Exercise – Age Bias and Precision

Answer the following questions with R code by creating (*and editing if you make a mistake*) an R script and iteratively running the code in RStudio.

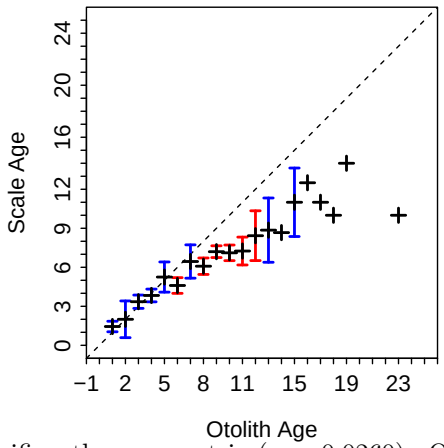
1. Herbst and Marsden (2012) (reprint is here) compared the precision, bias, and reader uncertainty of scales, dorsal fin rays, and otolith age estimates from 151 lake whitefish (*Coregonus clupeaformis*) from Lake Champlain in 2009. The data for their comparisons were recorded in **WhitefishLC.csv**. This file contains inital age assessments for two readers on three structures (variable names are the structure name with a "1" or "2" appended to denote the reader). In addition, the two readers developed a consensus age (variable name is the structure name with a "C" appended). Load these data into R to answer the following questions.

```
> setwd("C:/aaaWork/Web/fishR/Courses/MNAFS2013/CourseMaterial")
> wf <- read.csv("WhitefishLC.csv",header=TRUE)
> str(wf)
'data.frame': 151 obs. of  11 variables:
 $ fishID  : int  1 2 3 4 5 6 7 8 9 10 ...
 $ tl      : int  345 334 348 300 330 316 508 475 340 173 ...
 $ scale1  : int  3 4 7 4 3 4 6 4 3 1 ...
 $ scale2  : int  3 3 5 3 3 4 7 5 3 1 ...
 $ scaleC  : int  3 4 6 4 3 4 7 5 3 1 ...
 $ finray1 : int  3 3 3 3 4 2 6 9 2 2 ...
 $ finray2 : int  3 3 3 2 3 3 6 9 3 1 ...
 $ finrayC : int  3 3 3 3 4 3 6 9 3 1 ...
 $ otolith1: int  3 3 3 3 3 6 9 11 3 1 ...
 $ otolith2: int  3 3 3 3 3 5 10 12 4 1 ...
 $ otolithC: int  3 3 3 3 3 6 10 11 4 1 ...
```

2. Use a variety of methods (tabular, graphical, and statistical) to describe any apparent bias in *consensus* ages between scales and otoliths.

```
> ap1 <- agePrecision(~otolithC+scaleC,data=wf)
> summary(ap1,what="precision")
Precision summary statistics
   n R    CV   APE PercAgree
 151 2 21.11 14.93     19.87
> summary(ap1,what="agreement")
Percentage of fish by differences in ages between pairs of assignments
      0       1       2       3       4       5       6       7       8       9
19.8675 30.4636 16.5563 13.9073  5.9603  3.3113  5.2980  1.9868  1.3245  0.0000
     10      11      12      13
 0.0000  0.6623  0.0000  0.6623
>
> abOS <- ageBias(otolithC~scaleC,data=wf,col.lab="Otolith Age",row.lab="Scale Age")
> summary(abOS,what="symmetry",flip.table=TRUE)
Raw agreement table (square & flipped)
         Otolith Age
Scale Age  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
       23  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
       22  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
       21  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
       20  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
       19  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
```

```
      18  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      17  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      16  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      15  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1  -  -  -  -  -  -
      14  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1  -  -  -  1  -  -  -  -
      13  -  -  -  -  -  -  -  -  -  -  -  -  1  1  -  1  1  1  -  -  -  -  -
      12  -  -  -  -  -  -  -  -  -  -  -  1  -  -  1  1  -  -  -  -  -  -  -
      11  -  -  -  -  -  -  -  -  -  -  -  -  1  -  1  -  2  -  -  -  -  -  -
      10  -  -  -  -  -  -  1  -  -  -  -  1  1  -  -  1  -  -  -  -  -  -  1
      9   -  -  -  -  -  -  -  -  -  -  1  1  1  -  2  -  1  -  -  -  -  -  -
      8   -  -  -  -  1  -  1  1  3  3  3  1  -  -  -  -  -  -  -  -  -  -  -
      7   -  -  -  -  -  -  1  3  6  4  2  2  1  1  -  -  -  1  -  -  -  -  -
      6   -  -  1  1  2  1  3  4  1  2  1  1  2  1  -  -  -  -  -  -  -  -  -
      5   -  1  -  3  2  5  3  4  -  -  1  -  -  -  -  -  -  -  -  -  -  -  -
      4   -  -  5  7  3  3  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      3   -  1 10  6  -  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      2   4  1  -  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      1   5  4  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -

Bowker's (Hoenig's) Test of Symmetry
 df chi.sq       p
 54  75.98 0.02598
> plot(abOS,xlim=c(0,25),ylim=c(0,25))
```

