Initial Assessment of the South African round herring (*Etrumeus whiteheadi*) resource using data from 1988 to 2010

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Introduction

An initial assessment of the South African Round Herring (*Etrumeus whiteheadi*) resource, commonly referred to as Red Eye, has been undertaken.

Considering the proportion of females in different reproductive stages, Roel and Melo (1990) report that, although older round herring appear to be reproductively active throughout the year, the smaller, more abundant fish are reproductively active for just a short period in the winter, with a peak in June. Their histological analysis indicated peak spawning in May, July, August and November, with no data available for April, June, September or October. The abundance of round herring eggs and larvae per station from the CELP program (August 1977 - August 1978) indicates a very low level of spawning between January and April, with a peak in egg numbers in August and a peak in larvae in October (van der Westhuizen pers. comm.).

Taking this into consideration, together with the timing of the recruit survey, the round herring will be modelled to have an annual birth date of 1 June. The model predicted (just turned) 1 year olds on 1 June will therefore be assumed to correspond with the May survey estimates of recruitment.

Population Dynamics Model

The population dynamics model used for the South African round herring resource is detailed in Appendix A. The data used in this assessment are listed in Appendix B. The base case assumption of $M_j^{RH} = M_{ad}^{RH} = 1.3$ is based on unpublished data of Y. Geja and D. Durholtz.

Initial Results and Discussion

The model is able to fit the survey estimated November 1+ biomass and May recruitment reasonably well (Figures 1 and 2). However, the multiplicative bias associated with these surveys requires a more informative prior distribution. Given an uninformative prior distribution[1], k_N^{RH} is estimated at the posterior mode to be 0.26, while k_R^{RH} is estimated to be 0.05, suggesting the surveys are only able to pick up a very small fraction of the true biomass. These estimates are unrealistically low. When assigned uniform prior distributions between 0.5 and 1,

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[1] Uniform on the log of bias, corresponding to a bias range of between 0 and 2

k_N^{RH} is estimated at the posterior mode to be at the upper bound of 1.5, while k_R^{RH} is estimated to be at the lower bound of 0.5. It is clear that a more structured informative prior distribution is required for at least one of these parameters. Some potential ranges for a number of contributions to these biases (such as target strength and time of day) have recently been provided. This information has yet to be collated to try to provide a single informative prior distribution. The increasing trend evident in the residuals from the model fit to the recruitment estimates may disappear once reasonable priors for these biases can be incorporated.

The model fits to the commercial proportions-at-length are provided in Figure 3, for the minus group, and Figure 4. The model fits are poor, with an over-estimation of the commercial proportion-at-length 13- and a general under-estimation of the commercial proportion-at-lengths 15cm to 20cm. The model estimated length at age distributions are plotted in Figure 5. The estimated CV about the mean length at age, ϑ_a , is about 30%. Once a realistic multiplicative bias for the survey abundances can be estimated, the estimation of selectivity-at-age will be attempted. Alternative selectivity-at-age or natural mortality values may result in a lower model-estimated commercial proportion-at-length 13-.

Further work and Questions

The model estimated 1 year olds at 1 June are assumed to correspond to the May survey estimate of recruitment. According to the von Bertalanffy growth curve assumed in this model, the 1 year olds would had a mean length of about 12.8cm Lc. The recruit numbers estimated by the survey are calculated based on a cut-off length which varies annually and is estimated using a modal progression analysis. It will be important to establish whether this average cut-off length used correspond with that predicted by the von Bertalanffy growth curve in this model. Extensions of this work may fit directly to the length distribution data from the surveys.

The following robustness tests are proposed to test the sensitivity of the model to assumptions made:

RH_0 – base case assessment

RH_{M1} – alternative natural mortality: $M_j^{RH} = M_{ad}^{RH} = 0.8$

RH_{M2} – alternative natural mortality: $M_j^{RH} = M_{ad}^{RH} = 1.1$

RH_{M3} – alternative natural mortality: $M_j^{RH} = M_{ad}^{RH} = 1.5$

RH_{weight} - sensitivity to the weighting assumed for w_{com}

A “rough” linear regression was applied to the hydroacoustic survey stratum densities from November 1984 to 1997 and May 1987 to 1997 in order to correct the capped densities to uncapped values. This same regression was also applied to the interval densities. Thus the pre-1998 survey estimated November 1+ biomass and May recruitment numbers, and CVs, may not be as reliable as those estimated from 1998 to 2010. Thus we consider:

RH_{pre98} – a lower weight to the survey observations prior to 1998 OR the survey estimates of abundance from 1987 to 1997 being excluded from the analysis.

The survey effort in terms of number of transects and the offshore extent of the surveys have increased in recent years compared to the earlier part of the time series (Coetzee and Merkle 2009). The distribution of round herring extends further offshore and eastwards than that of sardine and anchovy. Coetzee and Merkle (2009) proposed that the increase in survey estimated abundance over the time series was "real" and not biased by the increase in survey effort and offshore coverage over time. In order to test this we will consider

RH_{effort} – fit to a time series of survey estimates of abundance which correspond to the same offshore distance.

Acknowledgements

Janet Coetzee, Deon Durholtz, Yonela Geja, Dagmar Merkle and Jan van der Westhuizen are thanked for providing the data input to this assessment.

References

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Roel, B.A., and Melo, Y.C. 1990. Reproductive Biology of the Round Herring *Etrumeus Whiteheadi*. South African Journal of Marine Science. 9:177-187.

