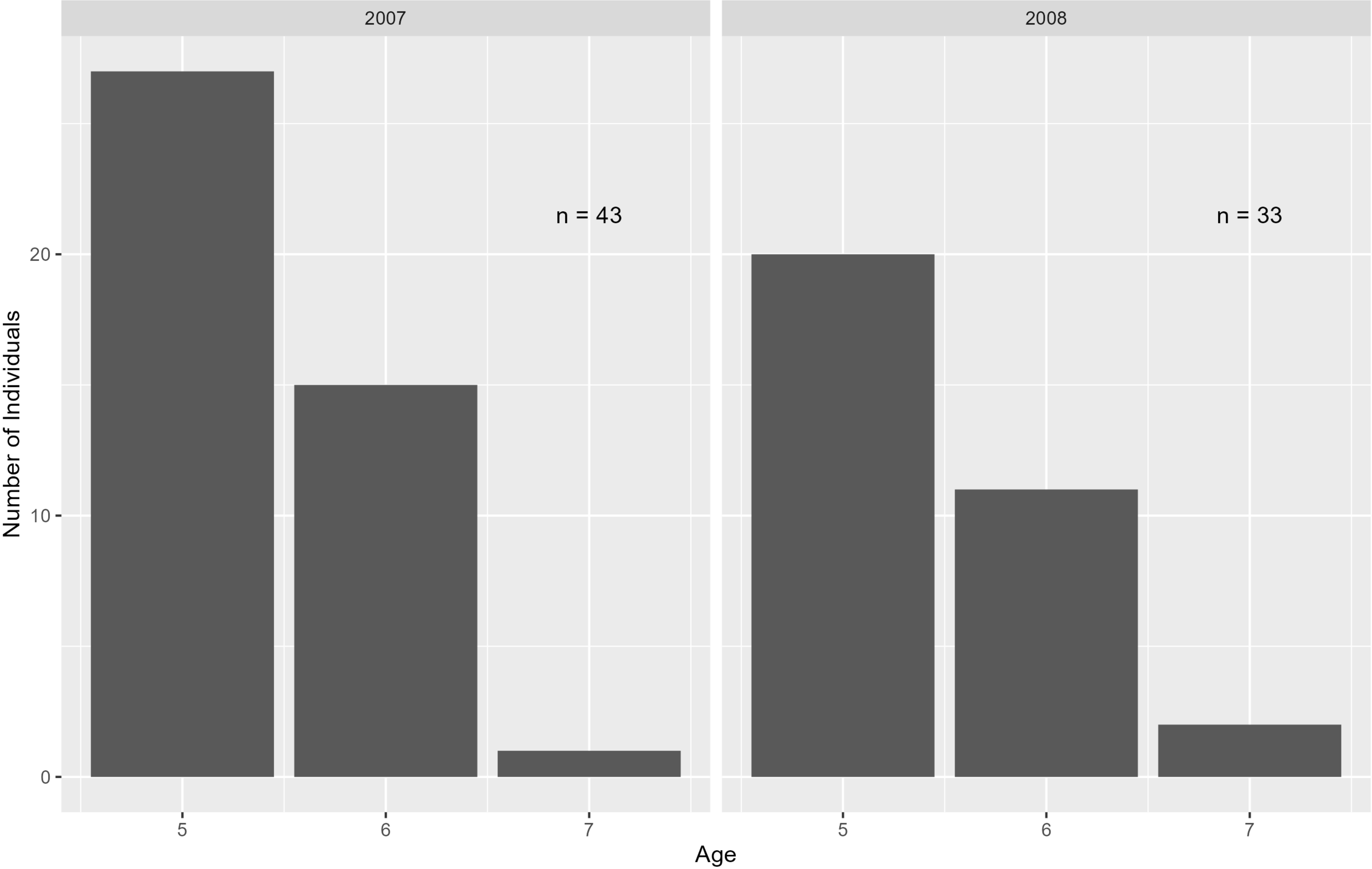
Mixed Stock NC_DMF_fi ALBEMARLESOUND_NOT IN RIVER Alewife AgeScale

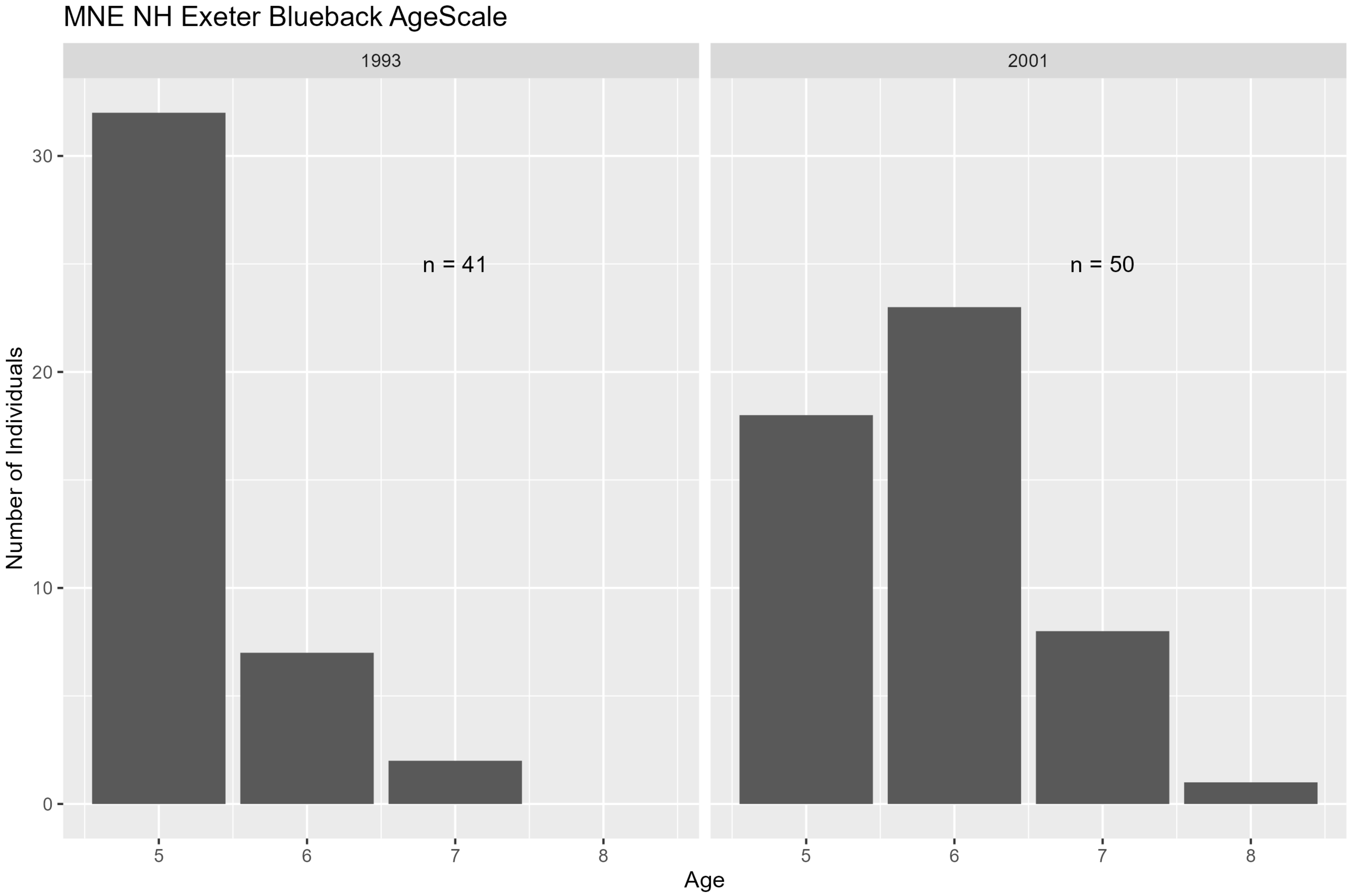
Mixed Stock NC_DMF_fi ALBEMARLESOUND_NOT IN RIVER Blueback AgeScale

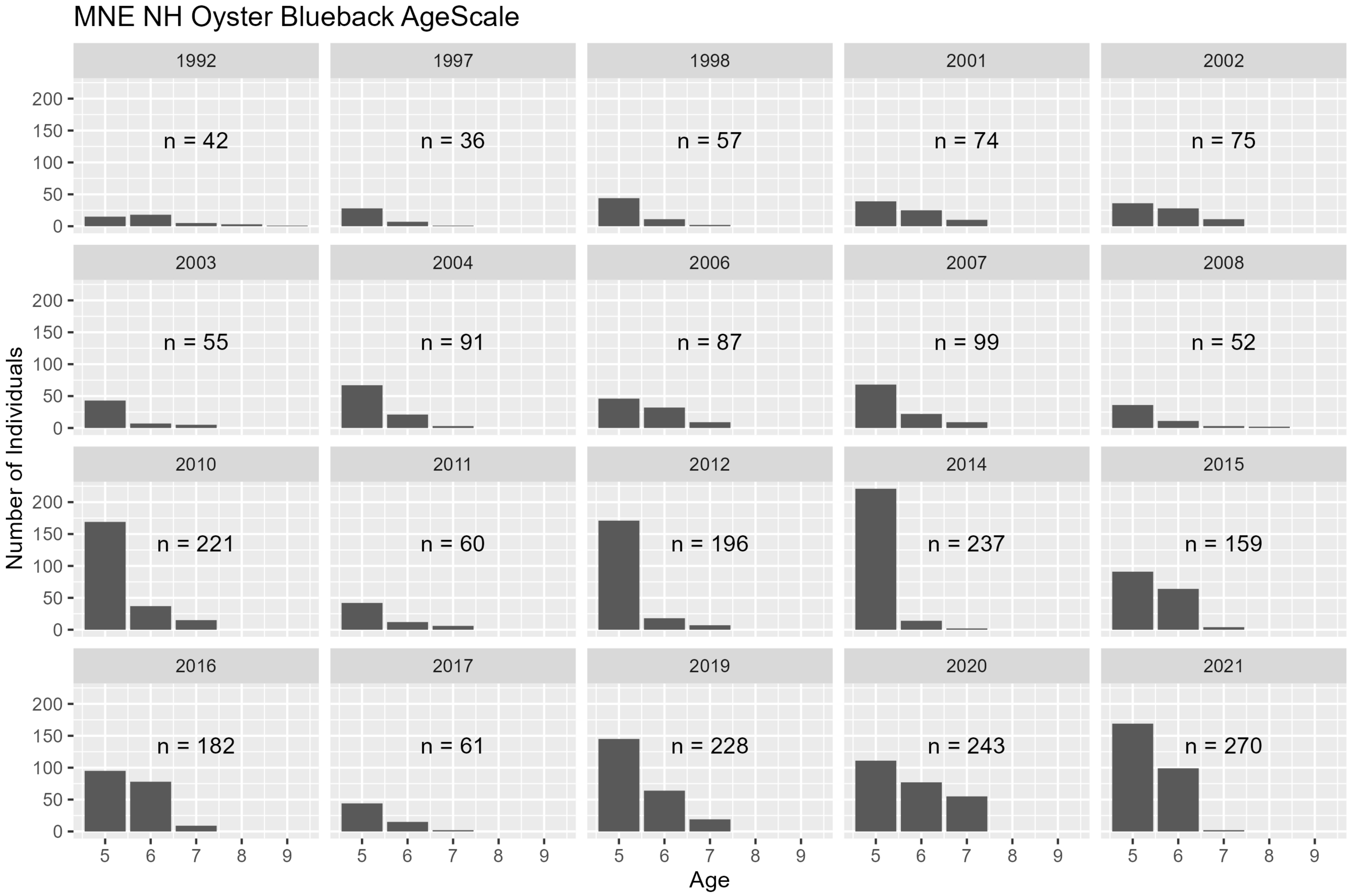



MNE MA Parker Blueback AgeOtolith
2013
2016
Number of Individuals
0
50
100
150
200
n = 96
n = 222
5
6
7
8
5
6
7
8
Age

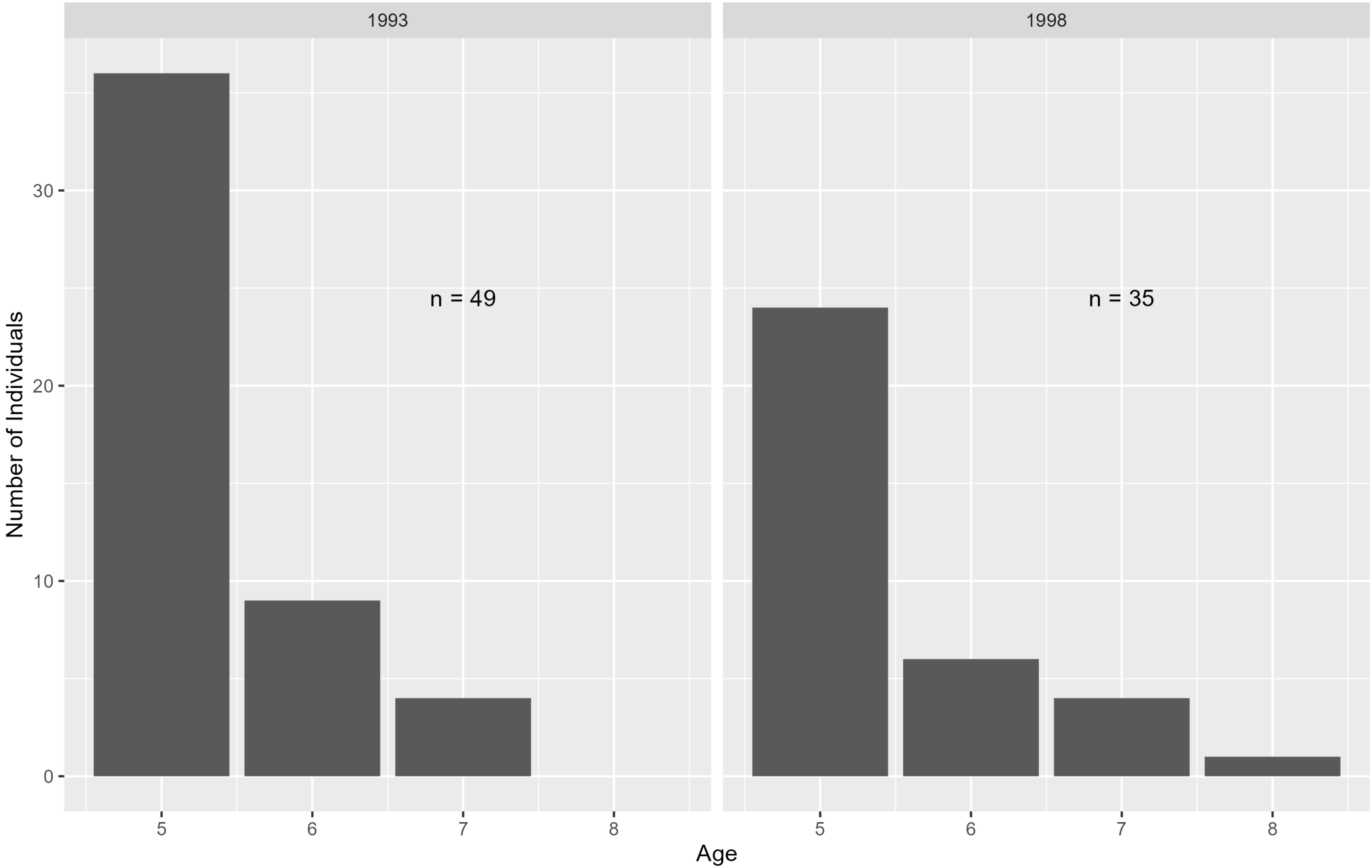
MNE NH Cocheco Blueback AgeScale



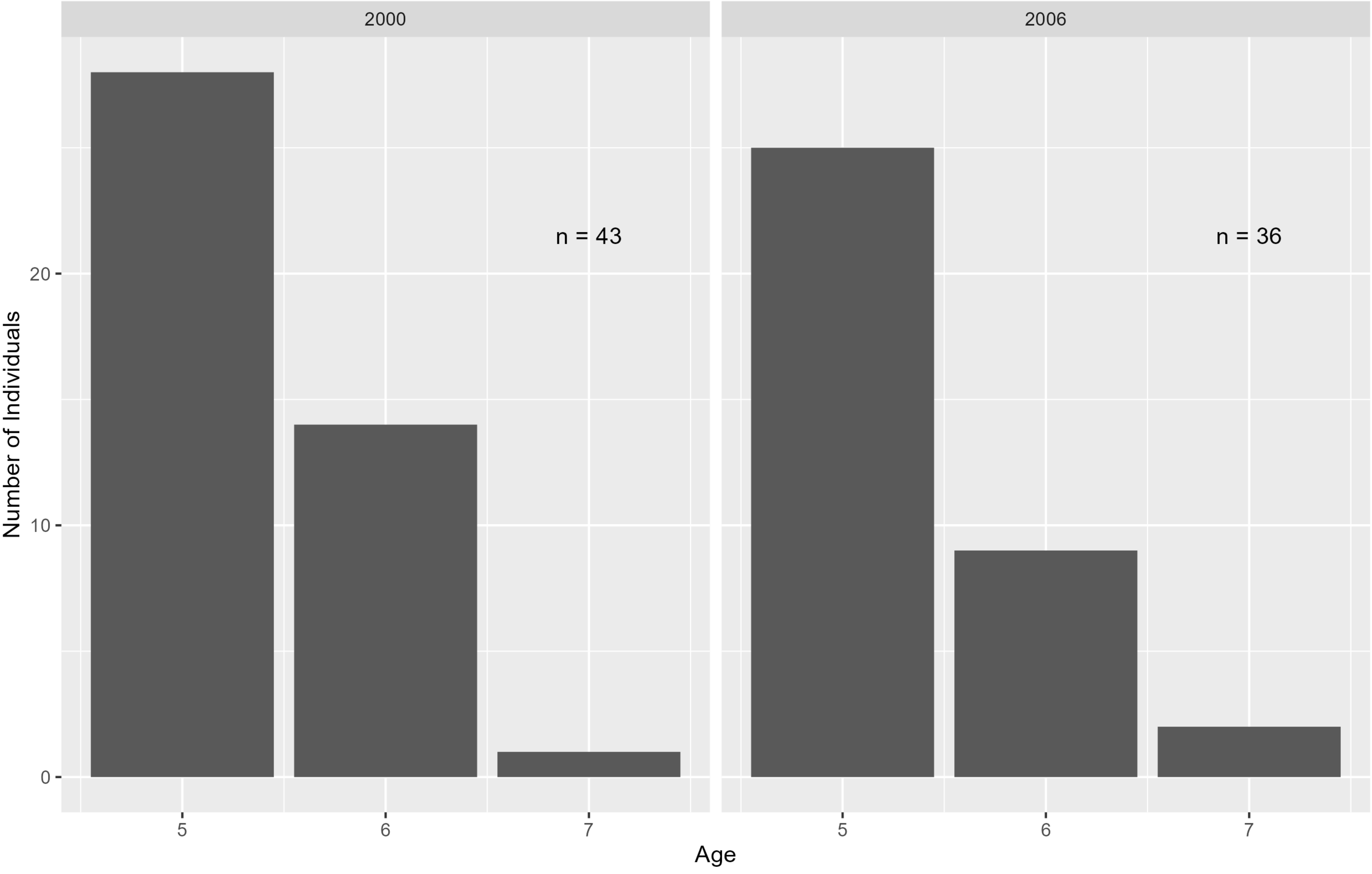

MNE NH Exeter Blueback AgeScale
1993
2001
n = 41
n = 50
Number of Individuals
0
10
20
30
5
6
7
8
5
6
7
8
Age

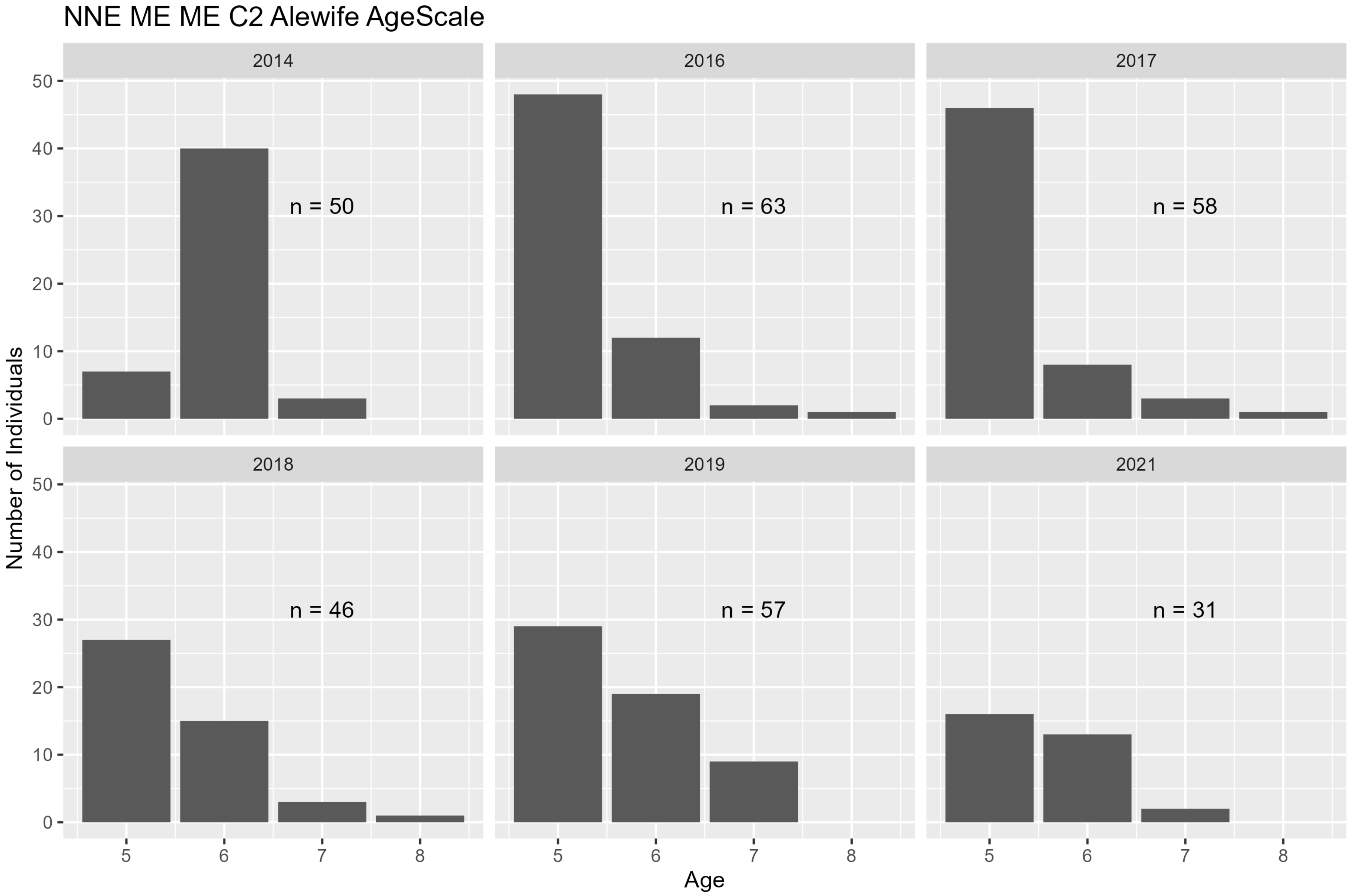

MNE NH Oyster Blueback AgeScale
1992
1997
1998
2001
2002
2003
2004
2006
2007
2008
2010
2011
2012
2014
2015
2016
2017
2019
2020
2021
n = 42
n = 36
n = 57
n = 74
n = 75
n = 55
n = 91
n = 87
n = 99
n = 52
n = 221
n = 60
n = 196
n = 237
n = 159
n = 182
n = 61
n = 228
n = 243
n = 270
200
150
100
50
0
5
6
7
8
9
Number of Individuals
Age

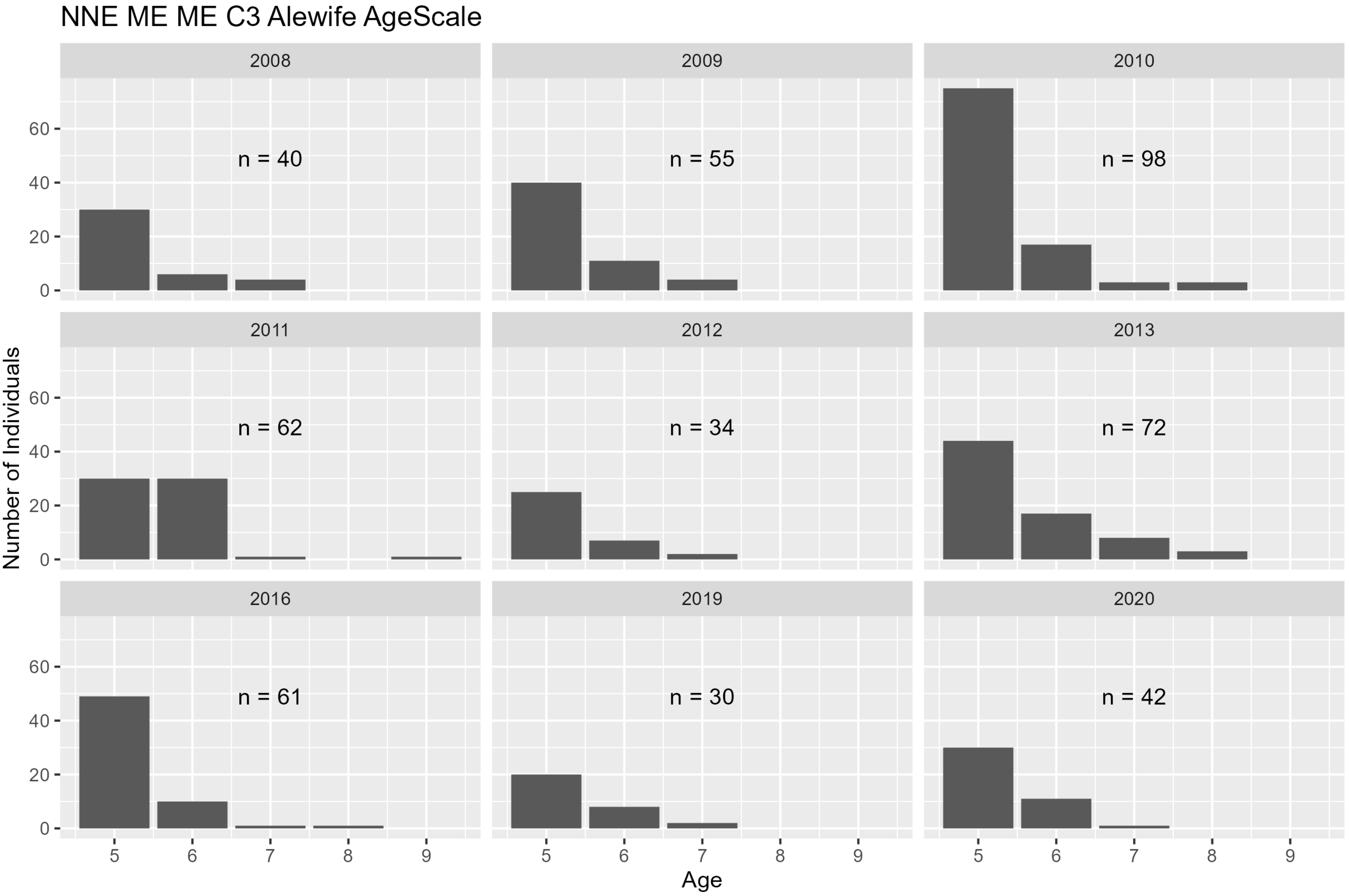
MNE NH Taylor Blueback AgeScale



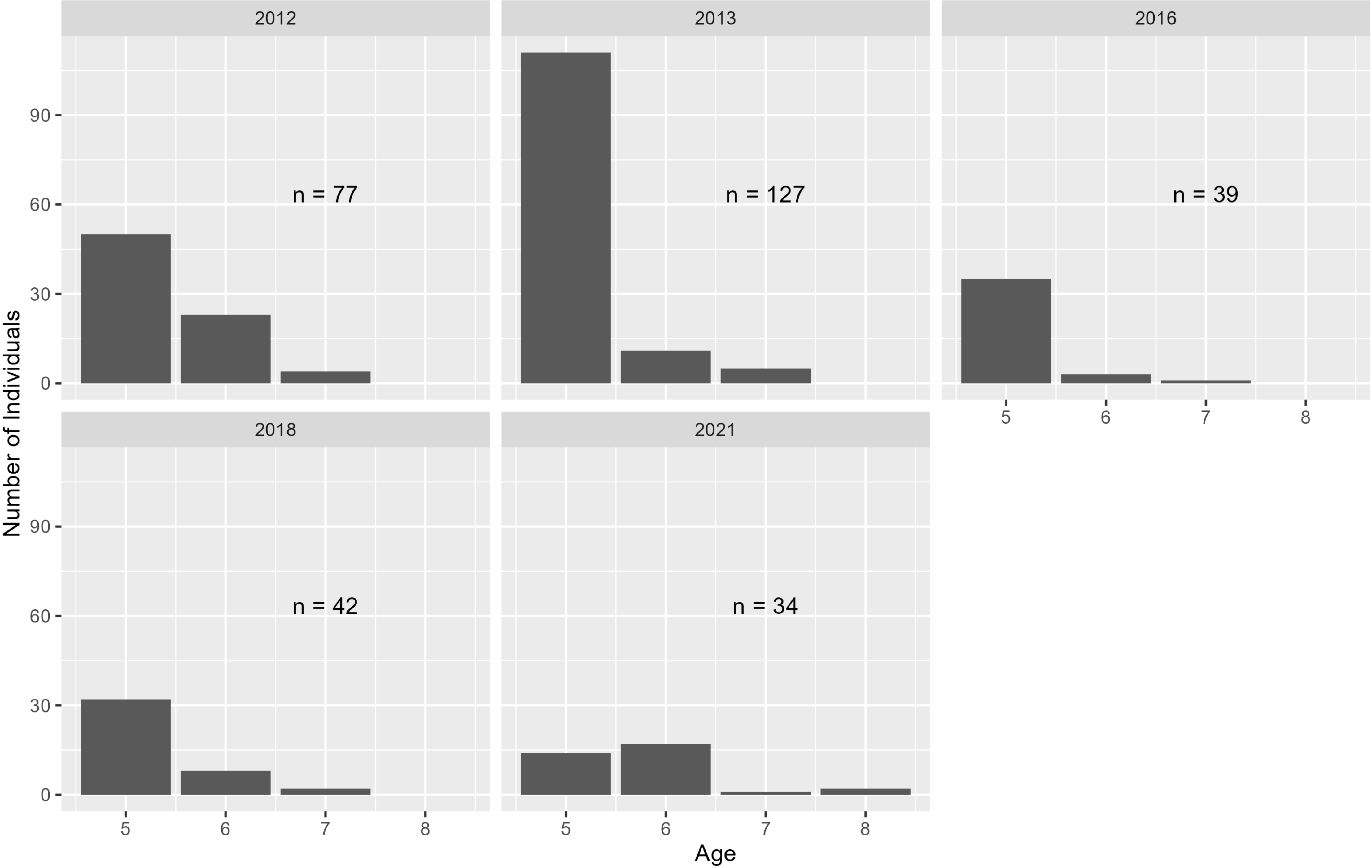
MNE NH Winnicut Blueback AgeScale

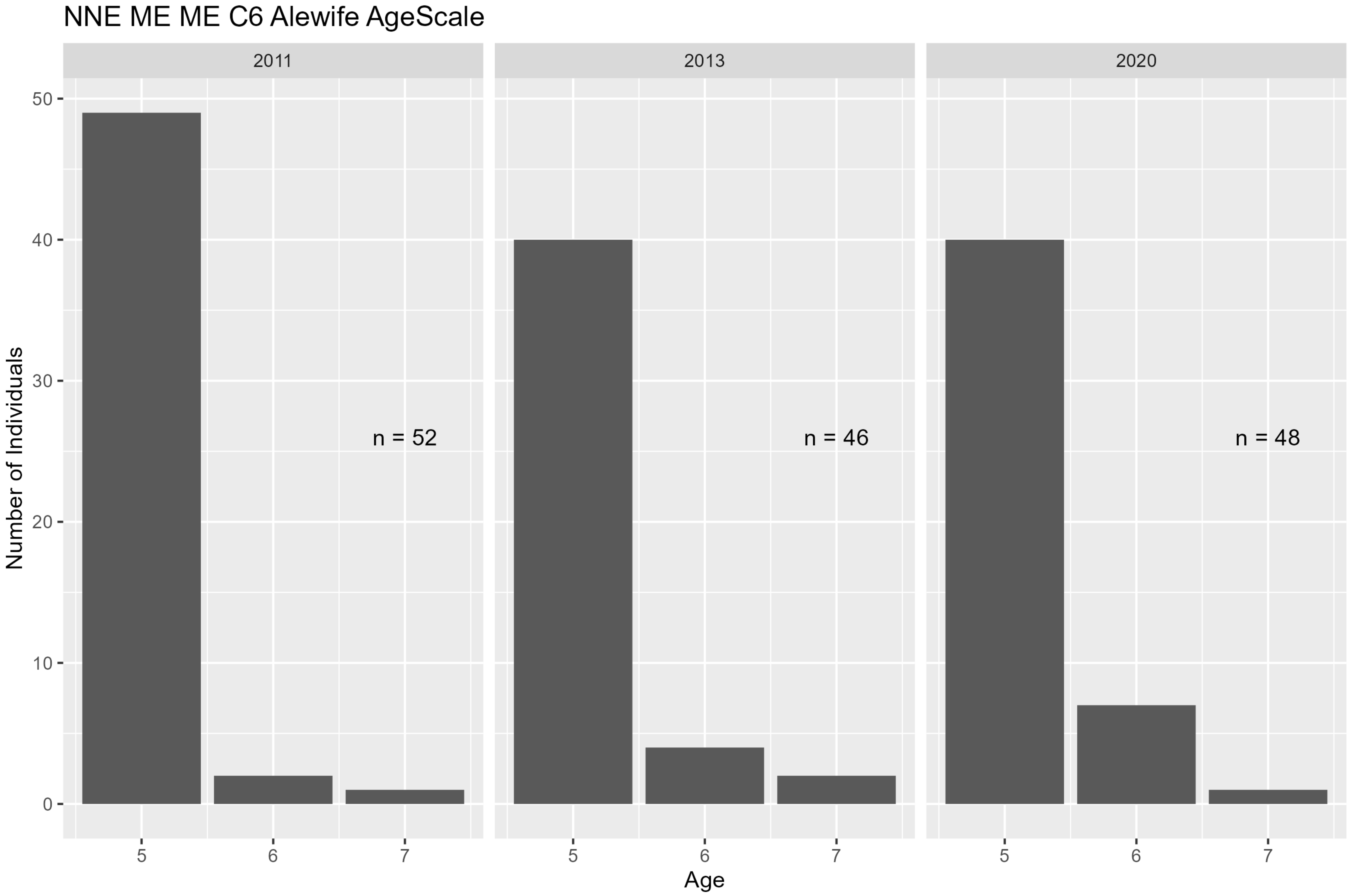



NNE ME ME C2 Alewife AgeScale
2014
2016
2017
2018
2019
2021
n = 50
n = 63
n = 58
n = 46
n = 57
n = 31
Number of Individuals
0
10
20
30
40
50
Age
5
6
7
8