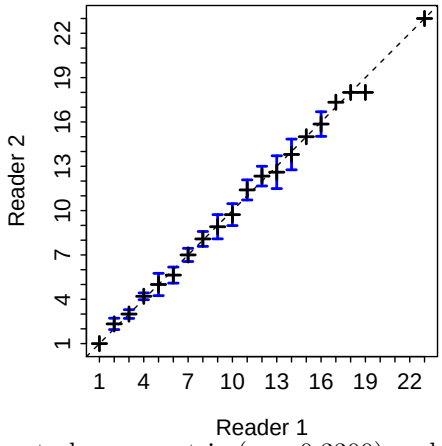


The age-agreement table is significantly asymmetric ($p = 0.0260$). Otolith ages appear to be significantly greater than scale age from age 6 on, with the exception of age-7 and also noting that significance is difficult to determine for ages beyond age-13 because of small sample sizes.

3. Describe any apparent bias in age assessment for otoliths between the two readers.

```
> abO <- ageBias(otolith1~otolith2,data=wf,col.lab="Reader 1",row.lab="Reader 2")
> summary(abO,what="symmetry",flip.table=TRUE)

Raw agreement table (square & flipped)
        Reader 1
Reader 2  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
      23  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1
      22  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      21  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      20  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      19  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      18  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1  1  1  -  -  -
      17  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  2  2  -  -  -  -  -
      16  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  2  -  -  -  -  -  -
```

```
      15  -  -  -  -  -  -  -  -  -  -  -  -  -  1  3  3  -  -  -  -  -  -  -
      14  -  -  -  -  -  -  -  -  -  -  -  -  1  -  2  -  -  -  -  -  -  -  -
      13  -  -  -  -  -  -  -  -  -  -  -  -  2  4  2  -  -  -  -  -  -  -  -
      12  -  -  -  -  -  -  -  -  -  -  -  2  5  -  -  -  -  -  -  -  -  -  -
      11  -  -  -  -  -  -  -  -  1  3  3  1  1  -  -  -  -  -  -  -  -  -  -
      10  -  -  -  -  -  -  -  1  2  4  -  -  -  -  -  -  -  -  -  -  -  -  -
      9   -  -  -  -  -  -  -  1  5  2  -  -  -  -  -  -  -  -  -  -  -  -  -
      8   -  -  -  -  -  -  1  8  1  2  -  -  -  -  -  -  -  -  -  -  -  -  -
      7   -  -  -  -  -  1  6  2  2  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      6   -  -  -  -  2  6  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      5   -  -  -  3  3  3  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      4   -  -  3 12  2  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      3   -  3 12  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      2   -  6  3  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      1   9  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -

Bowker's (Hoenig's) Test of Symmetry
 df chi.sq    p
 23   25.4 0.33
> summary(ab0,what="bias")
Summary of Reader 2 by Reader 1
 otolith1  n min max  mean    SE      t adj.p   sig   LCI   UCI
        1  9   1   1  1.00    NA     NA    NA FALSE    NA    NA
        2  9   2   3  2.33 0.167  2.000     1 FALSE  1.95  2.72
        3 18   2   4  3.00 0.140  0.000     1 FALSE  2.70  3.30
        4 15   4   5  4.20 0.107  1.871     1 FALSE  3.97  4.43
        5  7   4   6  5.00 0.309  0.000     1 FALSE  4.24  5.76
        6 11   4   7  5.64 0.244 -1.491     1 FALSE  5.09  6.18
        7  8   6   8  7.00 0.189  0.000     1 FALSE  6.55  7.45
        8 12   7  10  8.08 0.229  0.364     1 FALSE  7.58  8.59
        9 11   7  11  8.91 0.368 -0.247     1 FALSE  8.09  9.73
       10 11   8  11  9.73 0.333 -0.819     1 FALSE  8.99 10.47
       11  5  11  12 11.40 0.245  1.633     1 FALSE 10.72 12.08
       12  9  11  14 12.33 0.289  1.155     1 FALSE 11.67 13.00
       13  5  11  13 12.60 0.400 -1.000     1 FALSE 11.49 13.71
       14  5  13  15 13.80 0.374 -0.534     1 FALSE 12.76 14.84
       15  3  15  15 15.00    NA     NA    NA FALSE    NA    NA
       16  7  15  17 15.86 0.340 -0.420     1 FALSE 15.03 16.69
       17  3  17  18 17.33    NA     NA    NA FALSE    NA    NA
       18  1  18  18 18.00    NA     NA    NA FALSE    NA    NA
       19  1  18  18 18.00    NA     NA    NA FALSE    NA    NA
       23  1  23  23 23.00    NA     NA    NA FALSE    NA    NA
> plot(ab0)
Warning:  no non-missing arguments to min; returning Inf
Warning:  no non-missing arguments to max; returning -Inf
```



The age-agreement table appears to be symmetric ($p = 0.3300$) and there is no significant difference in assessed ages at any age between the two readers. The ages are, on average, the same from the two readers.

