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Comparison of Challenger Plateau (ORH 7A) orange roughy age estimates between 1987 and 2009

New Zealand Fisheries Assessment Report 2013/2

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Otoliths from the orange roughy trawl surveys of the Challenger Plateau (ORH 7A) spawning area conducted during June and July 1987 and 2009 were prepared and read by two readers (n=140 from each survey). The aim was to determine whether the spawning aggregations that reappeared in about 2007 were composed of new recruits or whether they were immigrants from another stock including older fish. When unreadable otoliths were excluded, the numbers of age estimates used in the analysis were 132 for 1987 and 131 for 2009. There was no apparent bias between readers and the between-reader precision had a c.v. of 7.8%. Data were scaled up to the whole survey area using the stratum abundance estimates (in numbers) and the relative tow catch density (numbers/km^2) within each stratum.

The 2009 fish were twenty years younger, on average, than those in 1987 (33 years compared with 53). The age composition difference between the two years is so marked that only 3% of the 2009 fish are older than the mean age in 1987. In addition 24% of the 2009 fish have no identifiable transition zone (which is believed to be linked to the onset of maturity) compared to just 0.8% with no zone in 1987. We conclude that 2009 fish are mainly a pulse of recently matured fish and not the result of migration from some other lightly fished stock.

1. INTRODUCTION

This work addresses the following objectives in MPI project DEE2010/08, Targeted ageing of otoliths from selected deepwater stocks.

1.1 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.

1.2 Specific objective

2. To estimate the age of orange roughy in Challenger (ORH 7A) by analysing research samples from one of the trawl surveys carried out from 1987 to 1990 and also from the trawl survey in 2009.

1.3 Orange roughy — Challenger Plateau (ORH 7A)

This fishery commenced in 1981 on the southwest Challenger Plateau. The TACC peaked at 12 000 t in 1987–88, and was reduced in 1989–90 and several times after that until the fishery was effectively closed from 1 October 2000 (with a TACC of 1 t). As part of the research for this stock, a series of trawl surveys were carried out during the spawning season from 1987 to 1990 (Clark & Tracey 1994). Starting in 2005, the Orange Roughy Management Company Ltd/Deepwater Group Ltd commissioned combined acoustic and stratified random trawl surveys for orange roughy to investigate the current state of the stock. These surveys were on spawning fish in the south-western part of the Challenger Plateau in 2005, 2006 and 2009 (Clark et al. 2005, 2006, Doonan et al. 2009), and also in 2010 (Doonan et al. 2010). These surveys used the same trawl gear design, core strata, and survey protocols (but a different vessel) as the earlier (1987 to 1990) trawl survey series.

In 2009 and 2010, spawning plumes were found close to the area where they were last observed in 1989. There are at least two hypotheses for their reappearance in 2009: that the new plumes are young fish, i.e., new recruits to the spawning population; or that older fish have re-colonised the area. Length frequencies are not helpful for testing these hypotheses because age structure estimated from length data is poorly determined after maturation. However, these hypotheses can be tested by constructing and comparing mean age and age frequencies directly estimated by reading otoliths from two surveys (i.e., 1987 and 2009).

2. METHOD

2.1 Ageing of orange roughy

Before 2007, age estimates produced by different agencies had poor comparability (Francis 2005, 2006, Hicks 2005), which led to low confidence in the age-frequency data and resulted in age data being excluded from the stock assessments carried out in 2006. Francis (2006) suggested that a significant source of between-agency bias was the method used to identify the transition zone (TZ), a feature believed to be associated with the switch from somatic growth to gamete production.

In response, an Orange Roughy Ageing Workshop was held in 2007 to improve otolith preparation and interpretation between agencies, especially in relation to the TZ. A new protocol for age interpretation was developed during the workshop. In 2009, the new protocol was tested by two NIWA readers and two FAS (Fish Ageing Services Pty. Ltd., Victoria, Australia) readers by ageing the otolith pairs from 160 fish, i.e., potentially eight age estimates per fish. The new protocol solved the inter-agency problems.

Early growth of orange roughy was validated by examining the otolith marginal increment type and length frequency analysis (Mace et al. 1990). Andrews et al. (2009) applied an improved lead-radium dating technique to otolith cores, grouped by growth-zone counts from thin sections. Results showed a high degree of correlation of the growth-zone counts to the expected lead-radium growth curve, and provided support for both a centenarian life span for orange roughy and the age estimation procedures using thin otolith sectioning.

Preparation and reading of otoliths

We used NIWA's preparation method since the CAF (Central Ageing Facility, Victoria, Australia) prepared otoliths have a higher proportion of unreadable otolith sections (Tracey et al. 2007). Briefly, the left otolith was individually embedded in resin and cured in an oven. Thin sections were cut along a line from the primordium through the most uniform postereo-dorsal axis. The section was mounted on a glass microscope slide under a glass cover slip.

To estimate ages of orange roughy, otoliths were read once by two different readers and the estimated ages averaged. Otolith interpretation and reading protocols followed those described in the Ageing Workshop Report (Tracey et al. 2007).

Total reader error analysis

Data with one readability code of 5 (i.e., unreadable) for either of the readings were excluded.

Only between-reader variability (consistency) for otolith readings was considered. First, 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 c.v. of between-reader error from the two readings for each otolith. This is related to the index of average percentage error (IAPE) (Campana et al. 1995, Campana 2001) by c.v. = 1.4 x IAPE%.

2.2 Analytical method

To simplify the method and to deal adequately with precision of estimates, we assigned a probability to each otolith collected which represents the contribution that the tow the otolith came from makes to the total abundance (in numbers), and also the number of samples in the tow, i.e., all otoliths in the same tow get the same probability. This assumes that the otolith sampling was random. (For non-random selection, you may be able to use the length frequency to give the sampling probability within the tow.) The selection probability is based on all otoliths that are available. The set of all otolith ages and their associated probabilities is an approximation to the age distribution. The probabilities collapse all survey structure into one number and so does not have to be considered again.