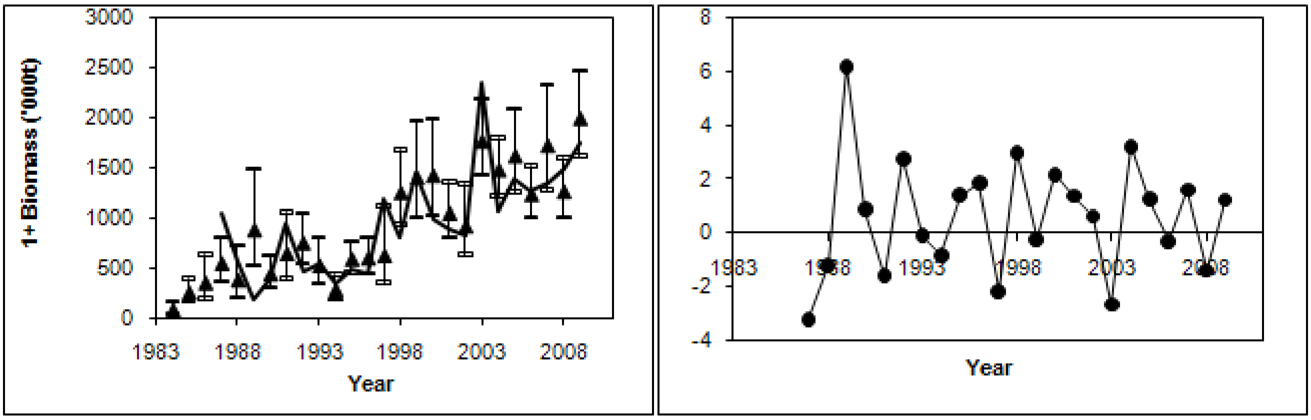

Figure 1. Acoustic survey observed and initial model estimated November round herring 1+ biomass from 1987 to 2009. The observed indices are shown with 95% confidence intervals. The standardised residuals from the fit are given in the right hand plot.

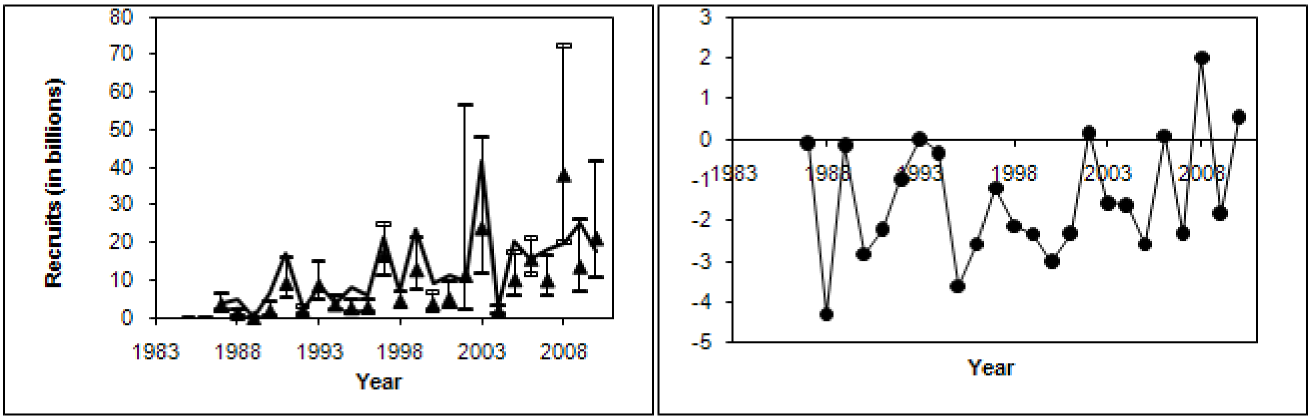

Figure 2. Observed and initial model estimated round herring recruitment numbers from May/June 1985 to 2010. The observed indices are shown with 95% confidence intervals. The standardised residuals from the fit are given in the right hand plot.

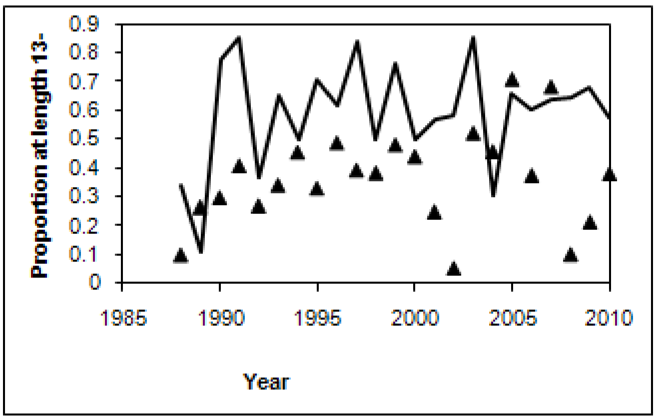

Figure 3. Observed (symbols) and initial model estimated (line) round herring proportion-at-length 13- in the commercial catch from 1988 (i.e. June 1987 to May 1988) to 2010 (i.e. June 2009 to May 2010).