4. Describe precision of age assessment between the two readers for otoliths.

```
> apO <- agePrecision(otolith1~otolith2,data=wf)
> summary(apO,what="precision")

Precision summary statistics
   n R    CV   APE PercAgree
 151 2 4.719 3.337     62.25

> summary(apO,what="agreement")

Percentage of fish by differences in ages between pairs of assignments
    0     1     2
62.25 31.79  5.96
```

The two readers agreed on age 62.3% of the time and were within one year 94.0% of the time. Using the criterion of Campana(2001), the age assessments from otoliths were precise (i.e., the CV=4.7<5.)

5. (*If time permits ...*) Describe any apparent bias in age assessment for scales between the two readers.

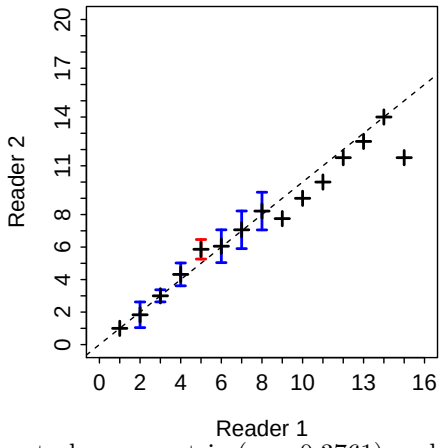
```
> abS <- ageBias(scale1~scale2,data=wf,col.lab="Reader 1",row.lab="Reader 2")
> summary(abS,what="symmetry",flip.table=TRUE)

Raw agreement table (square & flipped)
        Reader 1
Reader 2  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
      16  -  -  -  -  -  -  -  -  -  -  -  -  -  1  -  -
      15  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
      14  -  -  -  -  -  -  1  -  -  -  -  -  -  1  -  -
      13  -  -  -  -  -  1  -  1  -  -  -  -  3  -  -  -
      12  -  -  -  -  -  -  -  -  -  -  -  -  1  -  1  1  -
      11  -  -  -  -  -  -  -  -  -  -  1  1  1  1  -  1  -
      10  -  -  -  1  -  -  -  3  1  1  1  -  -  -  -  -
      9   -  -  -  -  -  -  1  -  -  -  1  -  -  -  -  -
      8   -  -  -  -  3  -  1  5  1  1  -  -  -  -  -  -
      7   -  -  -  -  6  5  7  3  1  1  -  -  -  -  -  -
      6   -  -  -  2  1  6  4  1  1  -  -  -  -  -  -  -
      5   -  -  1  4  9  5  1  1  -  -  -  -  -  -  -  -
      4   -  -  2  8  3  1  1  -  -  -  -  -  -  -  -  -
      3   -  1 14  7  -  -  -  -  -  -  -  -  -  -  -  -
      2   -  3  2  -  -  1  -  -  -  -  -  -  -  -  -  -
      1  10  2  1  -  -  -  -  -  -  -  -  -  -  -  -  -
```

```
Bowker's (Hoenig's) Test of Symmetry
 df chi.sq      p
 33  34.94 0.3761
```

```
> summary(abS,what="bias")
```

```
Summary of Reader 2 by Reader 1
 scale1  n min max  mean    SE      t  adj.p   sig  LCI  UCI
      1 10   1   1  1.00    NA     NA     NA FALSE   NA   NA
      2  6   1   3  1.83 0.307 -0.542 1.0000 FALSE 1.04 2.62
      3 20   1   5  3.00 0.178  0.000 1.0000 FALSE 2.63 3.37
      4 22   3  10  4.32 0.338  0.942 1.0000 FALSE 3.62 5.02
      5 22   4   8  5.86 0.289  2.988 0.0491  TRUE 5.26 6.46
      6 19   2  13  6.05 0.480  0.109 1.0000 FALSE 5.04 7.06
      7 16   4  14  7.06 0.544  0.115 1.0000 FALSE 5.90 8.22
      8 14   5  13  8.21 0.536  0.400 1.0000 FALSE 7.06 9.37
      9  4   6  10  7.75    NA     NA     NA FALSE   NA   NA
     10  4   7  11  9.00    NA     NA     NA FALSE   NA   NA
     11  3   9  11 10.00    NA     NA     NA FALSE   NA   NA
     12  2  11  12 11.50    NA     NA     NA FALSE   NA   NA
     13  4  11  13 12.50    NA     NA     NA FALSE   NA   NA
     14  3  12  16 14.00    NA     NA     NA FALSE   NA   NA
     15  2  11  12 11.50    NA     NA     NA FALSE   NA   NA
```

```
> plot(abS,xlim=c(0,16),ylim=c(0,20))
```



The age-agreement table appears to be symmetric ($p = 0.3761$) and there is no significant difference in assessed ages at any age between the two readers. The ages are, on average, the same from the two readers.

