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Comparison of the fraction of mature black oreo between Area 1 and Area 2&3 (OEO 3A)

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EXECUTIVE SUMMARY

Doonan, I.J.; McMillan, P.J.; Hart, A.H. (2016). Comparison of the fraction of mature black oreo between Area 1 and Area 2&3 (OEO 3A).

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Otoliths sampled from acoustic survey mark identification trawls in management area OEO 3A were prepared and read by two readers (n=1000). The aim of the work was to test the prediction from a previous stock assessment that mature fish in the unfished area (Area 1) comprised about 25% B_o and so there can be no sustainability concerns whilst this area is not fished. Ageing black oreo otoliths was problematical and there was a small between-reader bias and the precision of age estimates had a CV of 15%. Age data were scaled up to acoustic abundance in each mark-type and to the survey area for Area 1 (unfished) and Area 2&3 combined (the fished area).

The proportion of mature fish (by weight) was estimated from the age frequencies to be 21% (sd 8%) in Area 1 and 10% (sd 4%) in Area 2&3. Applying these ratios to the base case (RUN2) of the last (2009) OEO 3A stock assessment gave a $B_{current}$ of 19% B_o (versus 31% B_o, MPD 2009), and 18% if using mature fish in Area 1 only.

The ageing work has shown up some deficiencies in the previous stock assessment model because length data was used as a proxy for age distribution. The age frequency in Area 1 is similar to that from Area 2&3 when the model has them being very different. The model fit to the observed age frequency for Area 1 is good, but the fit to Area 2&3 is poor. Growth in Area 2&3 appears to be faster than in Area 1 and this may drive the observed differences since the model uses the same growth in all areas. Maturity may be related to length rather than age. When the length ogive for maturity was used to estimate the proportions of mature fish, 27% (sd 5%) were mature in Area 1, and 38% (sd 4%) in Area 2&3. Appling these ratios to RUN2 of the last (2009) OEO 3A stock assessment gave a $B_{current}$ estimate of 29% B_o, and 23% when using mature fish in Area 1 only.

1. INTRODUCTION

This work addresses the following objectives in MPI project DEE2010/08, Targeted ageing of otoliths from selected deepwater stocks. Overall objective: To determine the age distribution of deepwater populations of black oreo (*Allocyttus niger*) and orange roughy (*Hoplostethus atlanticus*) for use in stock assessment. Specific objective 3: To estimate the age of black oreo in OEO 3A by analysing research samples from the acoustic surveys in 1997, 2002 and 2006.

The last stock assessment of OEO 3A black oreo used three acoustic estimates of abundance, length data, and several CPUE indices of abundance (Doonan et al. 2009). The model divides the area into three sub-areas (Figure 1) and has small fish settling out from mid-water into Area 1 (shallow and largely unfished), with a migration from Area 1 into Area 2 and another from Area 2 into Area 3. The fishery is prosecuted in Area 2&3. The stock assessment suggested that the stock was slowly rebuilding or stable, but it also advised caution because of uncertainties associated with the abundance estimates. In particular, the hypothesis of a large reservoir of mature fish in Area 1 (Table 1) was again questioned since this depended on an assumed growth rate, and small changes in the growth rate can result in very few mature fish in Area 1. It was suggested that this mature reservoir hypothesis be tested by estimating the OEO 3A black oreo population age structure with otolith age readings.

Table 1: Total (immature plus mature) black oreo abundance estimates (t) for the 1997, 2002, and 2006 acoustic surveys and CV estimates (%), in parentheses, for the three spatial (model) areas in OEO 3A.

Survey	Area 1	Area 2	Area 3	Total
1997	148 000 (29)	10 000 (26)	5 240 (25)	163 000 (26)
2002	43 300 (31)	15 400 (27)	4 710 (38)	63 400 (26)
2006	56 400 (37)	16 400 (30)	5 880 (34)	78 700 (30)

Therefore, this work aimed to test the prediction from the stock assessment that mature fish in the unfished area (Area 1) was at 25% of virgin levels and that there are no sustainability concerns whilst this area is not fished.

2. METHODS

2.1 Selection of otoliths from acoustic survey trawl samples

Otolith samples were selected from the available collected sets in a way that would provide a representative sample of the black oreo population ages in each of two areas, Area 1 and Areas 2 & 3. Otoliths were selected from samples collected during three surveys carried out for black oreo in OEO 3A: a trawl survey in 1995 (TAN9511, Hart & McMillan 1998), and two acoustic surveys in 2002 (TAN0213, Smith et al. 2006) and 2006 (TAN0615, Doonan et al. 2008). Initial plans were to use otoliths from the first full acoustic survey of black oreo in the series carried out in 1997 (TAN9713, Doonan et al. 1999), but no black oreo otoliths were collected during that survey because priority was placed on gathering large amounts of fish length and weight data to aid work to estimate target strength of black oreo. Instead a small number of otoliths (151) were selected from samples taken during the pilot acoustic and stratified random trawl survey of oreos on the south Chatham Rise (including OEO 3A) carried out in 1995 (TAN9511, Hart & McMillan 1998).

The black oreo acoustic surveys in OEO 3A used a conventional stratified random approach (Jolly & Hampton 1990) over eight strata divided into three spatial areas (Figure 1). An abundance estimate was required for each area used in the stock assessment model (Hicks et al. 2002). The same strata were used in 2002 and 2006 (Smith et al. 2006) and six mark types were recognised.

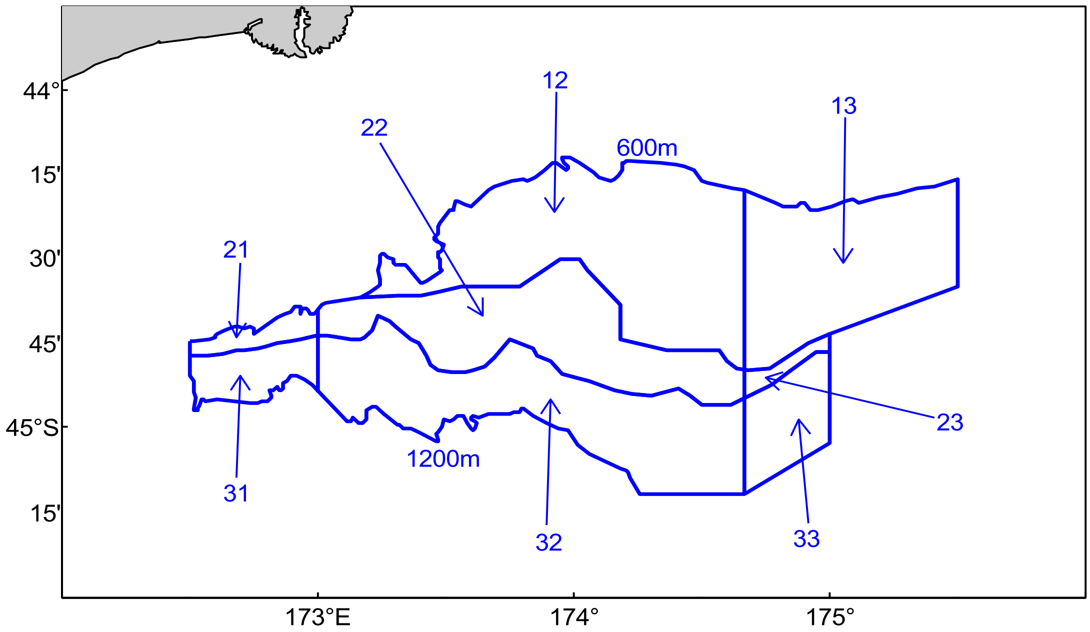

Figure 1: The 2002 and 2006 acoustic abundance survey area with stratum boundaries and stratum numbers. Area 1 is composed of strata 12 and 13; Area 2 is composed of strata 21, 22, and 23; and Area 3 is composed of strata 31, 32, and 33. The boundary that separates Area 1 and Area 2 is based on having 10% of the commericial catch in Area 1. The boundary between Area 2 and 3 separates the mean lengths from early commercial catch at a contour of 32.5 cm.