Otolith selection was a random sample with replacement (as is done in bootstrapping) using the otolith probabilities. Mean age was the mean over this sample.

2.2.1 Otolith probabilities

The mean age for the population from a stratified random trawl survey was a weighted average of the mean ages from each tow, i.e.,

$$\frac{\sum_{s}^{strata}\frac{A_s}{m_s}\sum_{i}^{tows\,in\,stratum\,s}\left(\frac{1}{n_{is}}\sum_{j}^{otoliths\,in\,tow\,is}a_{isj}\right)N_{is}}{\sum_{is}\frac{A_s}{m_s}N_{is}}$$

where a_{isj} is the age from the j^{th} otolith in the i^{th} tow in the s^{th} stratum, n_{is} is the number of otoliths sampled in the tow, $\frac{1}{n_{is}}\sum_{j}^{otoliths\,in\,tow\,is}a_{isj}$ is the mean age in a tow, N_{is} is the fish density in the is^{th} tow, A_s is the area of stratum s, and m_s is the number of tows in stratum s. For a single otolith, the probability of selection is

$$\frac{\frac{A_s}{m_s}N_{is}\frac{1}{n_{is}}}{\sum_{is}\frac{A_s}{m_s}N_{is}}.$$

Excluding the term $\frac{1}{n_{is}}$, the rest of the selection probability is the station's contribution to the overall population size, in numbers. N_{is} is obtained from the catch density using a mean weight from using aL^b, where L is the length and a = 9.21e^{-05} and b = 2.71.

<u>Otolith selection</u>

The number of otoliths prepared was n_{unique}. Ages associated with each otolith were selected with replacement using the otolith selection probabilities above. In selecting the ages, we implicitly select the otoliths. Ages are not known at selection time but this selection determines the data to use in the mean age or age frequency when the ages from otoliths were estimated. Since an age estimate may be used more than once the number of ages, n_{ages}, is likely to be greater than n_{unique}.

Random sampling of ages was carried out one at a time until the number of unique otoliths equals n_{unique}. The procedure was continued to provide a selection of spare otoliths which are needed to replace damaged or lost ones. The spares were used in the order of their selection.

<u>Analysis</u>

The data consisted of the age estimate from each otolith replicated by any repeat count. The mean age estimate is the sample mean. The age frequency is the fraction of data at each age over this sample. Standard error was assessed using a bootstrap analysis where tows were resampled along with the ages within each selected tow. Where there was little within-tow correlation, the analytic standard deviation is given by

$\sqrt{\sum_i^{otolith} n_i s^2 / n_{\text{ages}}{}^2}$, where n_i is the number of repeat counts for an otolith and s^2 is the sample standard variance.

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 function used density from the R statistical package (R Development Core Team, 2010). *Width* was set to 10.

Simulations of age estimates

The above method was new so we carried out simulations to test it. First, we simulated selections with and without age estimate replacement to show why replacement is needed i.e., why we need repeat counts for each unique otolith. Second, simulations were carried out selecting 130 otoliths, to mimic the new analysis.

Sampling with replacement was needed to make the age estimates unbiased. Figure 1 shows an artificial distribution of "ages" and selection based on taking 5 samples in each of 20 bins for a total of 100, i.e., over-sampling the younger ages. Simulated samples of 50 were taken from the 100 selected set using probability sampling from the selections and calculating the sample mean and standard deviation (s.d.). This was repeated 1000 times and the mean of the sample means and s.d. calculated as well as the number of means in the theoretical 95% confidence interval. Two versions were investigated: sampling with replacement, and sampling without replacement from the selection. The results are shown in Table 1 where the true mean age is 12.33 with a s.d. of 4.36 years. Sampling without replacement gave a small negative bias because sampling without replacement forced selections from lower probability bins when all 5 selections had been made from the higher probability bins.

Table 1: Results of sampling age estimates with and without replacement (see text for details).

	Mean age(years) for 1000 simulations	Mean s.d. (years)over 1000 simulations	Number of means in theoretical 95% C.I., expected = 950
With replacement	12.37	4.40	947
Without replacement	11.54	4.64	842

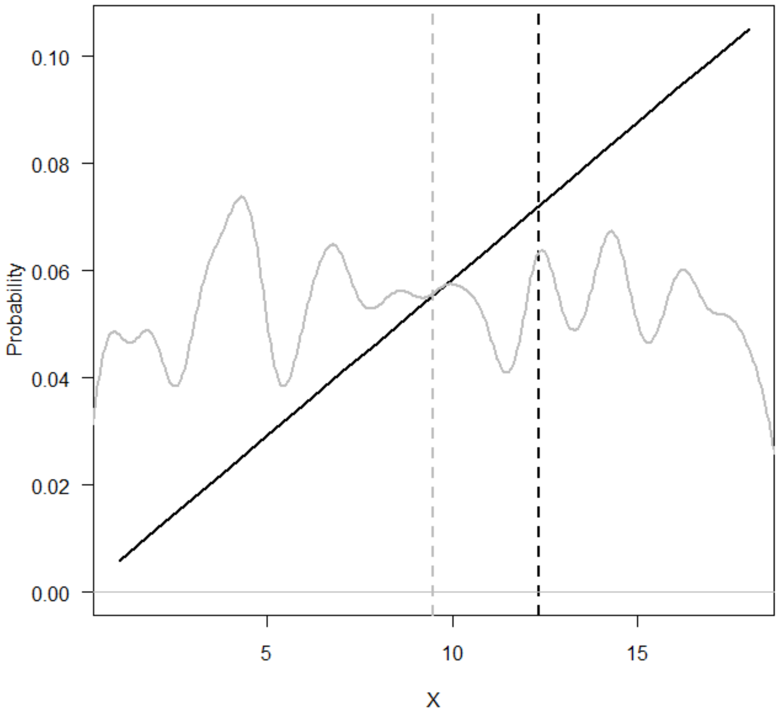

Figure 1: Probability distribution (black solid line) with its mean (vertical dark dashed line) and the distribution of one simulated sample of 5 from each X-bin (grey solid line) with its mean (vertical gray dashed line).