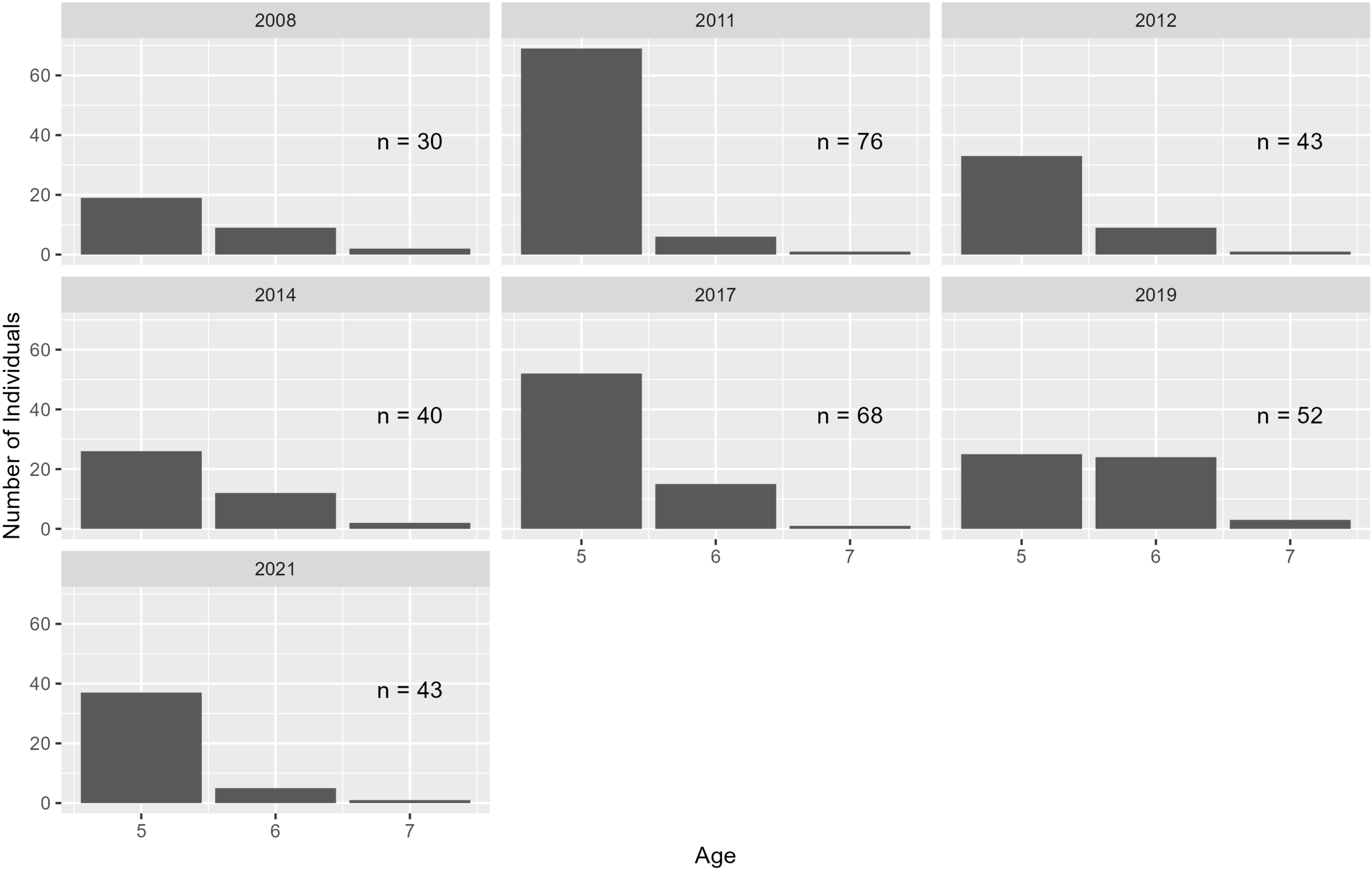
NNE ME ME C3 Alewife AgeScale
2008
n = 40
2009
n = 55
2010
n = 98
2011
n = 62
2012
n = 34
2013
n = 72
2016
n = 61
2019
n = 30
2020
n = 42
Number of Individuals
0
20
40
60
Age
5
6
7
8
9

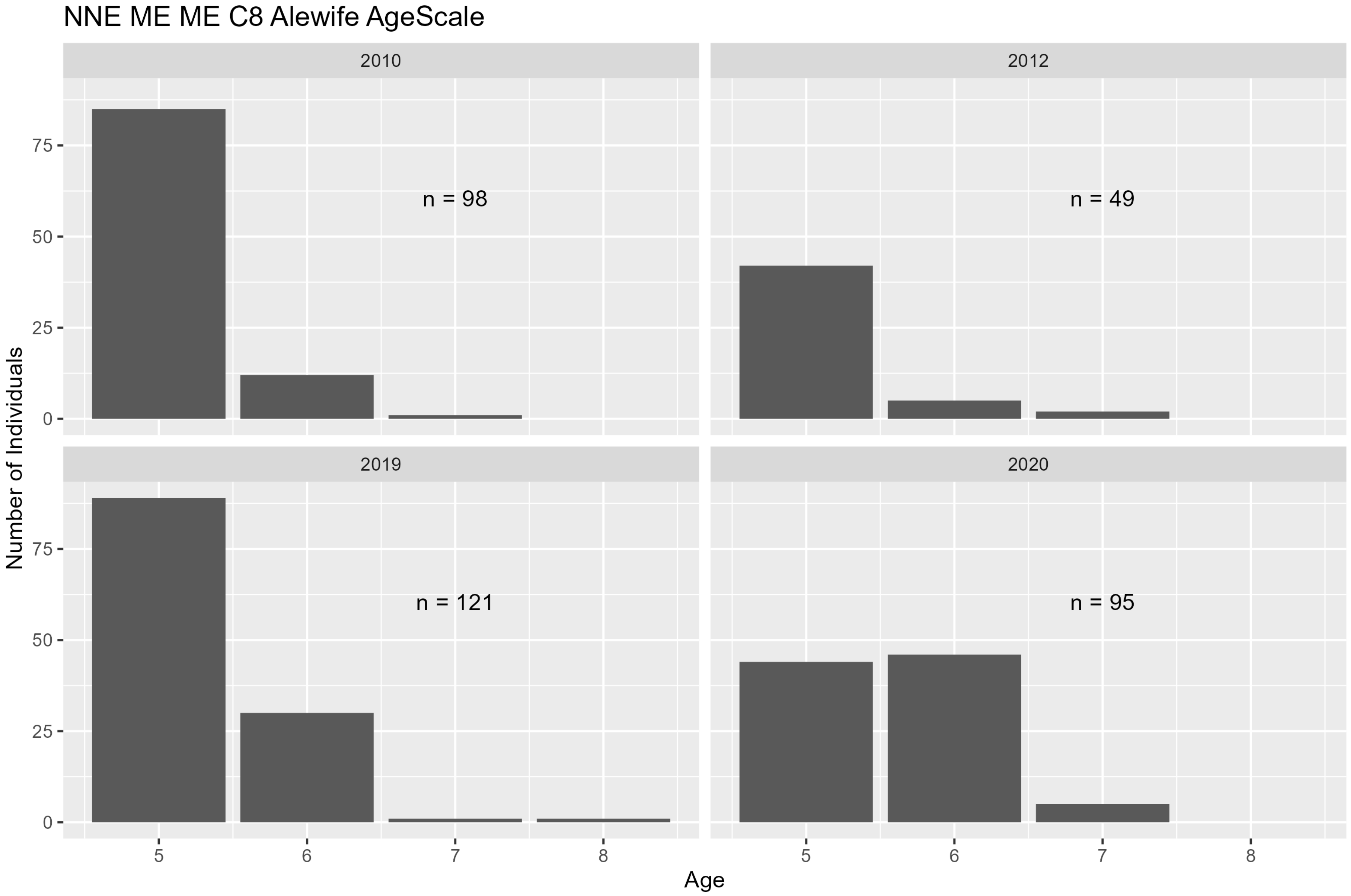
NNE ME ME C4 Alewife AgeScale

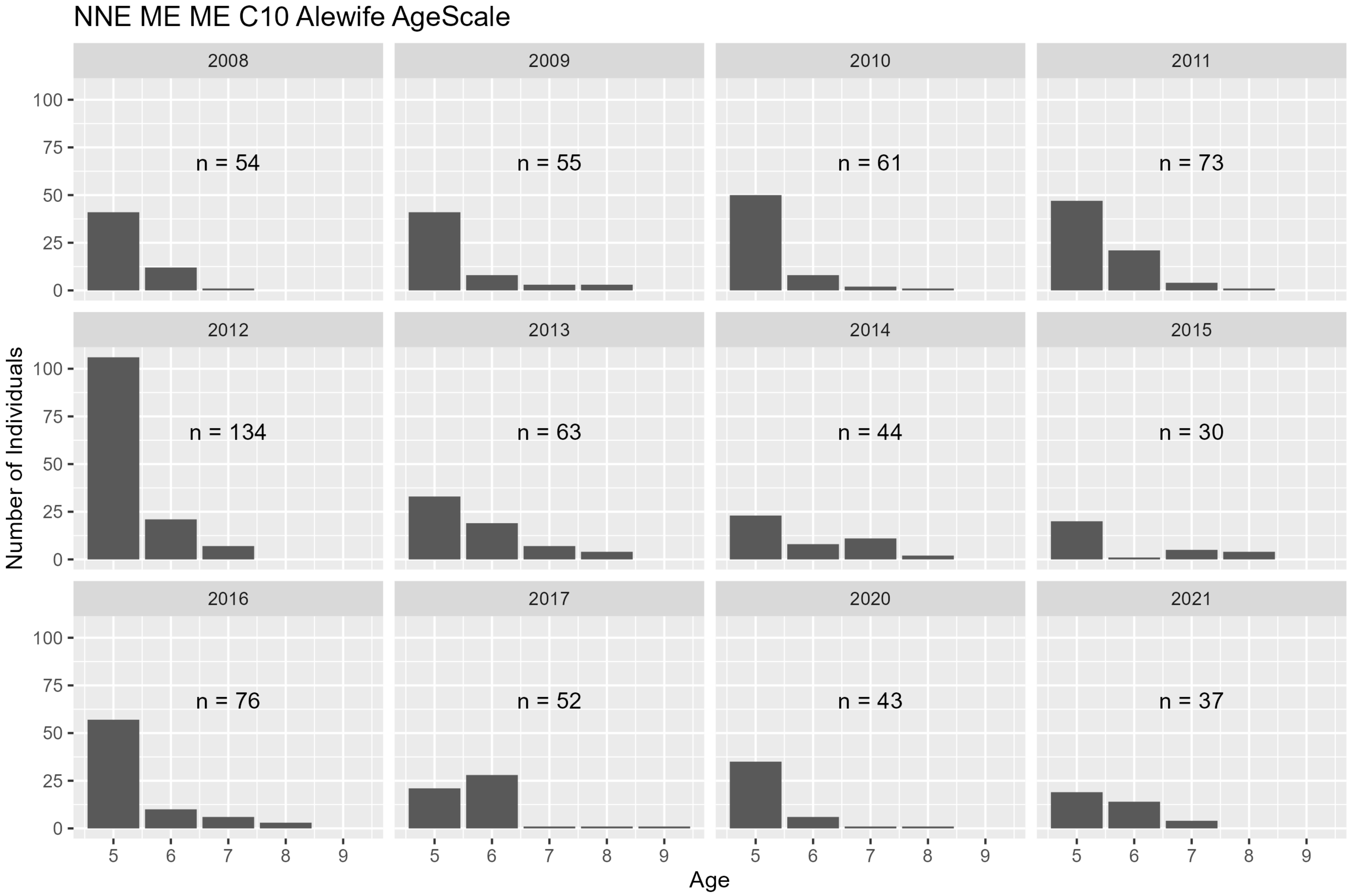


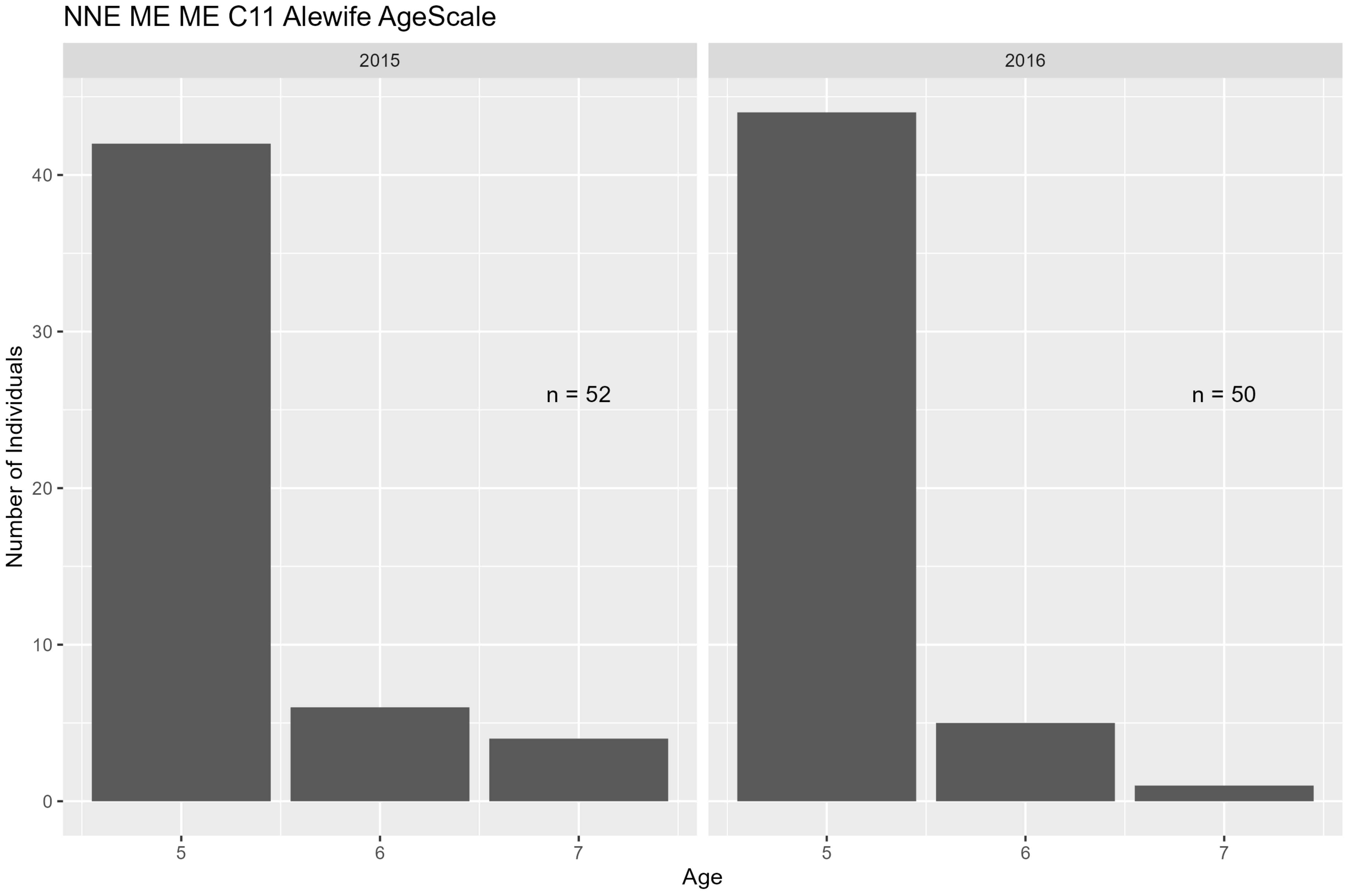

NNE ME ME C6 Alewife AgeScale
2011
2013
2020
50
40
30
20
10
0
Number of Individuals
n = 52
n = 46
n = 48
5
6
7
5
6
7
5
6
7
Age

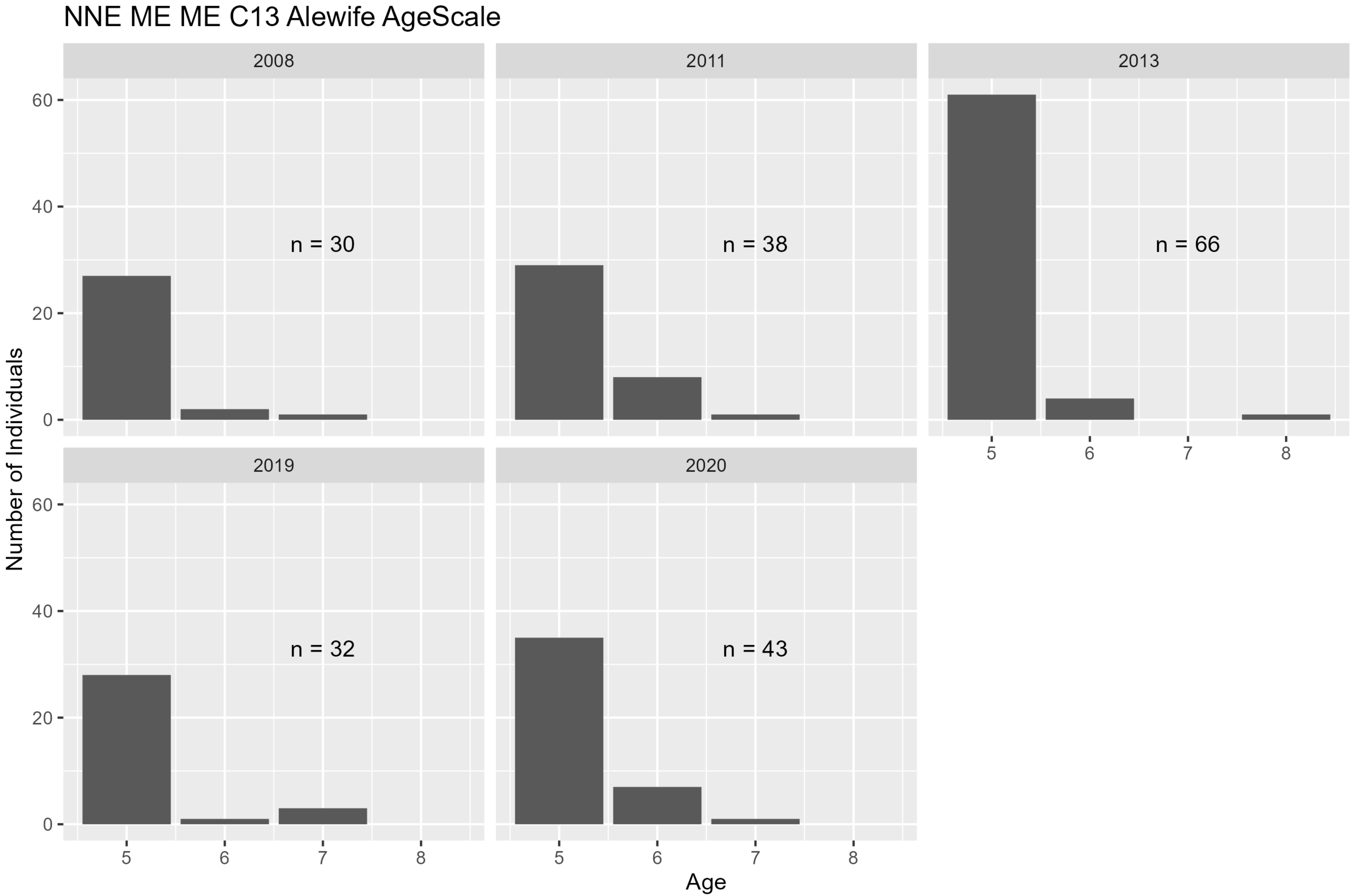
NNE ME ME C7 Alewife AgeScale



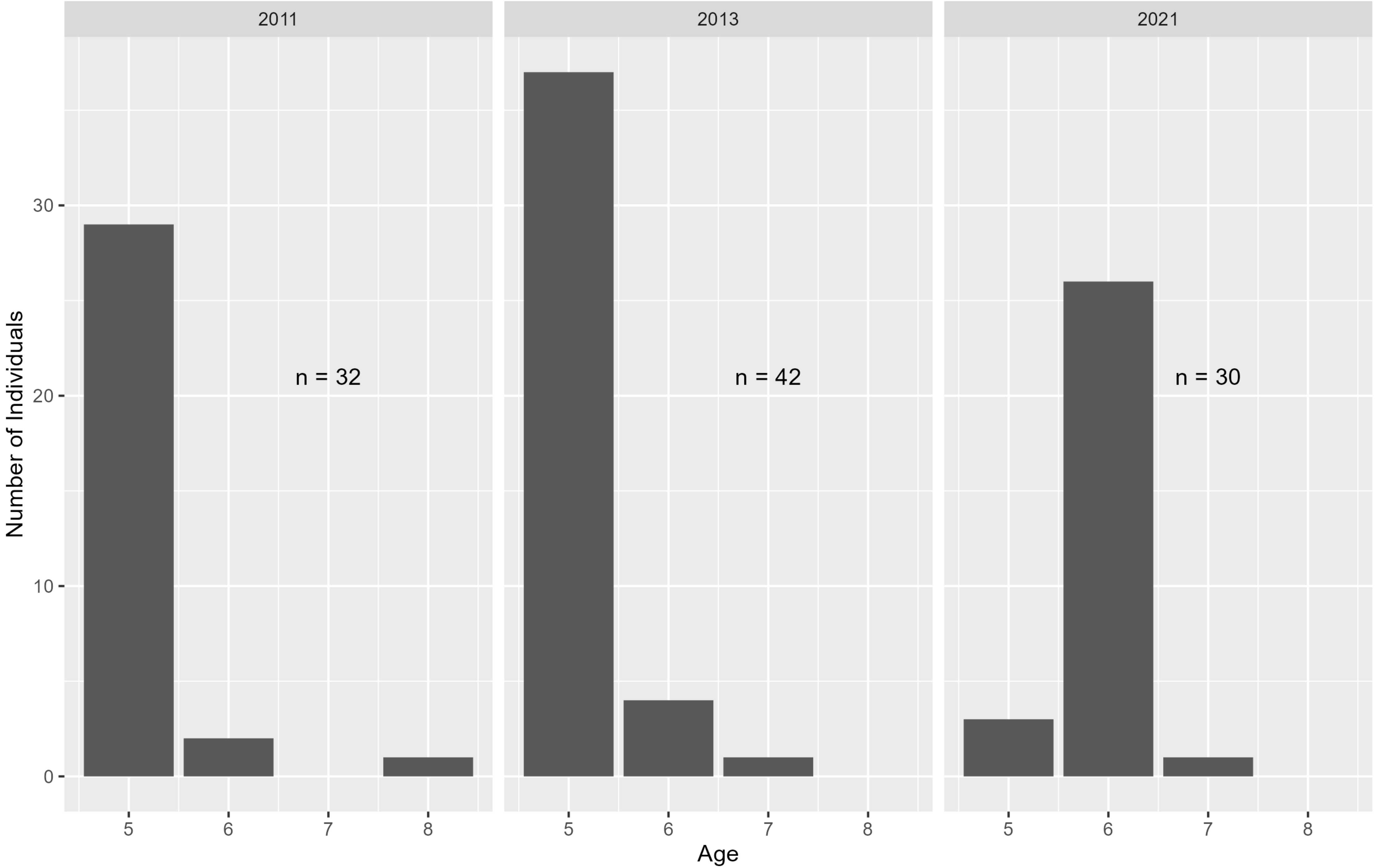
NNE ME ME C8 Alewife AgeScale
2010
2012
2019
2020
n = 98
n = 49
n = 121
n = 95
Number of Individuals
0
25
50
75
Age
5
6
7
8

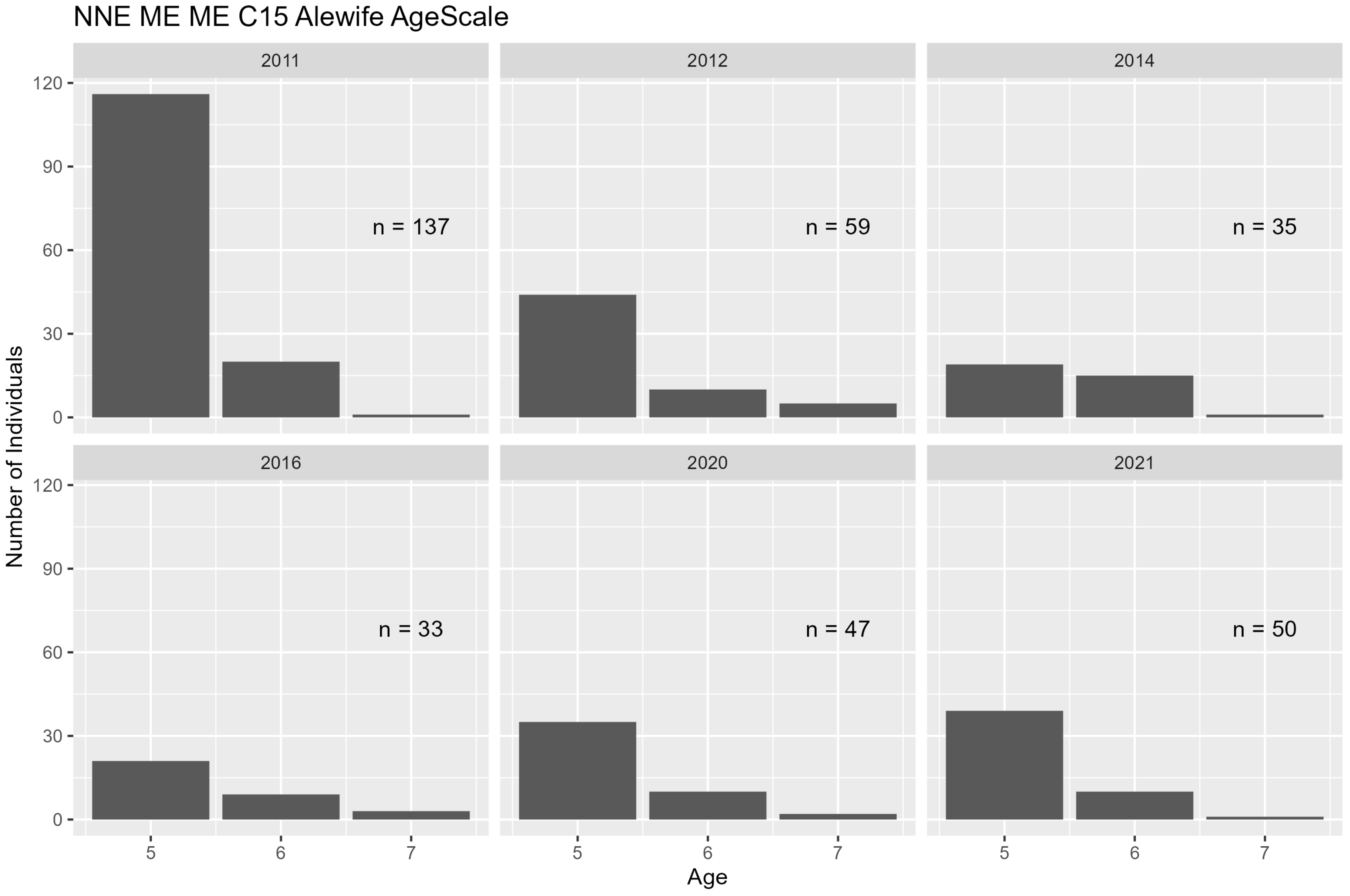

NNE ME ME C10 Alewife AgeScale
2008
n = 54
2009
n = 55
2010
n = 61
2011
n = 73
2012
n = 134
2013
n = 63
2014
n = 44
2015
n = 30
2016
n = 76
2017
n = 52
2020
n = 43
2021
n = 37
Number of Individuals
0
25
50
75
100
Age
5
6
7
8
9

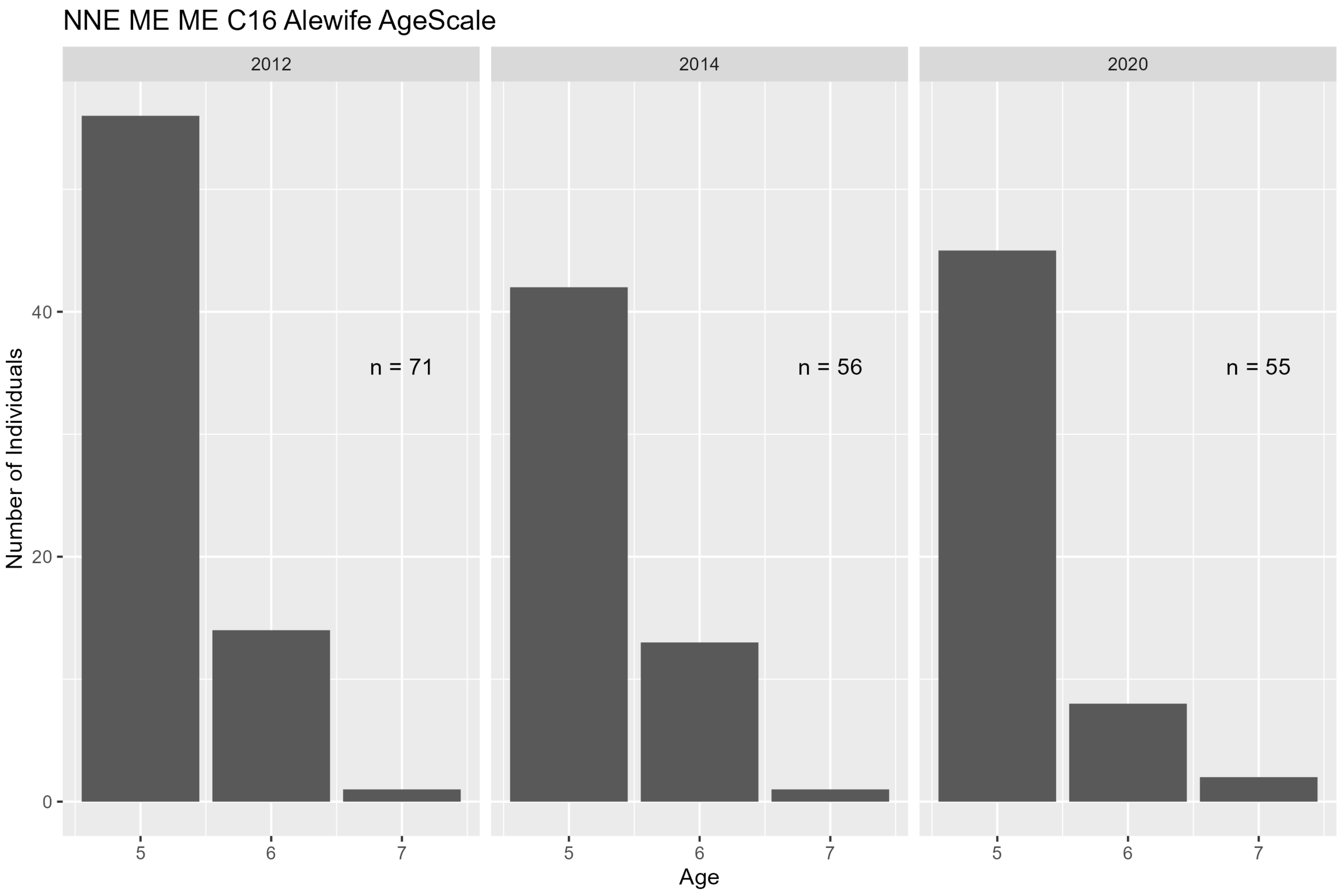

NNE ME ME C11 Alewife AgeScale
2015
2016
Number of Individuals
0
10
20
30
40
n = 52
n = 50
5
6
7
5
6
7
Age

