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Orange roughy age estimates: Chatham Rise (ORH 3B) spawning plumes in 2012, and mid-east coast North Island (ORH 2A) fishery from 1989–91 and 2010

New Zealand Fisheries Assessment Report 2014/24

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EXECUTIVE SUMMARY

Doonan, I.J.; Horn, P.L.; Ó Maolagáin, C. (2014). Orange roughy age estimates: Chatham Rise (ORH 3B) spawning plumes in 2012, and mid-east coast North Island (ORH 2A) fishery from 1989–91 and 2010.

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Otoliths from each of two spawning plumes (Main Plume and Rekohu Plume) were collected on an acoustic survey of the northeast Chatham Rise orange roughy (ORH 3B) spawning area conducted during June and July 2012. Otoliths were prepared and read by one reader following the accepted ageing protocol. The aim was to determine if mean age and the age frequency were different between the two plumes since fish from the Rekohu Plume had mean lengths that were 1 cm smaller than fish from the Main Plume. Data were scaled up to the whole plume using the catch size (in numbers). The Rekohu Plume fish were twelve years younger, on average, than those in Main Plume i.e., 42 compared with 53 years, statistically significant at the 1% level. The within-reader precision had a CV of 6%. The age composition difference between the two plumes was very marked and was also statistically significantly different. In addition, growth rates were similar from the two plumes.

Otoliths from the mid-east coast North Island orange roughy commercial fishery (ORH 2A) collected from 1989–91 and 2010 were prepared and read to produce age data for inclusion in an assessment of this stock. The age distribution of the 1989–91 sample differed to that produced from previous readings of the same sample. The differences were largely attributable to whether or not a transition zone was identified in the otolith. The new age estimates were included in the stock assessment because they were produced using an agreed protocol developed in 2007. The mean age of orange roughy taken by this fishery declined by about 12 years between 1989–91 and 2010.

1. INTRODUCTION

This report fulfils the reporting requirements for Objective 8 of Project MID201001C, “Routine age determination of hoki and middle depth species from commercial fisheries and trawl surveys”, funded by the Ministry for Primary Industries. The objective was: “To age other species as required for validation of the ageing technique or for targeted studies to meet specific research requirements”. The work identified for 2012–13 was the otolith preparation and ageing of samples of orange roughy from spawning plumes on the northeast Chatham Rise and the commercial fishery off the mid-east coast of North Island (MEC).

Before 2007, orange roughy age estimates produced by New Zealand and Australian readers 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 (Tracey et al. 2007). In 2009, the new protocol was tested by two NIWA and two FAS (Fish Ageing Services Pty. Ltd., Victoria, Australia) readers by ageing the otolith pairs from 160 fish, i.e., potentially 8 age estimates per fish. The new protocol solved the inter-agency problems, and provided a consistent and documented method for the interpretation of growth zones in orange roughy otoliths.

Early growth of orange roughy was validated by examining the otolith marginal increment type and by 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 for the age estimation procedures using thin otolith sectioning.

1.1 Northeast Chatham Rise spawning plumes

A new spawning plume (the Rekohu Plume) was observed (but not fished) in the winter of 2010 on the northeast Chatham Rise (ORH 3B) while steaming back to port after an acoustic survey of the regular spawning plume (the Main Plume). The acoustic survey series of the Main Plume started in 2002 and was conducted every year since. During the 2011 acoustic survey, the Rekohu Plume was fished and spawning orange roughy were caught in quantities expected from a spawning aggregation. Consequently, the Rekohu fish were included as part of the population in the area (Doonan et al. 2012). There is no record of the Rekohu Plume before 2010.

The estimate of abundance in the Main Plume in 2011 was 16 538 t (CV 7.5%), and the estimate for Rekohu Plume was 28 113 t (CV 18.3%) (Doonan et al. 2012). In 2012, the abundance estimates were 16 769 t (CV 9%), and 24 870 t (CV 10.8%) respectively (Ian Hampton, pers. comm.). In both the 2011 and 2012 surveys, the mean length was about 1 cm smaller in the Rekohu Plume relative to the Main Plume, suggesting that fish were younger at Rekohu.

It was difficult to reconcile the discovery of the new plume with the available information and assumptions about the biomass of orange roughy on the east and south Chatham Rise over the past few years. Consequently meetings of the Deepwater Fishery Assessment Working Group (DFAWG) in November and December 2012 recommended that otoliths collected during the 2012 survey should be aged to answer the following questions:

1. Is the average age of fish in the new plume younger (as they are 1 cm shorter on average)?
2. Are the age distributions from the two plumes different?