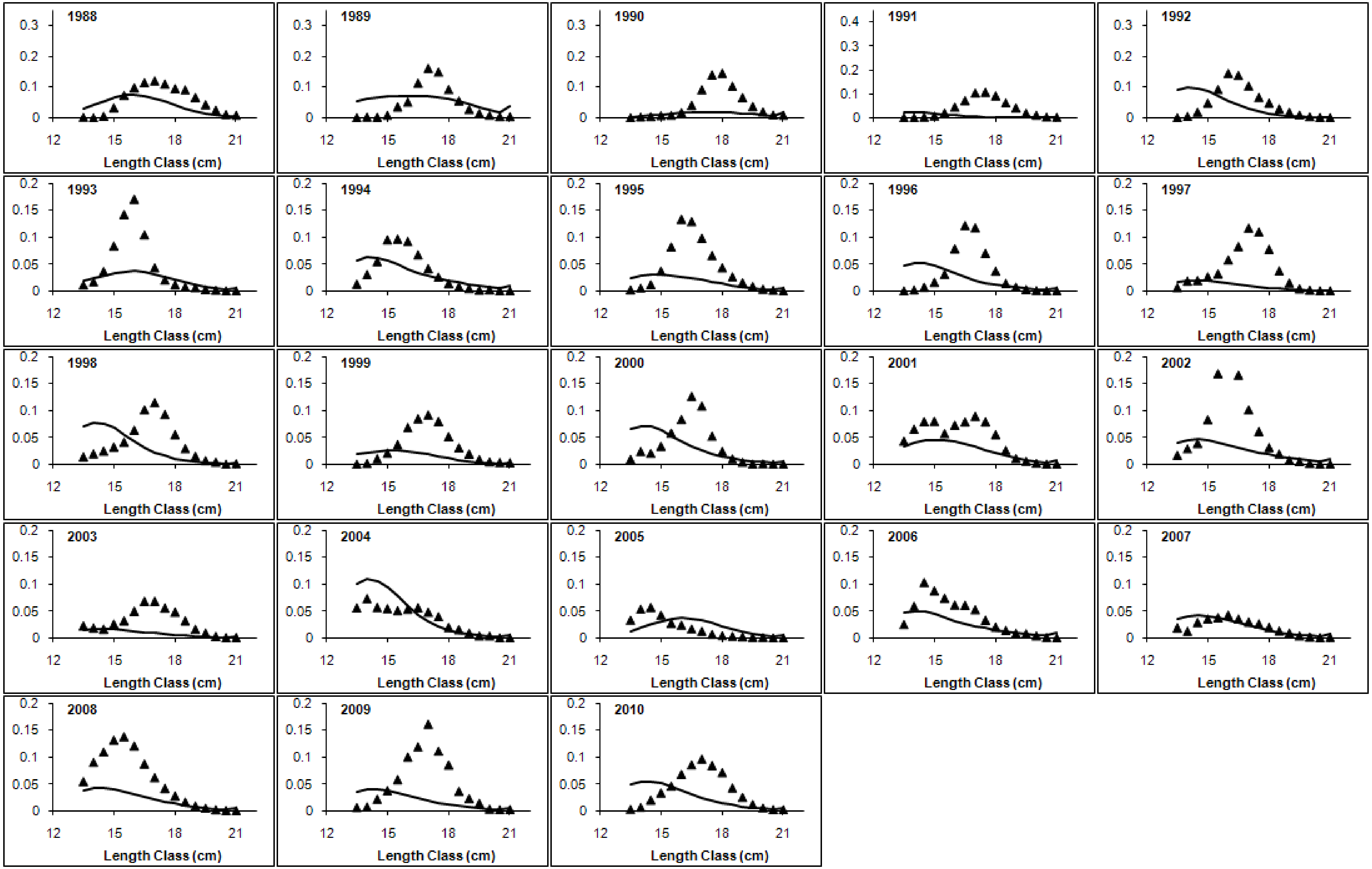

Figure 4. Observed and initial model estimated round herring proportion-at-length in the commercial catch from 1988 (i.e. June 1987 to May 1988) to 2010 (i.e. June 2009 to May 2010).

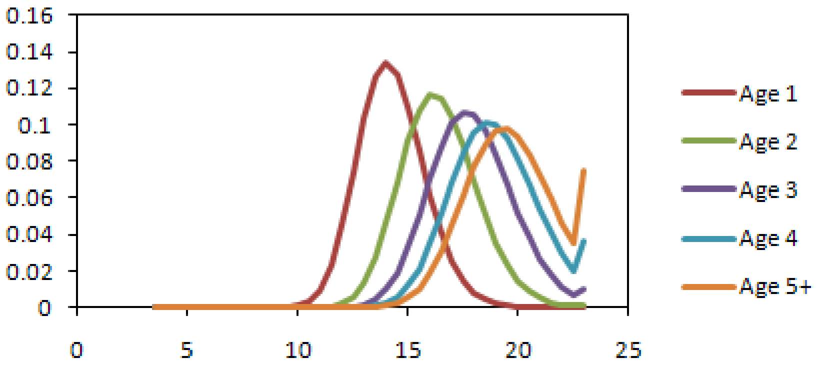

Figure 5. The model estimate age to length matrix, $A_{a,l}^{com}$, representing the proportion of round herring catch-at-age a that fall in the length group l.