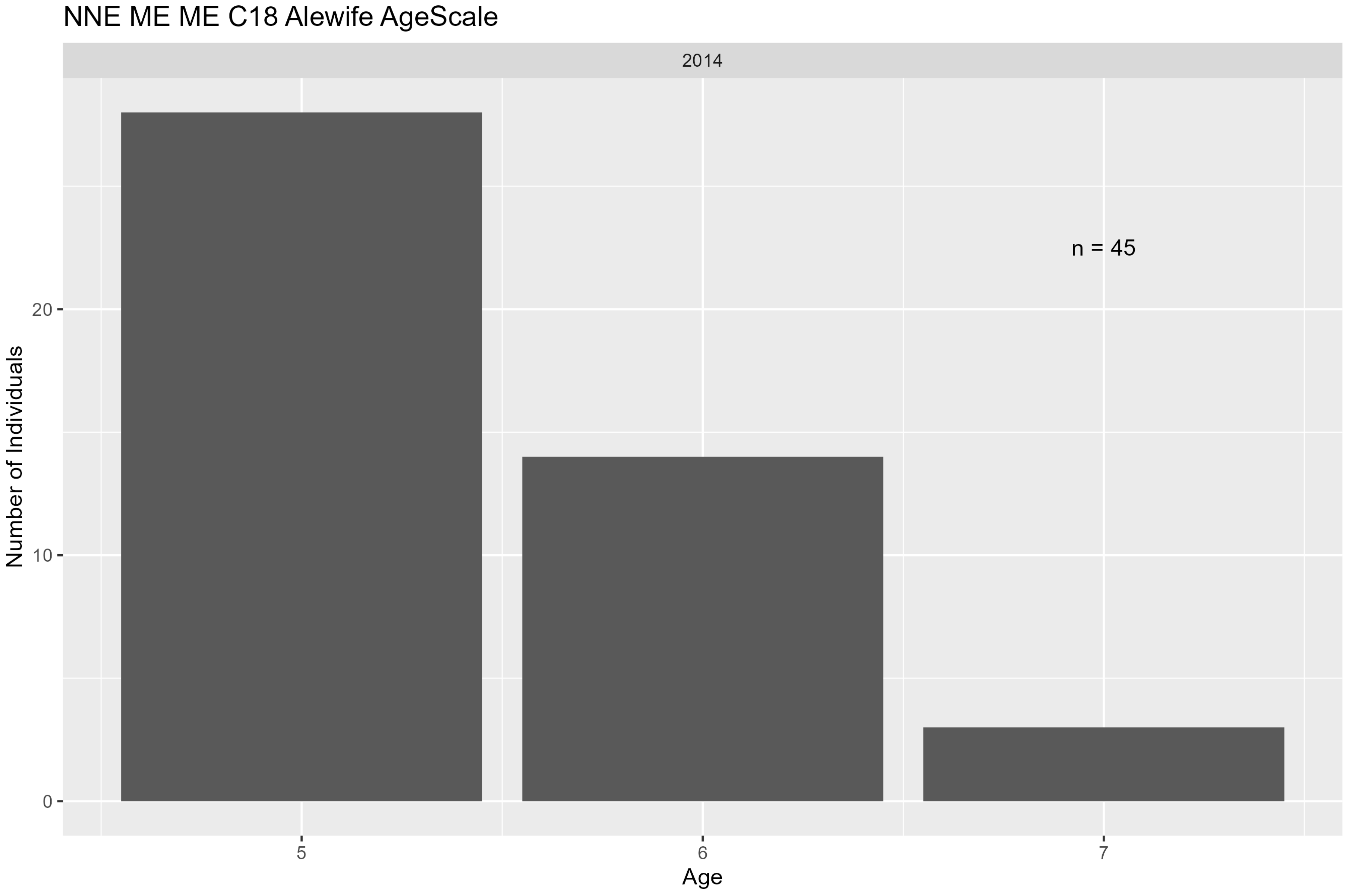

NNE ME ME C13 Alewife AgeScale
2008
2011
2013
2019
2020
n = 30
n = 38
n = 66
n = 32
n = 43
Number of Individuals
Age
0
20
40
60
5
6
7
8

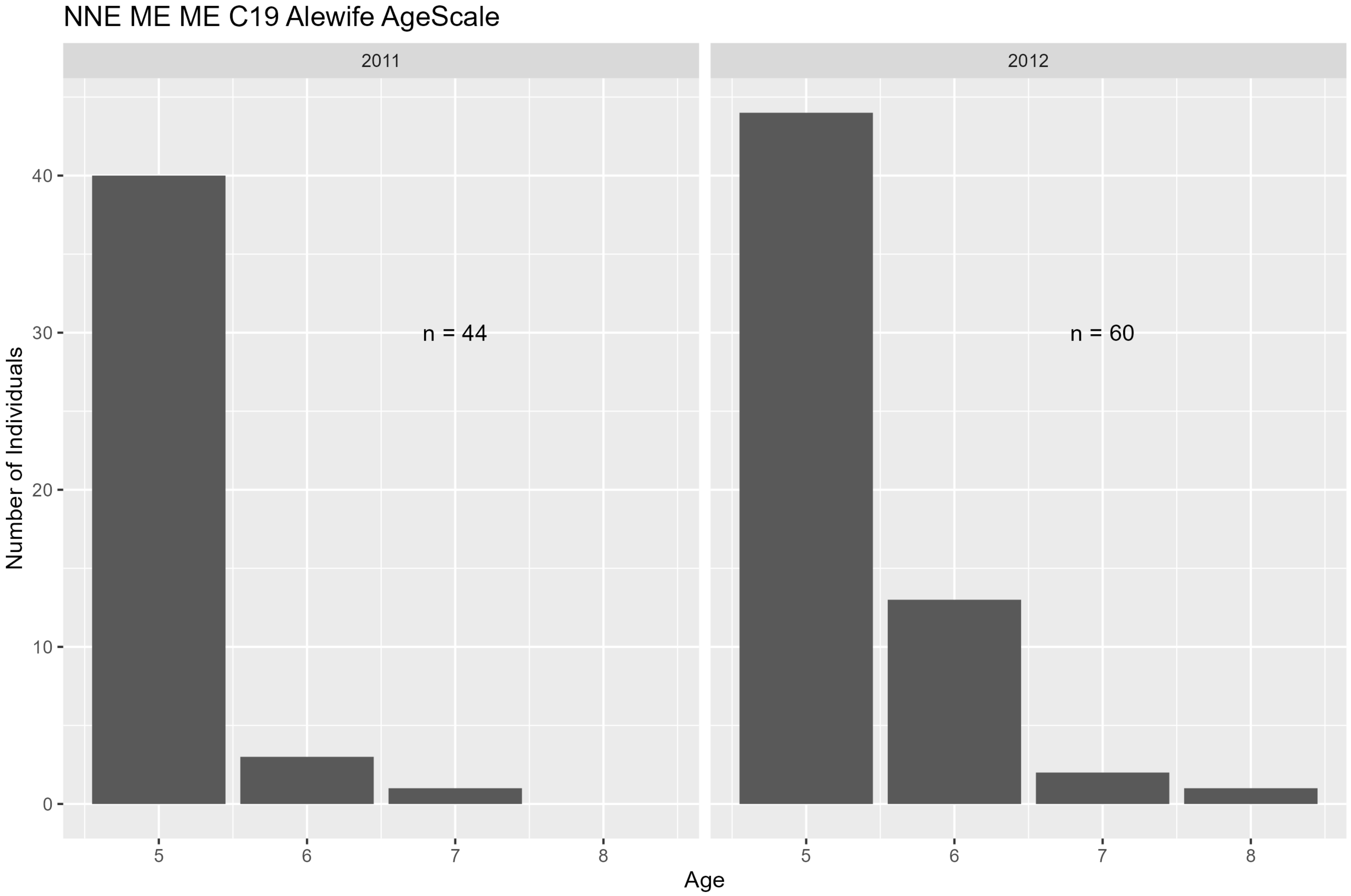
NNE ME ME C14 Alewife AgeScale

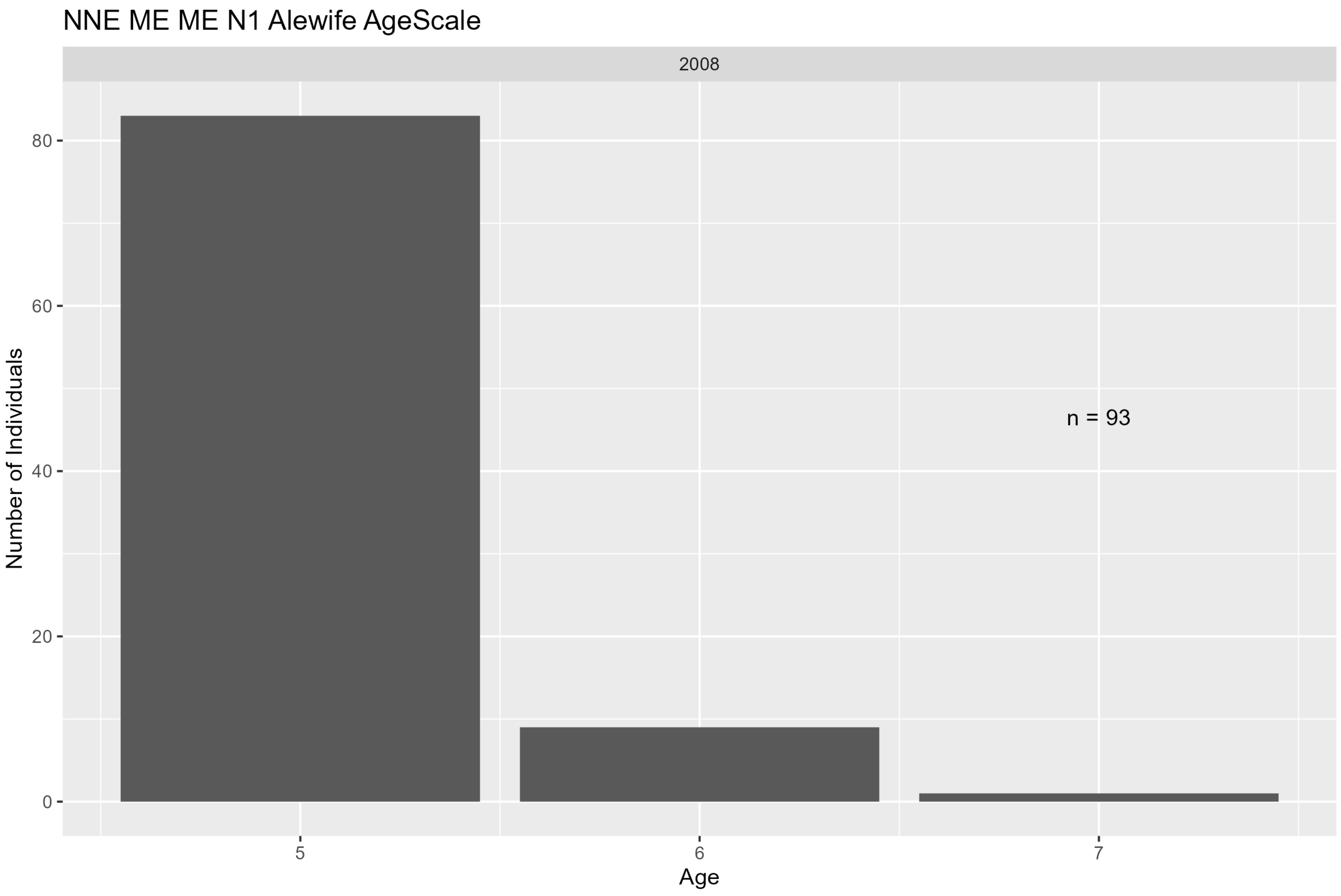


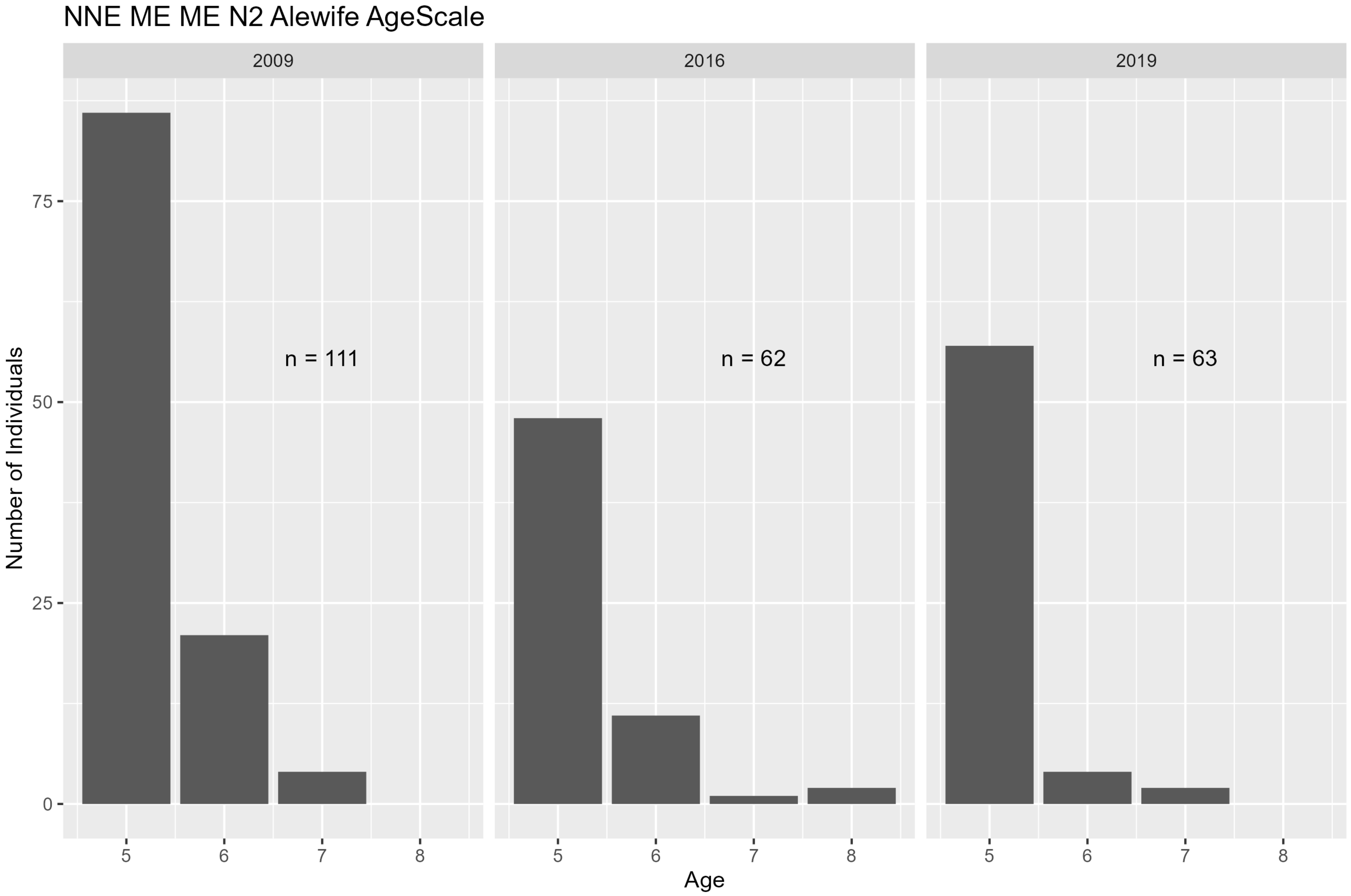

NNE ME ME C15 Alewife AgeScale
2011
n = 137
2012
n = 59
2014
n = 35
2016
n = 33
2020
n = 47
2021
n = 50
Number of Individuals
0
30
60
90
120
Age
5
6
7


NNE ME ME C16 Alewife AgeScale
2012
2014
2020
n = 71
n = 56
n = 55
Number of Individuals
0
20
40
5
6
7
5
6
7
5
6
7
Age

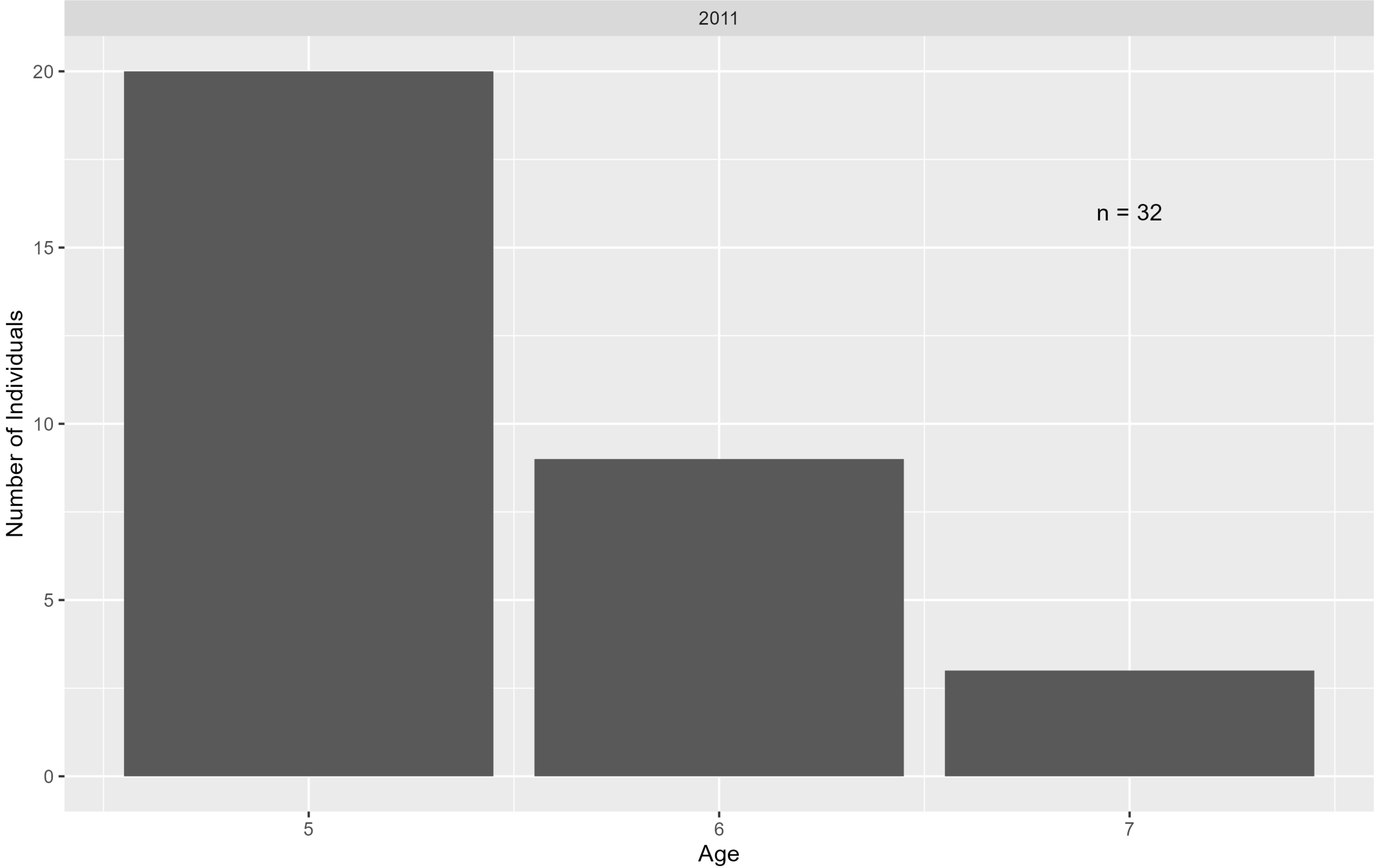

NNE ME ME C18 Alewife AgeScale
2014
n = 45
Number of Individuals
0
10
20
5
6
7
Age


NNE ME ME C19 Alewife AgeScale
2011
2012
n = 44
n = 60
Number of Individuals
0
10
20
30
40
5
6
7
8
Age

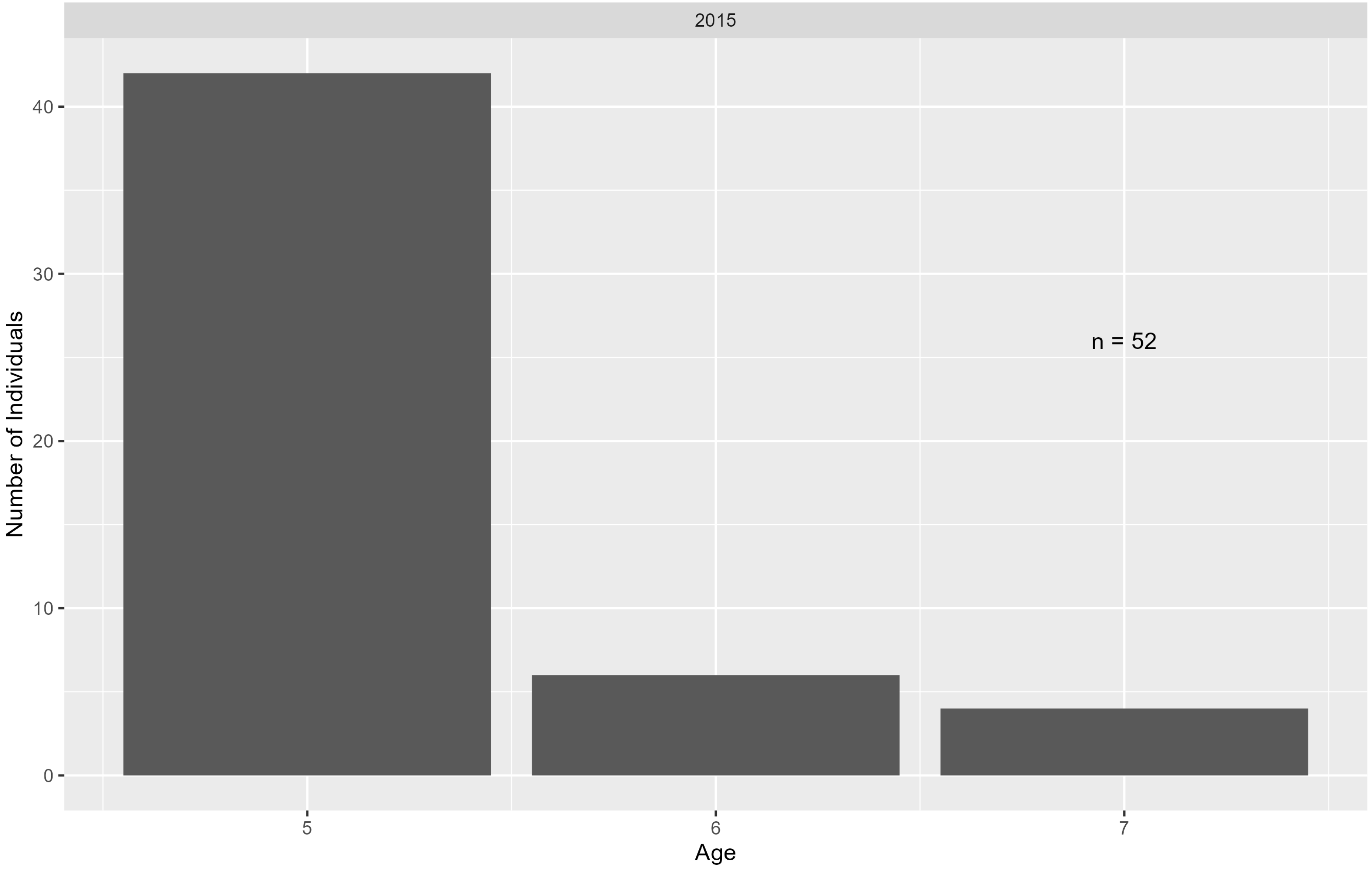

NNE ME ME N1 Alewife AgeScale
2008
Number of Individuals
0
20
40
60
80
n = 93
5
6
7
Age

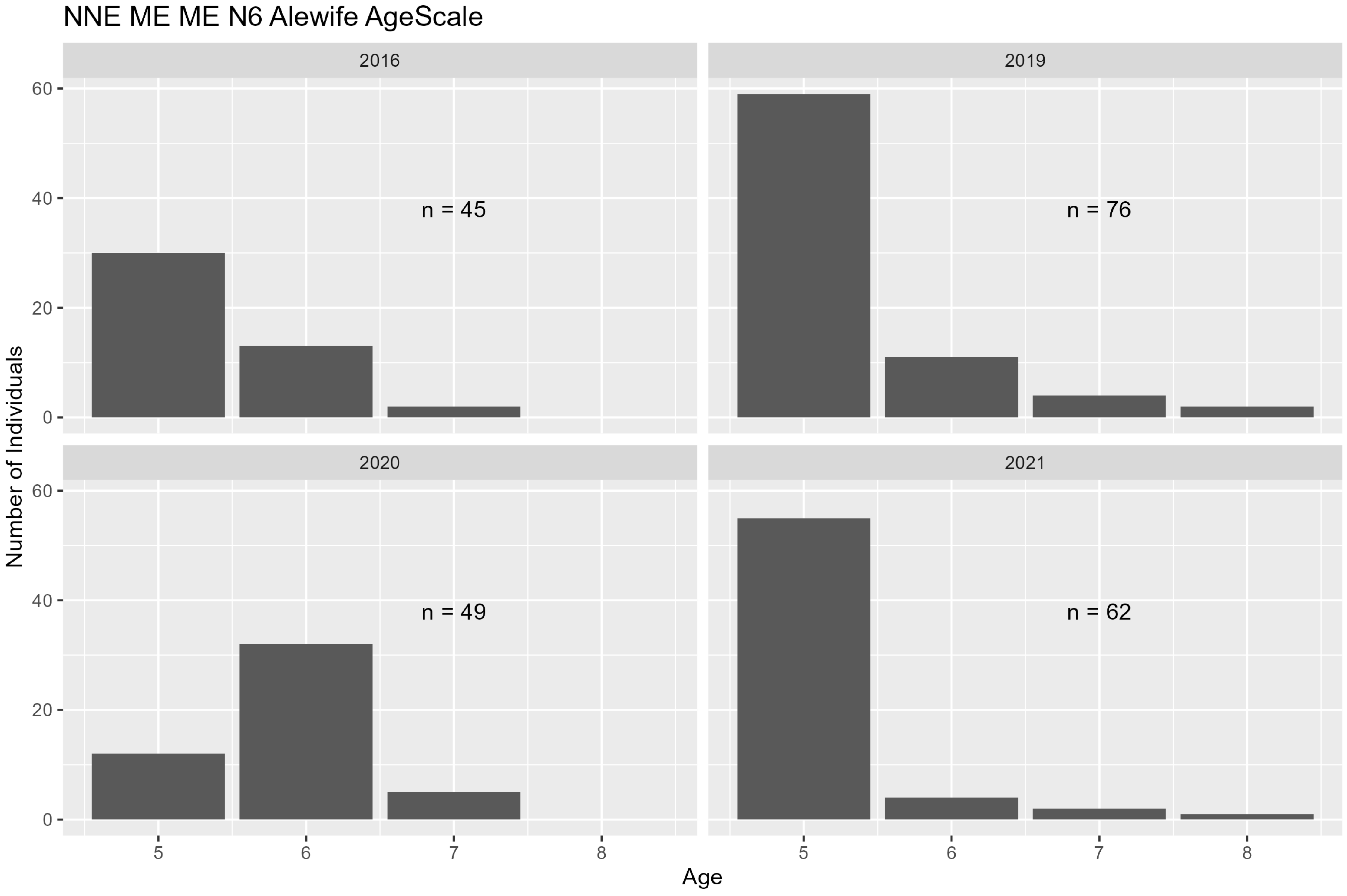

NNE ME ME N2 Alewife AgeScale
2009
2016
2019
n = 111
n = 62
n = 63
Number of Individuals
0
25
50
75
5
6
7
8
Age