Survey design and abundance estimation details are provided by Doonan et al. (2008). The overall approach to the survey was to measure acoustic backscatter together with information on the size structure of the black oreo samples and the mix of species present in acoustic marks obtained by trawling. The catches from each successful tow were sorted by species, weighed and recorded. A gonad-stage length frequency measurement (total length to mm, sex, gonad stage) for a random sample of 200 black oreo (and smooth oreo) from each tow was carried out. Up to 60 individuals of black oreo, smooth oreo, (and other quota species) were selected at random from each tow for a more detailed biological analysis which included measuring fish length, weight, sex, macroscopic gonad stage and weight, and extracting otoliths. Length and weight measurements were made for samples of up to 100 of all by-catch species from each tow.

Backscatter from just black oreo was calculated by accounting for backscatter from other species present via their target strengths and fraction in the species composition. Black oreo abundance was then estimated from the black oreo backscatter and mean weight. NIWA's research vessel *Tangaroa* was used to carry out all the acoustic work and the trawl sampling.

To better characterize species composition and increase the precision of the abundance estimates, backscatter was classified into six different mark-types (Table 2) and species composition obtained for each.

Table 2: Classification of echogram marks into black oreo mark-types.

Mark-type	Description
SHORT	Discrete marks < 500 m long
LONG	Discrete marks > 500 m long
LAYEROFF	Layers off the bottom
LAYER	Layers on the bottom
BACK	Background < 1000 m deep
BACKDEEP	Background > 1000 m deep

Table 3 shows how catch rates differed between mark-types for the two main species caught in the survey, black oreo (BOE) and smooth oreo (SSO), and the other species combined for trawls targeting each mark-type. For the 2002 analysis, catch data from the 1997 and 2002 surveys were used, and for the 2006 analysis, data from the 2006 survey were augmented by the 1997 data on the BACK and BACKDEEP mark-types. Relatively high BOE catch rates were observed in the LONG, LAYER, and BACK mark-types.

The species composition for the LONG and SHORT mark-types were nearly 100% oreo (both species), whilst the other mark-types contained some black oreo with a mixture of other species and very little smooth oreo. This broad pattern was seen in every survey, although details do differ between surveys. The distribution of black oreo mean length by tow within each mark-type showed that on average larger fish were observed in the LONG and SHORT mark-types (Figure 2).

Table 3: Catch rates (kg/n.mile) for BOE, SSO, and all other species (Total) combined for trawls targeting each mark type used in the black oreo acoustic abundance analysis.

Mark-type	Number of species	Number of trawls	BOE	SSO	Catch rates (kg/n.mile) All others Total other species	Highest species		Next highest	
Catch data used for the 2002 survey									
SHORT	14	11	1 890	2919	82	ETB	54	MCA	14
LONG	18	7	1 786	509	109	ETB	62	MCA	11
LAYEROFF	21	7	296	11	126	JAV	34	HOK	24
LAYER	19	7	714	16	71	ETB	29	GSP	19
BACK	21	13	95	6	69	JAV	25	ETB	15
BACKDEEP	12	7	2	3	73	SSM	21	MCA	21
Catch data used for the 2006 survey									
SHORT	12	4	581	4021	54	ETB	24	MCA	12
LONG	13	3	2 648	307	131	ETB	88	MCA	12
LAYEROFF	24	6	328	2	200	HOK	84	JAV	46
LAYER	25	8	1 336	27	114	HOK	41	ETB	16
BACK	13	11	66	7	41	ETB	19	MCA	9
BACKDEEP	15	8	2	4	84	SSM	24	MCA	21

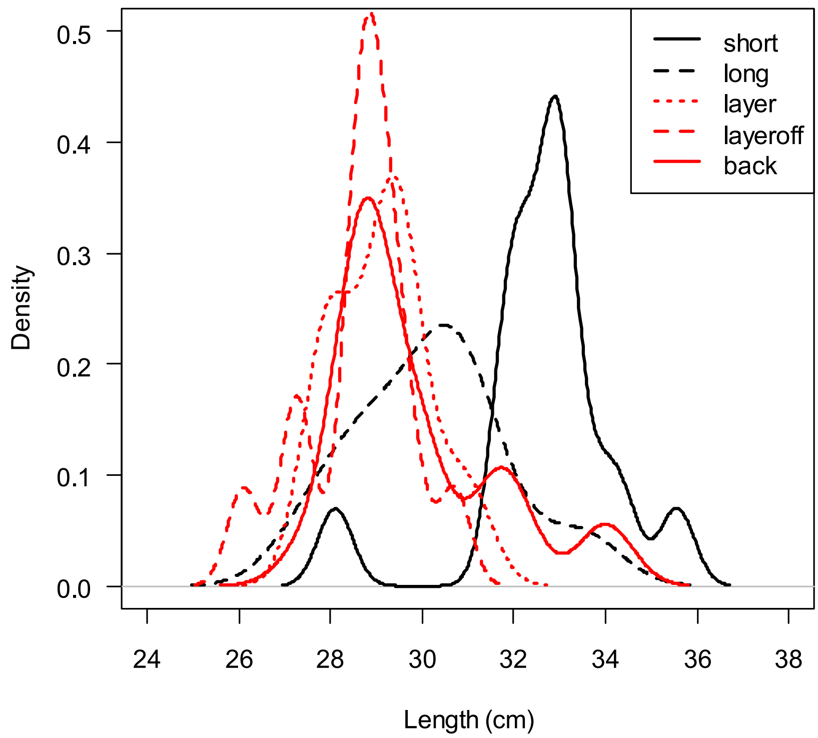

Figure 2: Black oreo mean length for tows by mark-type. The blip at 28 cm for SHORT is from one tow which caught 2.2 t of black oreo. There were too few data to present results for the BACKDEEP mark-type.

Tows selected for the analysis

To get an adequate estimate of error, there needs to be several tows in each mark-type and area, but since there are inadequate data in some combinations, there is a rather convoluted approach taken to achieve the final data set.

The proportion of the black oreo abundance estimates by mark-type from the 2002 and 2006 acoustic surveys separately is listed in Table 4. The BACKDEEP mark-type was dropped because it contained only 0.1% of the abundance (Table 4).

Table 4: Percentage of overall black oreo abundance (t) by mark-type and Area in the 2002 and 2006 surveys. Percentage rounded to nearest integer.