There is also a question of how well an age frequency is estimated using a small number of ages, e.g., 130, as in this study. This was tested using age distributions modelled as normal distributions, truncated at age 1 in each of three strata, but each stratum was made non-homogeneous, and was modelled as two sub-areas with different distributions in each sub-area. This allows for some correlation which commonly occurs in fisheries data, e.g., ages and lengths from a tow are more alike than those between tows.

Figure 2 shows the results of 100 simulations for age frequencies using 130 unique otoliths and a smoothing parameter of *width* = 10. The median of the simulated age frequencies followed the true age frequency and the median of the bootstrap (pointwise) 95% interval approximated the 95% pointwise interval from the simulated age frequencies, so on average the method gives good results. The worst result is shown for the simulation where the bootstrap pointwise 95% confidence intervals had the lowest percentage of the true age frequency within it (Figure 3). In an individual simulation, results are variable, but the bootstrap 95% interval does give guidance on where the true frequency is located and also on the main features .

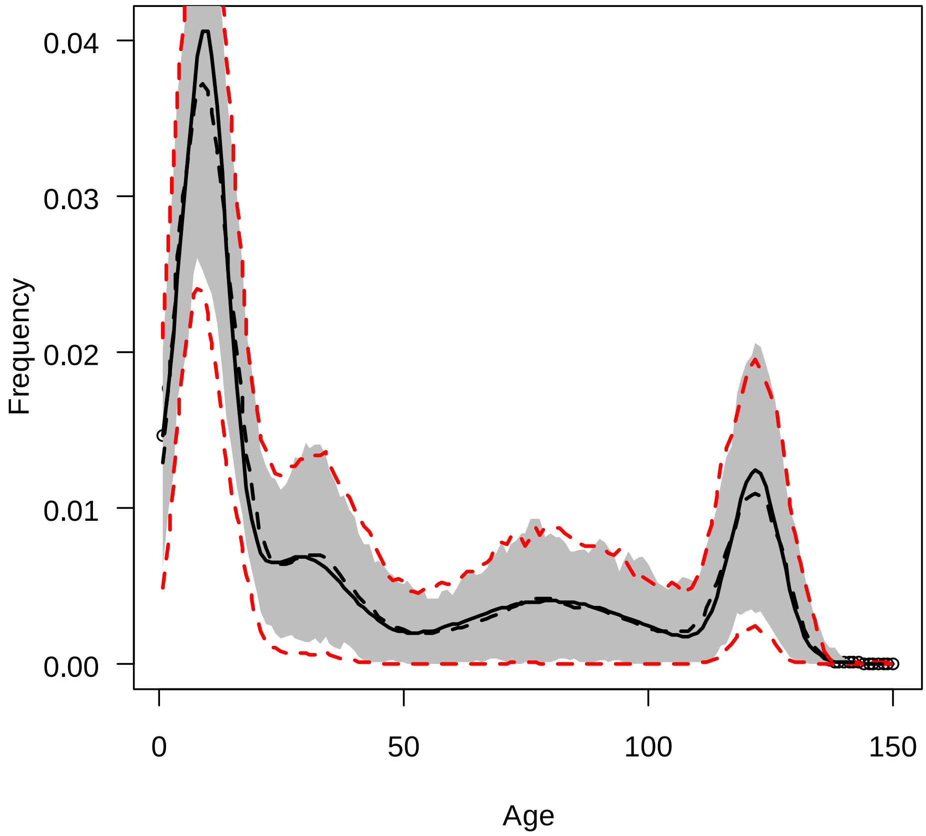

Figure 2: Age frequency using a sample size of 130 unique otoliths. True distribution, black solid line; median for the simulated age frequencies, black dashed line; median of the bootstrap upper 97.5% (pointwise),upper red dashed line; median of the bootstrap lower 2.5%, lower red dashed line; 95% pointwise area for the 100 simulated age frequencies, grey shading.