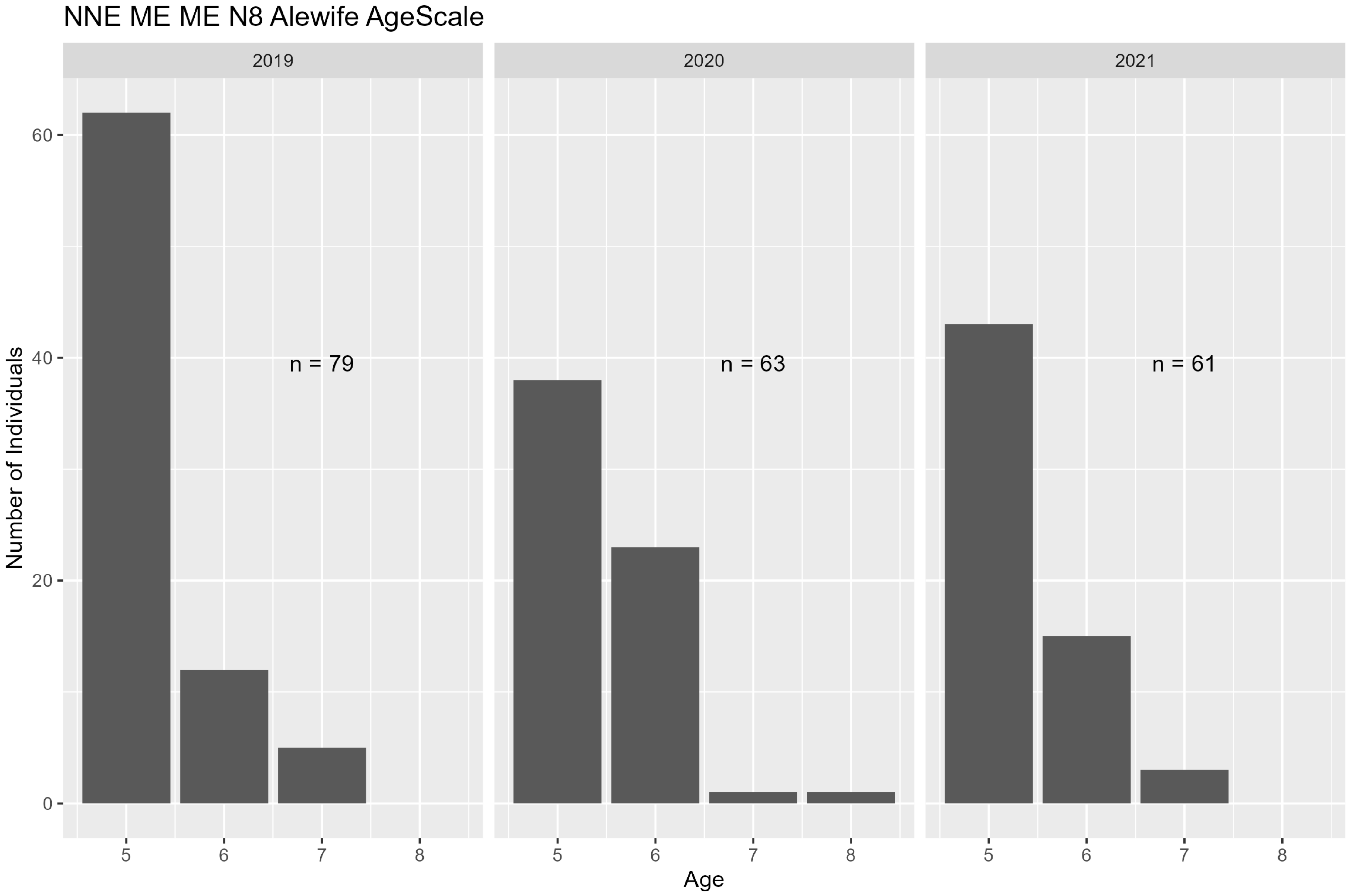
NNE ME ME N4 Alewife AgeScale

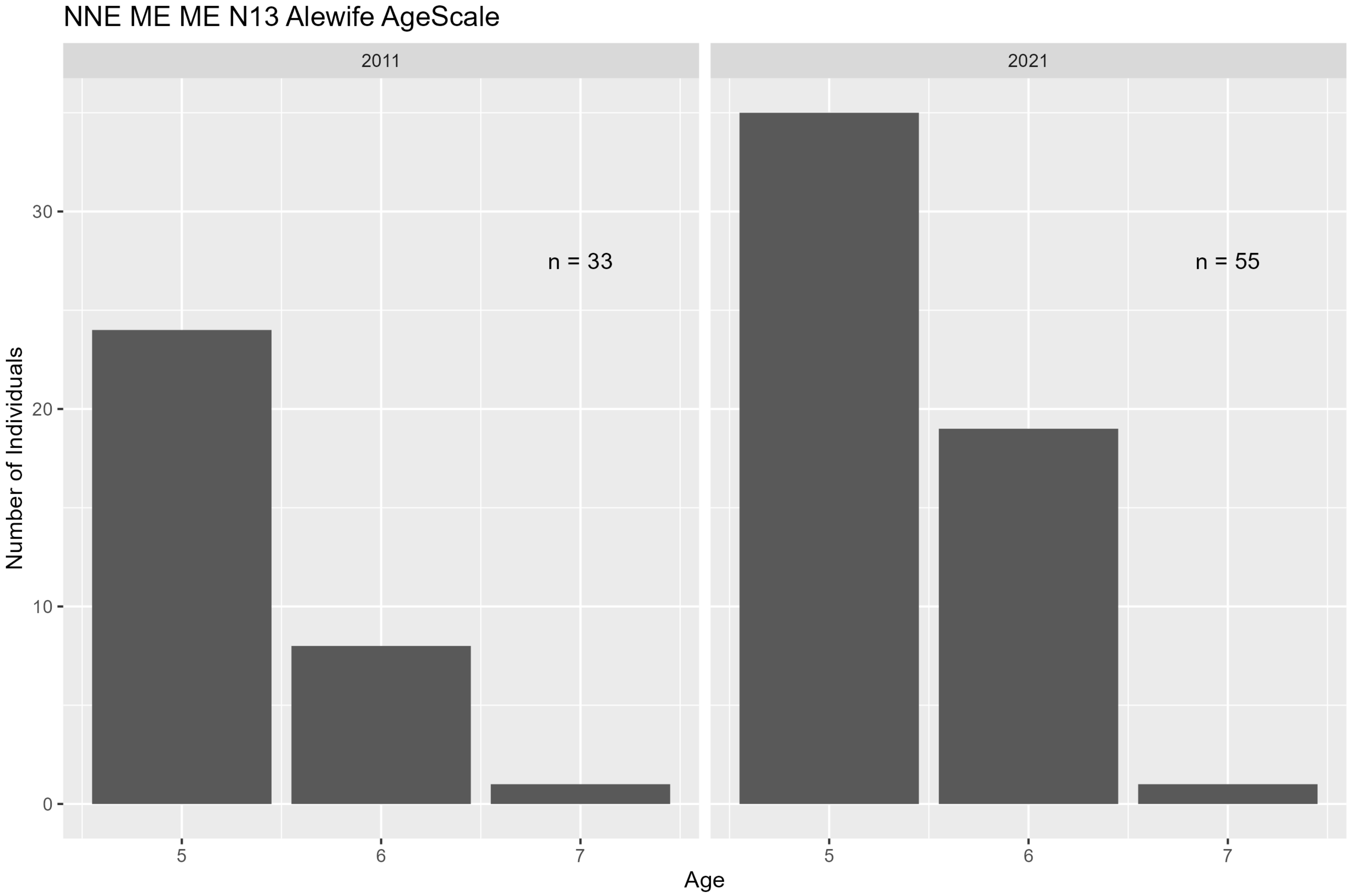


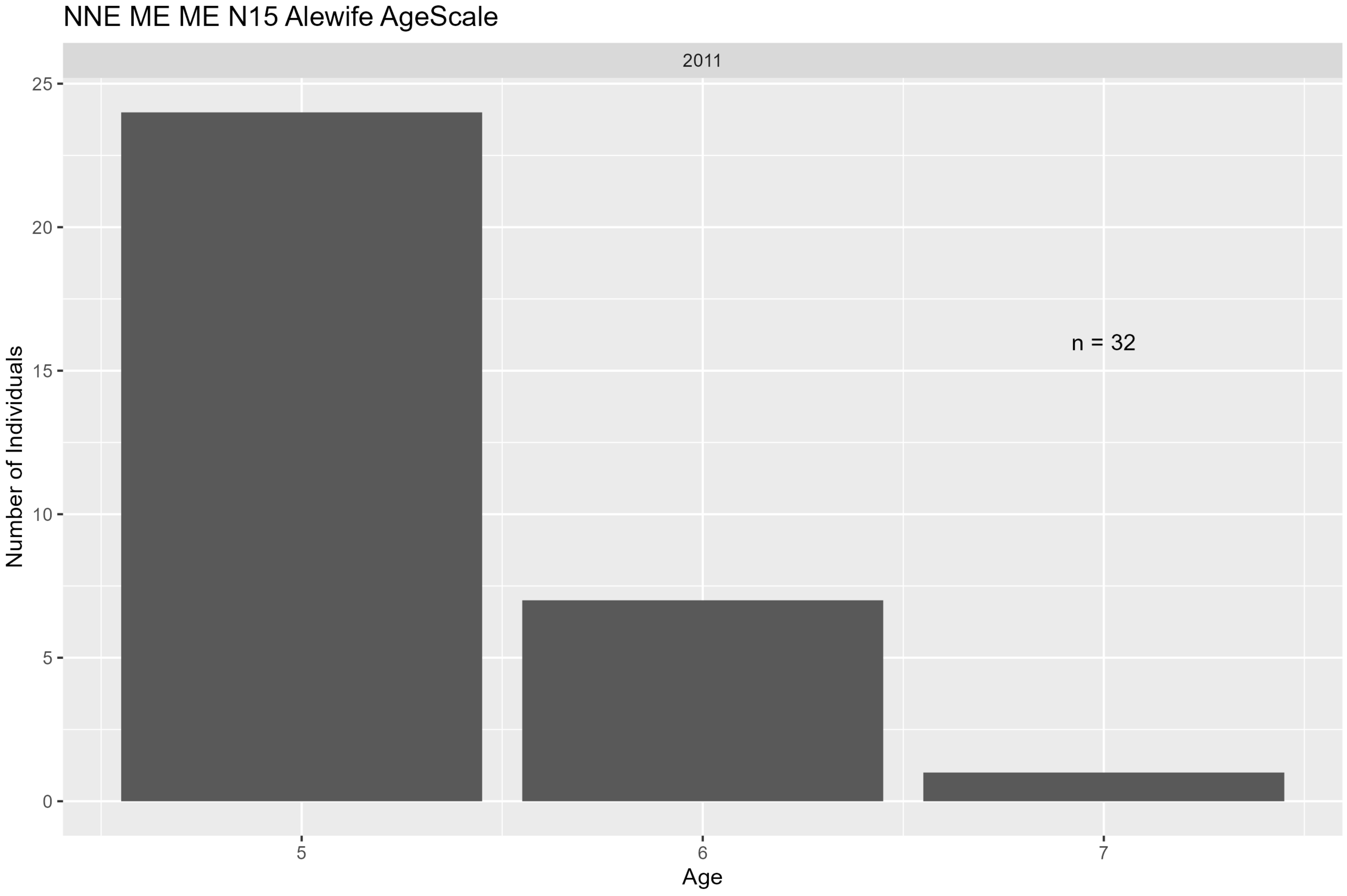
NNE ME ME N5 Alewife AgeScale

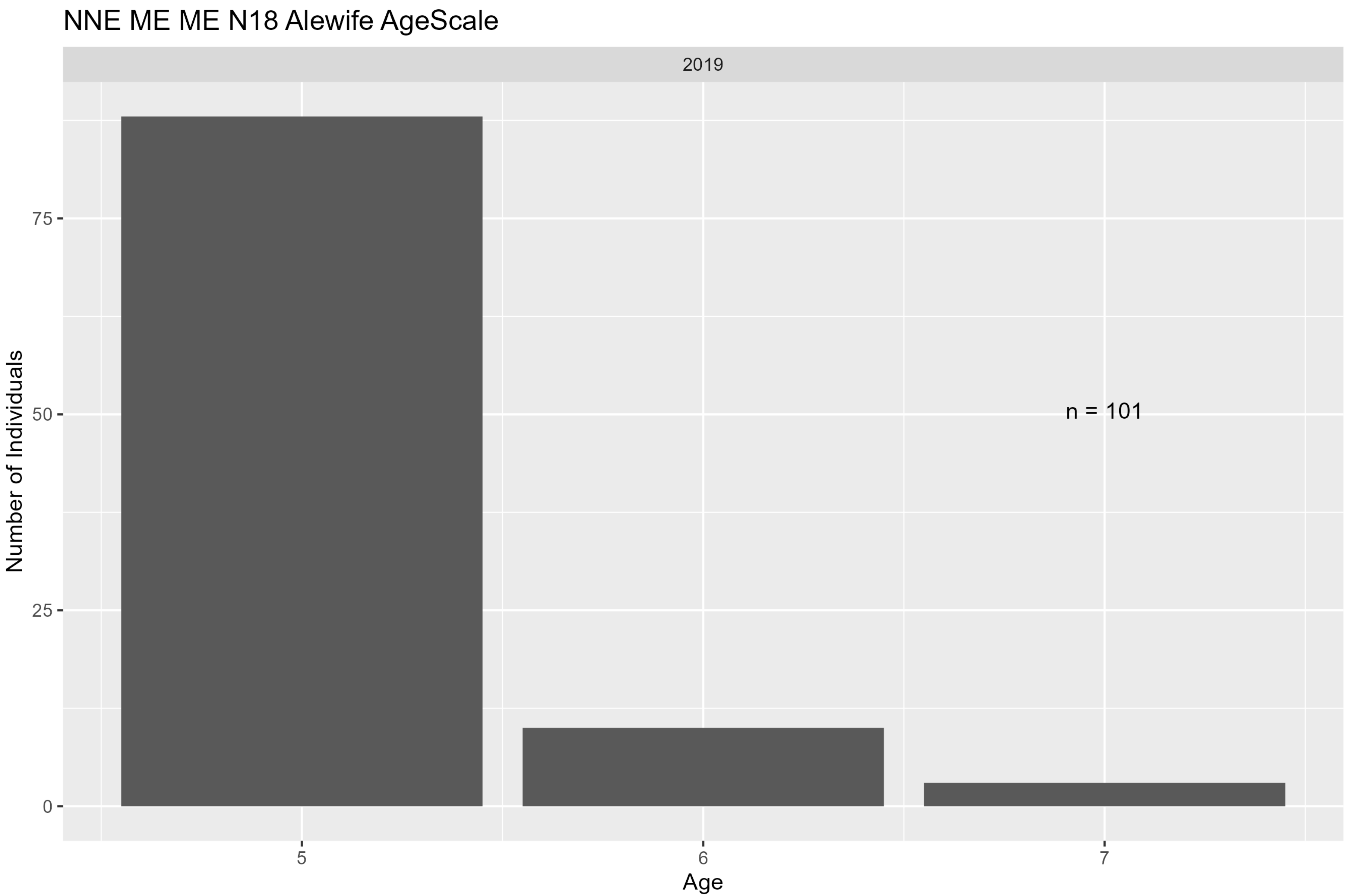



NNE ME ME N6 Alewife AgeScale
2016
2019
2020
2021
n = 45
n = 76
n = 49
n = 62
0
20
40
60
Number of Individuals
5
6
7
8
Age

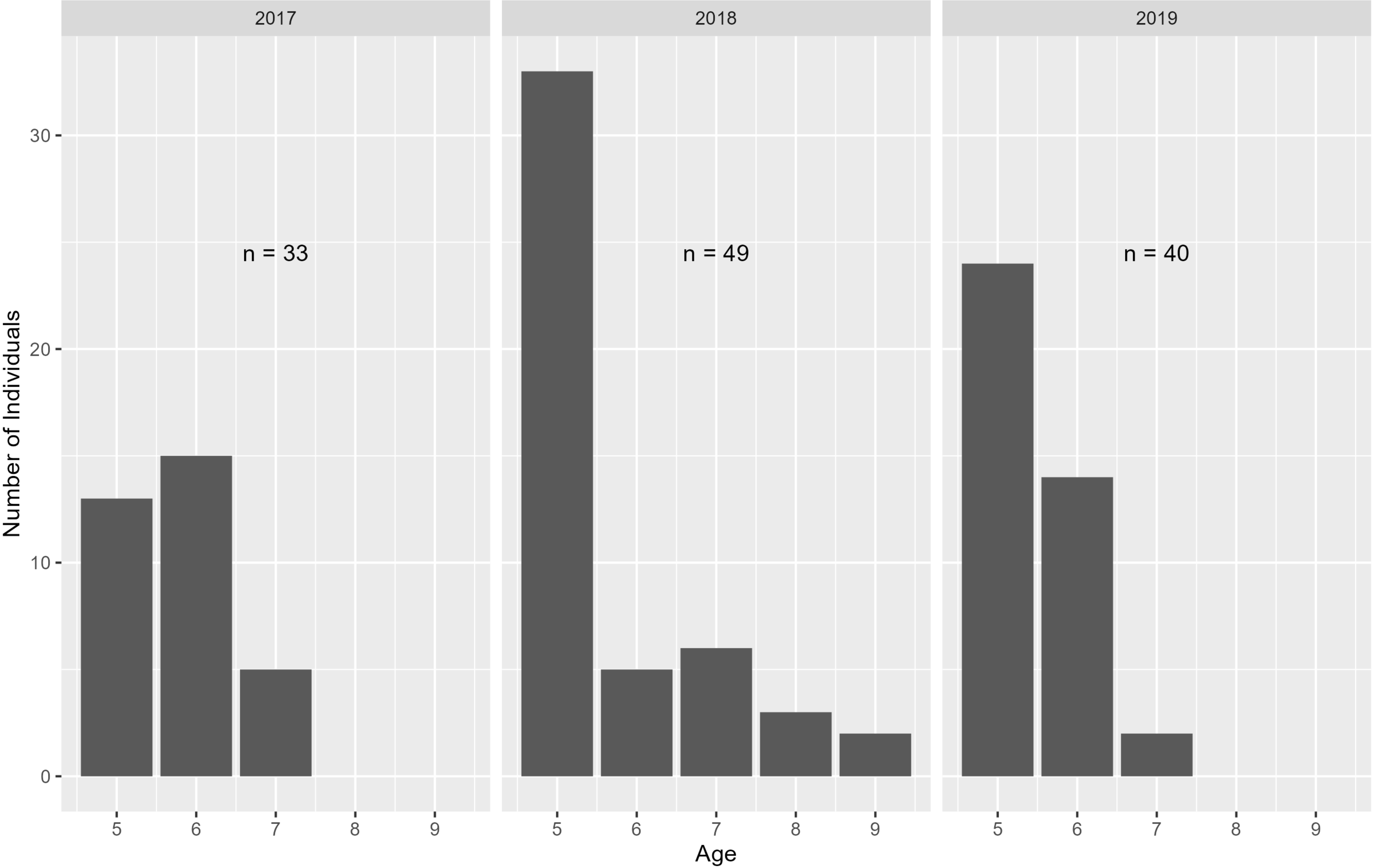

NNE ME ME N8 Alewife AgeScale
2019
2020
2021
Number of Individuals
0
20
40
60
n = 79
n = 63
n = 61
5
6
7
8
Age

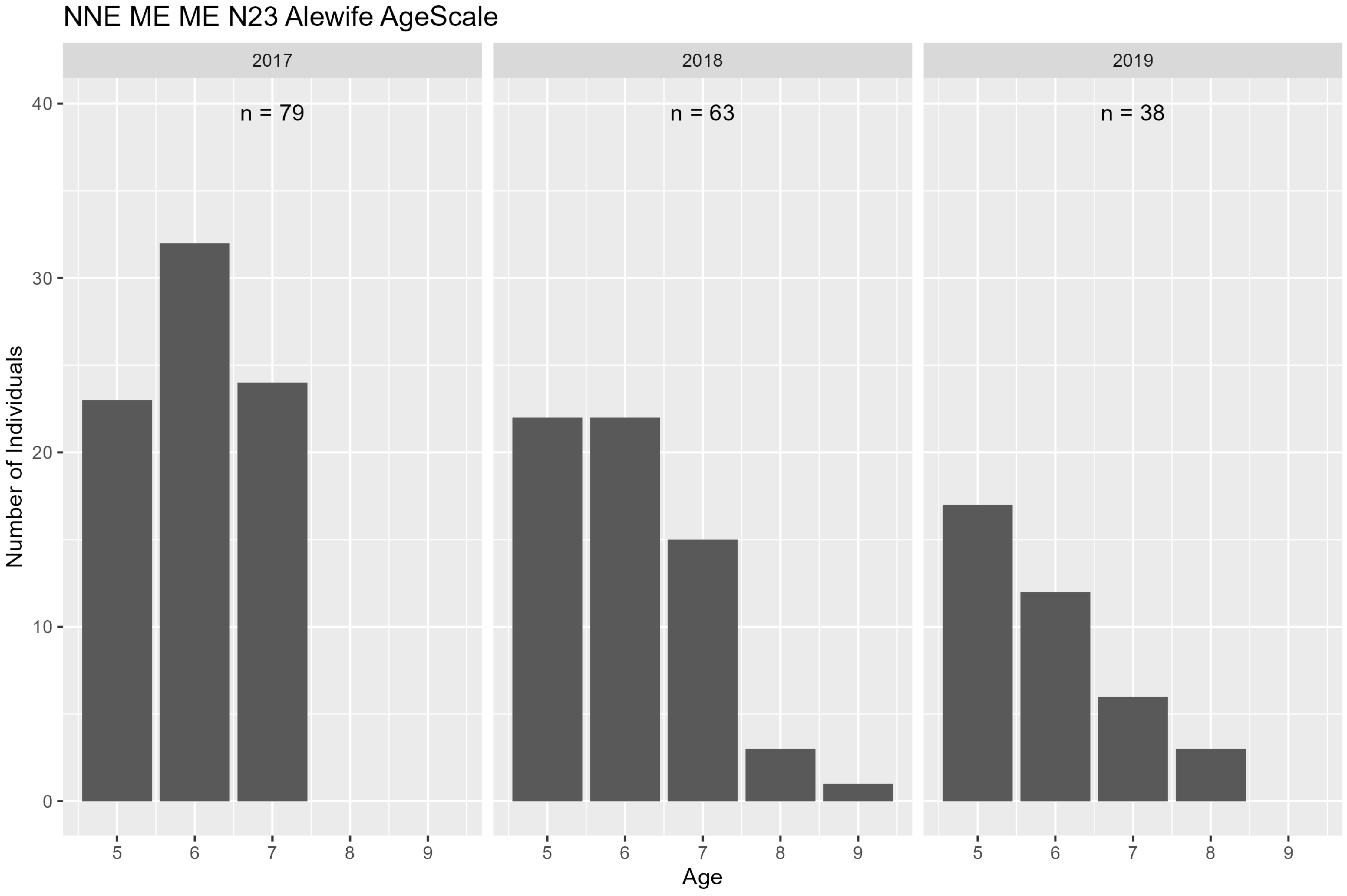

NNE ME ME N13 Alewife AgeScale
2011
2021
n = 33
n = 55
Number of Individuals
0
10
20
30
5
6
7
5
6
7
Age


NNE ME ME N15 Alewife AgeScale
2011
Number of Individuals
25
20
15
10
5
0
n = 32
5
6
7
Age

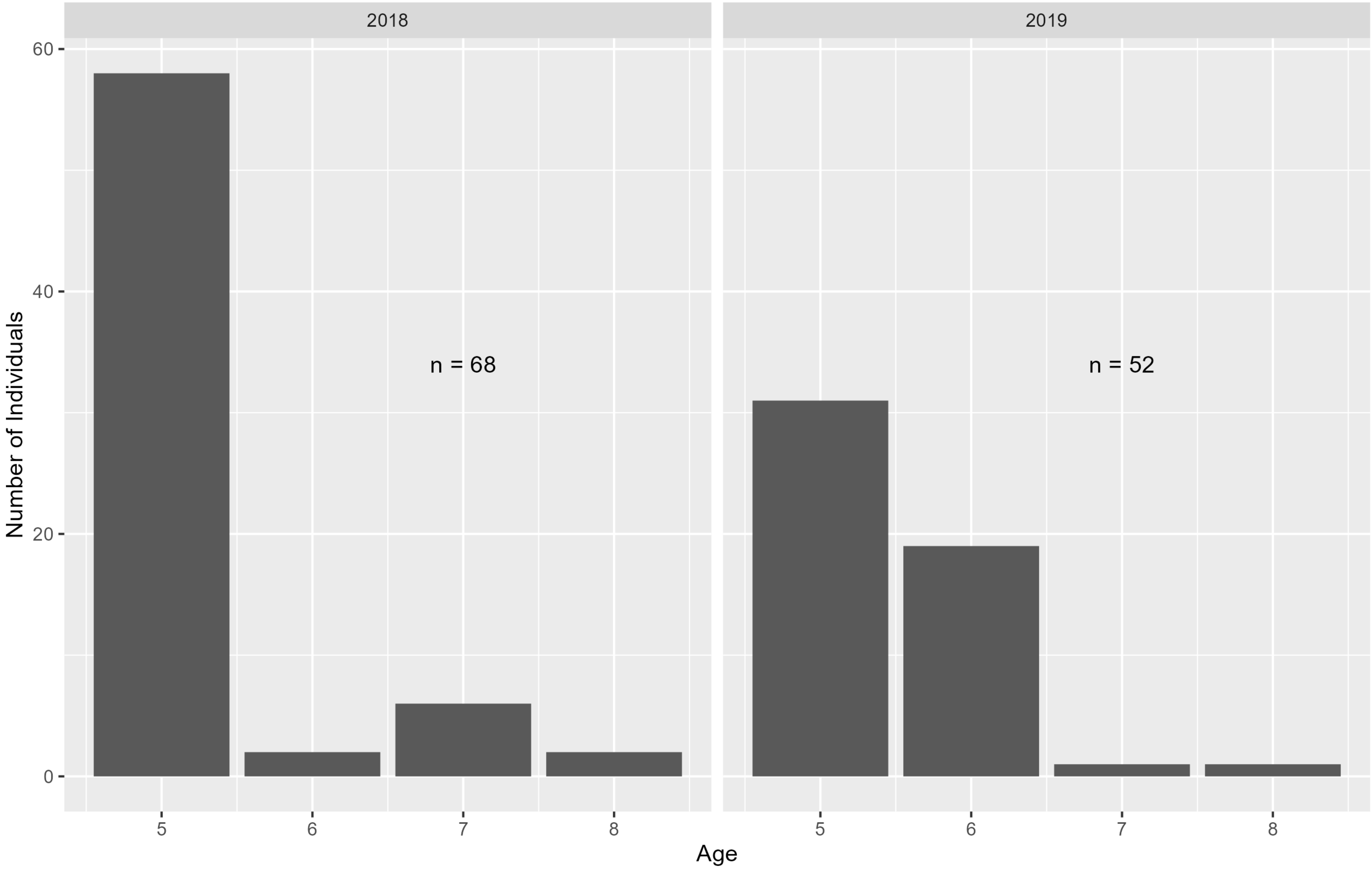

NNE ME ME N18 Alewife AgeScale
2019
Number of Individuals
0
25
50
75
n = 101
5
6
7
Age

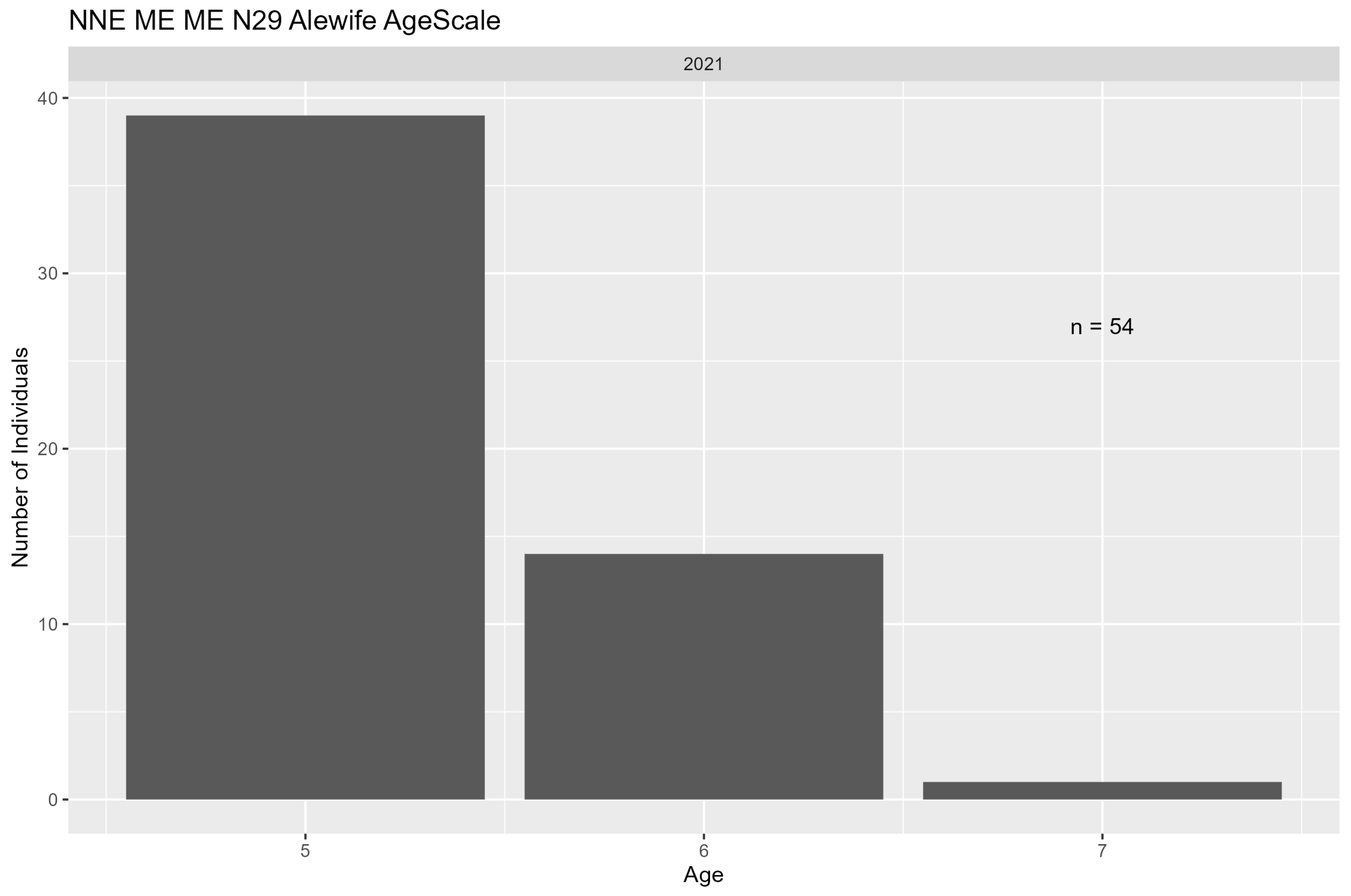
NNE ME ME N20 Alewife AgeScale



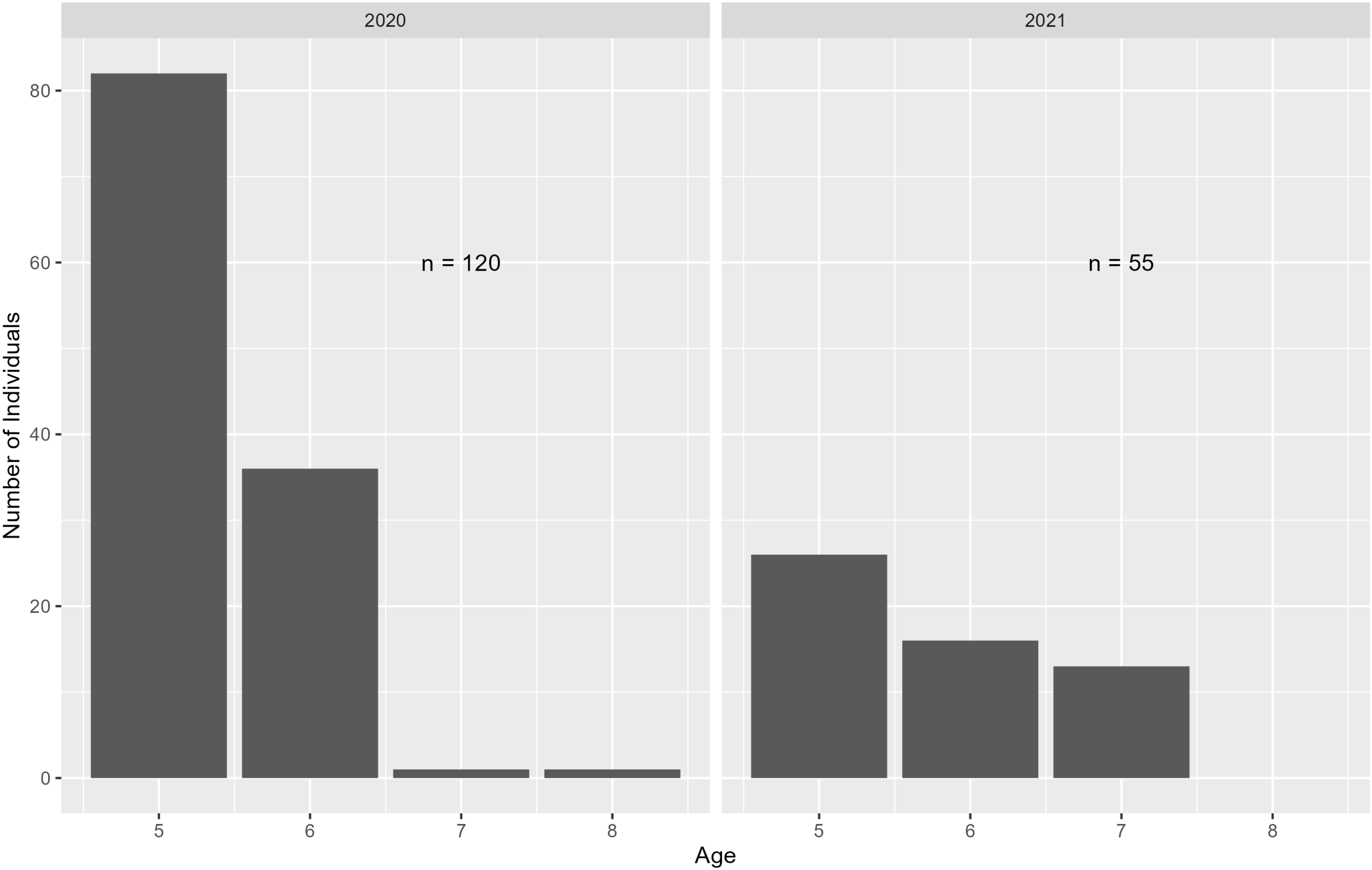

NNE ME ME N23 Alewife AgeScale
2017
2018
2019
n = 79
n = 63
n = 38
Number of Individuals
0
10
20
30
40
Age
5
6
7
8
9

NNE ME ME N25 Alewife AgeScale

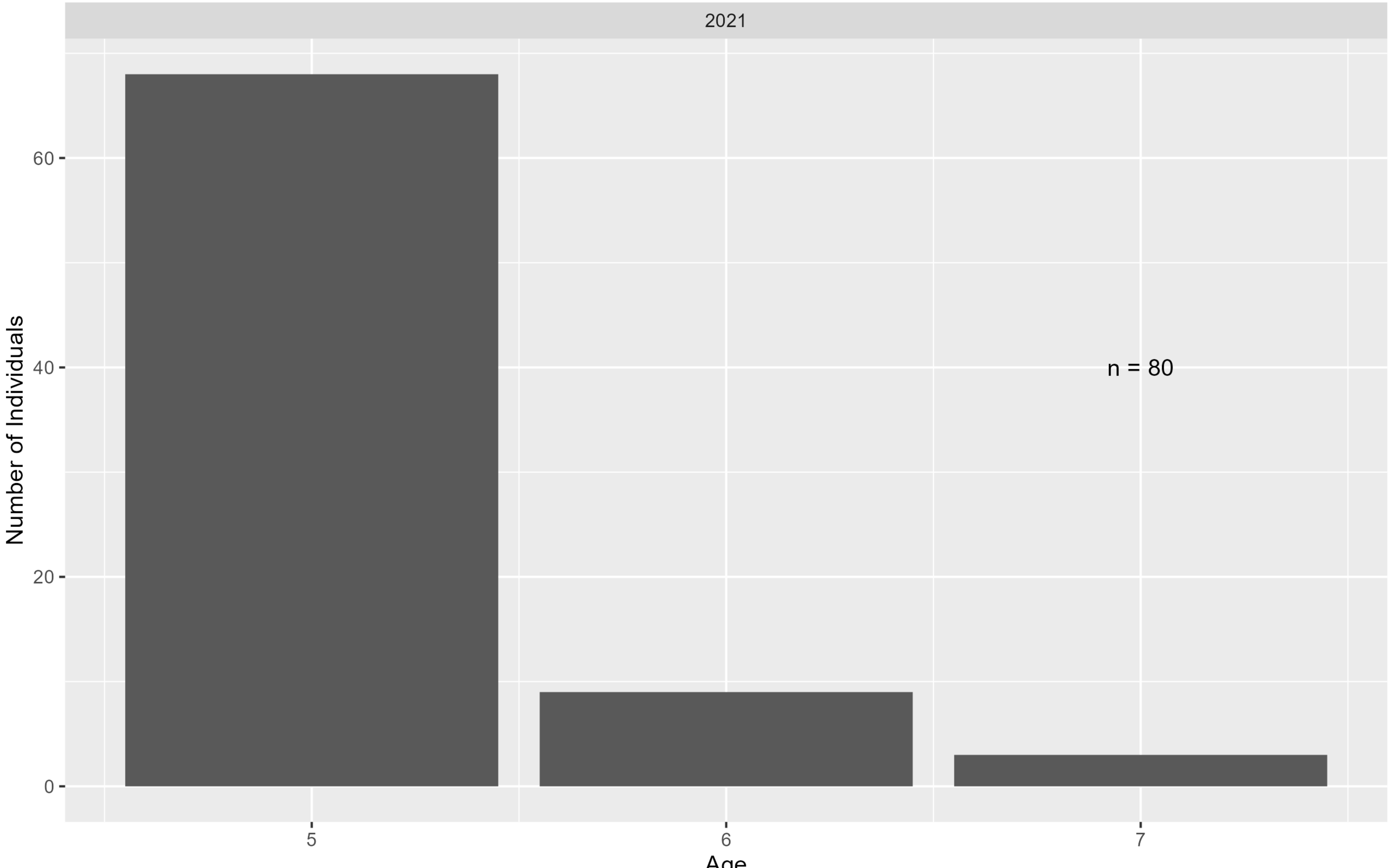



NNE ME ME N29 Alewife AgeScale
2021
n = 54
Number of Individuals
0
10
20
30
40
5
6
7
Age