	2002 survey		2006 survey	
Mark-type	Area 1	Area 2&3	Area 1	Area 2&3
BACK	17	7	7	9
BACKDEEP	0	0	0	0
LAYER	18	3	12	8
LAYEROFF	31	3	48	1
LONG	1	7	4	9
SHORT	2	11	1	1
TOTAL	69	31	72	28

Tows in the acoustic surveys were assigned to a mark-type in the abundance estimation. Tows for each mark-type were split by area (Table 5). Tow data was limited in some combinations of survey, mark-type, and area so data for the two surveys were combined. Even then, some mark-types lacked enough tows, e.g., 1 tow for BACK in Area 1 (Table 5). Tows were sought from the 1995 trawl survey to augment tows in some mark-types (see 5th column Table 5). This still did not solve the problem entirely, so the LONG and SHORT mark-types were ignored for Area 1 because these tows only provided 5% of the abundance in Area 1 (Table 6). Only mark-types with fewer than four tows were augmented with 1995 tows (Area 1: BACK, Area 2&3: BACK, LAYER, LAYEROFF). The 1995 trawl survey did not use mark-types so these had to be predicted from a cluster analysis using the tow results from the 1997, 2002, and 2007 acoustic surveys, method detailed in the next section.

Table 5: Number of tows by mark type within Area 1 and Area 2&3 by survey and in total. Extra tows needed from the 1995 survey designated as "×", –, no extra tows needed.

Mark-type	2002	2006	2002+2006	Extra tows needed from 1995 survey
Area 1				
BACK	1	0	1	×
LAYER	0	7	7	–
LAYEROFF	3	6	9	–
Areas 2&3				
BACK	1	0	1	×
LAYER	1	1	2	×
LAYEROFF	1	0	1	×
LONG	3	3	6	–
SHORT	5	4	9	–

Table 6: Average percentage black oreo abundance by mark-type and Area for the 2002 and 2006 surveys combined. The fourth and sixth columns were used to scale up the age data between mark-types. Percentages rounded to nearest integer. Note that mark-types cross area boundaries so although there are no tows, e.g., for SHORT in Area 1, Area 1 can have some abundance in SHORT mark-types.

	Percentage				
	Combined surveys		Within-area groups		
Mark type	Area 1	Area 2+3	Area 1 without LONG & SHORT	Area 1	Areas 2+3
BACK	12	8	18	17	28
BACKDEEP	0	0	0	0	0
LAYER	15	5	23	21	18
LAYEROFF	39	2	59	56	7
LONG	2	8	0	3	27
SHORT	1	6	0	2	19
Total	70	30	100	100	100

Assigning mark-type to 1995 survey tows

A supervised cluster analysis was applied to the 1997, 2002, and 2006 tows because the mark-types were known for these data. Predictions were based on converting these data into an equivalent 1.5 n.mile tow by assuming that a zero catch was caught outside the mark. In the three acoustic surveys tows were typically shorter than 1.5 n.miles but were standardised at 1.5 n.miles in the 1995 survey. The analysis proceeded on a 1.5 n.mile tow length since predictions are based on the 1995 catch. Predictors such as stratum were excluded since a preliminary analysis showed that it was significant, but such a variable would exclude picking tows from, e.g., LAYEROFF in Area 2&3.

Two R functions were trialled: `nnet` and `rpart` (R Development Core Team, 2010). The choice of method was based on the best cross-validation prediction rate. Here, one tow from each mark-type was randomly excluded, then a predictor made from the rest of the data, and this predictor used to assign mark-type for the excluded tows. This was repeated 500 times. Since differentiating back from LAYER and LAYEROFF was important, parameters were varied to get the best for those groups at the expense of SHORT and LONG mark-types.

The `rpart` method proved to be best (Table 7) but it was not perfect, especially for LAYER and LAYEROFF predictions. Figure 3 shows the estimated decision tree and the predicted tows for each mark-type. Estimates for LAYER, LAYEROFF, and BACK are essentially the same so perhaps it does not matter that much when predicting mark-type. This method was applied to the 1995 survey tow data to select otoliths.

Table 7: Prediction rates for `rpart` from cross-validation using parameter values minsplit=6 and control=rpart.control(cp=.05).

Known mark-type		Predicted mark-type (%)				
Mark-type	Total (%)	BACK	LAYER	LAYEROFF	LONG	SHORT
BACK	100	60	21	11	7	0
LAYER	100	10	34	28	22	6
LAYEROFF	100	7	47	34	7	5
LONG	100	18	1	0	42	39
SHORT	100	8	0	0	11	81

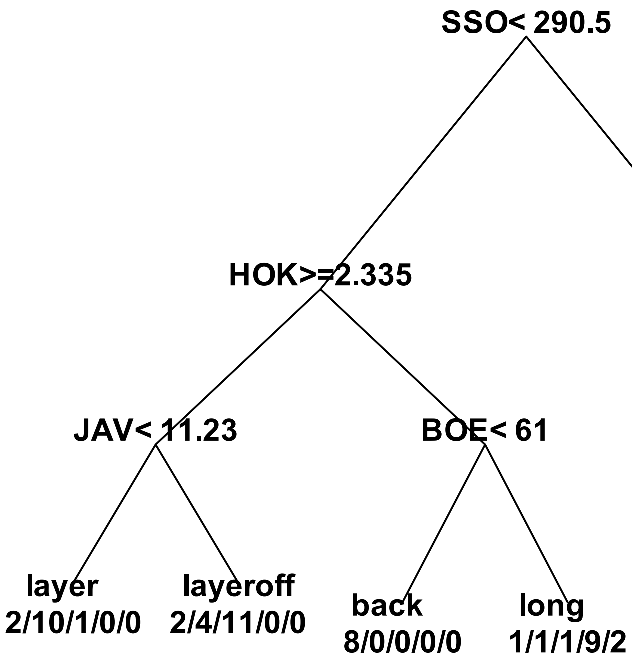

Figure 3: Prediction tree for mark-type using the R function, `rpart`. Terminal branches give the mark-type and the number of tows in each mark-type from the data used to generate the tree: the order is BACK, LAYER, LAYEROFF, LONG, and SHORT. Decision nodes are catch rates in kg/n.mile with catches adjusted to a 1.5 n.mile tow (see text).

Potential error from combining data from 1995, 2002, and 2006

In theory, age frequency will change from fishing pressure over time. Consequently, combining data over time may have a bias and the result will be a weighted average for the three years used. Figure 4 shows the predicted age frequency from the 2006 stock assessment (RUN2) for 1995, 2002, 2006 for the two areas: Area 1 and Area 2&3. For Area 1, the model shows very little difference between the years. For Area 2&3, there are some differences, mainly for 1995 compared to the other two years where 1995 has a higher proportion of older fish over age 70. Hence, ages for Area 2&3 will be slightly biased toward older fish when using the age frequency as a proxy for that in 2006. However, the model uses constant recruitment, so the actual difference between 1995 and 2006 may be more different than shown here if recruitment has varied greatly.

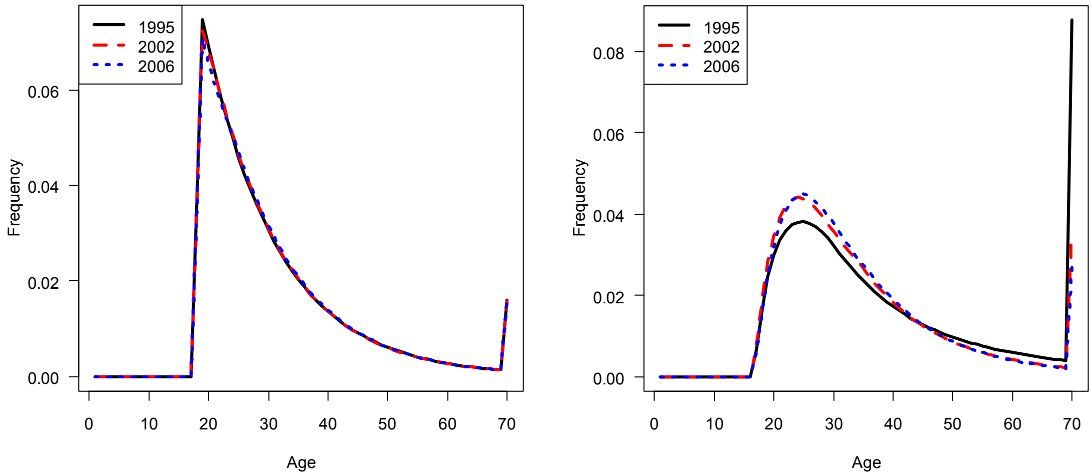

Figure 4: Age frequency distribution for 1995, 2002, and 2006 from the 2006 stock assessment (RUN2). Area 1 is in the left panel, and Area 2&3 in the right panel.