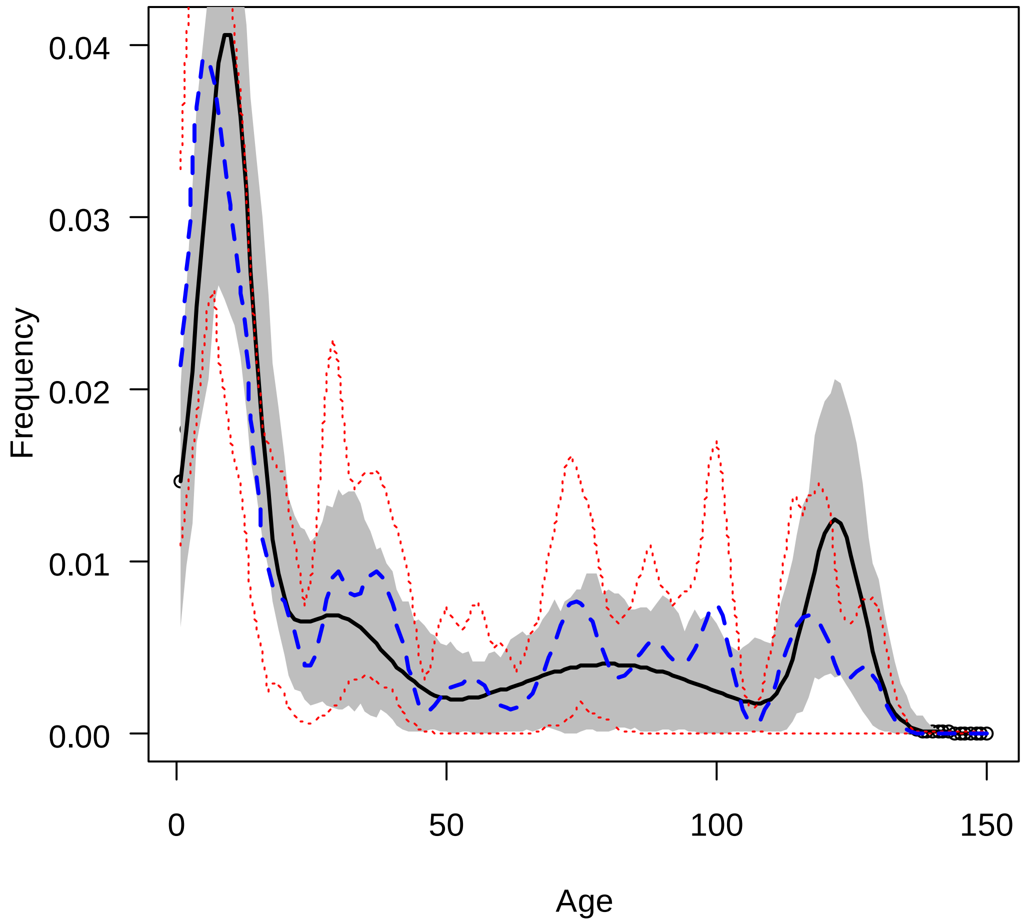

Figure 3: Age frequency using a sample size of 130 unique otoliths from tow simulations that had the lowest percentage of the true frequency within the bootstrap intervals (pointwise), i.e., worst case from 100 simulations. True distribution, black line; simulated age frequency, blue dashed line; bootstrap upper 97.5% (pointwise), upper red dotted line; bootstrap lower 2.5%, lower red dotted line; 95% pointwise area for the 100 simulated age frequencies, grey shading.

2.3 Surveys selected

2009 survey

The 2009 trawl survey was conducted from 26 June to 6 July using the FV *Thomas Harrison* (Doonan et al. 2009). This survey was the third in a re-vamped series starting in 2005, with the second survey in 2006. Strata are shown in Figure 4 and the design was a random stratified survey using two phases (after Francis 1984). Tow length was 1.5 n. miles. We excluded otolith samples from the Westpac Bank since these fish spawn later and may be a different stock.

The bottom trawl used for the survey was a four-panel net ("Arrow" trawl) with cutaway lower wings, a single lengthener, and two codends. The gear was set up in a similar manner to that used in trawl surveys in the 1980s, with a rubber and steel bobbin rig, 24 headline floats (1500 m rated), 0.5 m layback, 50 m bridles, and 70 m sweeps. Doors were High-aspect Super-Vees (2300 kg, 7 m^2). Doorspread was recorded at 120–147 m (average 137 m). The average headline height was 5.5 m and the average trawling speed was 3.1 knots.

Detailed biological sampling was carried out on 20 orange roughy from each tow, recording weight, sex, gonad stage, stomach fullness (and contents noted on some occasions), and otoliths extracted. Multiple samples were taken from large catches (one sample per 10 t).

The total number of valid abundance tows was 64, of which 59 were in the EEZ zone part of the survey. The total abundance index was 48 749 t (c.v. 26%).

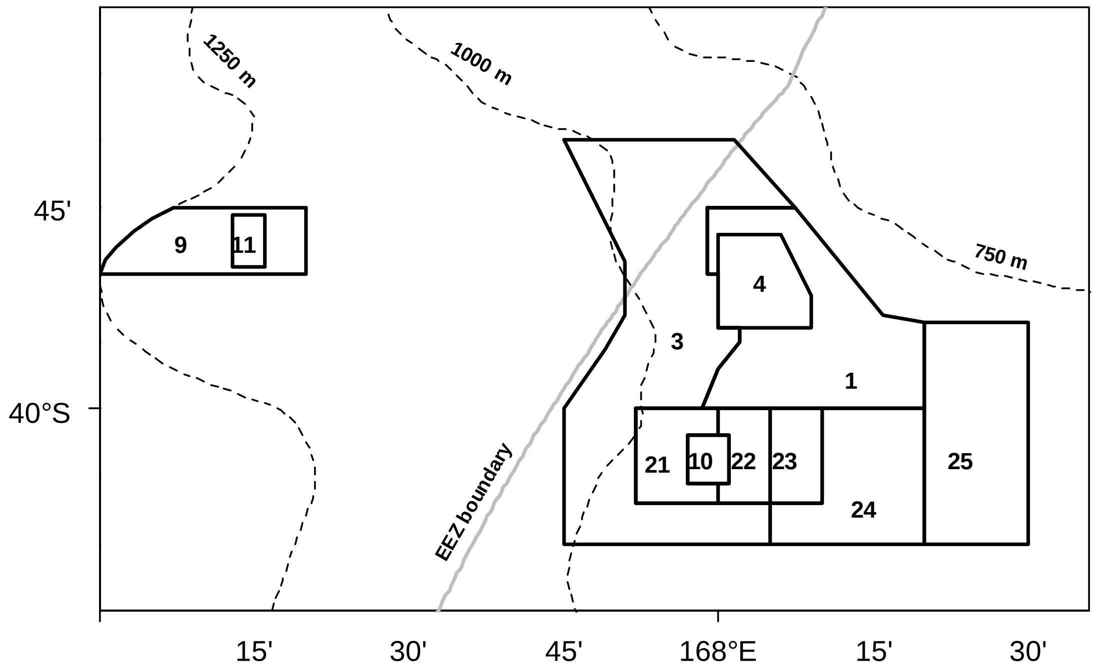

Figure 4: The 2009 survey area, showing the trawl survey strata. Strata 9 and 11 (Westpac Bank) were excluded from the analysis (from Doonan et al. 2009).