1.2 Mid-east coast North Island commercial fishery

In 2012–13, the age distribution of mid-east coast (MEC) orange roughy sampled in the 2010 research trawl survey was compared with the samples from the 1993 survey as one of three objectives in Project DEE2010-08. Age distributions from both surveys had modes at young ages, i.e., 20 in 1993, and 25 years in 2010 (I. Doonan, unpublished data). The observed frequencies were very different to those predicted in one of two reported assessment models for the MEC stock with the frequency at the modes being twice that for the predicted ones and with much smaller frequencies for fish aged over 40 years old. For the other reported model, the observed frequencies were shifted to older fish and the differences were not so extreme (Doonan et al. 2013b).

The DFAWG agreed that samples from the commercial fishery should be aged to determine whether this discrepancy was also observed for commercial samples. Commercial fishery (Market) samples from the MEC fishery collected in 1989, 1990 and 1991 fishery were previously aged by otolith readers from CAF (Central Ageing Facility, Victoria, Australia). However, these needed to be re-read using the orange roughy ageing protocol developed by Tracey et al. (2007). In addition, there were 239 otoliths collected from the fishery south of 38° 23′ S in June 2010 during a commercial fishing voyage by F.V. *Thomas Harrison*. The DFAWG agreed that these otoliths should be processed for ageing and then read. The new age data were made available for use in the 2013 MEC stock assessment.

2. METHODS

2.1 Ageing of orange roughy

Otoliths from the Chatham Rise spawning plumes and the 2010 MEC fishery were prepared using NIWA’s preparation method as reported by Tracey et al. (2007). Briefly, one complete otolith from each of the pairs was individually embedded in resin and cured in an oven. A thin section was cut along a line from the primordium through the most uniform posterior-dorsal axis using a sectioning saw with dual diamond impregnated wafering blades separated by a 380 µm spacer. The section was mounted on a glass microscope slide under a glass cover slip.

To estimate ages of orange roughy, all otoliths were read once by one reader. Otolith interpretation and reading protocols followed those described in the Ageing Workshop Report (Tracey et al. 2007). The data produced include counts of zones from the primordium to the TZ, and from the TZ to the otolith margin, and readability codes for those readings (on a 5-stage scale). Data with a readability code of 5, i.e., unreadable, for either the pre- or post-TZ readings were excluded.

Within-reader variability (consistency) for otolith readings was examined by re-reading about 50 otoliths from each of the two sampled areas. The pairs of age estimates 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 0.2). A lowess line that consistently deviates from the 1:1 line indicates bias between the two readings. Precision was quantified using the CV of between-reading 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 CV = 1.4 x IAPE%.

2.2 Analytical method for the Chatham Rise spawning plume data

The analysis method followed that of Doonan et al. (2013a) for ORH 7 orange roughy. 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 sampled orange roughy catch (in the tow the otolith came from) made to the total abundance (in numbers), and also the number of samples in the tow, i.e., all otoliths in the same tow had the same probability. This assumed that the otolith sampling was random. This selection probability was based on all otoliths that were available. The set of all otolith ages and their associated probabilities is an approximation to the age distribution. The probabilities collapsed all survey structure into one number and so does not have to be considered again. Otolith selection was a random sample with replacement (like bootstrapping) using the otolith probabilities. Mean age was the mean over this sample.

Otolith probabilities

A previous analysis (Doonan et al. 2012), used data from a stratified trawl survey but for the two Chatham Rise samples analysed here, there were no strata so the method was simplified. The mean age for the population was a weighted average of the mean ages from each tow, i.e.,

$$\frac{\sum_{i}^{tows}\left(\frac{1}{n_i}\sum_{j}^{otoliths\,in\,tow\,i} a_{ij}\right)N_i}{\sum_{i} N_i}$$

where a_{ij} is the age from the j^{th} otolith in the i^{th} tow, n_i is the number of otoliths sampled in the tow, $\frac{1}{n_i}\sum_{j}^{otoliths\,in\,tow\,i} a_{ij}$ is the mean age in a tow, and N_i is the fish density (in numbers) in the i^{th} tow. For a single otolith, the probability of selection is

$$\frac{N_i \frac{1}{n_i}}{\sum_{i} N_i}.$$

Excluding the term $\frac{1}{n_i}$, the rest of the selection probability is the contribution of the tow to the overall population size, in numbers. N_i 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.

Otolith selection

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 selected the otoliths. Ages were not known at selection time but this procedure 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 equaled n_{unique}. The procedure was continued to provide a selection of spare ototliths which were needed to replace damaged or lost samples. The spares were used in the order of their selection.