Otolith selection

We had a budget of 1000 otoliths so we planned to split them two ways (500 each) between Area 1 and Area 2&3. However, there were just enough otoliths collected from the tows used so all were prepared, giving 307 otoliths for area 1 and 693 otoliths for Area 2&3.

2.2 Ageing of black oreo

Background

NIWA has previously completed two studies that estimated black oreo age routinely using otoliths, plus a third study which estimated age using radiocarbon introduced into the environment from nuclear weapons testing in the Pacific Ocean in the 1950s. The first study used 227 readable otolith thin sections from samples taken during random trawl surveys on the Chatham Rise from 1988 to 1994 (Doonan et al. 1995). Two readers used a protocol set of 21 (16 readable) sections to consistently interpret the observed zones. Estimated between-reader variability was high, with a CV on the age estimates of up to about 15% for fish less than 20 years old, but declining to about 7% for fish of about 80 years (Doonan et al. 1995). A maximum age of 153 years (unvalidated) was estimated for a 45.5 cm TL female fish (Doonan et al. 1995).

A second study used 266 readable otolith thin sections from samples taken during a random trawl survey on the Puysegur Bank area in 1992 (TAN9208). The same two readers used the protocol set of 21 (16 readable) sections to consistently interpret the observed zones. Estimated average between-reader variability (CV on the age estimates) was 8.3%. A maximum age of 142 years (unvalidated) was estimated for a 42.3 cm TL female fish (McMillan et al. 1997). The Puysegur age estimates were used to estimate natural mortality from a lightly fished black oreo population.

The third study measured radiocarbon (^{14}C) levels in core micro-samples from large, previously-aged (by zone-count) otoliths from19 black oreo. A thin section from one otolith of the pair was re-read to confirm the original count, and thick sections from the other otolith were micro-milled to remove material for the analysis. The radiocarbon results supported the otolith age estimates up to about 80 years, and – by inference – a maximum age of at least 153 years (Neil et al. 2008).

Preparation and reading of black oreo otoliths

Each otolith was marked with a dorso-ventral line through the origin along the reading axis, 5 otoliths were oriented in a mould (all reading axes lined up), embedded, a thin section cut, the section was glued to a slide and polished down to about 300 μm to allow reading with transmitted light. The readability of each otolith was scored using a subjective five point scale, where 1 = clear and unambiguous, 2 = clear but one to a few counts are ambiguous, 3 = readable but difficult, 4 = counts made with great difficulty, 5 = unreadable. The same two readers who read the otoliths for the 1995 and 1997 studies read all the otoliths. The following steps were taken:

1. The previous (Doonan et al. 1995) protocol set of 16 readable otoliths was read to establish interpretation.
2. After consultation both readers read all the new otoliths (1000).
3. Comparison of the results from the first reading established that there was a substantial and unacceptable between-reader difference in interpreting the new otoliths, i.e., a variability of about 30%.
4. A new protocol set of 46 readable otoliths was selected from the original 1995 age study. This allowed comparison of the 1995 and current readings of the same otolith. The readers re-examined any otoliths with between-reader differences of 5 zones or more and agreed on an interpretation. Final counts for both readers were compared with previous counts from the 1995 study. Plotting the age obtained in 1995 with the ages in 2012 showed that there was no overall difference in ageing between the years (Figure 5).
5. Both readers read every fifth otolith of the new otolith set (200), and a further between-reader comparison was completed to establish whether both readers were interpreting the otoliths in the same way.
6. Both readers completed reading the complete set (1000) once, and then read the set again. Any otoliths that had a count difference between readers of 5 or more were read a third time. An average age estimate for each otolith was made based on the average of the third readings from each reader and these values were used in the analyses below (unless stated).

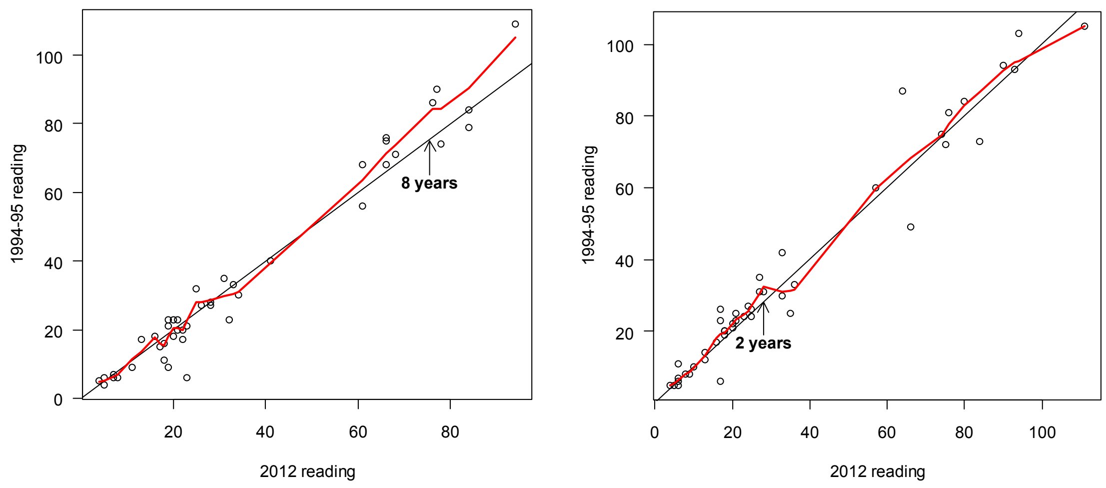

Figure 5: Comparison of ages obtained in 1995 with those in 2012 by reader (reader 1 left panel; reader 2, right panel). Black line is the 1:1 line and the red line was a smoother using `lowess`.

Between-reader error analysis

Data with one readability code of 5, i.e., unreadable by either or both readers, were excluded. Only between-reader variability (consistency) between otolith readings was considered. The readings by each reader were plotted against each other and a 1:1 line drawn as well as a `lowess` smoothing line (R Development Core Team (2010), parameter "f" set to 0.1). A lowess line that consistently deviates from the 1:1 line indicates bias between the two readers. Precision was quantified using the CV of between-reader error form the two readings for each otolith. This is related to the index of average percentage error (IAPE) (Campana et al. 1995) by CV = 1.4 * IAPE.

2.3 Estimating the age frequency

The method adapted that by Doonan et al. (2012). Each otolith was assigned a probability that represents the contribution that the sampled tow makes to the total abundance (in numbers), and also the number of samples in that tow, i.e., all otoliths in the same tow get the same probability. This assumes that the otolith sampling was random. The selection probability assumes that all otoliths are available to be aged. The set of all the otolith ages and their associated probabilities is an approximation of the age distribution of the fished population. The probabilities collapse all survey structure into one number. The probabilities were used directly to estimate the age frequency distribution.