<u>1987 survey</u>

Clark & Tracey (1994) reviewed data on the Challenger Plateau orange roughy stock, including the research trawl survey series from 1984 to 1990. These surveys were all carried out in the June-July period, but the survey stratification and the method were not standardised until 1987. The latter surveys were therefore selected as candidates to use in the analysis. The trawl survey series starting in 1996, including 2009, were based on the core strata used in 1987 to 1990, and also used a similar net, i.e., the Arrow style net. The aggregation on the flat was present in 1987 (Clark & Tracey 1994), but only a small aggregation was seen in 1988, and no aggregation was seen in 1989. Over the period 1988 to 1990, the commercial fleet switched fishing from the flats onto nearby hills.

Because it was the only candidate that sampled two spawning plumes, the 1987 survey was selected as the early survey to be analysed. It was conducted in June-July 1987 by the FV *Amaltal Explorer*. The survey had three parts (Clark & Tracey 1988) and the data used here came from the second part which covered the core survey area (similar to, but not quite the same as, in the 2009 survey) from 25 June to the 1 July (again similar to the first half of the 2009 survey). The first part covered a much wider area and was earlier in the year than the 2009 survey, and the third part targeted the two plumes on the central flats. In the second part of the survey, there were 54 tows and otoliths were collected from each tow from up to 20 individuals (or 60 for the largest catches - sampling from the start, middle and end of the catch bag). The strata used were 1, 2, and 3 (see A1, A2, and A3 in Figure 5, Table 2). Tows were 1.5 n. miles long.

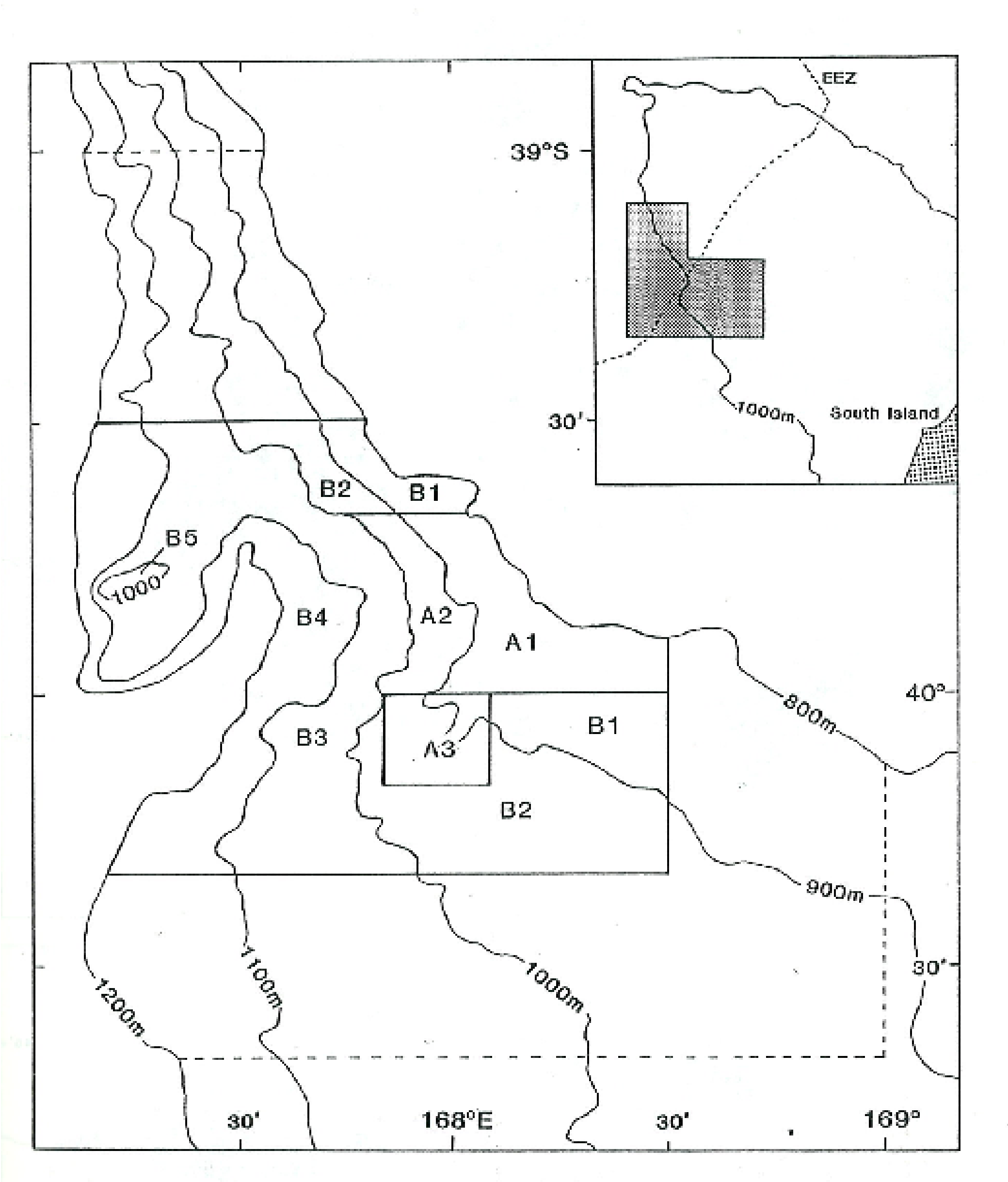

Figure 5: Survey strata for the 1987 Challenger Plateau survey. For part 2 of the survey, strata A1, A2, and A3 were surveyed (reproduced with permission from Clark & Tracey 1988).