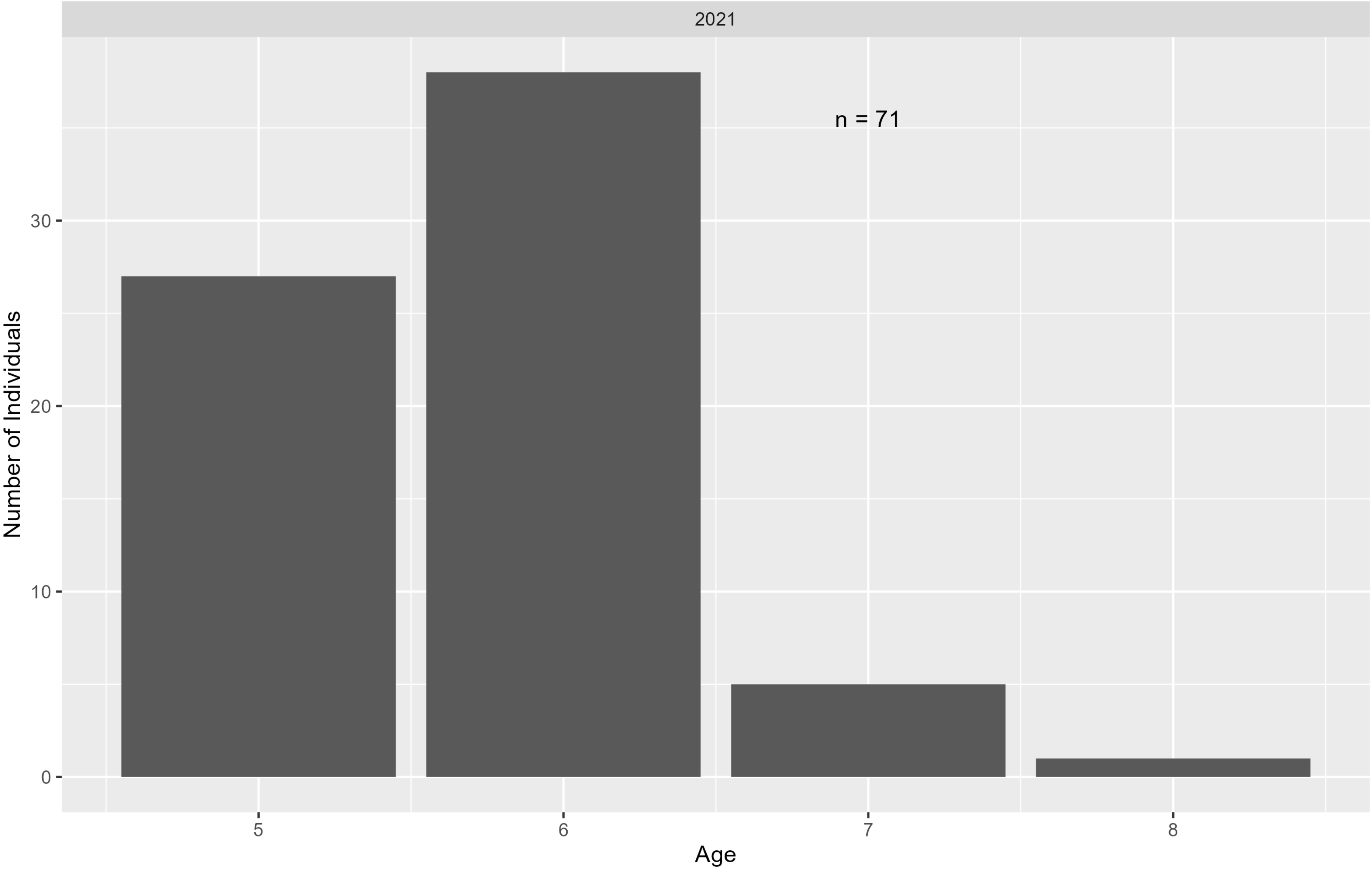
NNE ME ME N31 Alewife AgeScale



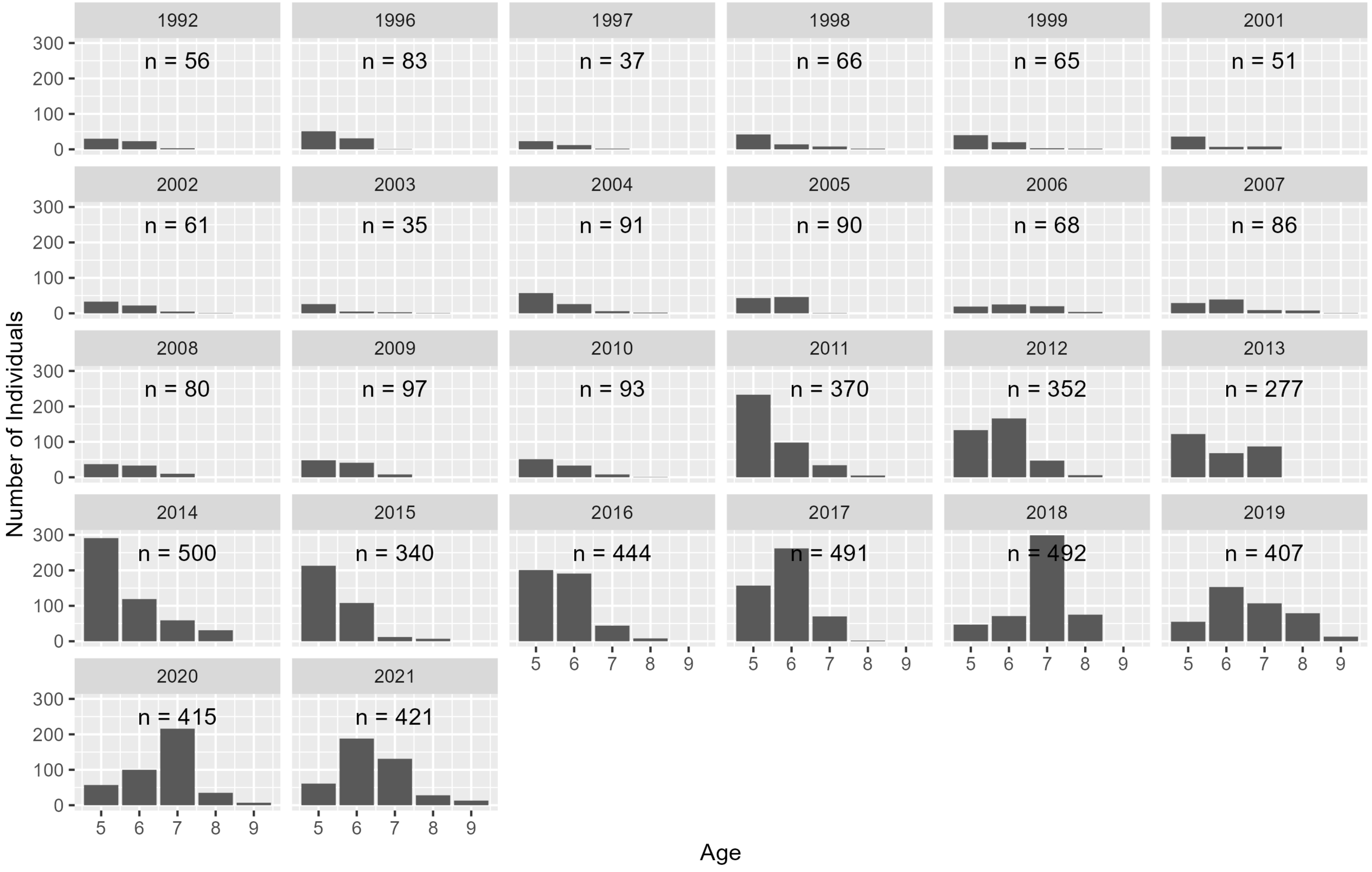
NNE ME ME N32 Alewife AgeScale

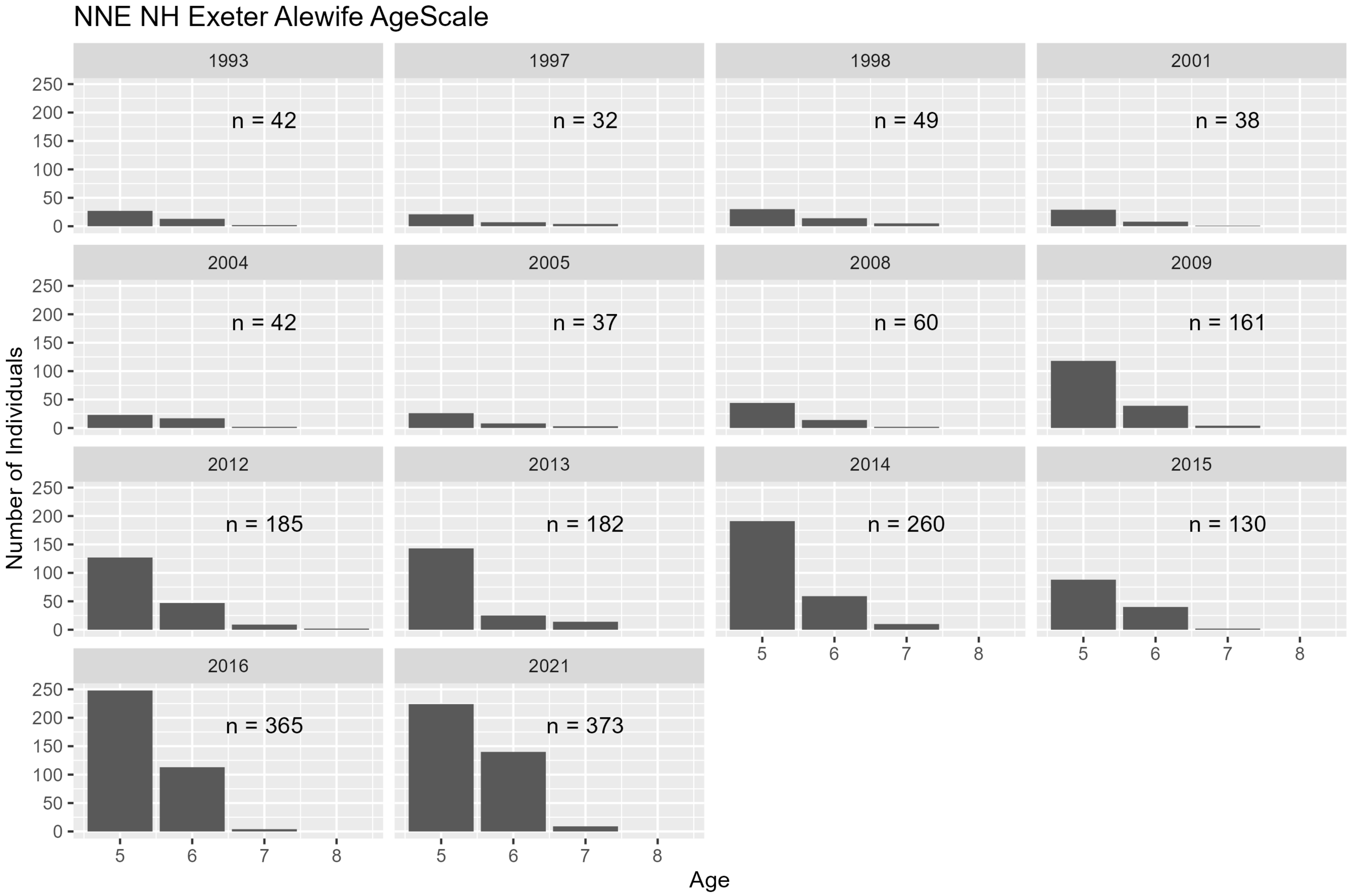


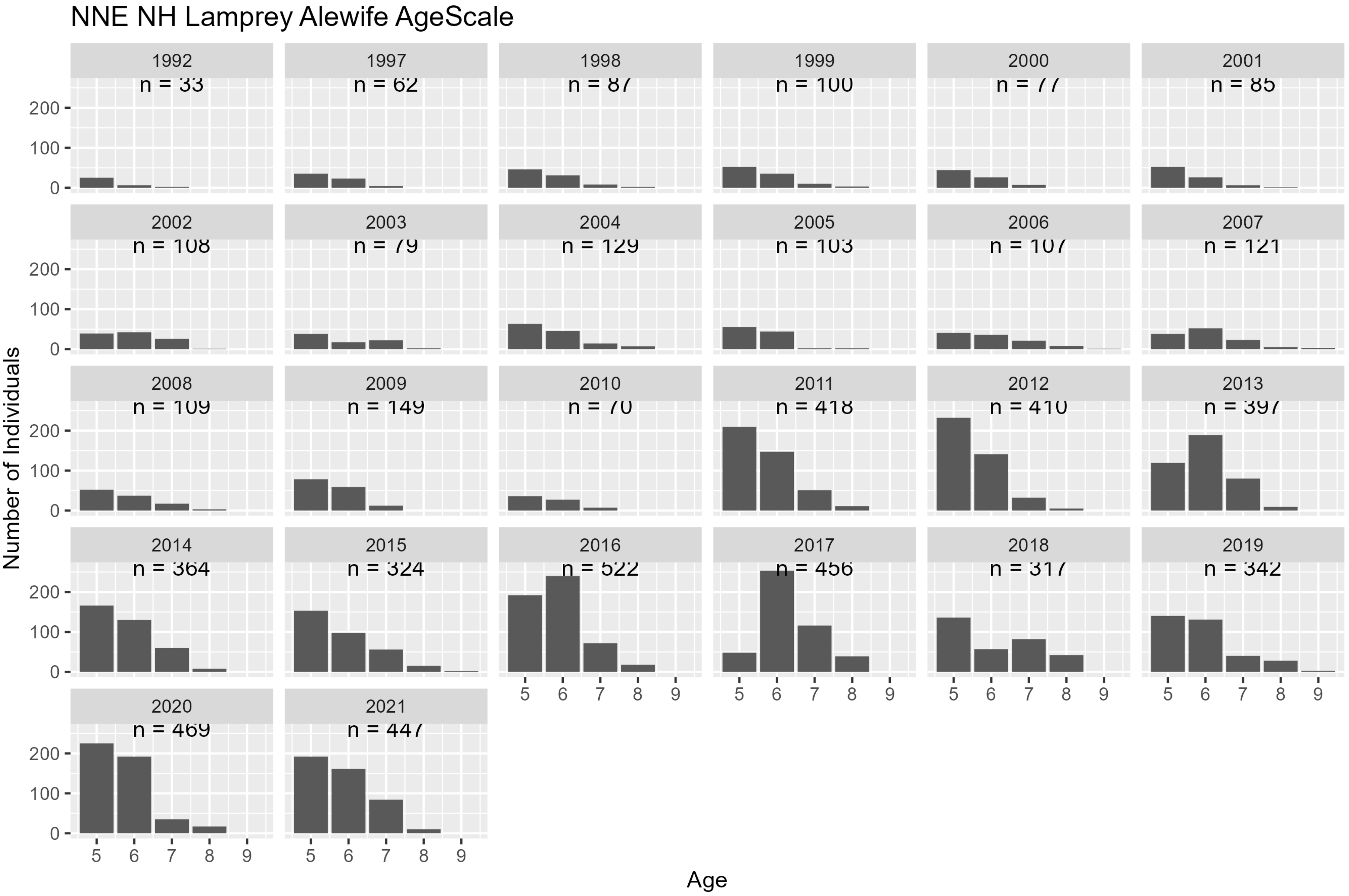
NNE ME ME N33 Alewife AgeScale

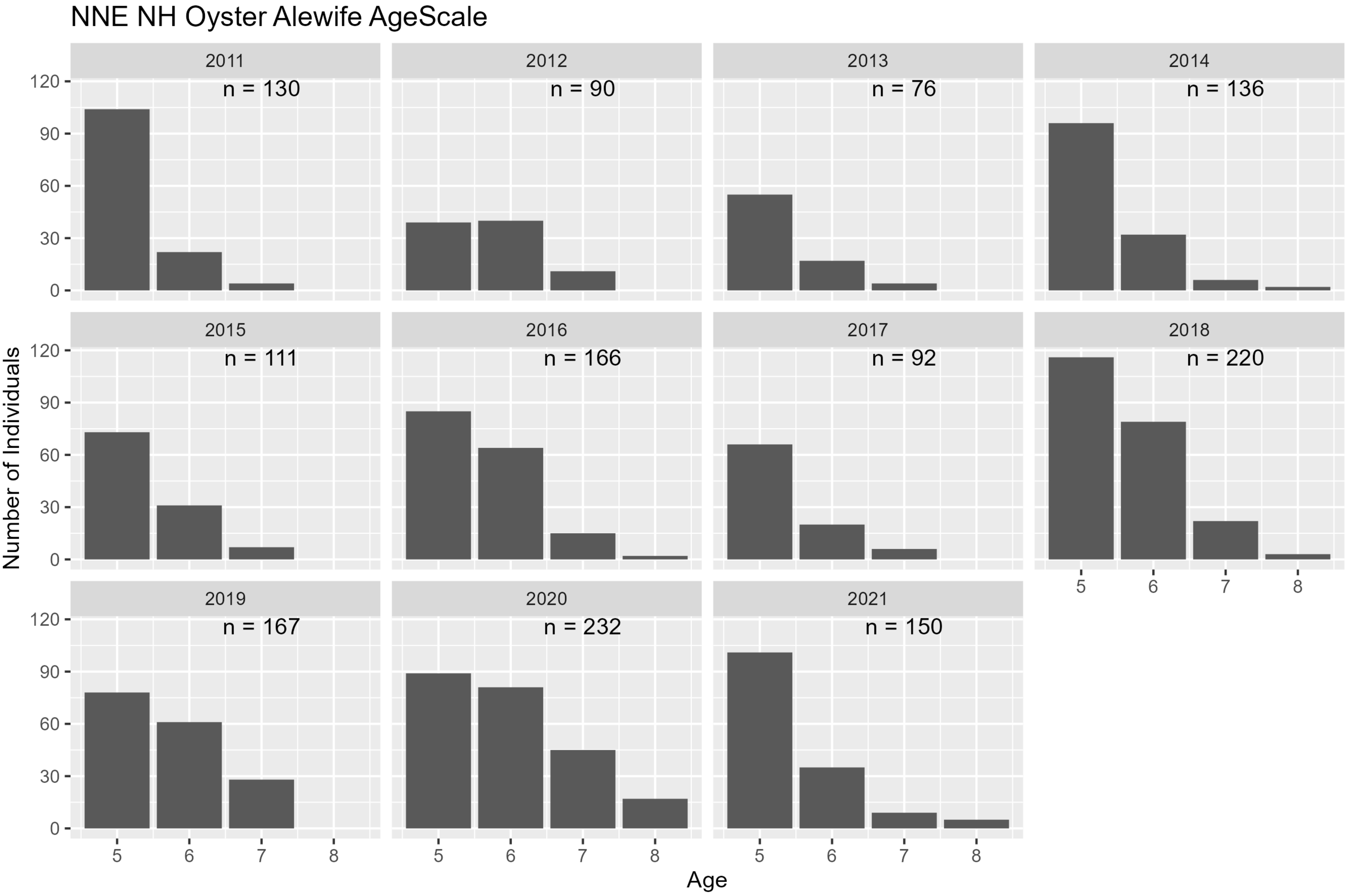


NNE NH Cocheco Alewife AgeScale

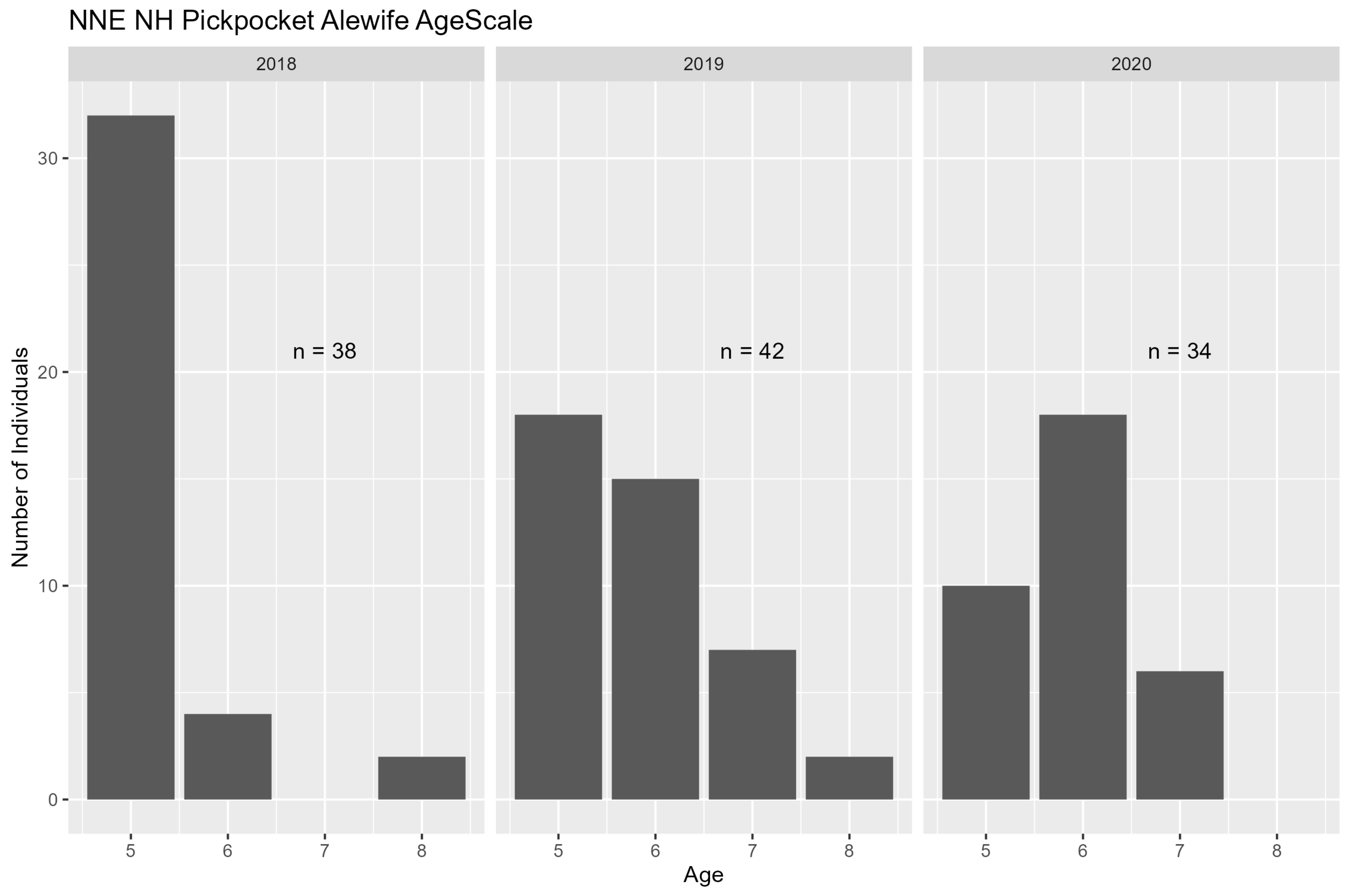



NNE NH Exeter Alewife AgeScale
1993
n = 42
1997
n = 32
1998
n = 49
2001
n = 38
2004
n = 42
2005
n = 37
2008
n = 60
2009
n = 161
2012
n = 185
2013
n = 182
2014
n = 260
2015
n = 130
2016
n = 365
2021
n = 373
Number of Individuals
0
50
100
150
200
250
Age
5
6
7
8

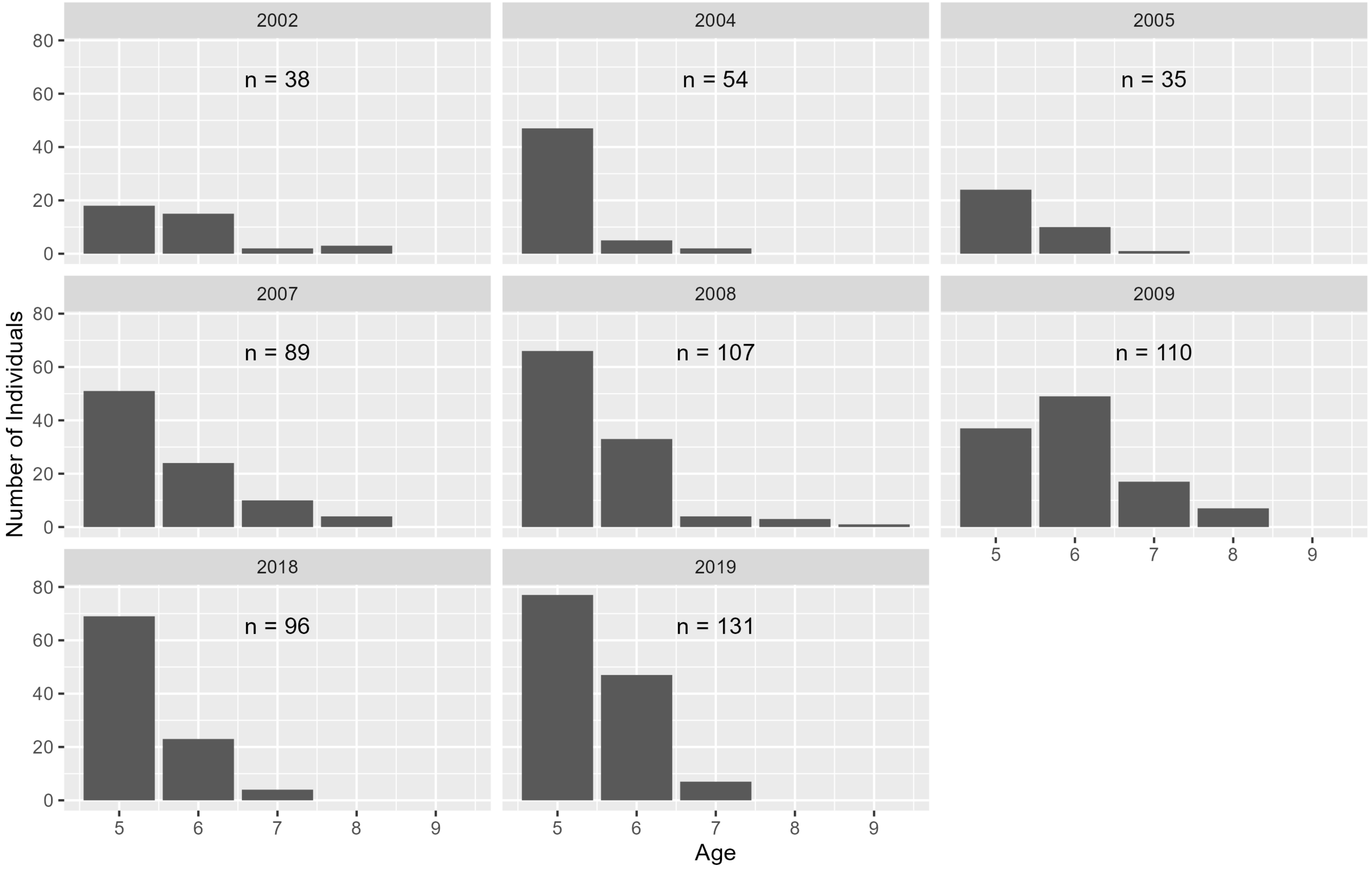

NNE NH Lamprey Alewife AgeScale
1992
n = 33
1997
n = 62
1998
n = 87
1999
n = 100
2000
n = 77
2001
n = 85
2002
n = 108
2003
n = 79
2004
n = 129
2005
n = 103
2006
n = 107
2007
n = 121
2008
n = 109
2009
n = 149
2010
n = 70
2011
n = 418
2012
n = 410
2013
n = 397
2014
n = 364
2015
n = 324
2016
n = 522
2017
n = 456
2018
n = 317
2019
n = 342
2020
n = 469
2021
n = 447
0
100
200
5
6
7
8
9
Number of Individuals
Age