Kernel smoothing was used to give more stable results. It uses one parameter, *width*, which is approximately the moving window width in which averaging is done. The R function `density` was used with observation weights set to the probabilities above (R Development Core Team, 2010). Here, *width* was set to 5.

2.4 Comparisons of modelled and observed (estimated) age frequencies

Length was plotted against estimated age and compared to the growth curve used in the stock assessment. This is important because the length distribution is converted into ages in the model and if the distributions are not similar then the model predicted age frequency distribution is likely to be flawed.

The base case "Run2" stock assessment model was used (Doonan et al. 2009), except that to fit the LHS of age frequencies better the mid-water to Area 1 migration (i.e., settlement onto the bottom) was set to logistic with A50 (ages up to 50% level) of 5.5 and A50.95 (ages from 50–95% level) of 0.5, and the data were re-fitted as in Run2. In the original run of Run2, A50 was estimated at 17 yr. $B_{current}$ was slightly lower with this treatment (29% vs 31% B_o), and the log-likelihood increased by 0.07, i.e., a slightly worse fit, but trivially so.

2.5 Estimation of mature abundance

The age frequencies were converted into proportion of abundance at age by using the weight-at-age curve estimated from each area's data. The regression used to estimate weight from age (W in kilograms) was

$$W_{Area\ 1,age} = {0.986}/{(1 + e^{-0.055(age-18.6)})}$$
$$W_{Area\ 2\&3,age} = {1.061}/{(1 + e^{-0.060(age-13.1)})}$$

The abundance-at-age was used to estimate the proportion of mature fish for the two areas based on an age-at-maturity of 38 yr. Applying these proportions to the total estimated abundance for the two areas from the base case (Run2) of the last stock assessment (Doonan et al. 2009) will give an estimate of $B_{current}$, which is then expressed as a percentage of B_o. Bootstrap age frequencies were used to get the 95% confidence intervals for $B_{current}$, i.e., error in the abundances from the model were ignored here.

This assumes that the age frequency data from 1995, 2002, and 2006 approximates that for 2006, the year in the model that $B_{current}$ refers to. As seen above, the 1995 data will give a small bias to older fish for Area 2&3.

We have anticipated the results from the growth comparison so we have used an alternative version for $B_{current}$ based on maturity being driven by length rather than age. Lengths were converted to weight (W in grams) using a log regression of weight on length for each area. The estimated regressions were:

$$W_{Area\ 1} = 0.0095\ Length^{3.22}$$
$$W_{Area\ 2\&3} = 0.0203\ Length^{3.00}$$

Plots of the relationships show little difference over the range of lengths in the data between areas. Proportion mature by length, g(length), is given by

$$g(length) = {1}/{\left(1 + 19^{\frac{32.5-length}{3.5}}\right)}$$

The length ogive was the same as that used to estimate the age maturity ogive (Doonan et al. 2009). The same method as described above was used to get $B_{current}$ and the confidence interval.

3 RESULTS

3.1 Tows selected for otolith samples

When assigning mark-type to the 1995 survey tows, two tows including one on a hill (Neil's pinni) were excluded which left 26 tows in the acoustic survey area since there are no hills in the black oreo acoustic surveys. The number of tows by predicted mark-type is shown in Table 8 and includes two BACK tows for Area 1, four BACK tows for Area 2&3, and 3 LAYER tows for Area 2&3 (total nine). There were no extra tows for LAYEROFF in Area 2&3. No further searches for tows were carried out since LAYEROFF was not that important in Area 2&3. The trawl survey in 1993 (TAN9309) had some tows in the acoustic survey area, but they did not help to boost numbers in the right mark-types/Area, i.e., BACK in Area 1, LAYEROFF in Area 2&3. The final tow numbers by Area and mark-types are shown in Table 9.

Table 8: Predicted mark-types for 1995 survey tows based on `rpart` regression. BACKDEEP were BACK tows deeper than 1000 m. See Figure 1 for stratum boundaries.

Area	Acoustic survey stratum	BACK	BACKDEEP	LAYER	LAYEROFF	LONG	SHORT
1	12	1	0	2	1	1	0
1	13	1	0	2	0	0	0
2&3	22	1	0	3	0	4	0
2&3	31	1	0	0	0	0	0
2&3	32	2	5	0	0	0	2

Table 9: Number of tows used in the analysis by mark-type, Area, and survey, plus totals.

Mark-type	1995	2002	2006	Total
Area 1				
BACK	2	1	–	3
LAYER	–	–	7	7
LAYEROFF	–	3	6	9
Area 2&3				
BACK	4	1	–	5
LAYER	3	1	1	5
LAYEROFF	–	1	–	1
LONG	–	3	3	6
SHORT	–	3	4	7

3.1 Otoliths and precision

The number of otoliths processed from each survey was 151 from 1995, 486 from 2002 and 363 from 2006. The number of otoliths used in the analysis was 307 for Area 1 and 682 for Area 2&3 (one tow number was in error in the selection spreadsheet and the so otoliths from OEO 4 were prepared, but they were excluded from the analysis (n=11)). The number of otoliths removed from the analysis because they were unreadable was 111 (11%) (Table 10). Reading black oreo otoliths was difficult and it took three complete readings and extra time calibrating consistent readings using a new protocol set compared to the 1995 study (Doonan et al. 1995). Both readers struggled to maintain a consistent interpretation because the readability of sections was highly variable and the last time reading was done was 16 years ago in 1995.

Table 10: Summary of unreadable otoliths by reader and Area.

Survey	Reader 1	Reader 2	Both readers	Total	Total prepared
Area 1	18	5	6	29	307
Area 2&3	38	26	18	82	682
Total	56	31	24	111	989

To get an approximate effect of losing the unreadable otoliths, the percentage of ages with an unreadable score (at least one reader) were compiled in 3 age bins: ages 19 years and younger, 20 to 39 years, and 40 years and over. The cut-offs were based on the raw age distribution which had a mode at about 20 years with a tail of older ages from 40 years onwards. The percentages were 8, 9, and 27 respectively. The percentages of all readable ages in the same age bins, irrespective of reader, were 51, 42, and 7, i.e., older fish were relatively more unreadable than younger.

The between-reader comparison of estimated ages is plotted in Figure 6 and shows some bias overall, with a between-reader gap of about 3 at age 30 years. The mean between-reader CV was 15% which is high, the same as the highest CV obtained in 1995 (Doonan et al. 1995, figure 15). There were still some problem otoliths (about 12%); see Figure 6. When the problem otoliths were excluded the mean between-reader CV reduced to 8% and the bias at 30 years reduced to about 1 year.