APPENDIX A: Bayesian Assessment Model for the South African Round Herring (Red Eye) Resource

Model Assumptions

1) All fish have a theoretical birthdate of 1 June.
2) A plus group of age 5 is used. No males older than 4 have been observed, though females up to 8 years of age have been observed (Y. Geja and D. Durholtz pers. comm.).
3) Two acoustic surveys are held each year: the first takes place in November and surveys the 1+[2] stock; the second is in May/June (known as the recruit survey) and surveys 0 year old round herring (which age to 1 years old at 1 June).
4) The November acoustic survey provides a relative index of abundance of unknown bias.
5) The recruit survey provides a relative index of abundance of unknown bias.
6) The survey designs have been such that they result in survey estimates of abundance whose bias is invariant over time.
7) Pulse fishing occurs mid-March for all ages (higher round herring catches have historically been recorded between January and May, with a peak in March).
8) Catches are measured without error.
9) Age 0 fish are at most 13cm long.
10) Selectivity is assumed to be year, but not age, invariant.
11) Natural mortality is year-invariant for juvenile and adult fish, and age-invariant for adult fish.

Population Dynamics

The basic dynamic equations for round herring, based on Pope's approximation (Pope, 1972), are as follows, where $y_n = 2010$.

Numbers-at-age at 1 June

$$\hat{N}^{RH}_{y,1} = (\hat{N}^{RH}_{y-1,0} e^{-9.5M_0/12} - \hat{C}^{RH}_{y,0}) e^{-2.5M_0/12} \qquad y = 1988, \ldots, y_n$$

$$\hat{N}^{RH}_{y,a} = (\hat{N}^{RH}_{y-1,a-1} e^{-9.5M_{a-1}/12} - \hat{C}^{RH}_{y,a-1}) e^{-2.5M_{a-1}/12} \qquad y = 1988, \ldots, y_n,\ a = 2,3,4$$

$$\hat{N}^{RH}_{y,5+} = (\hat{N}^{RH}_{y-1,4} e^{-9.5M_{a-1}/12} - \hat{C}^{RH}_{y,4}) e^{-2.5M_{a-1}/12} + (\hat{N}^{RH}_{y-1,5+} e^{-9.5M_{a-1}/12} - \hat{C}^{RH}_{y,5+}) e^{-2.5M_{a-1}/12}$$
$$y = 1988, \ldots, y_n \qquad \text{(A.1)}$$

where

$\hat{N}^{RH}_{y,a}$ is the number (in billions) of round herring of age *a* at the beginning of June in year *y*;

[2] "1+" denotes the age 1, 2, 3, 4 and 5+ fish, which are technically 1, 2, 3, 4 or 5years and 5 ½ months old at the time of the November survey.

$\hat{C}^{RH}_{y,a}$ is the number (in billions) of round herring of age *a* caught from 1 June in year $y-1$ to 31 May in year y; and

M_a is the natural mortality (in year^{-1}) of round herring of age a.

Biomass associated with the November survey

$$\hat{N}^{RH}_{Nov,y,a} = (\hat{N}^{RH}_{y,a} e^{-2.75M_a/12} - \hat{C}^{RH}_{Nov,y,a})e^{-2.75M_a/12} \qquad y = 1987,\ldots,y_n - 1\ ,\ a = 1,\ldots,5+$$

$$\hat{B}^{RH}_{y,N} = \sum_{a=1}^{5+} \hat{N}^{RH}_{Nov,y,a} w_a \qquad y = 1987,\ldots,y_n - 1 \qquad \text{(A.2)}$$

where

$\hat{N}^{RH}_{Nov,y,a}$ is the number (in billions) of round herring of age *a* at mid-November in year *y*;

$\hat{C}^{RH}_{Nov,y,a}$ is the number (in billions) of round herring of age *a* caught from 1 June to mid-November in year y;

$\hat{B}^{RH}_{y,N}$ is the biomass (in thousand tons) of 1+ round herring at the beginning of November in year *y*, which are taken to be associated with the November survey; and

w_a is the mean mass (in grams) of round herring of age *a* sampled during the November survey.

Catch

The catch at age by number is given by:

$$\hat{C}^{RH}_{y,a} = \hat{N}^{RH}_{y-1,a} e^{-9.5M_a/12} S_a F_y, \qquad y = 1988,\ldots,y_n,\ a = 0,\ldots,5+ \qquad \text{(A.3)}$$

where

S_a is the commercial selectivity at age a, which is assumed to be year-independent; and

F_y is the fished proportion in year y for a fully selected age class.

In the equations above the difference in the year subscript between the catch-at-age and initial numbers-at-age is because these numbers-at-age pertain to June of the previous year, while the catch is assumed to be taken in a pulse in mid-March.

The fished proportion is estimated by:

$$F_y = \frac{C^{ObsTon}_y}{\sum_{a=0}^{5+} w_a \hat{N}^{RH}_{y-1,a} e^{-4.75M_a/12} S_a} \qquad y = 1988,\ldots,y_n \qquad \text{(A.4)}$$

where

C^{ObsTon}_y is the observed catch tonnage of year y (June $y-1$ to May y) from the RLFs.