The largest catch of orange roughy was 35 t and five catches were 19 t or more. The smallest catch was 4.4 kg. The abundance was estimated as 60 000 t using wingtip spread as the swept area (22.8 m).

Table 2: Stratum detail and results from Part 2 of the 1987 survey. Abundance estimates are wingtip values.

Stratum	Area (km^2)	Number of tows	Abundance (t)	Description
0001	727	30	48 800	Stratum A1, 800–900 m
0002	382	12	2 200	Stratum A2, 900–1000 m
0003	228	12	9 000	Stratum A3, around the Pinnacles

3. RESULTS

3.1 Otoliths and precision

The number of otoliths processed from each survey was 140. Appendix 1 lists the stations used and their relative contribution to the abundance. The number of unreadable otoliths removed was 17 (Table 3).

Table 3: Unreadable otoliths by reader and year.

Survey	Reader 1 only	Reader 2 only	Both readers	Total
1987	0	7	1	8
2009	1	4	4	9
Total	1	11	5	17

The number of otoliths used in the analysis was 132 for 1987 and 131 for 2009. When the repeat counts were applied, there were 149 ages for 1987 and 169 ages for 2009.

Reader’s estimated ages are plotted against each other in Figure 6 and mostly show no bias, except for a difference of 1.5 to 3 years in the interval 50–72 yr. The between-reader c.v. was 7.8% which compares favourably to the 15% obtained in the protocol testing study which used four readers (Tracey et al. 2007).

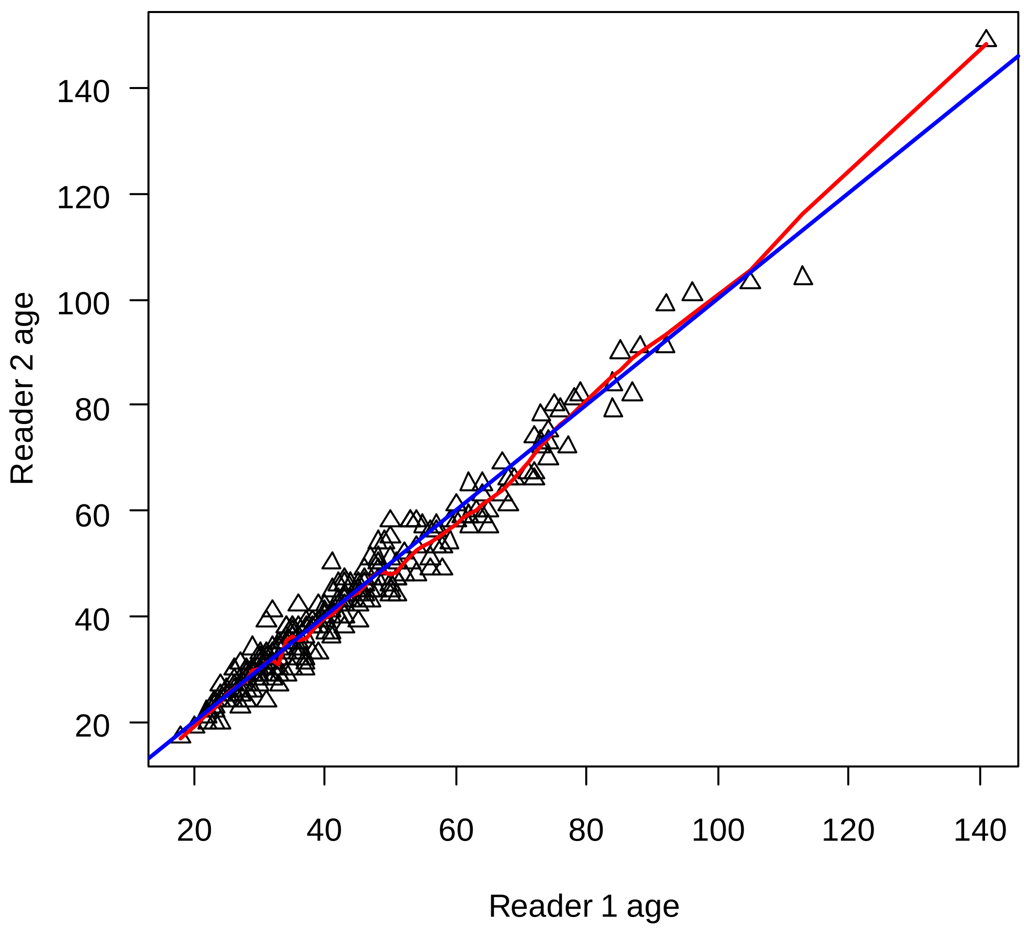

Figure 6: Comparison of ages from two readers for the same otolith. Also shown are the 1:1 line (blue) and a smoothed curve (red).

3.2 Mean age

The mean ages were very different between the two surveys, with the 2009 fish being 20.5 years younger than those in 1987 (Table 4). The difference was highly statistically different (t-test value of 7.64 using the bootstrap s.e.; 5% level is 1.96).

Table 4: Estimated mean age for the 1987 and 2009 trawl surveys (bootstrap s.e. did not use resampling within strata).