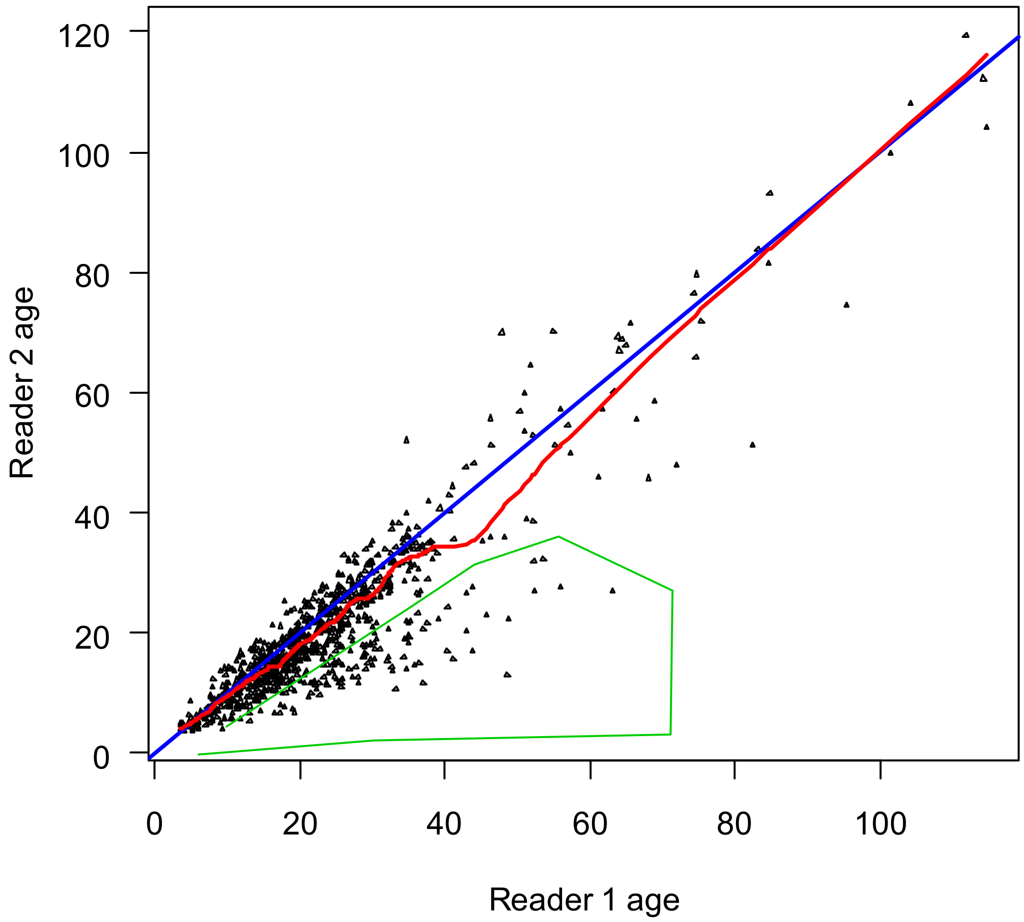

Figure 6: Between-reader comparison of age estimates for the same otolith. Also shown are the 1:1 line (blue) and a smoothed curve (red). The green box encloses about 12% of the otoliths which are problematic.

3.2 Growth comparison

Figure 7 shows the growth curves (lowess curves) estimated from the data created under the current study, and the growth model used previously in stock assessments. The growth curve in Area 1 matches the stock assessment growth reasonable well, but for Area 2&3, growth is faster and the mean length at age 20 is about 1.6 cm larger than that in Area 1. Since growth is used to estimate the age structure in the model, the model predicted age frequency will be shifted to older fish in Area 2&3 than that in the observed data.

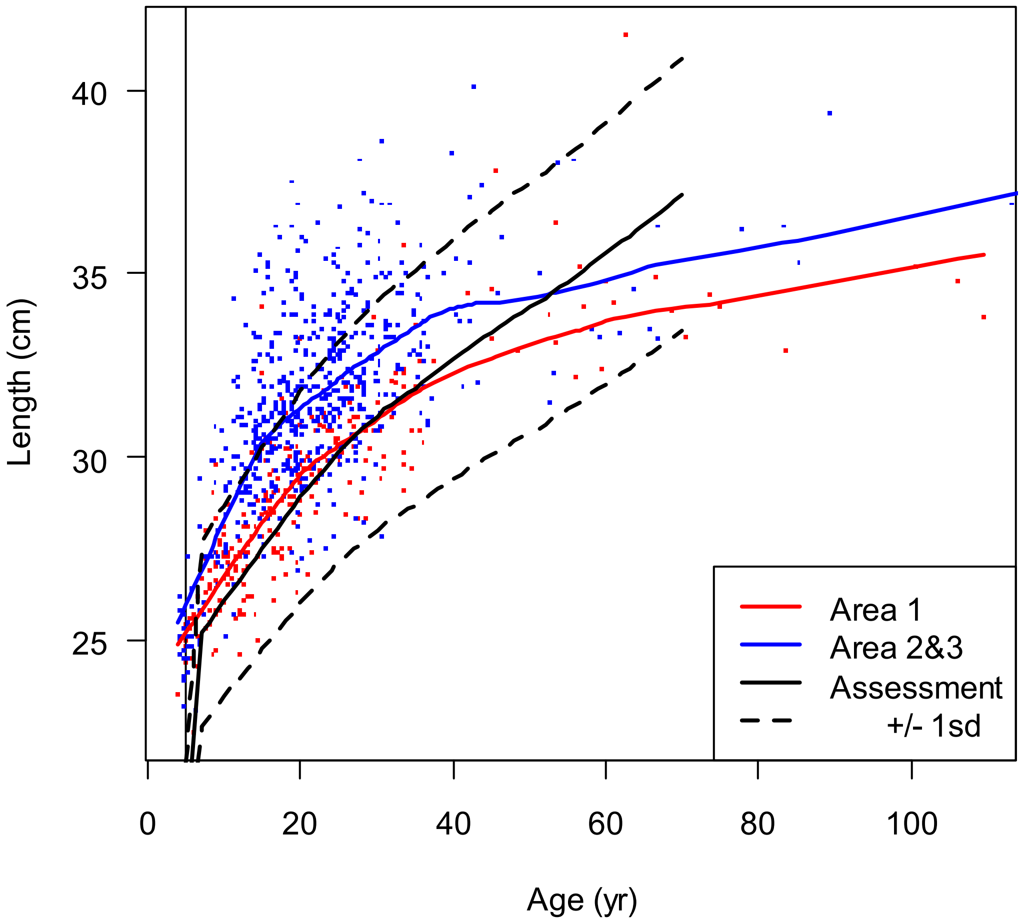

Figure 7: Growth curves using the new estimated ages (red and blue curves) compared to the growth curve used in the stock assessment model (black curves). Area 1 fish, red points; Area 2&3 fish, blue points. Lowess curves: Red line for Area 1, and blue line for Area 2&3. Vertical line is at age 5 years.

3.2 Age frequency distributions

The minimum estimated age was 4 years for both areas, and the maximum was 110 for Area 1, and 115 years for Area 2&3 (Figure 8). Appendix A has the station scaling factors for each tow used to derive the probabilities for each otolith.

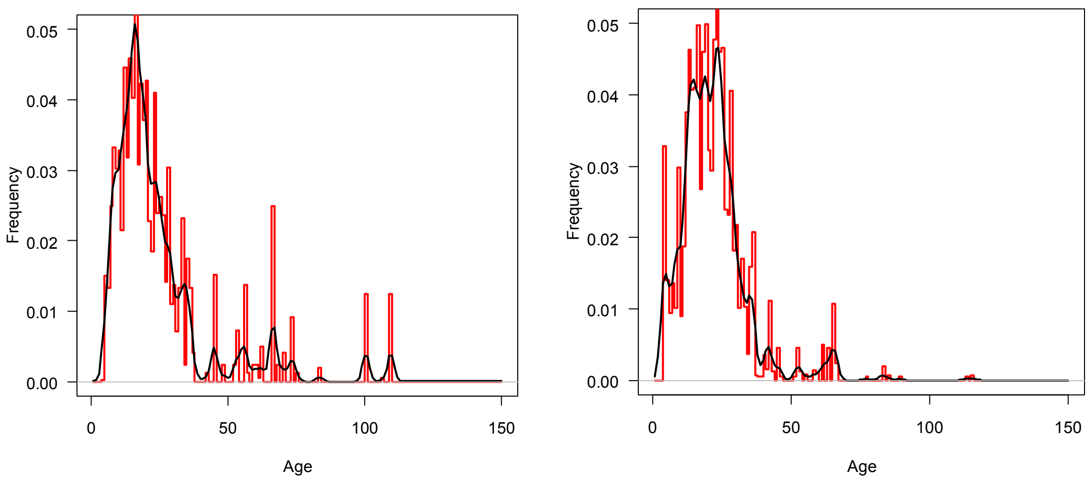

Figure 8: Smoothed age frequency distributions (black curve) and the raw frequencies (red histogram) for Area 1 (left panel) and Area 2&3 (right panel).