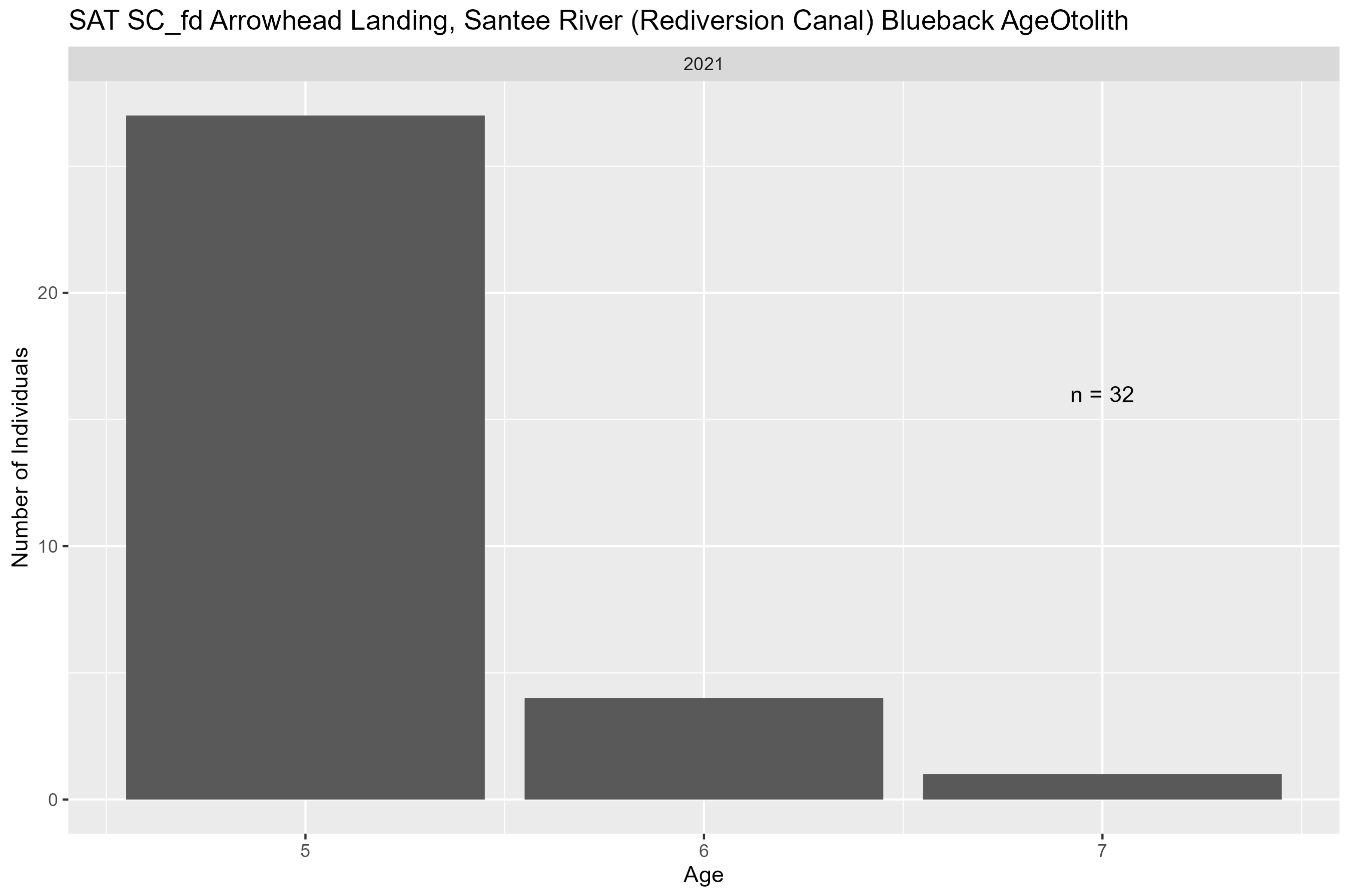


NNE NH Oyster Alewife AgeScale

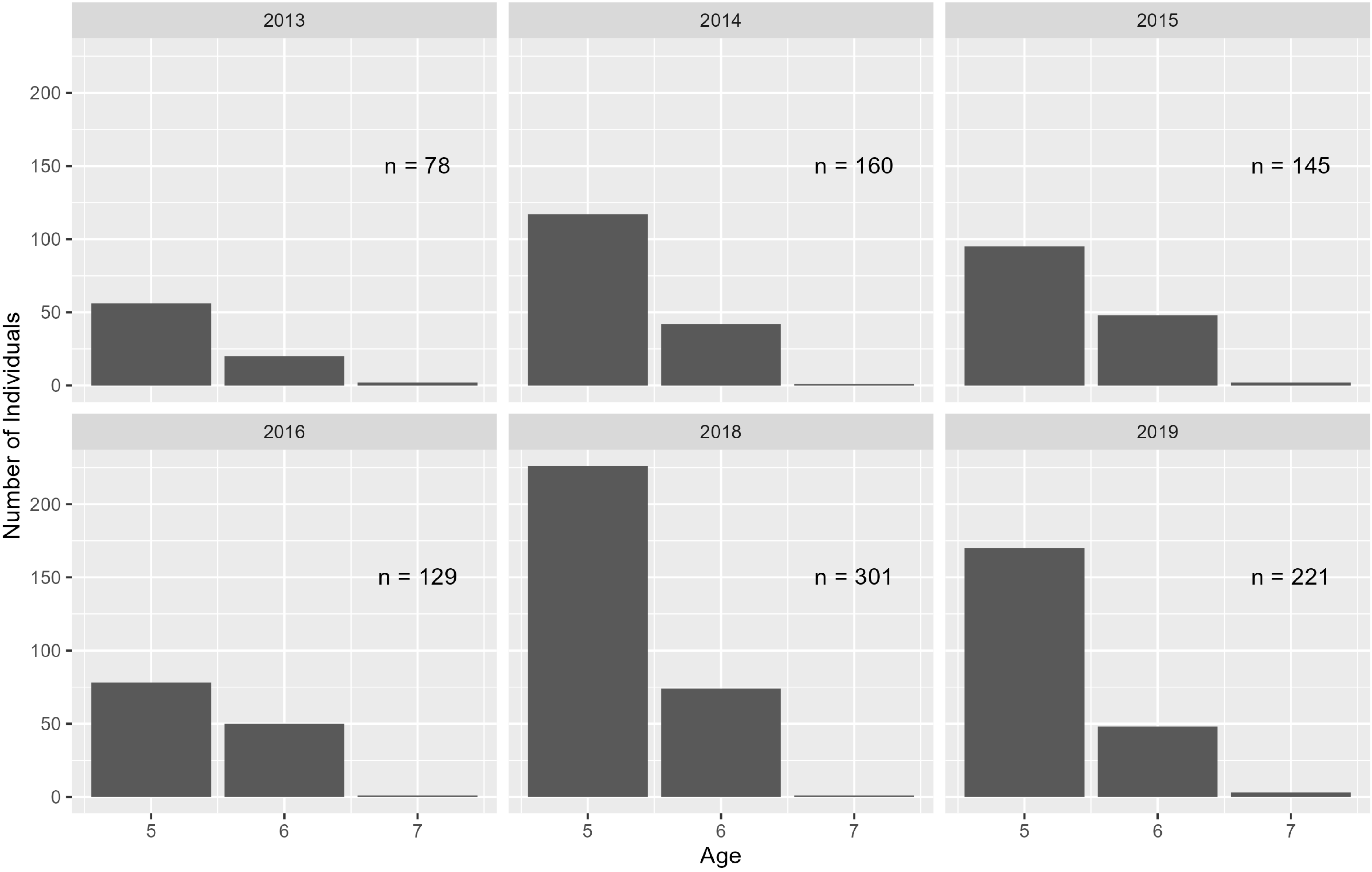

NNE NH Pickpocket Alewife AgeScale
2018
2019
2020
n = 38
n = 42
n = 34
Number of Individuals
0
10
20
30
5
6
7
8
Age

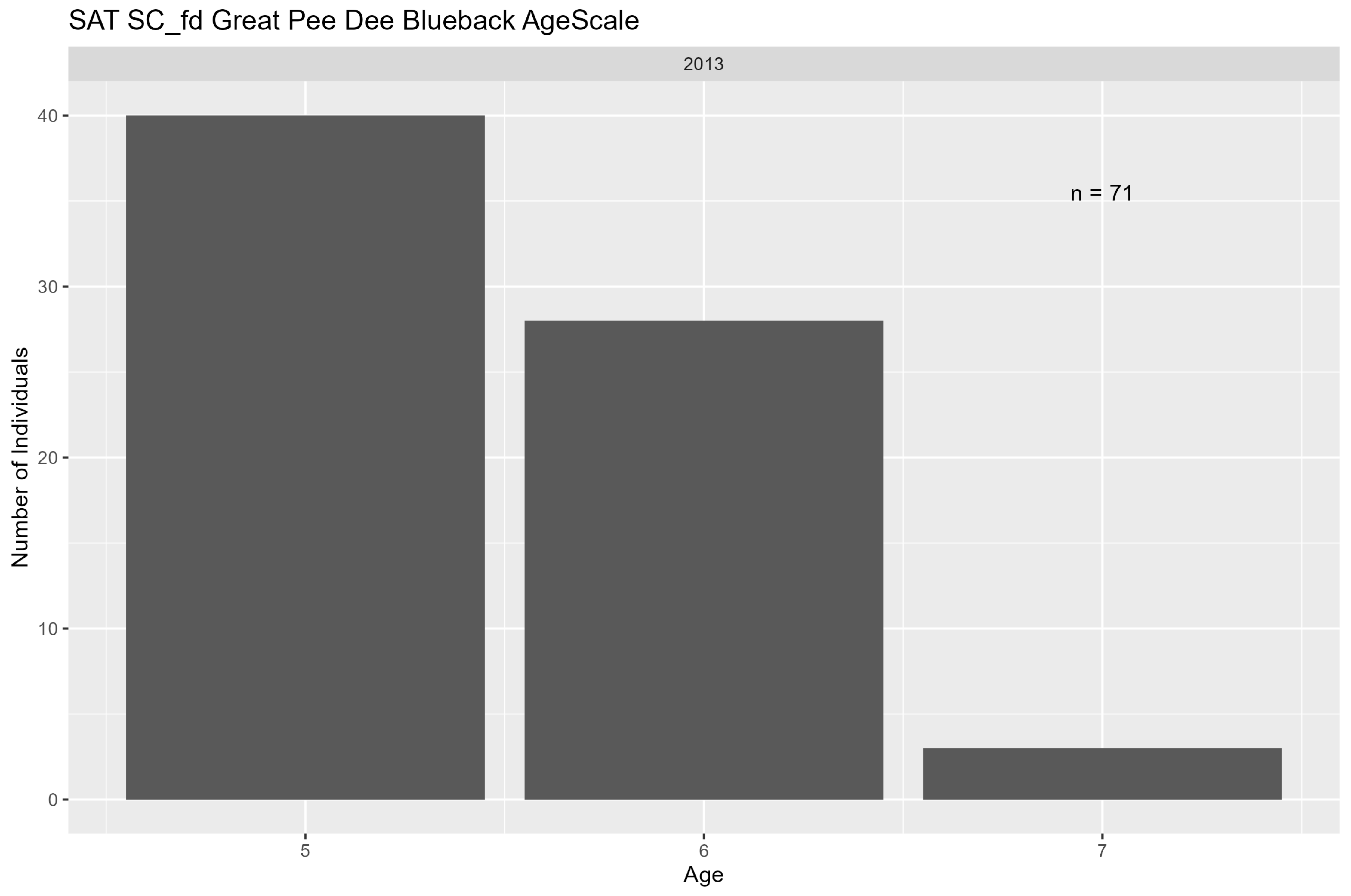
NNE NH Winnicut Alewife AgeScale

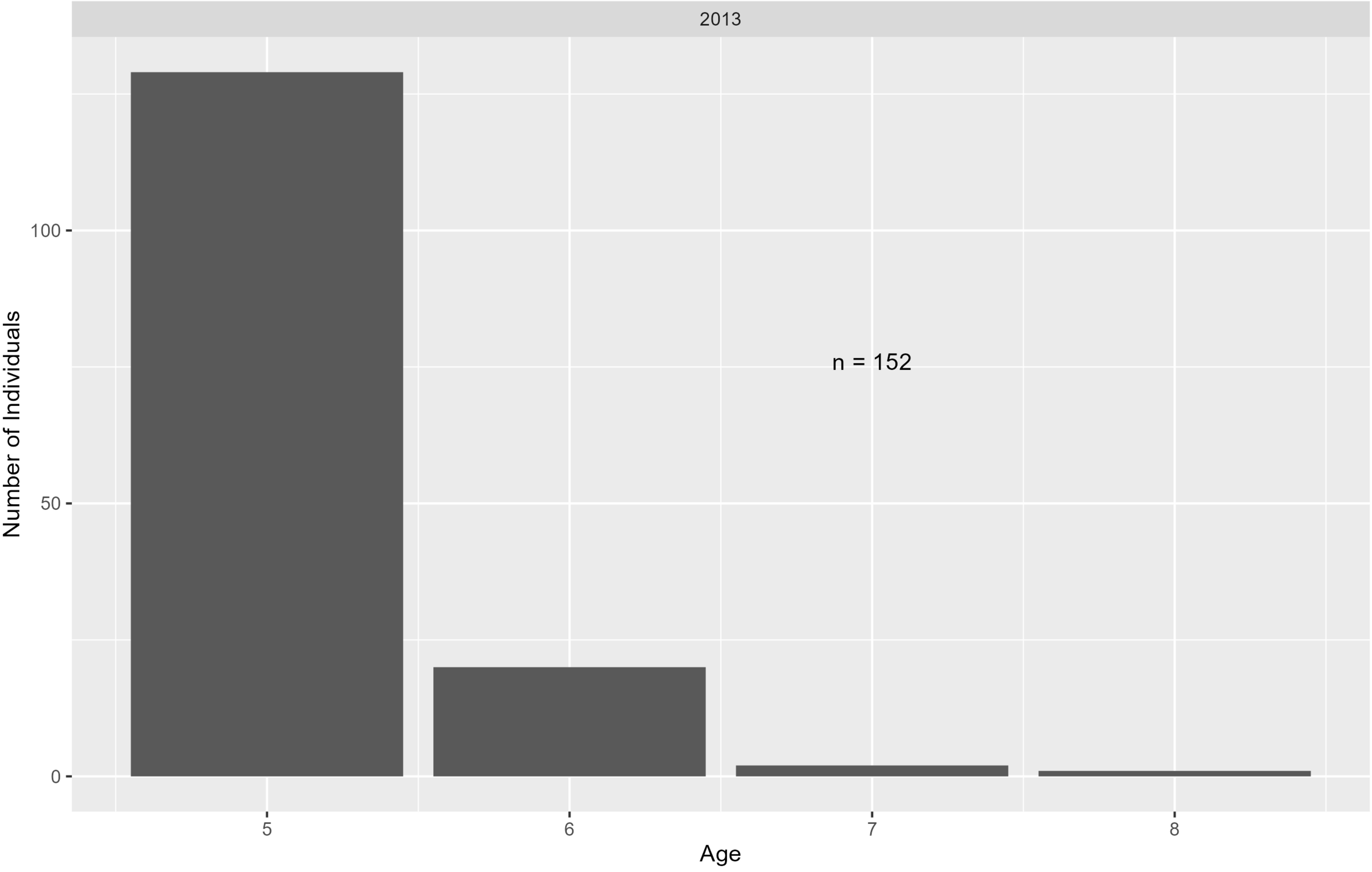



SAT SC_fd Arrowhead Landing, Santee River (Rediversion Canal) Blueback AgeOtolith
2021
Number of Individuals
0
10
20
n = 32
5
6
7
Age

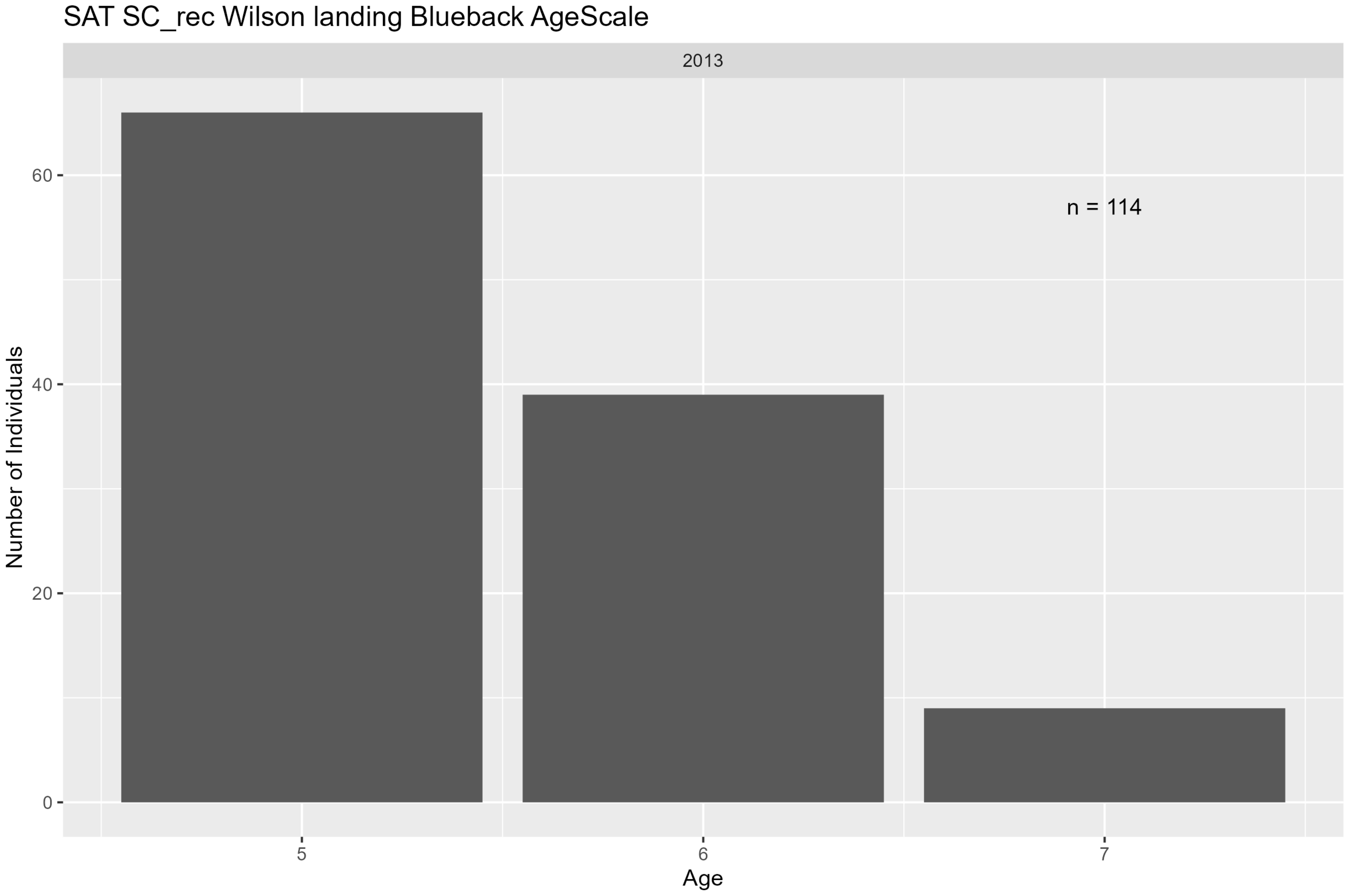
SAT SC_fd Arrowhead Landing, Santee River (Rediversion Canal) Blueback AgeScale



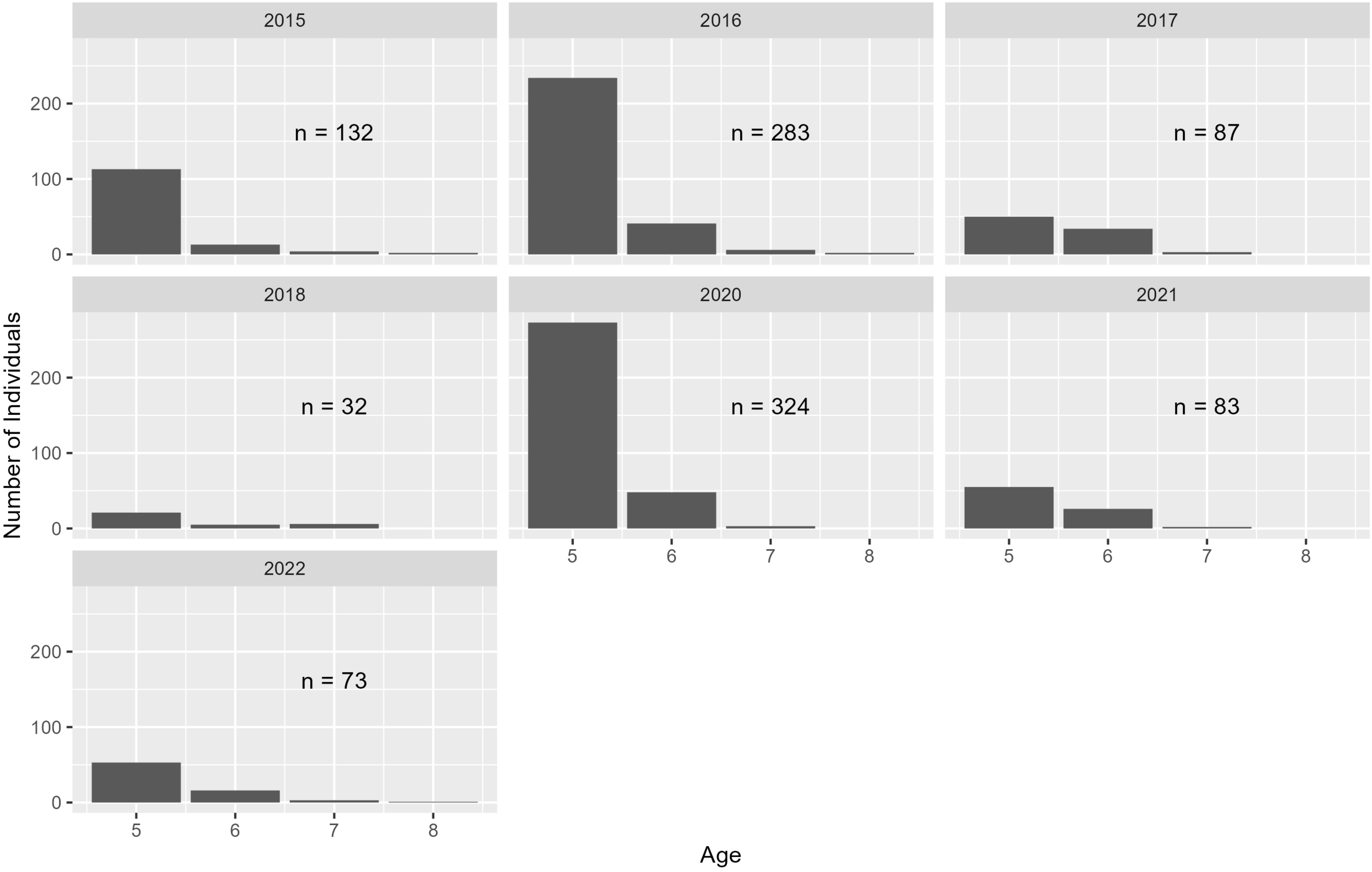

SAT SC_fd Great Pee Dee Blueback AgeScale
2013
n = 71
Number of Individuals
0
10
20
30
40
5
6
7
Age

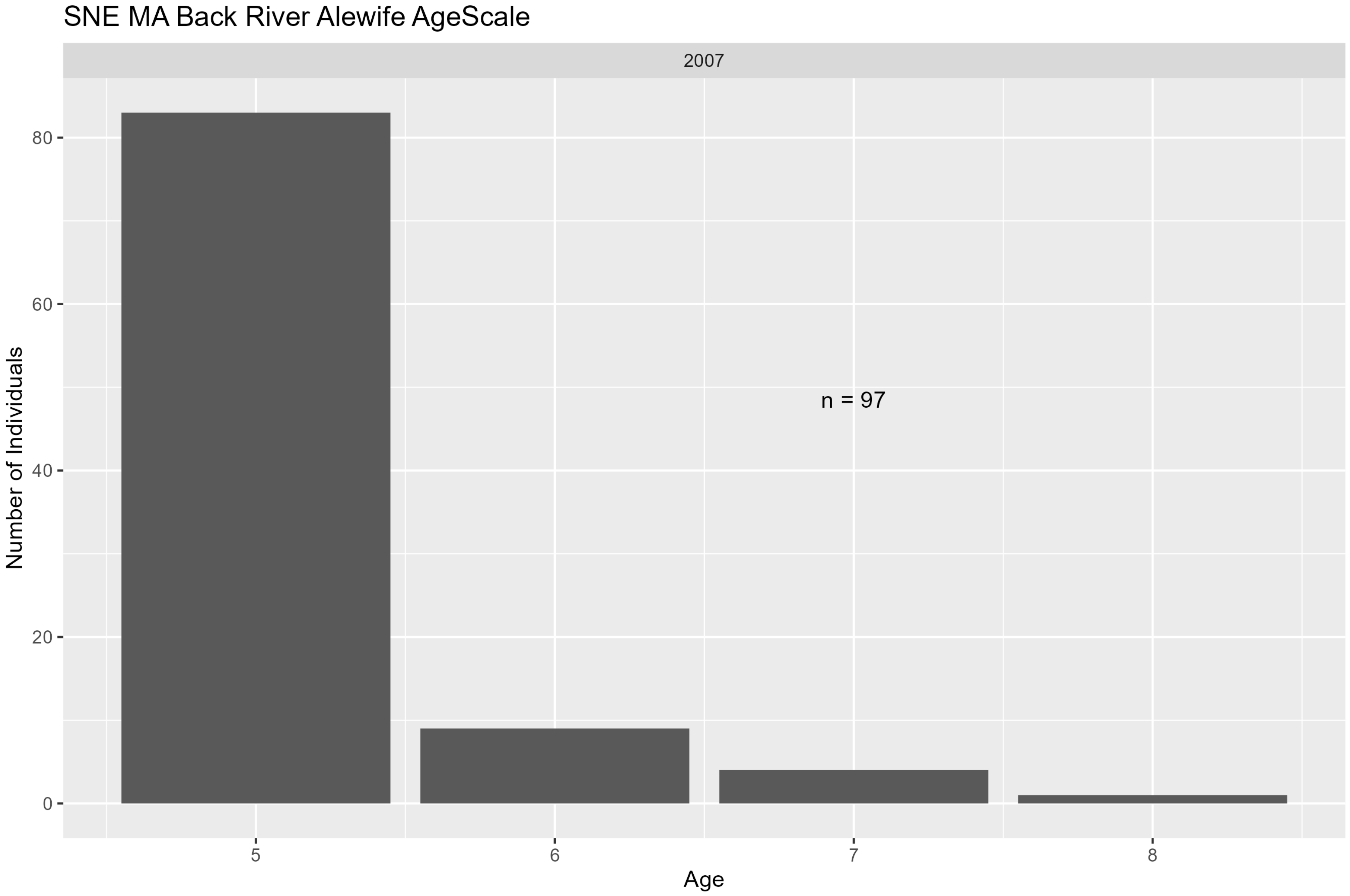


SAT SC_rec Cooper River Blueback AgeScale

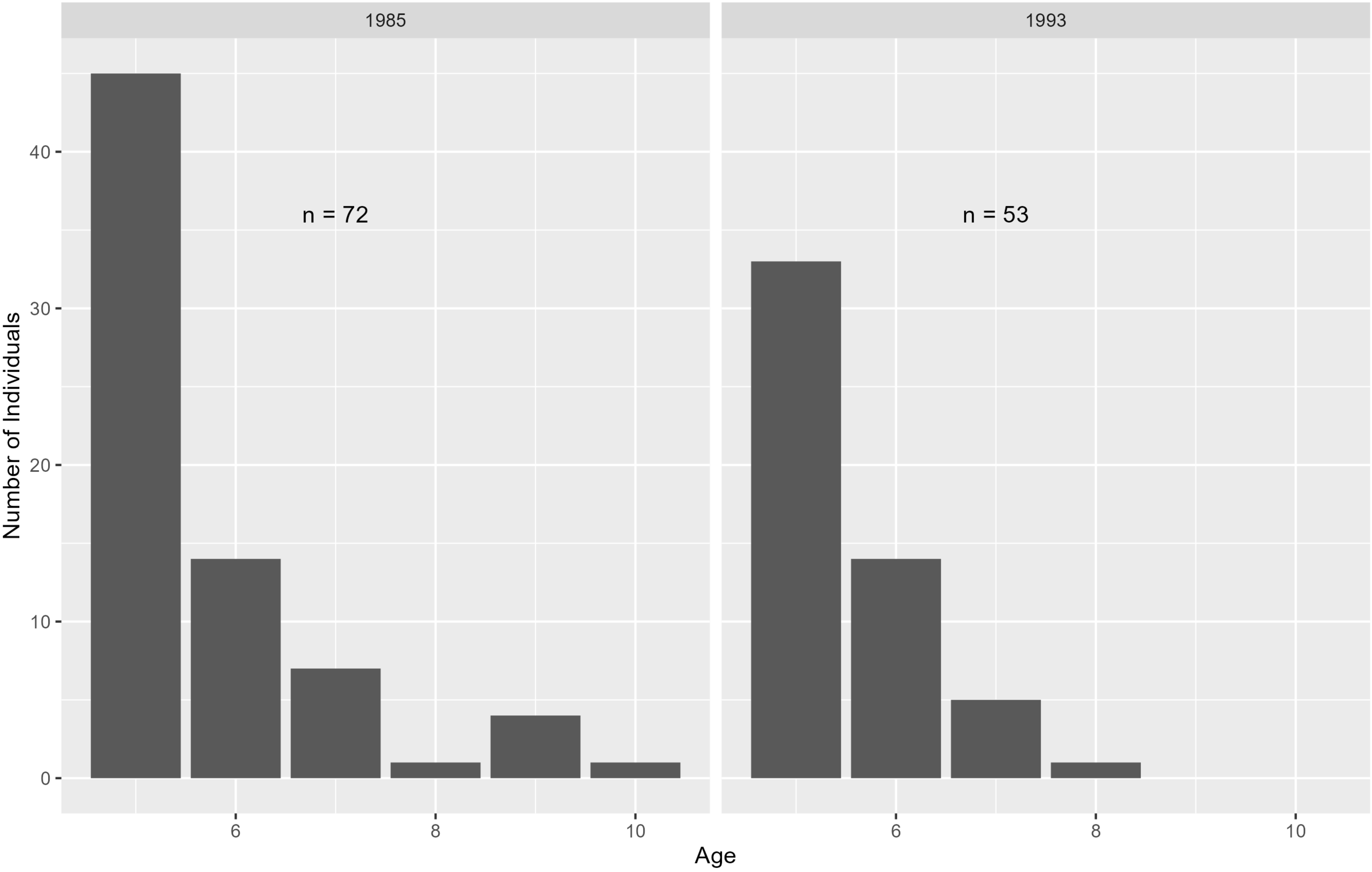

SAT SC_rec Wilson landing Blueback AgeScale
2013
n = 114
Number of Individuals
0
20
40
60
5
6
7
Age

SNE MA Back River Alewife AgeOtolith

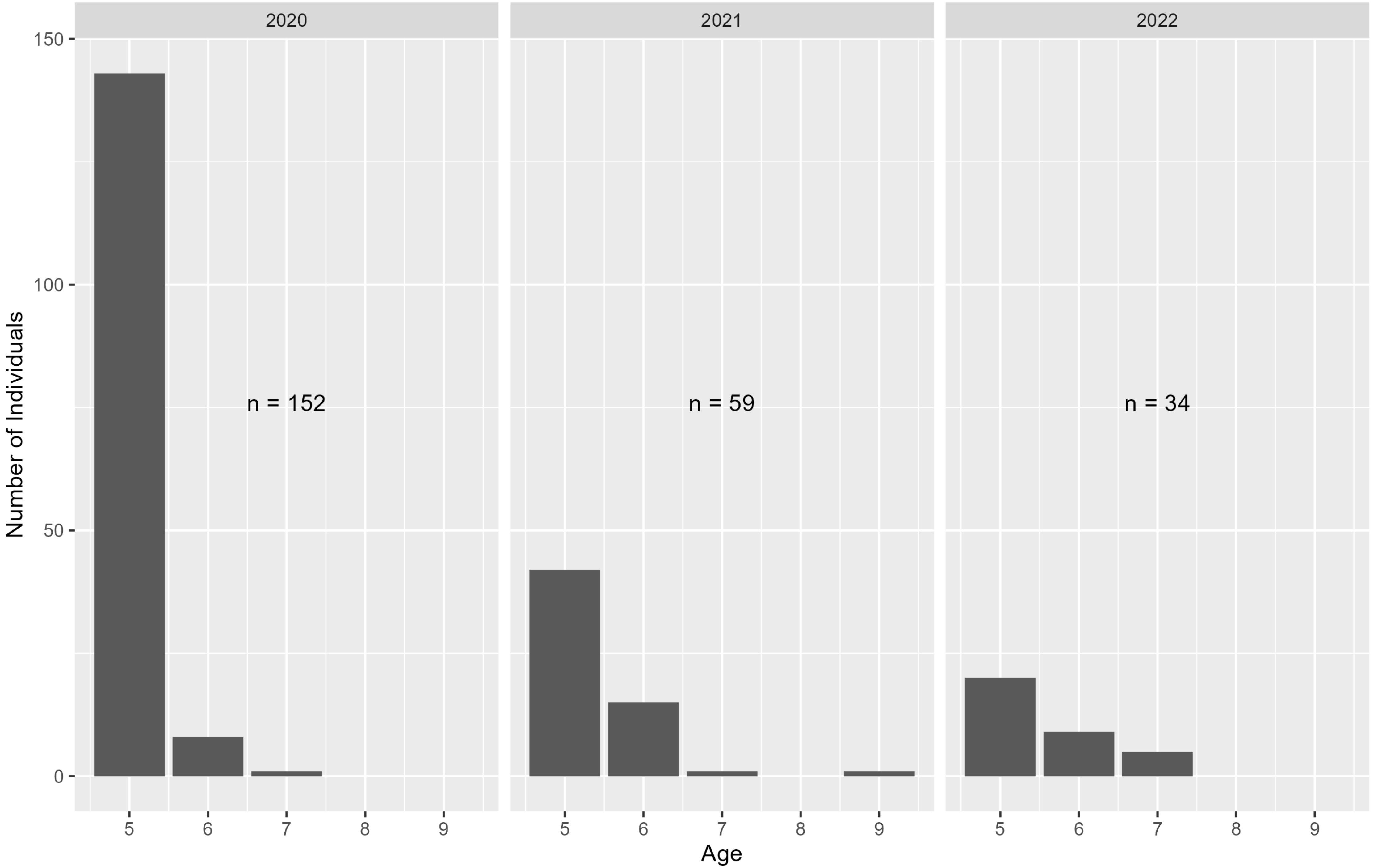



SNE MA Back River Alewife AgeScale
2007
Number of Individuals
0
20
40
60
80
n = 97
5
6
7
8
Age