Year	Number of unique otoliths	Total number of ages in mean	Mean age (yr)	Analytical s.e.	Bootstrap s.e.	Weighted c.v. for age frequency
1987	132	149	53.3	1.8	2.4	85.5
2009	131	169	32.8	0.9	1.2	64.4

3.3 Age frequencies

Figure 7 shows the estimated age frequencies for the two surveys. The age range was from 26 to 145 in 1987, and from 18 to 90 in 2009.

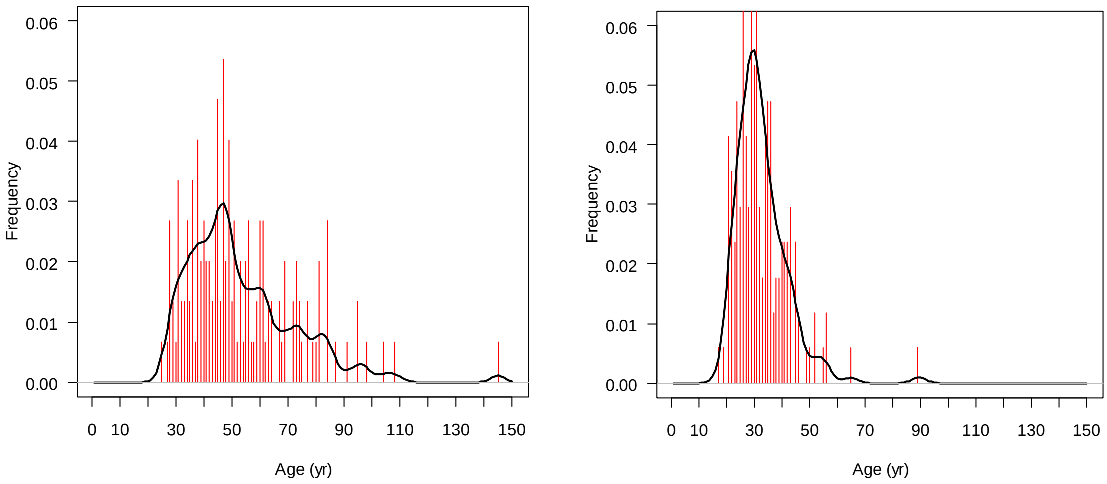

Figure 7: Smoothed age frequency (curve) and the raw frequency (vertical lines) for 1987 survey (left panel) and the 2009 survey (right panel).

Almost all overlap of the 95% pointwise confidence intervals (CI) is between ages 34 and 48 (Figure 8) and so the pattern looks highly significant even though the weighted c.v. for each age frequency is over 60% (Table 4). The difference between the surveys is so great that only 3% of the 2009 fish are older than the mean age in 1987.

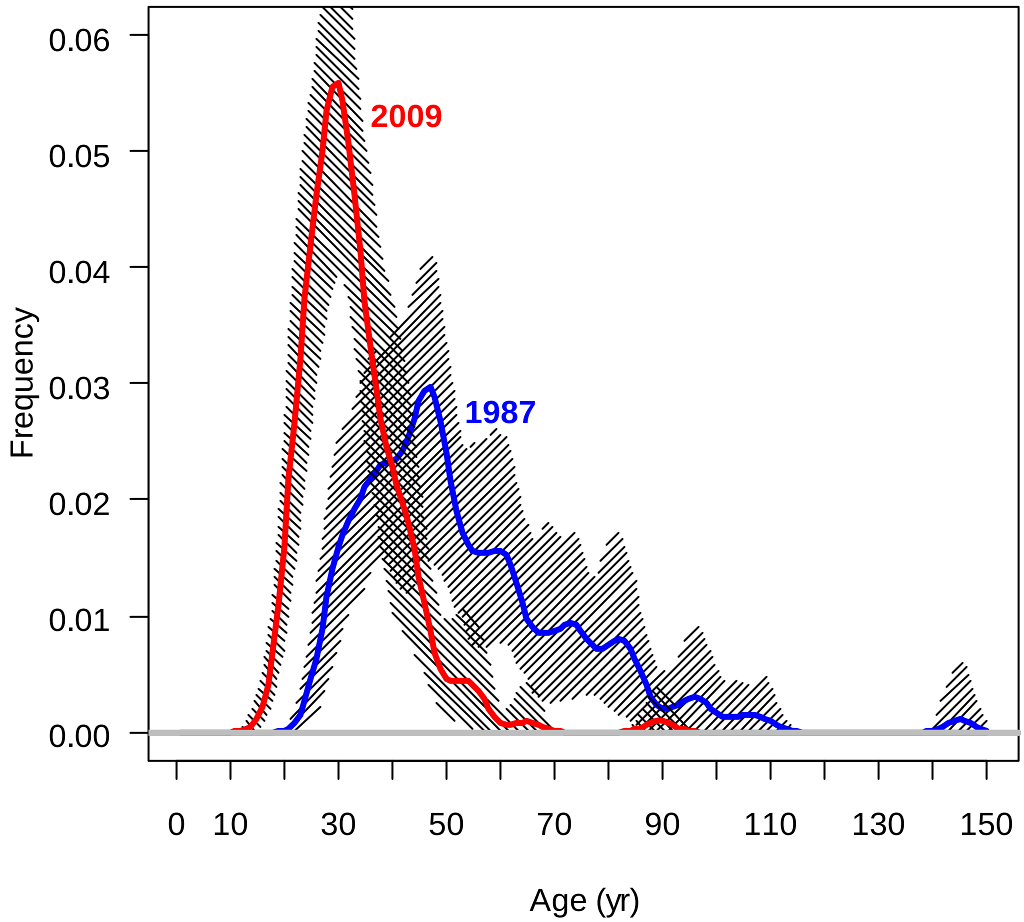

Figure 8: Comparison of age frequencies (curved lines) for 1987 and 2009 with their pointwise 95% confidence intervals (slanted lines).