A comparison of age frequency distributions from each area is shown in Figure 9. The distributions both show a strong mode at about 20 years. The 95% point-wise confidence intervals (CI) of the estimated age frequency distributions for the main mode for both areas coincide. Some gaps appear for ages over 70 years, but that is probably due to variability of ages seen in the tail of the distribution. Overall, the age frequency distributions are similar. The mean age was 25 years (standard error, 3.5) for Area 1 and 22 years (1.4) for Area 2&3 and these means are not significantly different at the 5% level (t-test).

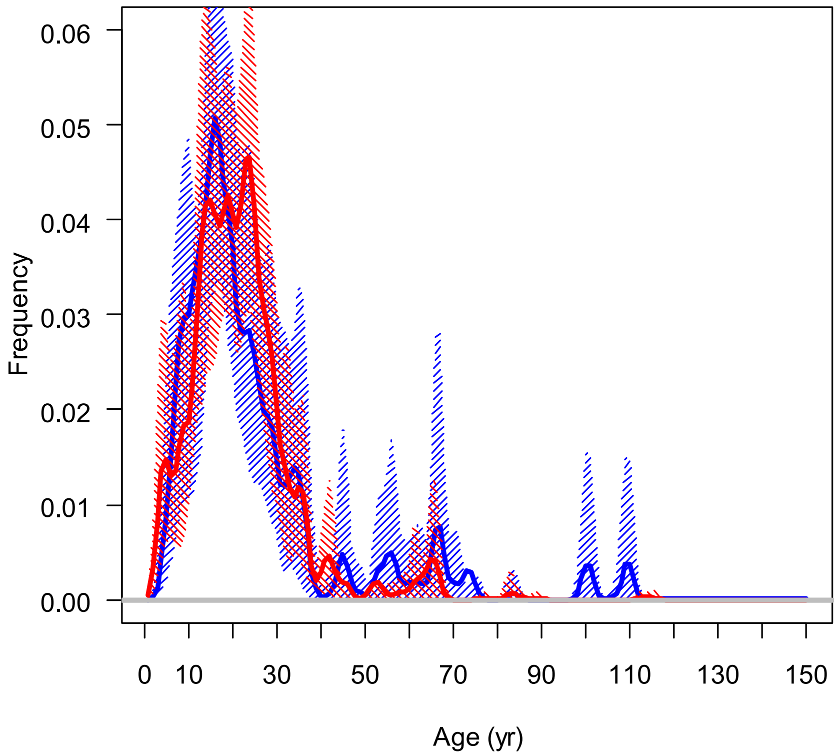

Figure 9: Comparison of age frequency distributions for Area 1 (blue) and Area 2&3 (red) with point-wise 95% confidence intervals (slanted lines).

3.3 Comparison with predicted age frequency distributions from the stock assessment

Figure 10 shows the comparison of model predicted and observed age frequency distributions. The observed frequency distribution for Area 2&3 does not fit well with the predicted distribution. Growth in Area 2&3 is not in accordance with that used in the model. The observed and predicted age frequency distributions match reasonably well for Area 1.

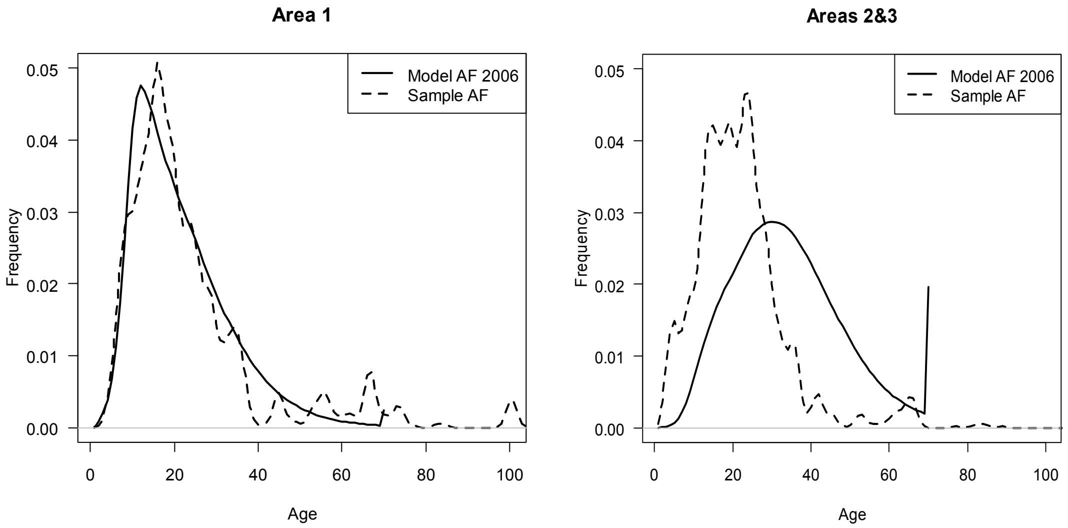

Figure 10: Comparison of observed (Sample) and model predicted (Model) age frequency distributions (AF) for Area 1 (left panel) and Area 2&3 (right panel).

3.4 Mature abundance (%B_0)

The proportion of mature abundance from the age frequency was 21.2 % (sd 8.0%) for Area 1 and 9.5% (sd 3.1%) for Area 2&3. This compares to 28% and 40% from the model run, RUN2. When applied to RUN2's abundances, $B_{current}$ was estimated to be 19.3% with the 95% confidence interval from 7 to 31%. For Area 1, it was 18%, which implies that if Area 1 is not fished then $B_{current}$ will not drop below this level whatever the catch.

The proportion of mature abundance from the length frequency was 27.1% (sd 4.9%) for Area 1 and 38.1% (sd 4.3%) for Area 2&3. This compares to 28% and 40% from the model run, RUN2. When applied to RUN2's abundances, $B_{current}$ was estimated to be 28.9% with the 95% confidence interval from 19 to 36%. For Area 1, it was 22.6%, which implies that if Area 1 is not fished then $B_{current}$ will not drop below this level whatever the catch.

4 DISCUSSION

The aim of the work was to test the predicted reservoir of mature fish in Area 1 which if true would mean that the $B_{current}$ (2006–07) could not fall below 25% B_o, whatever the catch level, as long as Area 1 remains unfished. The value of $B_{current}$ from the last stock assessment was 31% B_o (MPD) (Doonan et al. 2009). The stock assessment model used a growth curve to infer age structure from the length distribution. The current work tests this directly by ageing fish from otoliths.