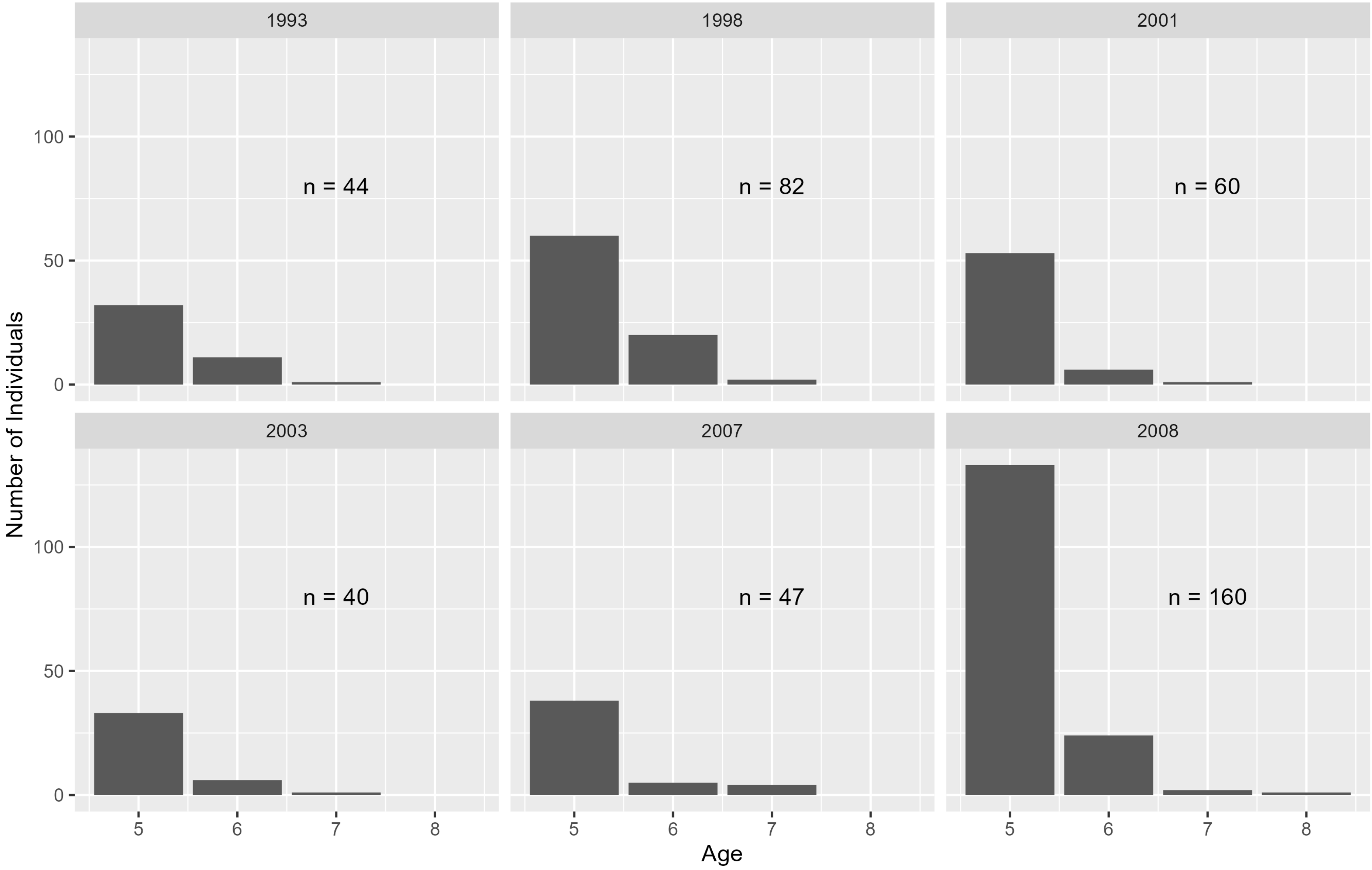
SNE MA Charles Blueback AgeScale



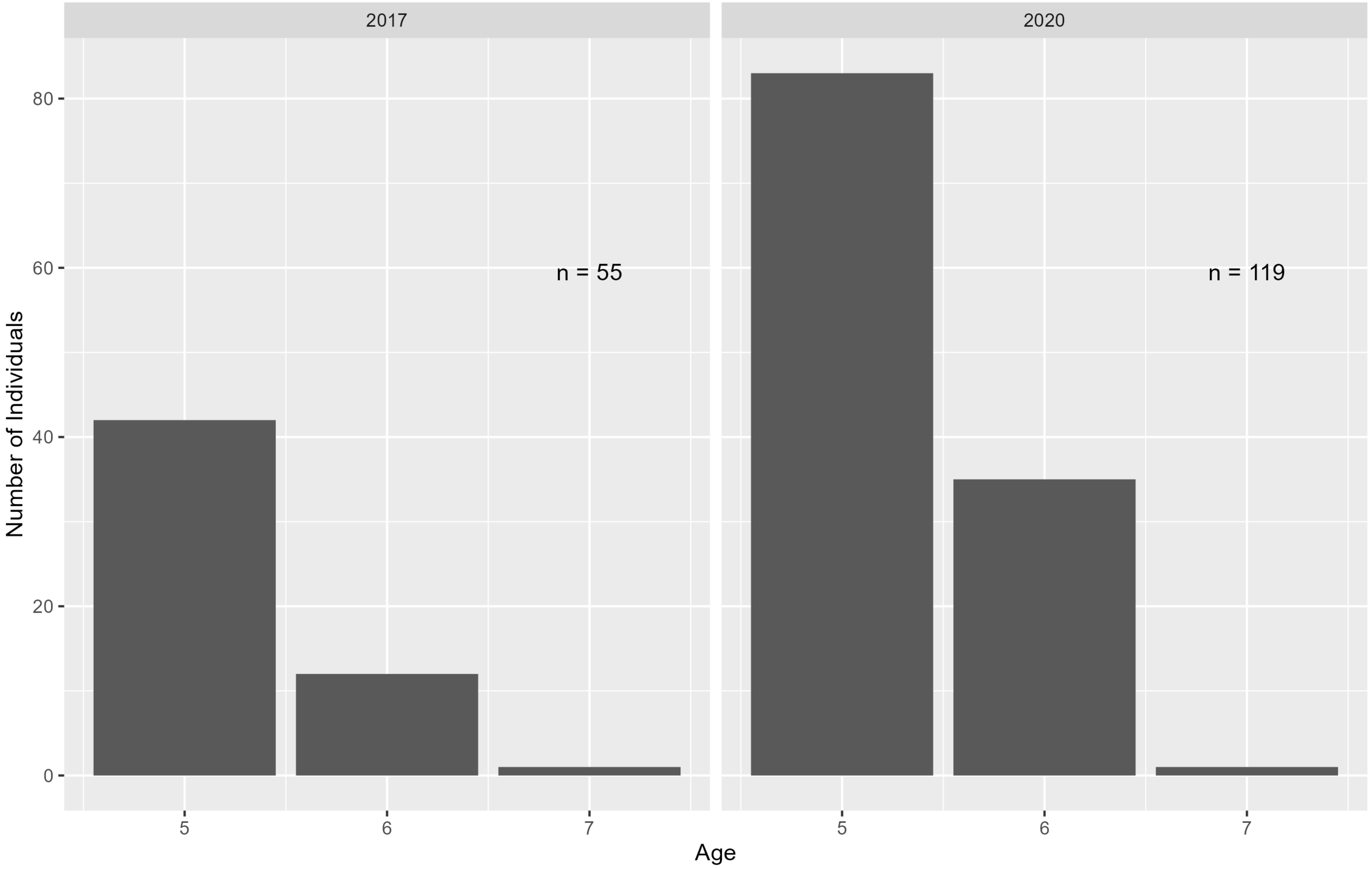
SNE MA Monument Alewife AgeOtolith

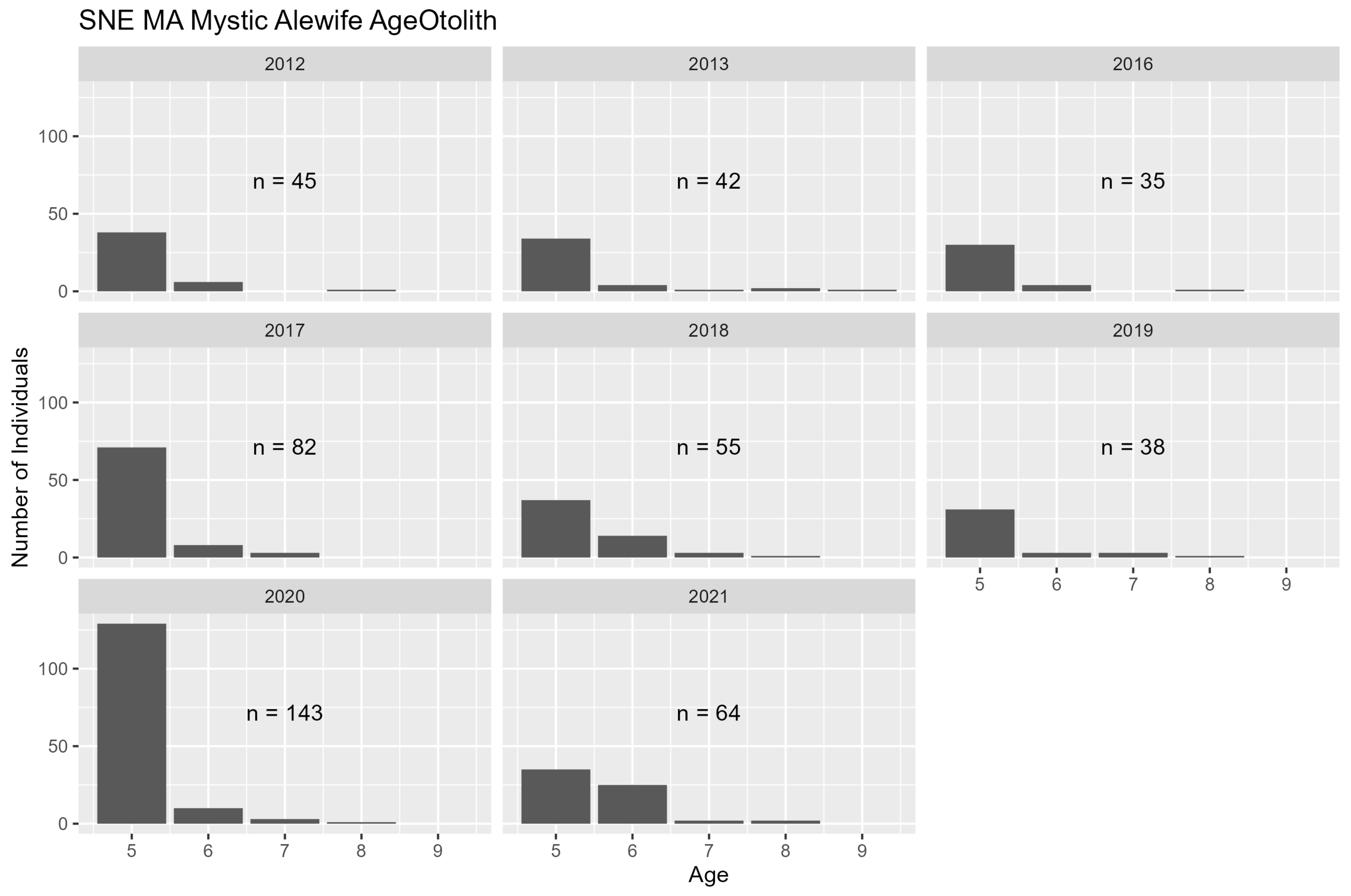


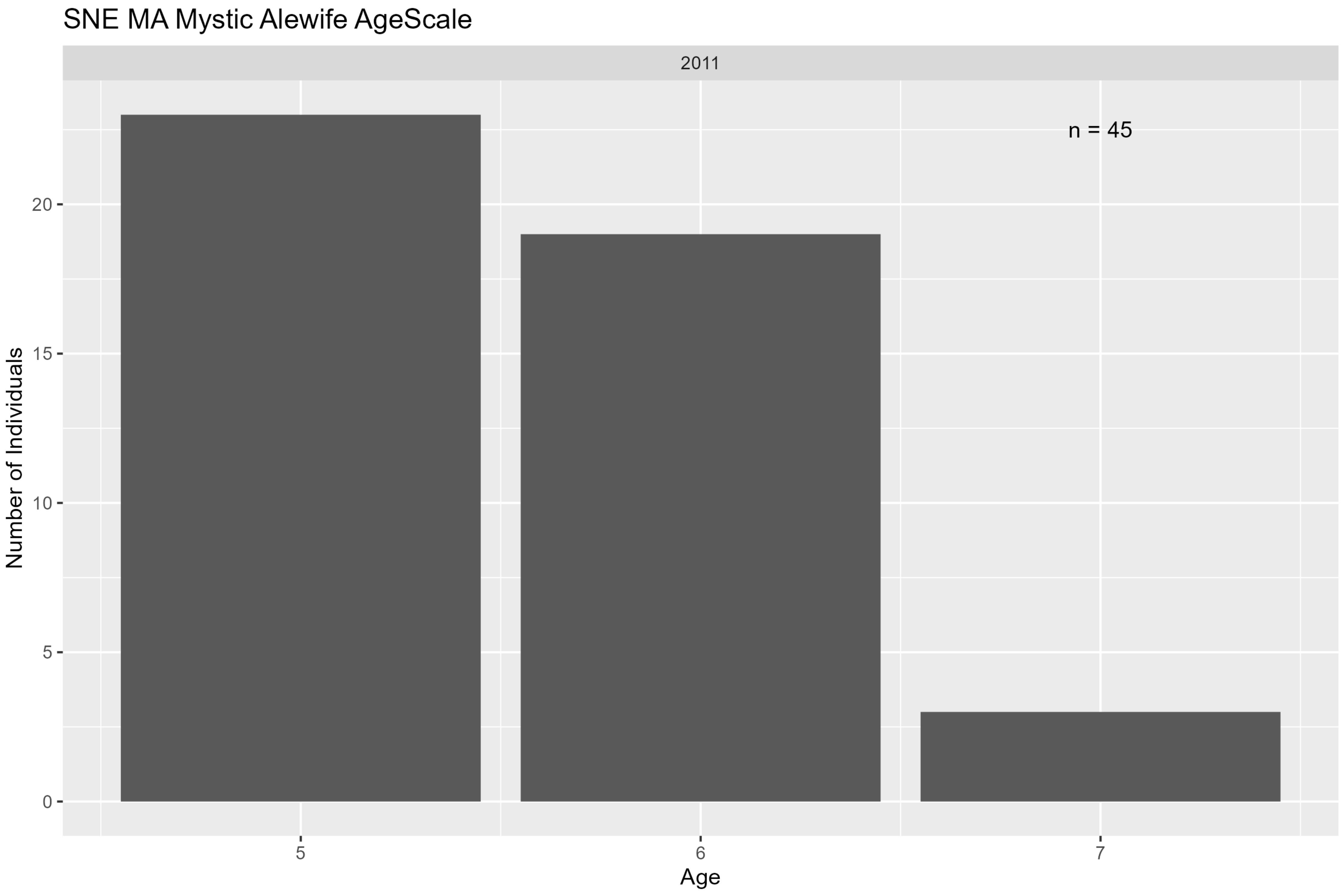
SNE MA Monument Alewife AgeScale

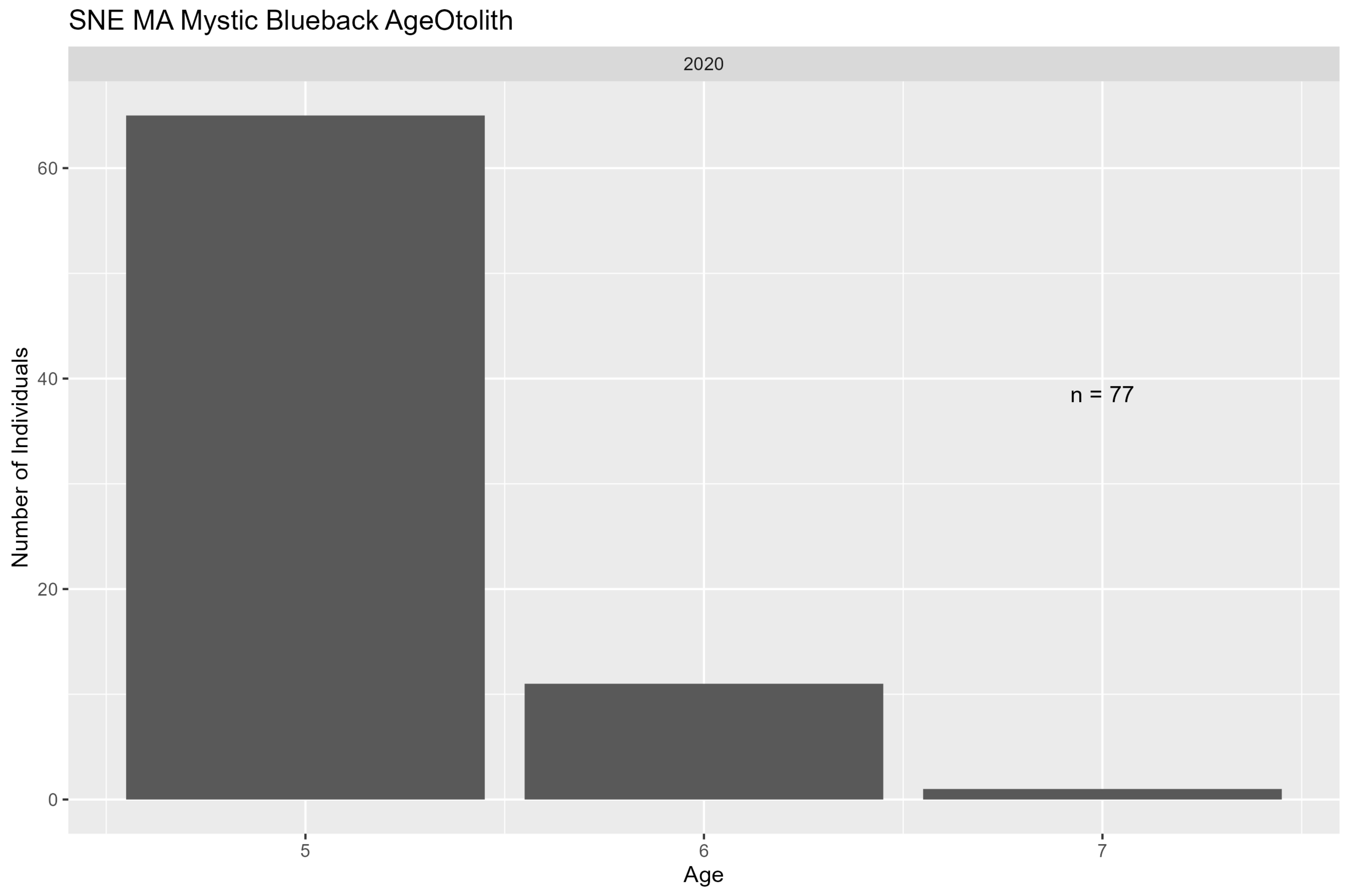


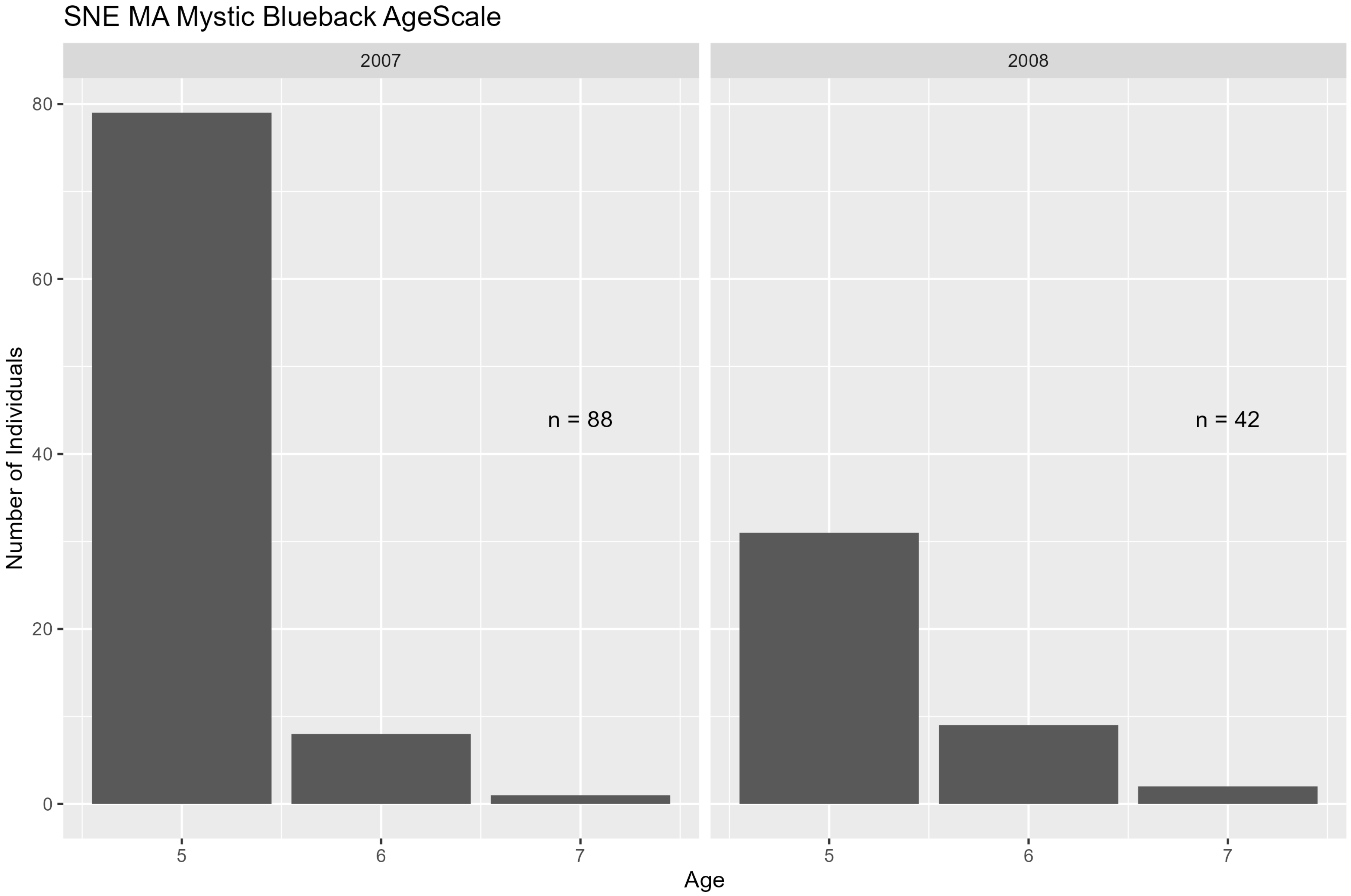
SNE MA Monument Blueback AgeOtolith

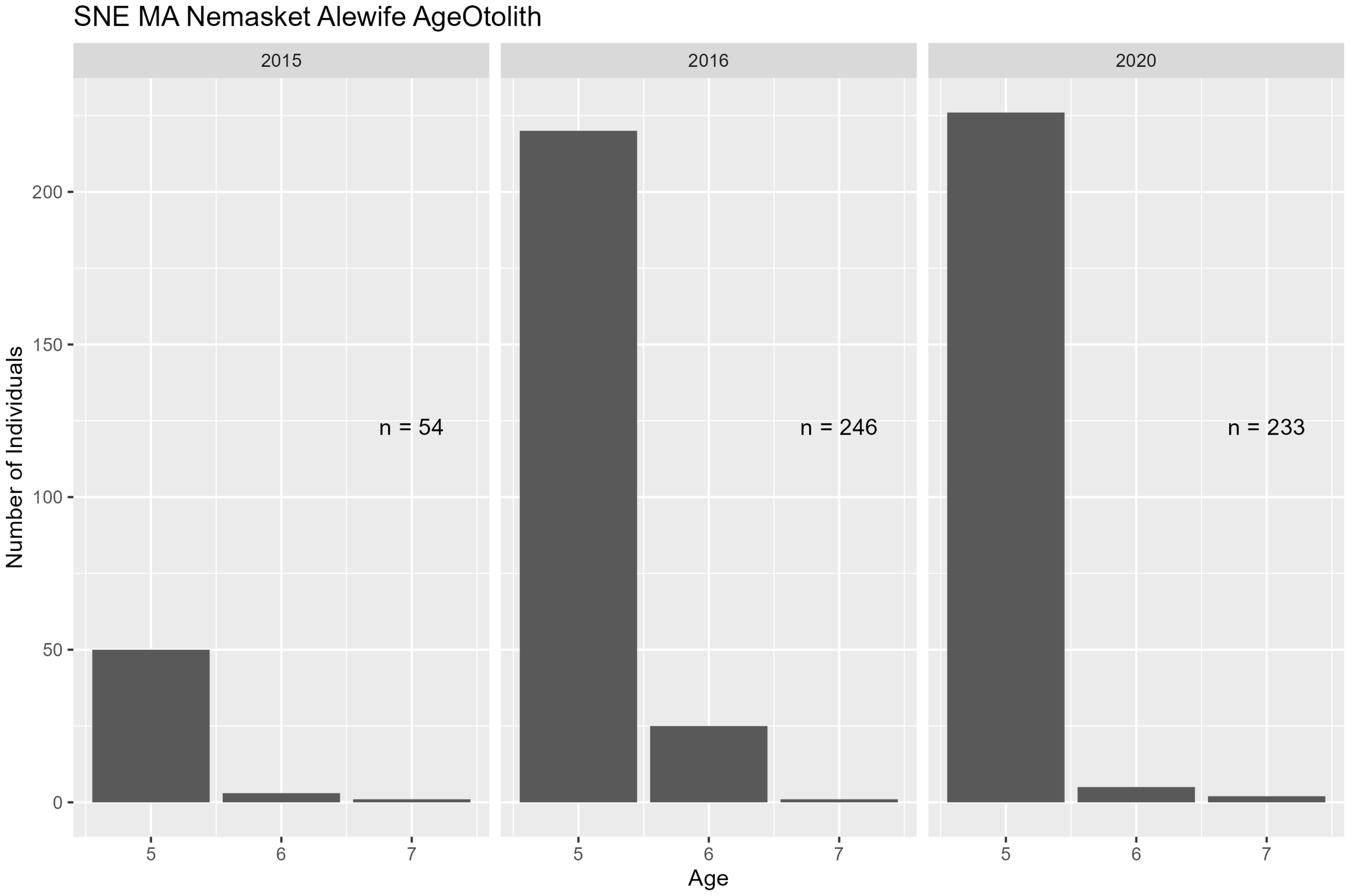


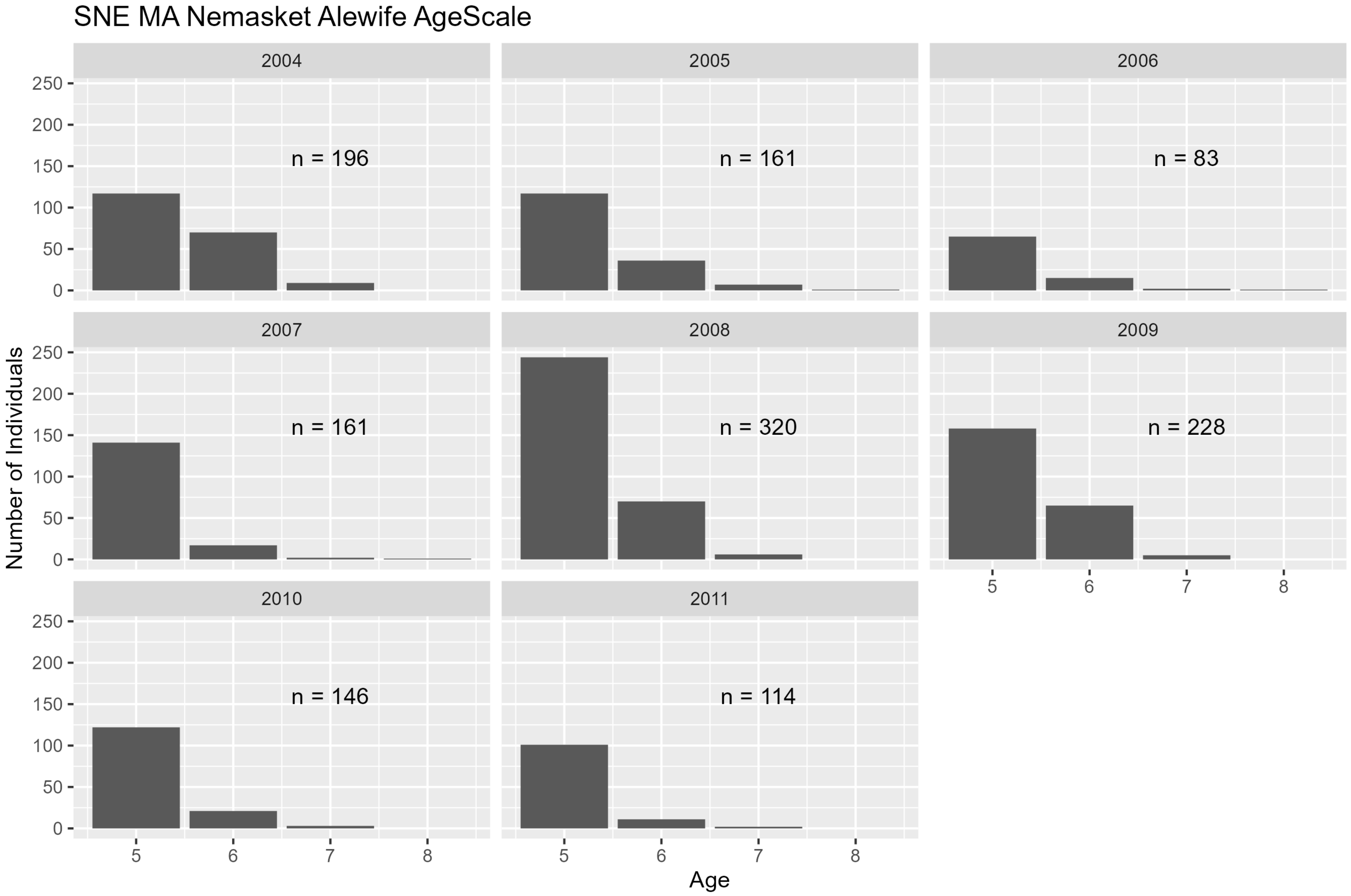

SNE MA Mystic Alewife AgeOtolith
2012
n = 45
2013
n = 42
2016
n = 35
2017
n = 82
2018
n = 55
2019
n = 38
2020
n = 143
2021
n = 64
Number of Individuals
0
50
100
Age
5
6
7
8
9

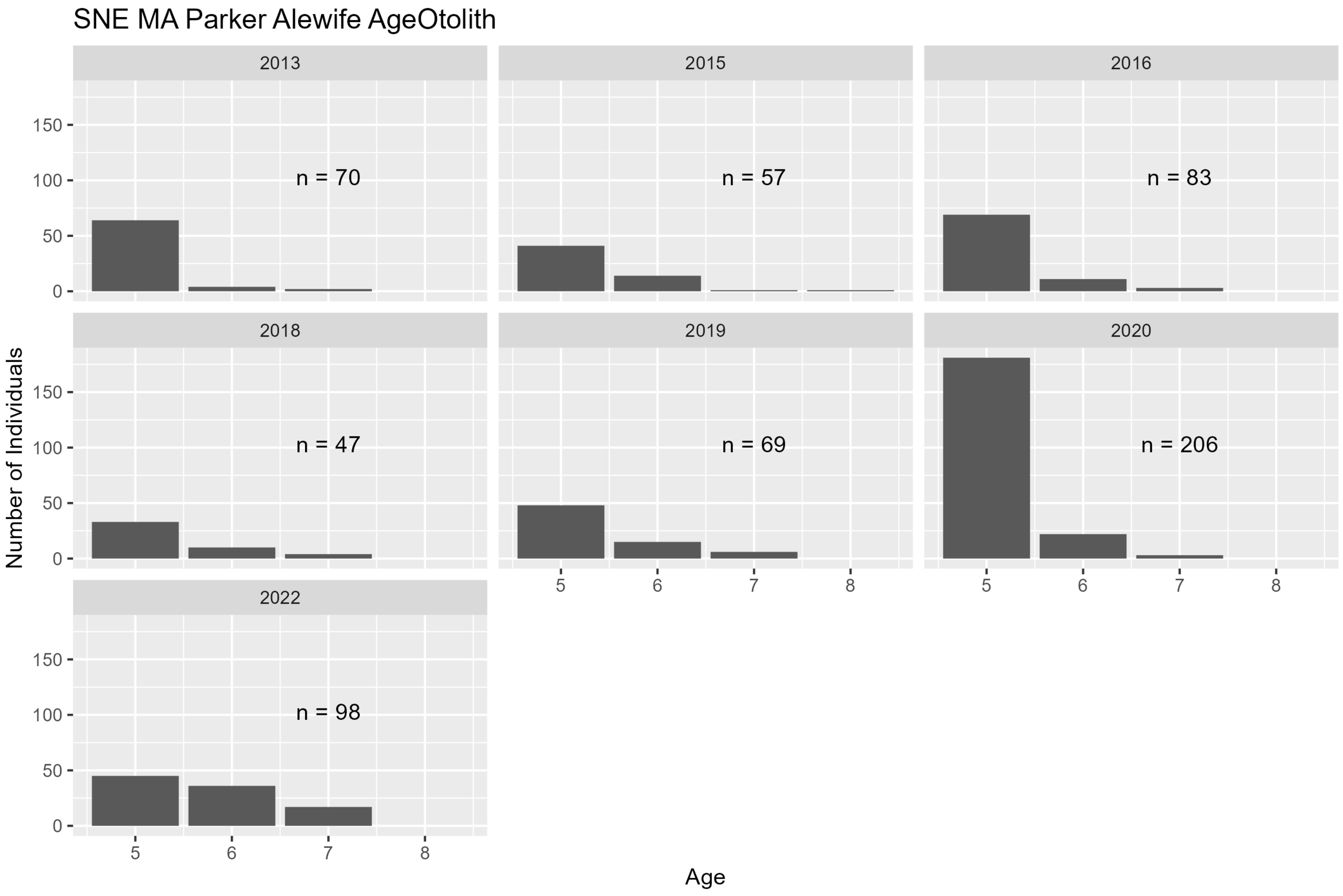

SNE MA Mystic Alewife AgeScale
2011
n = 45
Number of Individuals
0
5
10
15
20
Age
5
6
7