Growth comparison

Age-length data from the two samples were plotted on the same figure and a lowess smoother was applied through the data from each plume. The lowess curves were compared visually.

Analysis

The data consisted of the age estimate from each otolith replicated by any repeat count. The mean age estimate was the sample mean. The age frequency was 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 analytical standard deviation was given by

$\sqrt{\sum_i^{otolith} n_i s^2 / {n_{\mathrm{ages}}}^2}$, 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 used one parameter, *width*, which is approximately the moving window width over which the average age was calculated. The function used density from the R statistical package (R Development Core Team, 2010). *Width* was set to 10.

To test for significant differences in the age frequencies, a randomisation test was applied (Welch 1990). The test statistic was $\sum_{age} \left| cf_{Main\ Plume,age} - cf_{Rekohu,age} \right|$, where cf is the cumulative distribution. The null hypothesis was that there was no difference in the age frequencies between the two plumes. Under the null hypothesis, we randomly assigned the collective data between the two plumes, i.e., 296 for the Main Plume and 298 for the Rekohu Plume, recalculated the cumulative distributions, and calculated the test statistic. The procedure was repeated 500 times and gave the distribution of the test statistic under the null hypothesis. At the 5% level, the difference is statistically significant if the actual test statistic is in the 2.5% tails of the null hypothesis distribution.

2.3 Analytical method for the MEC fishery data

For the two MEC samples, no otolith selection was necessary. Only 239 otoliths were available from the June 2010 voyage and all were prepared. The 1989–1991 otoliths were already prepared, with sample sizes of 150, 200, and 249 from the three years, respectively.

The 2010 data did not have catches assigned for the tows where data were collected. It also included a few otoliths from ORH 2A south, whereas all data from the 1989 to 1991 landings were from ORH 2A, but this difference was ignored.

The raw age frequency distributions were plotted to compare years, because the 2010 data did not have catches by sampled tow, and the mean ages from the raw ages were also compared. Growth was compared between years 1989–91 and 2010 using a lowess smoother. For the 1989–91 data, a weighted age frequency was produced by scaling the age data from each sampled trip to the total catch weight from that trip.

3. RESULTS

3.1 Chatham Rise spawning plumes

Otoliths and ageing precision

The number of otoliths processed from each plume was 300. Appendix 1 lists the stations used and their relative contribution to the abundance. Five unreadable otoliths were removed, three from the Main Plume and two from the Rekohu Plume. There were 296 Main Plume and 298 Rekohu Plume otoliths used in the analysis.

Estimated ages where two readings were available for a single otolith (i.e., 50 repeat counts for Rekohu otoliths) are plotted against each other in Figure 1 and mostly show no bias. Within-reader CV was 6% which compares favourably to the 15% obtained in the protocol testing study which used four readers (Tracey et al. 2007).