Unfortunately, conclusions about the proportion of mature fish are still uncertain because growth appears to be different in the two areas, whilst the model has them being the same. Thus, the underlying biology of black oreo appears to be different from that used in the stock assessment model. Our previous hypotheses about the life history of black oreo were that small individuals settle out from mid-water into Area 1. Area 2&3 were populated by a migration from Area 1 into Area 2 and with another from Area 2 into Area 3. The stock assessment model is built on the latter structure which was used to solve the patterns of fish size distributions in the three areas that occurred in observers' samples from the fishery, i.e., there are no direct experimental data on these migrations. However, since growth is quite different in Area 1 compared to Area 2&3 it may be that small black oreos settle out at all depths and that growth then determines any differences. Fish in Area 1 could contribute to the population survival, but in an inter-generational time scale via recruitment from spawning. However, if growth is slower in Area 1, it may be that expected reproductive effectiveness is lower there too.

Apart from the growth differences, there is only anecdotal evidence for the new structure. One author (PJM) reported that small fish are seen all over the depth zones, not just in Area 1; the implicit assumption previously was that the small fish migrated up the slope into Area 1. On the last survey, PJM observed many Area 1 fish in poor condition, and a higher proportion there than in Area 2&3 that were reabsorbing eggs.

Given the different growth rates, we investigate maturity being mainly controlled by length. When estimating maturity (Doonan at al. 2009), it was found that the maturity ogive by length was very similar across all depth zone (200 m bins) so that ogives for each area overlapped (Figure 11). When these were put into the CASAL model and maturity estimated (by age), the resultant maturity by age had a very poor fit to the maturity-at-length observations (Figure 12). Given this poor fit and the unusual result above, we wondered whether maturity is determined by length rather than age. Using a length ogive gave more optimistic estimates of $B_{current}$ than using an age ogive.

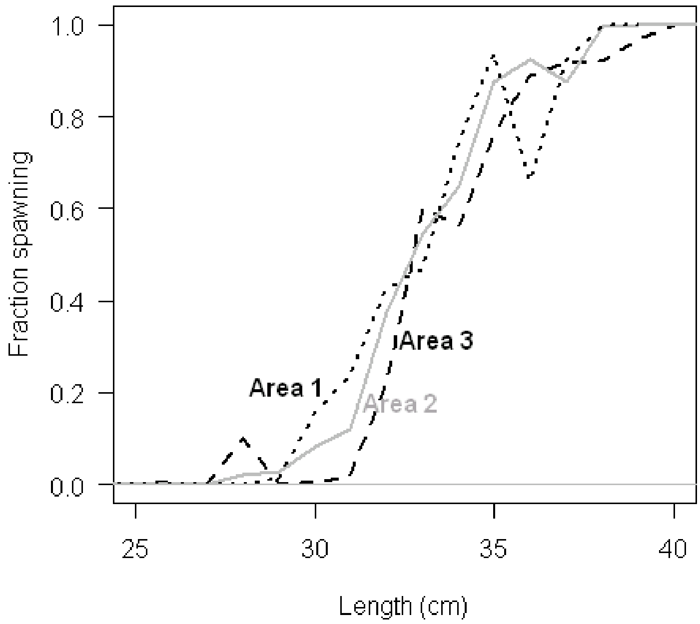

Figure 11: Proportion spawning by length class for the three OEO 3A areas from data collected on the 1986 and 1987 random trawl surveys. These were used to estimate maturity-at-age within the stock assessment model in the year 1987. Entered as a multinomial distribution with a sample size of 1 to avoid disturbing the fits to other data (Doonan, author's unpublished data.).

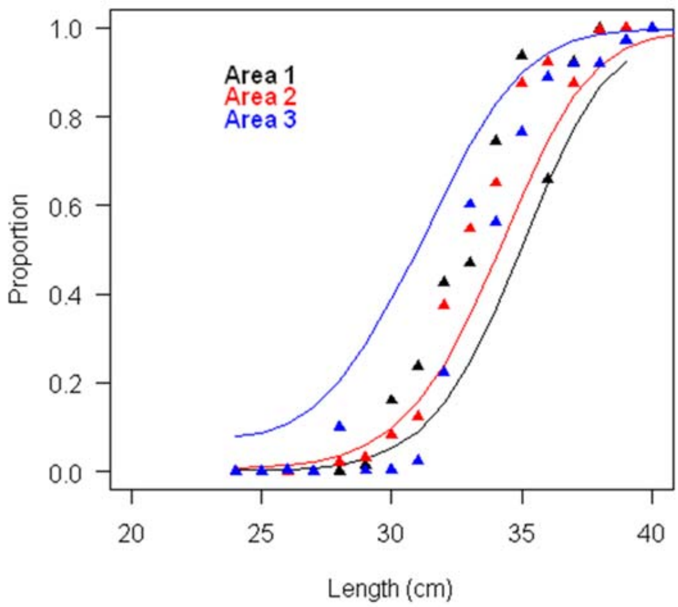

Figure 12: Fits of length ogive of maturity in the stock assessment model (Doonan, author's unpublished data.).

This is only the third piece of work to routinely age black oreo and we suggest that future effort should concentrate on refining the preparation of otolith thin sections. This could include:

1. Investigating the optimal dorsal-ventral cutting/reading plane (angle). The cutting angle is critical because the otoliths are so small.
2. Processing larger otoliths (greater than a certain size) more carefully to ensure that there is a better chance of producing a readable section. The method used here involved cutting a section through a block containing 5 otoliths aligned approximately along the cutting axis. This may not provide the best preparations but was used to conserve resources. Previous preparation, e.g., 1995 included preparation of 1–3 larger otoliths embedded in a single block as well as blocks of 5 smaller otoliths in a single block.

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APPENDIX A: STATION SCALING FACTOR

Table A1.1: Station scaling factors for tows used in age frequency estimates for Area 1. Coded station numbers are station number for the 2002 survey, station number + 100 for the 2006 survey, and station number times 100 for the 1995 survey.

Station number	Mark-type	Scale factor	Recorded catch (kg)
17	LAYEROFF	8.910	180
16	LAYEROFF	1.044	2
19	LAYEROFF	1.124	2
18	BACK	15.415	401
110	LAYER	0.343	8
111	LAYER	4.800	2 121
112	LAYER	7.439	3 108
113	LAYER	2.846	596
114	LAYEROFF	1.487	4
115	LAYER	0.899	102
116	LAYER	4.078	2 152
117	LAYEROFF	1.941	8
118	LAYEROFF	23.716	1 644
120	LAYER	2.107	524
121	LAYEROFF	11.347	354
122	LAYEROFF	1.616	8
119	LAYEROFF	4.184	46
1000	BACK	3.288	36
1900	BACK	3.415	39

Table A1.2: station weights for tows used in age frequency for Area 2&3. Coded station numbers are station number for 2002, station number + 100 for 2006, and station number times 100 for 1995. Note that station 100 is station 1 from the 1995 survey.

Station number	Mark-type	Scale factor	Recorded catch (kg)
2	LONG	2.677	287
3	SHORT	3.448	2 270
5	SHORT	0.987	319
11	LONG	4.138	1 424
12	LONG	6.712	3 063
13	SHORT	4.953	7 450
15	LAYER	6.179	646
20	BACK	15.35	121
21	LAYEROFF	8.043	918
101	SHORT	0.107	4
102	SHORT	1.584	528
103	LONG	2.398	277
104	LONG	5.89	3 182
105	LAYER	8.985	1 119
106	LONG	5.876	2 341
108	SHORT	0.328	14
107	SHORT	2.343	619
100	BACK	7.503	57
400	BACK	3.17	10
1400	BACK	3.445	11
16000	BACK	3.481	12
600	LAYER	1.742	147
700	LAYER	0.663	21