6. (*If time permits ...*) Describe precision of age assessment between the two readers for scales.

```
> apS <- agePrecision(scale1~scale2,data=wf)
> summary(apS,what="precision")
```

```
Precision summary statistics
   n R    CV   APE PercAgree
 151 2 11.68 8.259      45.7
```

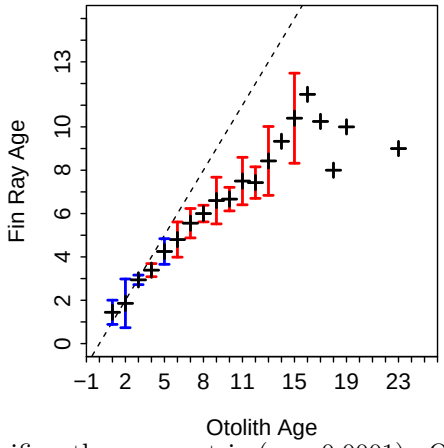
```
> summary(apS,what="agreement")
```

```
Percentage of fish by differences in ages between pairs of assignments
      0       1       2       3       4       5       6       7
45.6954 29.8013 15.2318  5.2980  1.3245  0.6623  0.6623  1.3245
```

The two readers agreed on age 45.7% of the time and were within two years 90.7% of the time. Using the criterion of Campana(2001), the age assessments from otoliths were NOT precise (i.e., the CV=11.7<5.)

7. (*If time permits ...*) Use a variety of methods (tabular, graphical, and statistical) to describe any apparent bias in *consensus* ages between fin rays and otoliths.

```
> ap2 <- agePrecision(~otolithC+finrayC,data=wf)
> summary(ap2,what="precision")

Precision summary statistics
   n R    CV   APE PercAgree
 151 2 21.52 15.22      24.5

> summary(ap2,what="agreement")

Percentage of fish by differences in ages between pairs of assignments
      0       1       2       3       4       5       6       7       8       9
24.5033 21.1921 17.8808 11.9205  7.2848  7.9470  3.3113  2.6490  0.6623  1.3245
     10      11      12      13      14
 0.0000  0.6623  0.0000  0.0000  0.6623

>
> abOF <- ageBias(otolithC~finrayC,data=wf,col.lab="Otolith Age",row.lab="Fin Ray Age")
> summary(abOF,what="symmetry",flip.table=TRUE)

Raw agreement table (square & flipped)
           Otolith Age
Fin Ray Age  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
         23  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         22  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         21  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         20  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         19  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         18  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         17  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         16  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         15  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         14  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  1  -  -  -  -  -  -  -
         13  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         12  -  -  -  -  -  -  -  -  -  -  -  -  -  1  2  -  -  -  -  -  -  -  -
         11  -  -  -  -  -  -  -  -  -  -  -  -  1  -  -  2  2  -  -  -  -  -  -
         10  -  -  -  -  -  -  -  -  1  -  -  -  1  -  2  1  1  -  1  -  -  -  -
         9   -  -  -  -  -  -  -  -  -  -  2  1  1  1  -  -  1  1  -  -  -  -  1
         8   -  -  -  -  -  -  -  -  1  1  2  1  2  -  1  -  -  -  -  -  -  -  -
         7   -  -  -  -  -  -  1  2  2  4  3  5  1  1  -  -  -  1  -  -  -  -  -
         6   -  -  -  -  -  4  4  8  4  4  -  -  1  -  -  -  -  -  -  -  -  -  -
         5   -  -  -  -  3  1  3  2  2  -  1  -  -  -  -  -  -  -  -  -  -  -  -
         4   -  1  1  8  4  4  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         3   1  1 14  9  1  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         2   2  1  2  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
         1   6  4  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -

Bowker's (Hoenig's) Test of Symmetry
 df chi.sq         p
 53  100.4 9.178e-05

> plot(abOF,xlim=c(0,25),ylim=c(0,15))
```



The age-agreement table is significantly asymmetric ($p = 0.0001$). Otolith ages appear to be significantly greater than fin ray age from age 7 on, but also noting that significance is difficult to determine for ages beyond age-14 because of small sample sizes. Also, note that fin ray age for age-4 otoliths were significantly less than 4, indicating that the divergence in ages could begin as early as age-4.