The catch at age by number from 1 June to mid-November, for use in calculating the round herring biomass surveyed, is calculated as follows:

$$\hat{C}^{RH}_{Nov,y,a} = \hat{N}^{RH}_{y,a} e^{-2.75 M_a/12} S_a F_{y+1}, \qquad y = 1987, \ldots, y_n - 1,\ a = 0, \ldots, 5+ \quad \text{(A.5)}$$

Given the predicted proportion-at-age in the quarterly commercial catch

$$\hat{p}^{com}_{y,a} = \frac{\hat{C}^{RH}_{y,a}}{\sum_{a=0}^{5+} \hat{C}^{RH}_{y,a}}, \qquad y = 1988, \ldots, y_n,\ a = 0, \ldots, 5+ \quad \text{(A.6)}$$

and the assumption that all age 0 fish are at most 13cm L_c, the predicted proportion-at-length is then estimated as follows:

$$\hat{p}^{com}_{y,13-} = \hat{p}^{com}_{y,0} + \sum_{l=3.5}^{13} \sum_{a=1}^{5+} \hat{p}^{com}_{y,a} A^{com}_{a,l} \qquad y = 1988, \ldots, y_n$$

$$\hat{p}^{com}_{y,l} = \sum_{a=1}^{5+} \hat{p}^{com}_{y,a} A^{com}_{a,l} \qquad y = 1988, \ldots, y_n,\ l = 13.5, \ldots, 20.5\,\text{cm}$$

$$\hat{p}^{com}_{y,21+} = \sum_{l=21}^{23} \sum_{a=1}^{5+} \hat{p}^{com}_{y,a} A^{com}_{a,l} \qquad y = 1988, \ldots, y_n \quad \text{(A.7)}$$

where the length groups are in 0.5cm L_c and

$A^{com}_{a,l}$ is the proportion of round herring catch-at-age a that fall in the length group l (thus $\sum_{l=l\min}^{l\max} A_{a,l} = 1$).

The matrix A^{com} is calculated under the assumption that length-at-age is normally distributed about a von Bertalanffy growth curve:

$$L^{com}_a \sim N\left(L_\infty \left(1 - e^{-\kappa(a - t_0)}\right), \vartheta^2_a\right) \qquad a = 1, \ldots, 5+ \quad \text{(A.1)}$$

where

L_∞ denotes the maximum length of the individual;

κ denotes the annual growth rate;

t_0 denotes the age at which the growth rate is zero; and

ϑ^2_a denotes the variance about the mean length for age a.

Fitting the Model to Observed Data (Likelihood)

The survey observations are assumed to be log-normally distributed, and sampling CVs (squared) of the untransformed survey observations are used to approximate the "sampling" component of the total variance of the corresponding log-distributions. The commercial proportions at length from the raised length frequencies are assumed to be lognormally distributed. Thus we have:

$$
\begin{aligned}
-\ln L = & \tfrac{1}{2}\sum_{y=1987}^{yn-1}\left\{\frac{\left(\ln B_{y,N}^{RH} - \ln(k_N^{RH}\hat{B}_{y,N}^{RH})\right)^2}{(\sigma_{y,N}^{RH})^2 + (\lambda_N^{RH})^2} + \ln\left[2\pi\left((\sigma_{y,N}^{RH})^2 + (\lambda_N^{RH})^2\right)\right]\right\} \\
& + \tfrac{1}{2}\sum_{y=1987}^{yn}\left\{\frac{\left(\ln N_{y,r}^{RH} - \ln(k_r^{RH}\hat{N}_{y,1}^{RH})\right)^2}{(\sigma_{y,r}^{RH})^2 + (\lambda_r^{RH})^2} + \ln\left[2\pi\left((\sigma_{y,r}^{RH})^2 + (\lambda_r^{RH})^2\right)\right]\right\} \\
& + w_{com,\min}\sum_{y=1988}^{yn}\left\{\frac{p_{y,l\min}^{com}\left(\ln p_{y,l\min}^{com} - \ln \hat{p}_{y,l\min}^{com}\right)^2}{2\left(\sigma_{com}^S\right)^2} + \ln\left(\frac{\sigma_{com}^S}{\sqrt{p_{y,l\min}^{com}}}\right)\right\} \\
& + w_{com}\sum_{y=1988}^{yn}\sum_{l=l\min+1}^{l\max}\left\{\frac{p_{y,l}^{com}\left(\ln p_{y,l}^{com} - \ln \hat{p}_{y,l}^{com}\right)^2}{2\left(\sigma_{com}^S\right)^2} + \ln\left(\frac{\sigma_{com}^S}{\sqrt{p_{y,l}^{com}}}\right)\right\}
\end{aligned}
\qquad (A.9)
$$

where

$B_{y,N}^{RH}$ is the acoustic survey estimate (in thousand tons) of 1+ round herring biomass from the November survey in year y, with associated CV $\sigma_{y,N}^{RH}$ and constant of proportionality (multiplicative bias[3]) k_N^{RH};

$N_{y,r}^{RH}$ is the acoustic survey estimate (in billions) of round herring recruitment from the recruit survey in year y, with associated CV $\sigma_{y,r}^{RH}$ and constant of proportionality k_r^{RH};

$(\lambda_{N/r}^{RH})^2$ is the additional variance (over and above the survey sampling CV $\sigma_{y,N/r}^{RH}$ that reflects survey inter-transect variance) associated with the November/recruit surveys;

$p_{y,l}^{com}$ is the observed proportion (by number) of the commercial catch in length group l during year y (June $y-1$ to May y);

$w_{com,\min}$ is the weighting applied to the commercial proportion at length 13cm (the minus group);

w_{com} is the weighting applied to the remainder of the commercial proportion at length data;

σ_{com}^S is the standard deviation associated with the proportion-at-length data in the commercial catch, which is estimated in the fitting procedure by:

$$
\sigma_{com}^S = \sqrt{\sum_{y=1988}^{yn}\sum_{l=l\min}^{l\max} p_{y,l}^{com}\left(\ln p_{y,l}^{com} - \ln \hat{p}_{y,l}^{com}\right)^2 \Big/ \sum_{y=1988}^{yn}\sum_{l=l\max}^{l\max} 1}\,.
$$

The raw commercial catch data are in 0.5cm length classes in terms of caudal length L_c. A minus group ($l\min$) of 5cm L_c and a plus group ($l\max$) of 21cm L_c were assumed to ensure that all observations were non-zero.