Another indication that the 2009 ages are much younger is that 24% of the 2009 fish have no identifiable TZ, compared to just 0.8% in 1987. The TZ has been linked with the onset of maturity which is relevant to fish migrating to a spawning aggregation. Note that the TZ is not identified until a number of subsequent zones are put down so all of these fish may have had a TZ, but it could not be identified by the readers.

4. DISCUSSION

The 2009 fish are twenty years younger, on average, than those in 1987. The mode in the age frequency reduced from about 45 to 30 years over the 22 year period between surveys. In 1987–88 the fishery had built to a peak and the 2000 stock assessment estimated the 1987 stock size at approximately 30% B_0 (Ministry for Primary Industries, 2012) so that fishing up to 1988 would have had an impact on the shape of the age frequency. A similar change in age frequency occurred in the fishing down phase of the Australian Eastern Zone Orange Roughy stock (mainly St Helen's Hill). There, the abundance was approximately 25% B_0 in 1992 after three years of fishing and the age frequency had a mode at about 50 years, which reduced to 30 years in 2004 with few fish aged over 60 (Wayte 2006). After a low point in 1994, the stock assessment indicated that the stock was rebuilding slowly so that the fish in 2004 were mainly new recruits from the previous decade.

The recovery of the Challenger Plateau orange roughy stock following the fishery closure was probably the result of new recruitment. The youngest age in the 2009 data was about 18 years and the mode was 30 years so these fish were spawned well before the time of the stock collapse and the fishery closure (1997–98). One alternative view is that the Challenger Plateau fishery did not collapse as reported in the 2000 stock assessment which led to the closure, that fishing disturbed the spawning fish and they did not come back again. Another alternative view was that there were pockets of other fish that were never fished and that these migrated into the area and subsequently came to spawn there. If either of these alternatives were true, then the fish in the re-formed spawning aggregations should have included a substantial proportion of older fish that had either survived from the earlier fishery or were migrants. The results presented here do not support these views, and given the similarities with the collapse of the Australian Eastern fishery it is most likely that the Challenger Plateau orange roughy stock collapsed because most of the older fish were caught.

5. ACKNOWLEDGMENTS

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APPENDIX 1: STATIONS USED IN THE MEAN AGE CALCULATION FOR THE 1987 AND 2009 CHALLENGER PLATEAU SURVEYS.

Table 1.1: 1987 survey stations and catch and relative population by station (%) used to randomly sample otoliths (probability to select one otolith from a station is relative to station population and the number of otoliths sampled in the station).

Station number	Stratum	Relative station population (%)	Catch (kg)
76	1	0.456	668
77	1	0.736	1128
78	1	1.119	1901
79	1	0.176	258
80	1	0.010	14
81	1	5.218	3231
82	1	12.301	19575
83	1	0.430	688
84	1	0.464	736
85	1	0.462	690
86	1	0.891	1375
87	1	1.020	1730
88	1	11.581	19247
89	1	4.279	7201
90	1	16.448	25932
91	2	0.725	845
92	2	0.245	306
93	1	20.76	34987
94	2	1.149	1469
95	1	0.040	64
96	1	0.430	739
97	1	0.098	146
98	1	2.012	3262
99	1	0.210	324
100	2	0.605	738
101	1	0.298	478
102	1	0.017	28
103	1	0.007	12
104	1	0.207	296
105	1	0.193	318
106	3	0.234	465
107	3	14.935	27247
108	3	0.124	226
109	3	0.079	142
110	3	0.144	239
111	3	0.058	98
112	3	0.035	60
113	3	0.057	98
114	3	0.238	440
115	3	0.094	176
116	3	0.089	153
117	3	0.419	743
118	2	0.101	113
119	2	0.040	45
120	2	0.035	35
121	2	0.059	77
122	2	0.090	93
123	2	0.045	45
124	2	0.092	111
125	2	0.360	475

Station number	Stratum	Relative station population (%)	Catch (kg)
126	1	0.019	30
127	1	0.012	17
128	1	0.004	4
129	1	0.051	76

Table 1.2: 2009 survey, stations and catch and relative population by station (%) used to randomly sample otoliths.

Station number	Stratum	Relative station population (%)	Catch (kg)
1	1	0.015	2
2	1	0.119	18
3	1	0.135	20
4	4	0.349	186
5	3	0	0
6	3	0.728	44
7	3	0.125	7
8	4	0.055	22
9	4	0.046	24
10	1	0.201	29
11	23	0.287	852
12	23	2.546	7587
14	22	0.030	78
15	22	0.010	33
16	22	0.049	137
17	22	0.944	2738
18	22	10.756	16087
19	10	0.753	3105
20	10	0.112	824
21	10	0.055	577
22	22	4.356	11777
23	22	2.283	6332
24	23	14.004	38175
32	21	0.771	451
33	21	1.13	710
34	21	0.047	28
36	10	2	5101
37	23	0.928	3026
38	23	11.452	16023
39	25	0.011	3
40	25	0.023	7
41	22	0.656	1765
42	22	0.035	97
43	23	0.668	1984
44	23	0.074	239
45	24	0.262	245
46	24	11.295	10000
47	25	0.023	9
48	25	0.316	150
49	24	2.045	1689
50	23	0.115	320
51	23	0.249	705
52	23	0.243	705

Station number	Stratum	Relative station population (%)	Catch (kg)
53	24	0.103	91
54	23	0.102	303
55	22	3.108	7649
56	24	0.057	54
57	24	0.021	18
58	25	0.107	47
59	25	0.170	69
60	25	0.080	35
61	25	0.098	44
62	24	0.103	91
63	24	0.274	244
64	24	0.288	262
65	24	4.837	4428
66	24	18.209	7675
67	24	0.072	68
68	23	2.065	5806