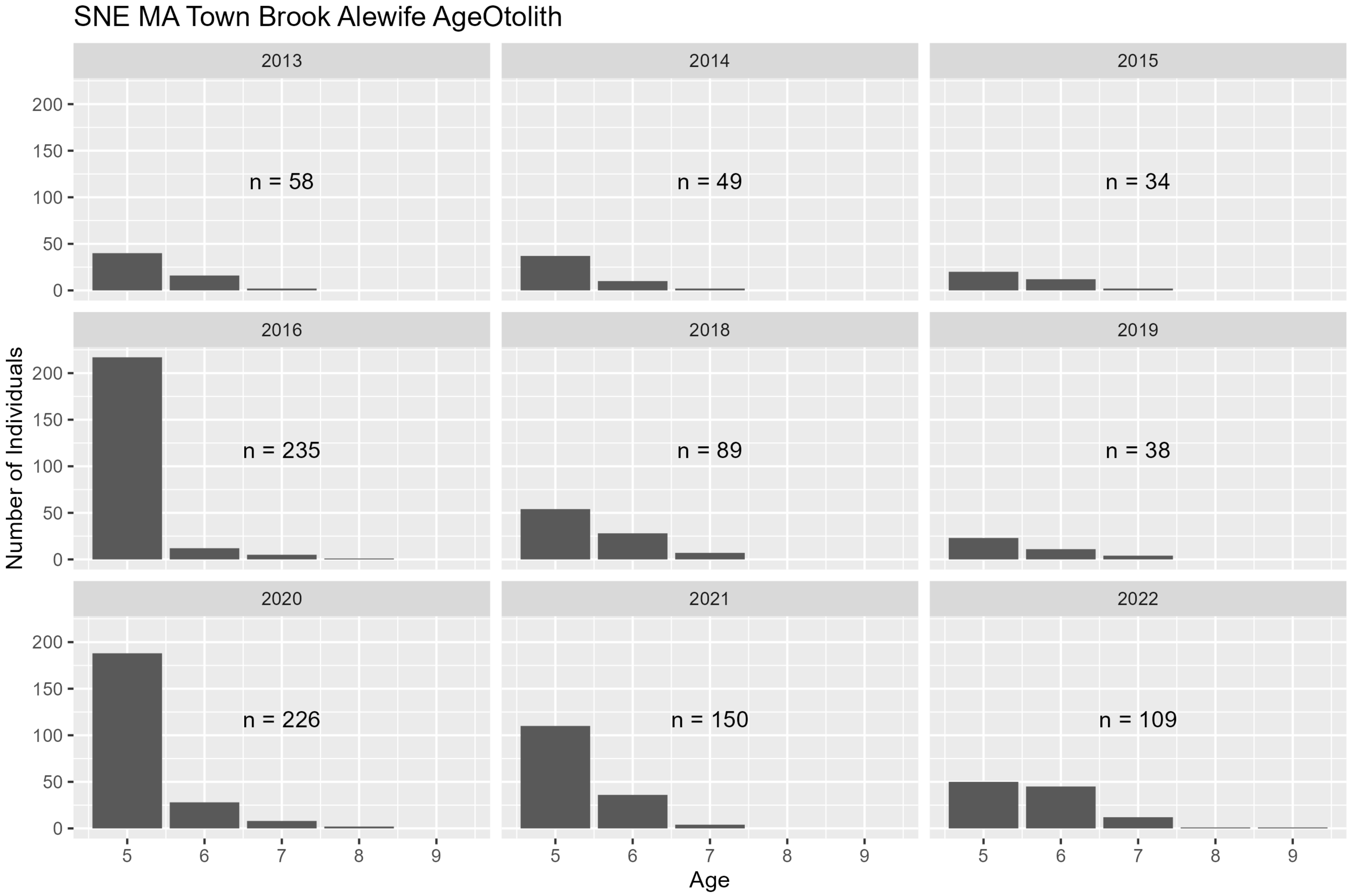

SNE MA Mystic Blueback AgeOtolith
2020
Number of Individuals
0
20
40
60
Age
5
6
7
n = 77

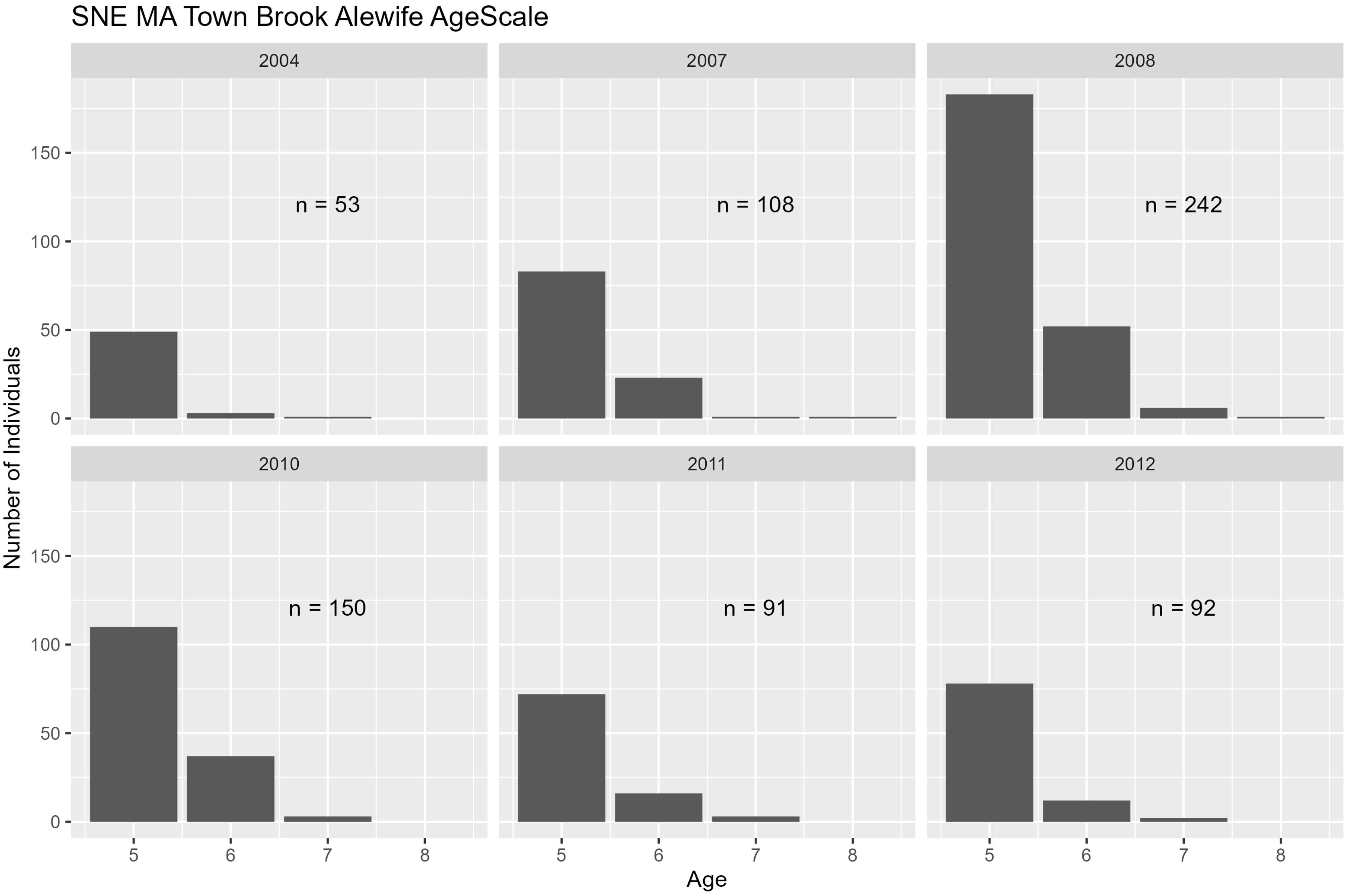

SNE MA Mystic Blueback AgeScale
2007
2008
Number of Individuals
80
60
40
20
0
n = 88
n = 42
5
6
7
5
6
7
Age


SNE MA Nemasket Alewife AgeOtolith
2015
2016
2020
Number of Individuals
0
50
100
150
200
n = 54
n = 246
n = 233
5
6
7
Age

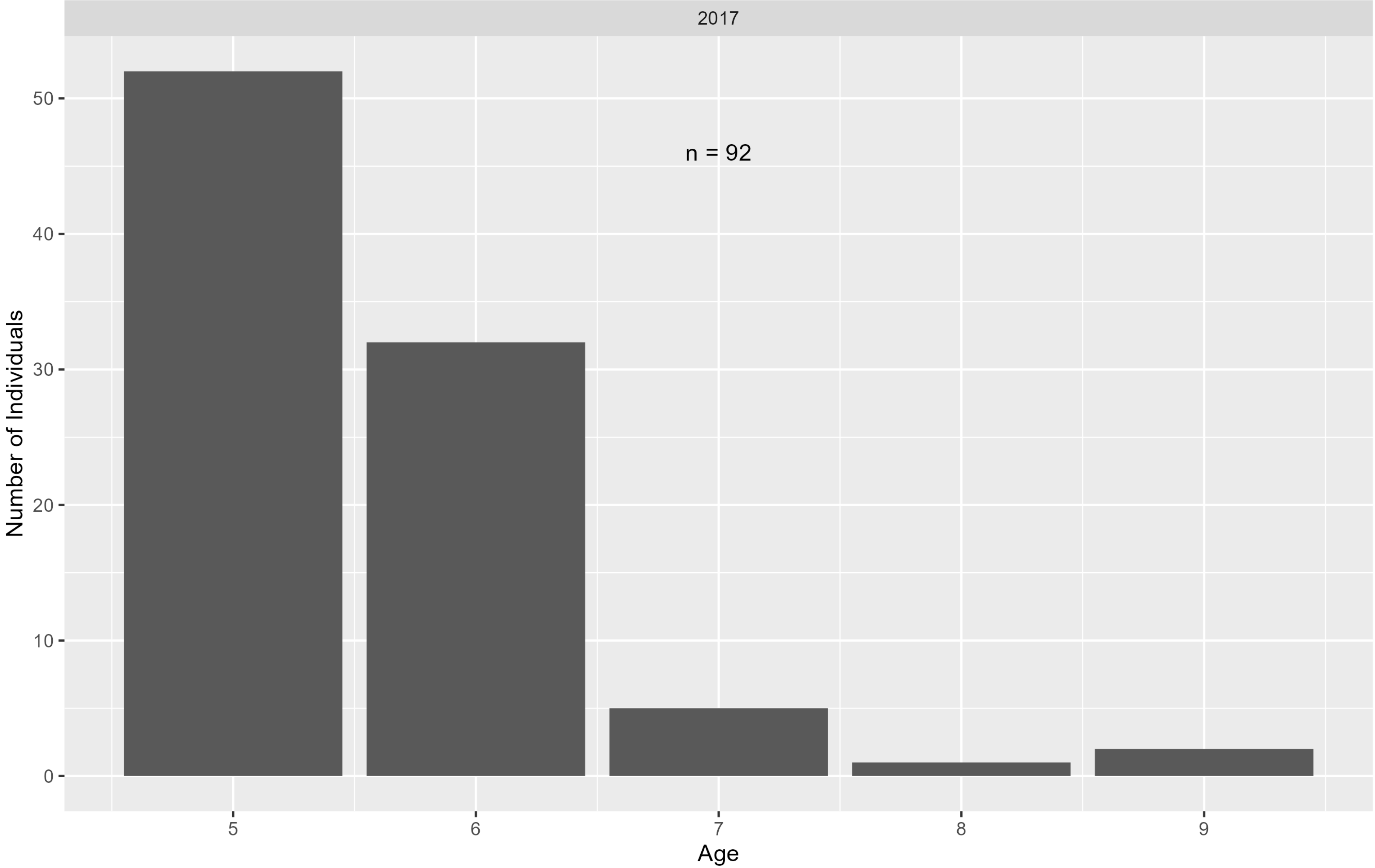

SNE MA Nemasket Alewife AgeScale
2004
n = 196
2005
n = 161
2006
n = 83
2007
n = 161
2008
n = 320
2009
n = 228
2010
n = 146
2011
n = 114
Number of Individuals
0
50
100
150
200
250
Age
5
6
7
8

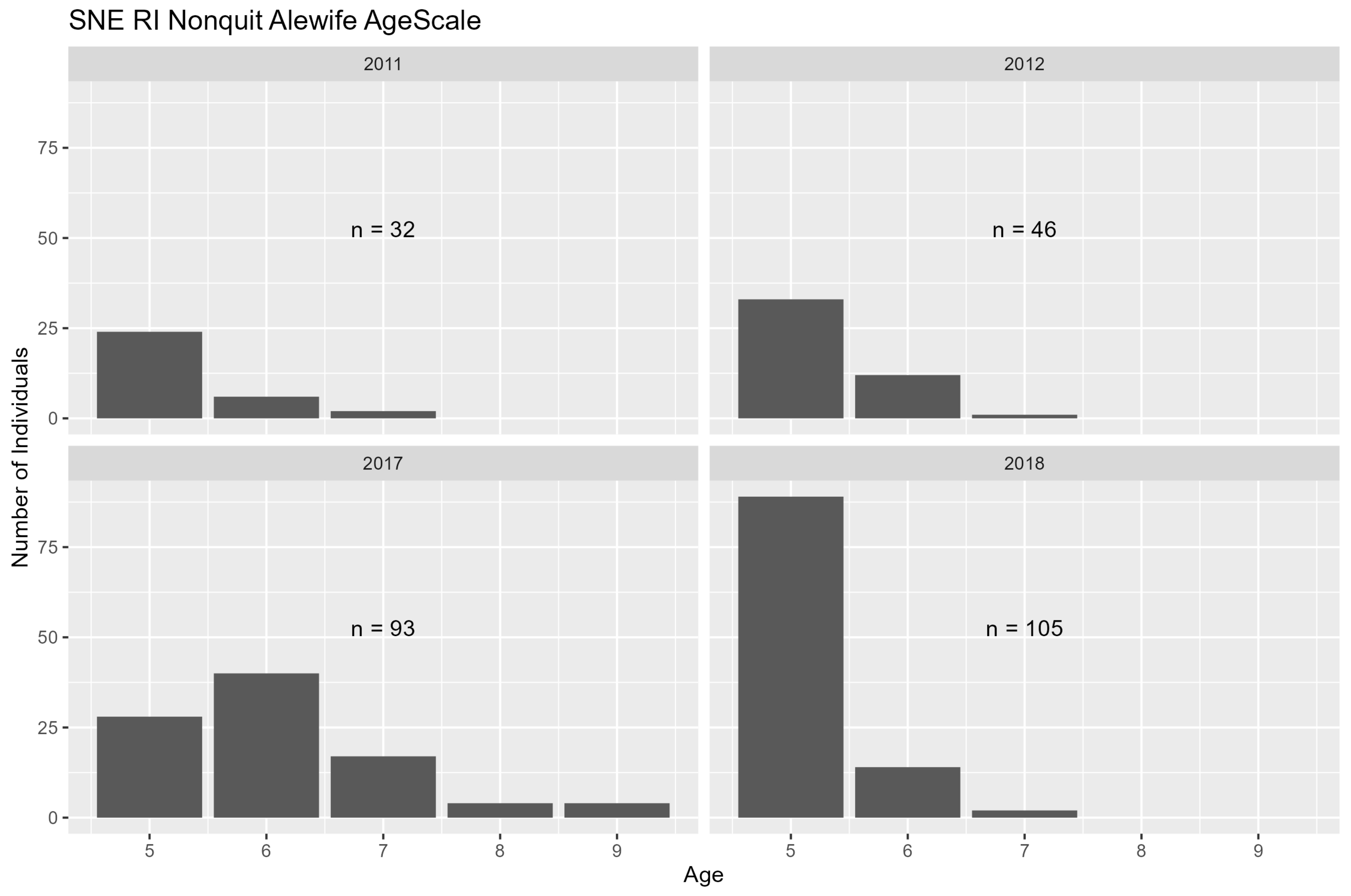

SNE MA Parker Alewife AgeOtolith
2013
n = 70
2015
n = 57
2016
n = 83
2018
n = 47
2019
n = 69
2020
n = 206
2022
n = 98
Number of Individuals
0
50
100
150
5
6
7
8
Age

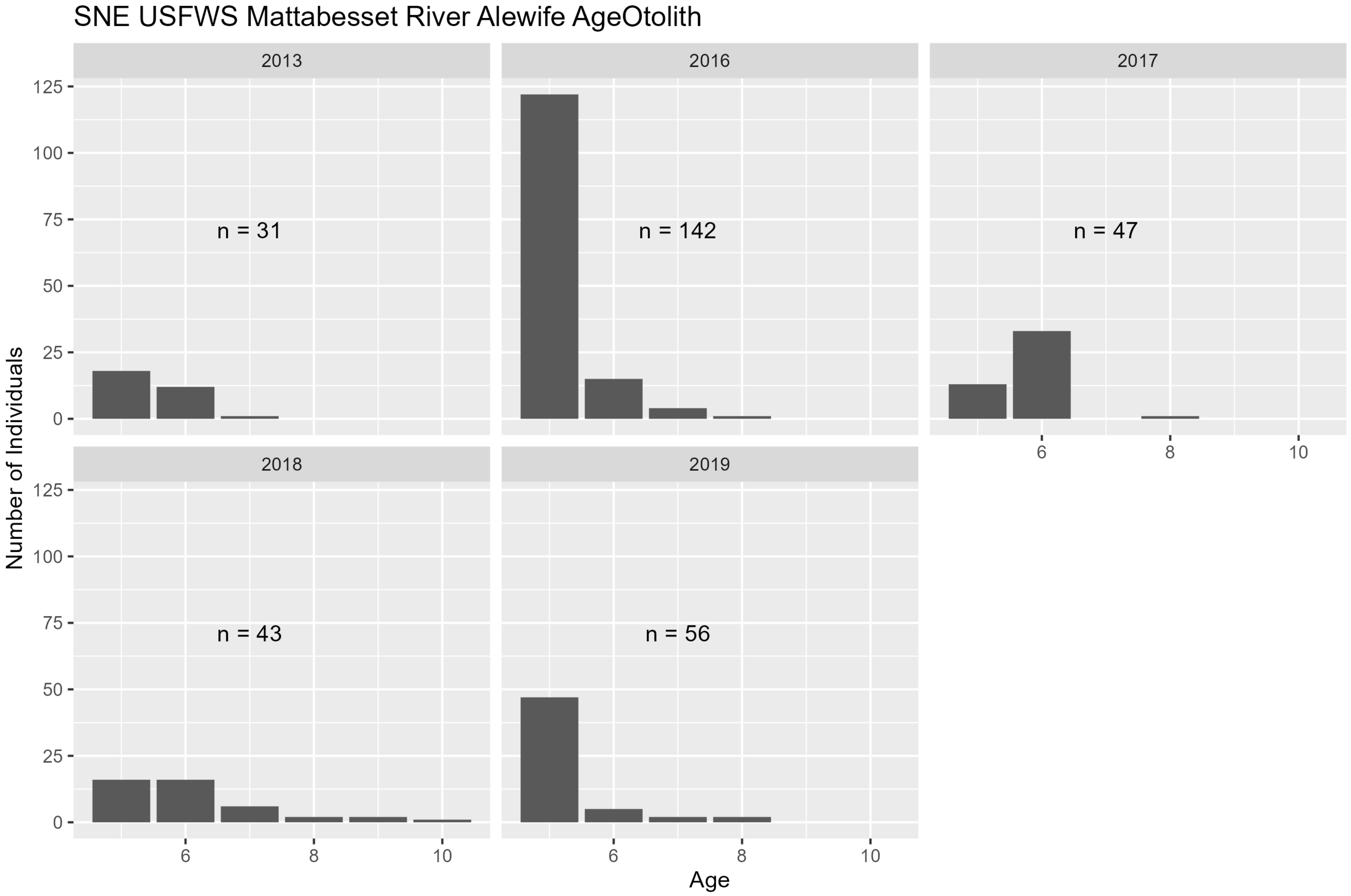

SNE MA Town Brook Alewife AgeOtolith
2013
n = 58
2014
n = 49
2015
n = 34
2016
n = 235
2018
n = 89
2019
n = 38
2020
n = 226
2021
n = 150
2022
n = 109
Number of Individuals
0
50
100
150
200
Age
5
6
7
8
9


SNE MA Town Brook Alewife AgeScale
2004
2007
2008
2010
2011
2012
n = 53
n = 108
n = 242
n = 150
n = 91
n = 92
Number of Individuals
0
50
100
150
Age
5
6
7
8

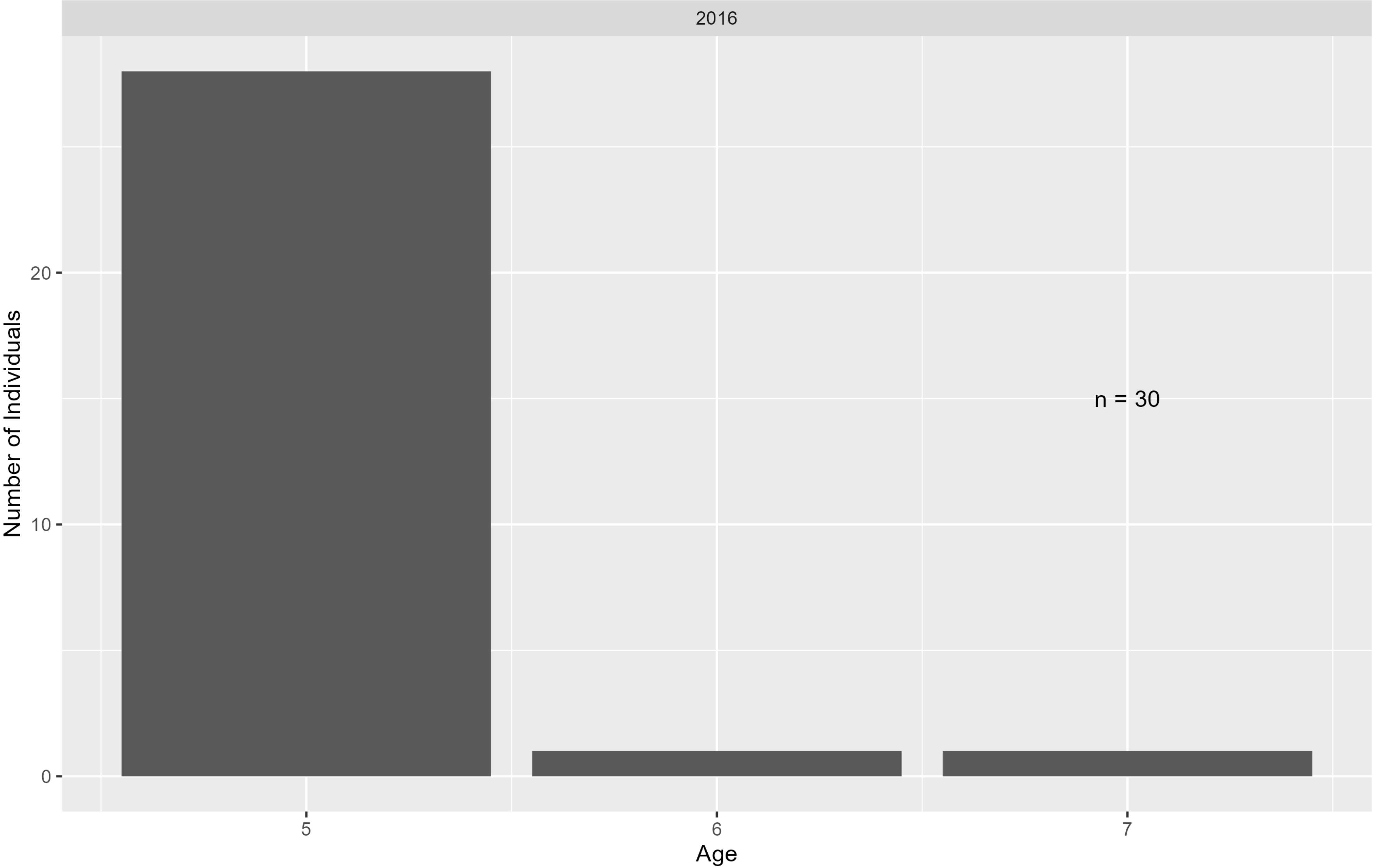
SNE RI Gilbert Stuart Alewife AgeScale



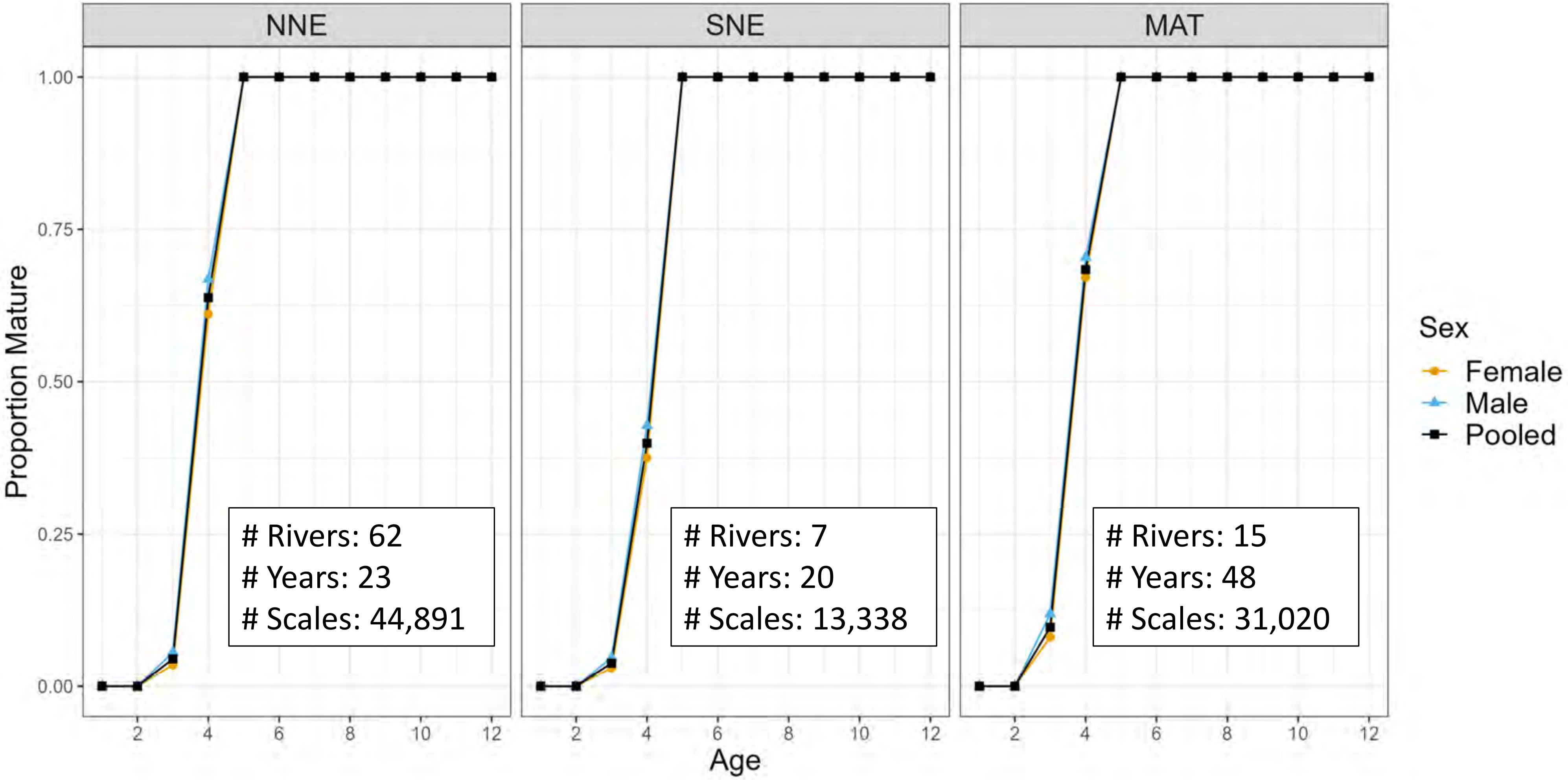

SNE RI Nonquit Alewife AgeScale
2011
2012
2017
2018
n = 32
n = 46
n = 93
n = 105
0
25
50
75
5
6
7
8
9
Number of Individuals
Age


SNE USFWS Mattabesset River Alewife AgeOtolith
2013
2016
2017
2018
2019
n = 31
n = 142
n = 47
n = 43
n = 56
Number of Individuals
Age
0
25
50
75
100
125
6
8
10

SNE USFWS Wethersfield Cove Alewife AgeOtolith



Alewife Maturity

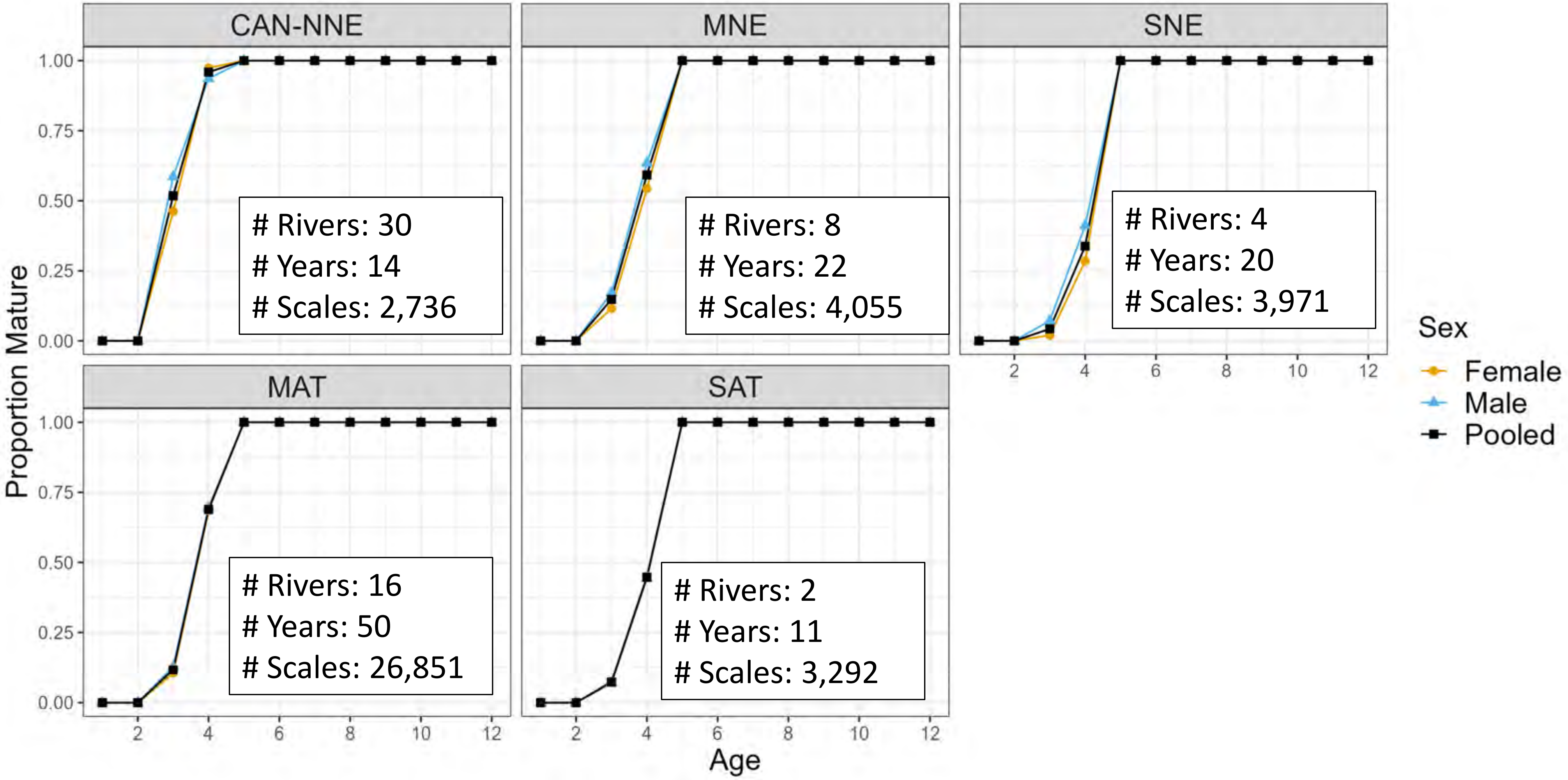


Rivers: 62
Years: 23
Scales: 44,891

Rivers: 7
Years: 20
Scales: 13,338

Rivers: 15
Years: 48
Scales: 31,020

Blueback Herring Maturity



Rivers: 30
Years: 14
Scales: 2,736

Rivers: 8
Years: 22
Scales: 4,055

Rivers: 4
Years: 20
Scales: 3,971

Rivers: 16
Years: 50
Scales: 26,851

Rivers: 2
Years: 11
Scales: 3,292