Fixed Parameters

The following parameters are fixed externally in this assessment:

[3] This includes an estimate of all bias associated with the survey, including the bias introduced due to the use of a target strength for a species other than round herring.

M_j^A and M_{ad}^A =1.3.

$\left(\lambda_N^{RH}\right)^2 = \left(\lambda_r^{RH}\right)^2 = 0$. These parameters may be estimated, if the data allows, in the final assessment.

There are 16 length classes in the data. However, these length classes are not all independent as there are only about 5 age groups. Therefore dividing the length data contribution to the likelihood by 3 gives it a weighting close to the 5 age groups. Thus $w_{com} = 0.33$.

The assumption is made that $w_{com,\min} = 1$ as it represents a single age group.

$S_0 = 0.25$, $S_1 = 0.5$, $S_2 = 0.75$, $S_{3+} = 1$.

Estimable Parameters and Prior Distributions

Annual recruitment: $N_{y,0}^{RH} \sim U(0{,}5000)$, $y = 1987,\ldots, y_n - 1$

November survey multiplicative bias: $\ln\left(k_N^{RH}\right) \sim U\left(-0.693{,}0.405\right)$ (corresponding to $0.5 \le k_N^{RH} \le 1.5$)

Recruit survey multiplicative bias: $\ln\left(k_r^{RH}\right) \sim U\left(-0.693{,}0.405\right)$ (corresponding to $0.5 \le k_r^{RH} \le 1.5$)

Initial numbers at age: $N_{1987,a}^{RH} \sim U(0{,}50)$, $a = 1,\ldots,5+$

Variance about the mean length at age 1+: $\vartheta_{1+}^2 \sim U(0{,}0.15)$

<u>Further Outputs</u>

The spawning stock biomass at 1 June is calculated as follows:

$$SSB_y^{RH} = \sum_{a=1}^{5+} \phi_a N_{y,a}^{RH} \left(\frac{5.5 w_{a-1} + 6.5 w_a}{12} \right) \qquad y = 1987,\ldots, y_n - 1 \qquad \text{(A.10)}$$

where

ϕ_a denotes the proportion mature at age a.

APPENDIX B: Data and standard inputs used in the South African Round Herring Assessment

November acoustic survey

A time series of estimates of annual biomass from November 1984 to November 2009 are available, together with CVs (Table 1). The assumption is made that these estimates of abundance are comparable. Coetzee and Merkle (2009) compared visually survey effort and biomass, noting too the general correlation between increased survey estimated recruitment (which should be less influenced by offshore extensions of survey effort) and subsequent increased survey November biomass, and concluded that the increase in biomass for the duration of the time series was 'real' and not correlated to the increase in survey effort.

Although the November survey length frequencies indicate that some recruits (<12cm L_c) are sampled by the survey, the numbers are low (Janet Coetzee pers. comm.). The weight of these recruits and their contribution to the total biomass would therefore be small. Thus the survey estimates of abundance are assumed to measure the relative 1+ biomass.

May recruit acoustic survey

A time series of estimates of annual recruitment numbers and biomass is available from May 1987 to May 2010, together with CVs (Table 1). The assumption is made that these estimates of recruitment are comparable. As round herring eye recruits tend to be distributed inshore, overlapping with sardine and anchovy recruits, the effect of an increase in survey effort offshore would be less (Coetzee and Merkle, 2009).

Von Bertalanffy Growth Curve

The von Bertalanffy parameters are assigned averages of estimates from the November 2005 and 2006 surveys (Y. Geja and D. Durholtz pers. comm.): $L_\infty = 21.15$ L_c, $\kappa = 0.37$, $t_0 = -2.0$. In calculating the von Bertalanffy curve, the round herring aged 1 in November of year y correspond to round herring born between January and December of year y-1. Assuming a birthdate of 1 June, according to this model, the age 1 fish on the von Bertalanffy curve corresponds to round herring between 11 months and 1 year and 11 months old. Similarly for older ages. This ageing corresponds with the use of the von Bertalanffy curve in the assessment model:

i) Estimating catch-at-age from catch-at-length. Catch is assumed to be taken mid-March (equation A.3), when the fish are eg 1 year and 9 ½ months old.
ii) W eight-at-age. This applies to the November survey.

Weight at age

A length-weight relationship has been calculated from the 5 years of November survey data between 2005 and 2009 (Y. Geja and D. Durholtz pers. comm.):

$W = 0.0084 \times L_c^{3.0883}$

where weight is in grams and caudal length (L_c) in cms. This length-weight relationship was applied to the length-at-age calculated by the mean von Bertlanffy relationship assumed for the model to give the weight-at-age values listed in Table 2. The weight-at-age 5+ was calculated as $w_{5+} = \frac{\sum_{a=5}^{20} w_a \, prop_a}{\sum_{a=5}^{20} prop_a}$, where $prop_a = e^{-(a-5)M_{ad}}$ denotes the relative proportion at age, assuming a low fishing mortality on older ages.

Maturity at age

Using gonad stage data, the level of 50% maturity was found to range from between 12.5-13.5 cm L_c in August 1986 to 14 cm L_c in November 1987 (Roel and Melo 1990). When using histology, 50% maturity was found to be attained at 14.5 cm L_c while all were mature by 19 cm L_c in November 1987 (Roel and Melo 1990). More recent results suggest all males in November are mature by age 2 (L_c = 16 cm) and all females are mature by age 4 (L_c = 18 cm), with 50% maturity attained by 0.8 yrs for males (L_c = 13.1 cm) and 1.5 years for females (L_c = 14.5 cm) (Y.Geja and D.Durholtz pers. comm.).

Basing the maturity of SSB on the female data only and using the input of a proportion mature of 1 at “June” age 4 and a proportion mature of 0.5 at “June” age 2, a piece-wise linear curve gives the proportion mature at age listed in Table 3.

Commercial catch

Commercial catch raised length frequencies are available by month from 1987 onwards. The annual data listed in Table 4 is the sum of the months of June of the previous year to May of the reported year.

Table 1. Time series of annual estimates of 1+ biomass from the November acoustic survey (in tons), with CVs, and estimates of recruitment from the May acoustic survey (in billions), with CVs.

Year	November survey		May survey	
	Biomass	CV	Numbers	CV
1984	80546	0.337		
1985	253750	0.227		
1986	349282	0.305		
1987	545522	0.201	3.513	0.312
1988	380531	0.323	1.169	0.329
1989	881286	0.264	0.046	0.265
1990	440117	0.181	1.787	0.469
1991	642954	0.250	9.221	0.282
1992	751462	0.170	1.909	0.240
1993	523388	0.220	8.616	0.286
1994	284887	0.213	3.545	0.267
1995	586870	0.135	2.610	0.310
1996	596511	0.156	2.725	0.308
1997	624054	0.295	16.642	0.204
1998	1247966	0.149	4.445	0.226
1999	1398329	0.171	12.789	0.266
2000	1420454	0.169	3.629	0.308
2001	1045517	0.131	5.109	0.334
2002	917853	0.189	11.260	0.824
2003	1761631	0.108	23.871	0.358
2004	1475464	0.100	1.803	0.281
2005	1616260	0.130	10.134	0.274
2006	1228446	0.106	15.640	0.155
2007	1720865	0.153	10.000	0.261
2008	1260460	0.118	38.040	0.328
2009	1990831	0.108	13.570	0.336
2010			21.140	0.347

Table 2. The weight-at-age (in grams) corresponding to the November survey.

Age	Weight
0	14.047
1	30.268
2	46.859
3	61.347
4	72.951
5+	83.983

Table 3. The proportion mature-at-age corresponding to 1 June.

Age	Proportion mature
0	0
1	0.25
2	0.5
3	0.75
4	1
5+	1

Table 4. The numbers at length (in thousands) in the commercial catch, and the corresponding catch (in tons). Note that the catch for year *y* consists of the catch from June of *y*-1 to May of *y*.

Length Class (L_c in cm)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Tonnage	64582	44600	46276	33550	47005	46054	60448	81819	43512	90107	57663	57336
3.5	0	0	0	0	0	0	0	1210	0	0	0	0
4.0	0	0	188	136	344	933	0	4033	0	0	0	0
4.5	0	20	1590	3802	42	1396	3	5451	264	0	1027	1142
5.0	9	436	1560	18107	644	11656	3278	17966	5717	1402	2918	91752
5.5	132	1312	4112	24879	32578	72276	31932	13226	28412	2044	14124	3812
6.0	1228	20776	12596	37549	9808	43569	88839	82300	28940	3703	35206	30732
6.5	15795	21662	10209	63102	25452	29200	119539	113561	55497	6037	54445	21765
7.0	22868	127778	55153	57340	36893	35559	88063	88795	72965	36038	61051	59664
7.5	12226	22966	45484	45462	34696	26987	63975	65737	119077	148602	40950	88257
8.0	6729	2988	40204	33918	26483	22613	283301	68331	111041	132460	32035	156403
8.5	3058	4870	36379	20096	22533	28108	95722	66983	49106	83287	39678	124366
9.0	4708	9780	22763	9712	20849	26834	47427	50800	37392	132225	43534	76824
9.5	6509	12952	13304	8572	18682	28838	42161	47815	38429	105417	34327	54855
10.0	7500	11244	6010	3053	17083	25657	24391	39363	51578	101222	19499	49394
10.5	6659	4814	3893	384	18878	24017	12950	28011	41749	45901	22480	17651
11.0	5038	2168	1764	219	13731	19798	9684	13505	17607	43712	27557	18421
11.5	2526	1785	463	148	8272	17082	4497	5061	5926	27754	32206	7219
12.0	2346	1833	626	2097	6143	11738	4581	2605	1740	8444	39926	4293
12.5	1867	165	422	289	2630	9134	5238	2263	783	5476	44173	470
13.0	2267	927	1221	492	2109	11601	9803	3634	713	21051	27825	924
13.5	2235	1435	777	337	922	15123	27055	5910	938	16216	22024	1889
14.0	968	3114	3350	662	6293	23003	63718	13002	3907	44289	30556	4016
14.5	5979	2354	3910	1905	21313	48125	113041	26941	10425	46367	38148	18667
15.0	34697	8311	6808	5852	54216	110940	196053	82506	23207	61819	48845	36325
15.5	76580	34783	7315	16042	103608	188813	198565	181847	43286	75067	62061	62604
16.0	102302	49349	15379	36821	161932	226282	189852	296054	108218	134197	95323	115229
16.5	119760	106594	35935	59041	154602	138816	139083	286859	167712	190492	151824	142682
17.0	125465	151644	80222	84928	115861	57493	86520	217875	161957	269486	171789	153853
17.5	114880	141090	122301	87714	75105	27162	53894	146720	96829	252920	138899	133992
18.0	99058	87488	126588	74923	54165	15541	29239	96800	51393	178824	83154	87150
18.5	95477	52635	90429	51736	33495	10290	17069	59433	20568	87594	44962	52519
19.0	69588	26878	57948	33950	20346	8032	9292	35549	10703	35864	23275	33807
19.5	45410	14189	32785	15663	10240	3657	4045	19385	4770	11312	11404	16563
20.0	26329	8321	17370	8845	4508	1909	5103	8588	1965	5176	6800	8898
20.5	11553	4694	8119	2999	1921	383	779	3788	1167	2542	1297	7085
21.0	5192	2560	4315	1246	683	175	179	885	501	1944	1472	3990
21.5	2433	1293	1804	242	172	0	193	79	616	234	416	2133
22.0	806	568	889	156	121	0	23	162	132	0	570	195
22.5	358	37	202	144	33	0	97	0	186	0	0	0
23.0	124	3	28	0	12	0	670	0	0	0	0	65

Table 4 (continued).

Length Class (L_c in cm)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Tonnage	36346	56703	56815	34941	40171	39444	37814	53650	66651	36989	89152
3.5	0	0	0	0	0	0	0	0	0	0	0
4.0	0	275	0	4	196	0	0	74	0	0	257
4.5	1192	688	0	1523	3321	0	134	496	0	0	3376
5.0	11450	321	4	4438	14270	6207	6030	6577	712	378	18651
5.5	35039	125	11	19670	183961	33083	5678	41347	100	1087	99617
6.0	63035	6432	14	24780	26944	82217	8543	127469	315	6098	102628
6.5	84150	37148	547	40858	36528	108793	23529	183168	4417	16971	84844
7.0	78973	43545	2413	54890	40369	125373	40999	218400	11669	23122	224061
7.5	26290	41098	6409	48228	49446	167992	67744	172644	18771	19210	167132
8.0	29705	6405	5258	29945	56747	125025	68441	267471	11324	13098	111732
8.5	38184	30105	7231	23683	47262	88430	75416	235538	18666	6450	34107
9.0	24748	7949	6412	31420	30321	55699	57736	86507	6597	11662	27878
9.5	8632	26369	4196	40279	14053	82027	35880	30578	7562	6664	13358
10.0	5364	27965	16714	12369	5434	116156	15237	20868	8279	3714	10293
10.5	6427	23672	646	11671	4837	130120	9070	34572	2280	7932	7691
11.0	16943	9648	668	19239	5773	122409	7029	49602	2621	5503	6071
11.5	7215	9781	384	39320	12406	92964	6470	29637	1294	13035	10353
12.0	7965	27725	226	57984	15463	60157	4783	89153	6305	6364	6521
12.5	6192	20581	1106	58749	24343	65392	5530	89402	7637	12429	1667
13.0	14955	27998	9166	40492	55310	60594	8973	54335	46794	15098	5018
13.5	10318	61858	20629	25414	77530	73402	31605	48990	85095	5038	9613
14.0	26121	93757	35362	21438	100981	118835	71706	33521	140802	5940	19121
14.5	22166	113375	47090	19203	78765	125703	124276	73678	170200	17159	52565
15.0	36337	114009	99863	28821	75099	94089	105847	90036	204847	29836	85427
15.5	62425	81671	202682	35635	70288	60513	89128	95659	214324	46223	116385
16.0	89618	103865	253809	53999	73909	53355	74529	107805	187902	79515	170832
16.5	135751	112680	199878	73355	77908	37704	74136	90062	135926	94850	214739
17.0	116358	127691	122076	73376	66474	28054	64269	76487	96997	128300	241224
17.5	56383	112969	73704	60171	55146	15520	41053	66708	65951	88425	211322
18.0	26062	78831	37771	52317	27437	9804	25769	51371	43888	67805	179034
18.5	11273	37670	23546	35419	22215	7510	18671	35062	26616	28851	108929
19.0	4232	15546	9521	18854	13175	5020	11949	24049	15292	18296	64755
19.5	792	8283	6436	11327	5865	2615	11102	11869	8729	11344	32209
20.0	1067	2763	2095	4995	5780	2083	6318	6340	4847	2706	15368
20.5	414	607	418	2133	745	475	2794	2880	2181	1872	8788
21.0	203	93	515	1822	72	367	1216	2157	972	1739	5690
21.5	0	96	164	439	650	3	667	1647	315	294	1462
22.0	174	40	0	117	0	103	0	694	88	0	782
22.5	0	0	0	67	0	0	0	350	0	0	183
23.0	0	0	0	33	0	0	0	170	0	0	31