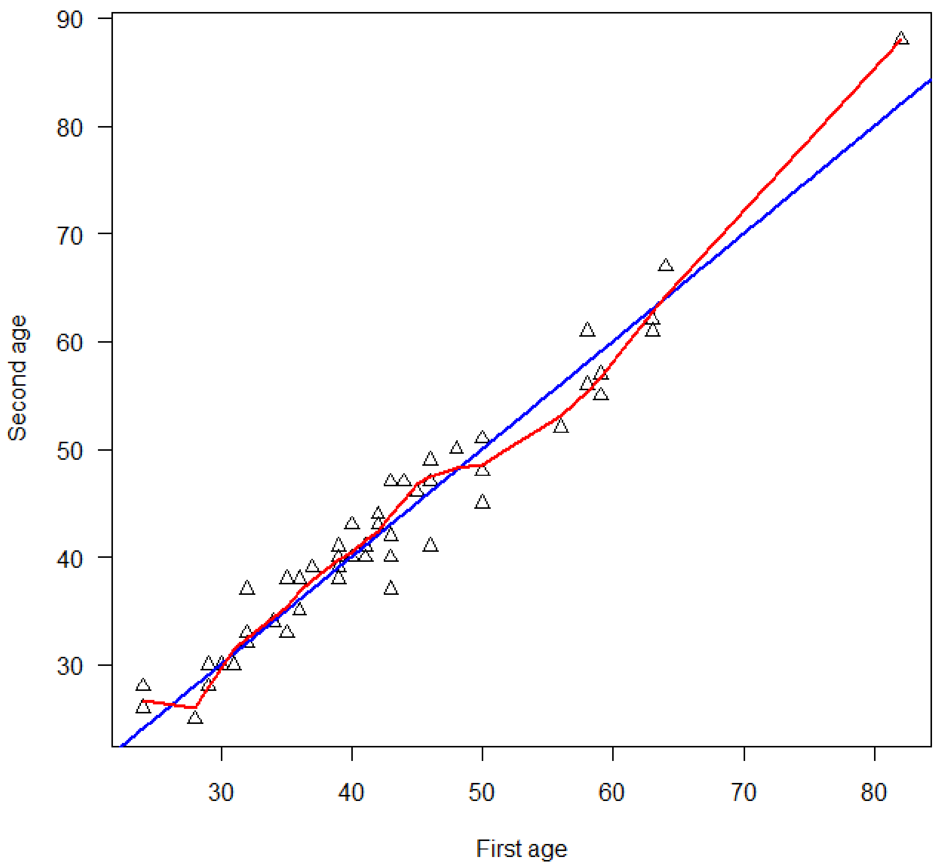

Figure 1: Comparison of ages from two readings of the same Rekohu Plume Chatham Rise otolith. Also shown are the 1:1 line (blue) and a smoothed curve (red).

Growth comparison

The growth distribution for both plumes was similar, particularly in the interval where the ages from each plume overlap strongly (Figure 2).

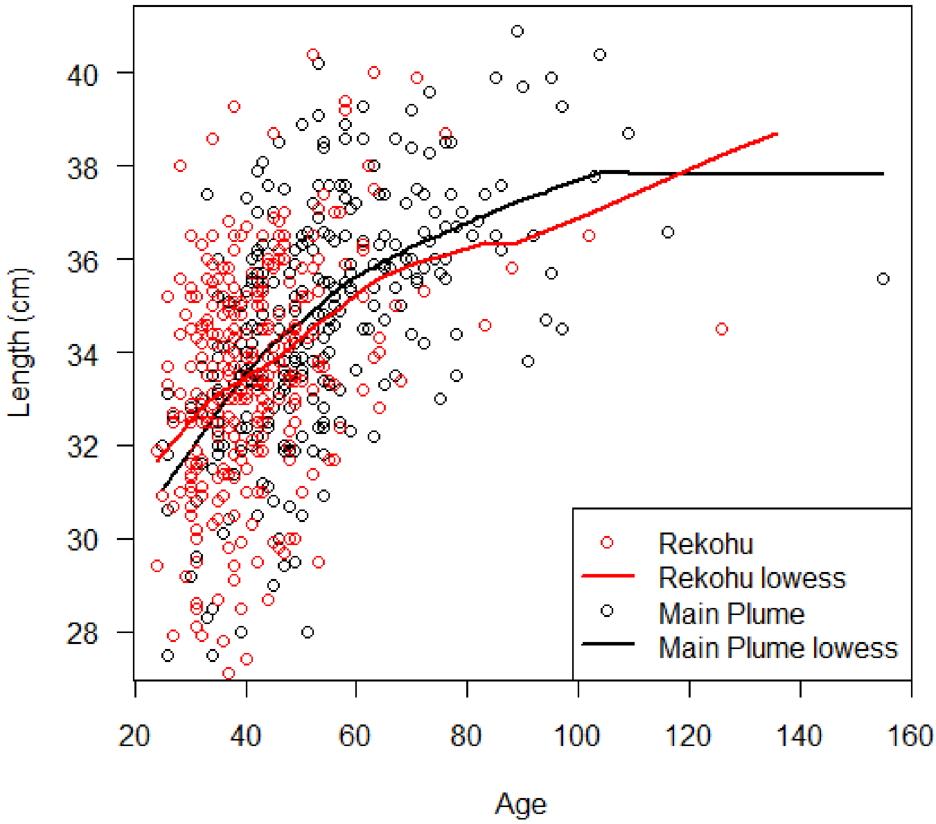

Figure 2: Length versus age for the Chatham Rise Main Plume and Rekohu Plume, showing raw data points and lowess fits to the data.

Mean age

The mean ages were statistically significantly different between the two surveys, with the Rekohu fish being 12 years younger than those in the Main Plume (Table 1). The t-test value was 7.1 using the bootstrap s.e. (5% level is 1.96).

Table 1: Estimated mean age for the Main Plume and Rekohu Plume.

Sample	Number of unique otoliths	Total number of ages in mean	Mean age (yr)	Analytical s.e.	Bootstrap s.e.	Weighted CV for age frequency (%)
Main Plume	296	443	53.3	1.1	1.4	59.1
Rekohu Plume	298	371	41.9	0.8	1.0	50.0

Age frequencies

Figure 3 shows the estimated age frequencies for the two plumes and the detailed results are in Appendix 2.

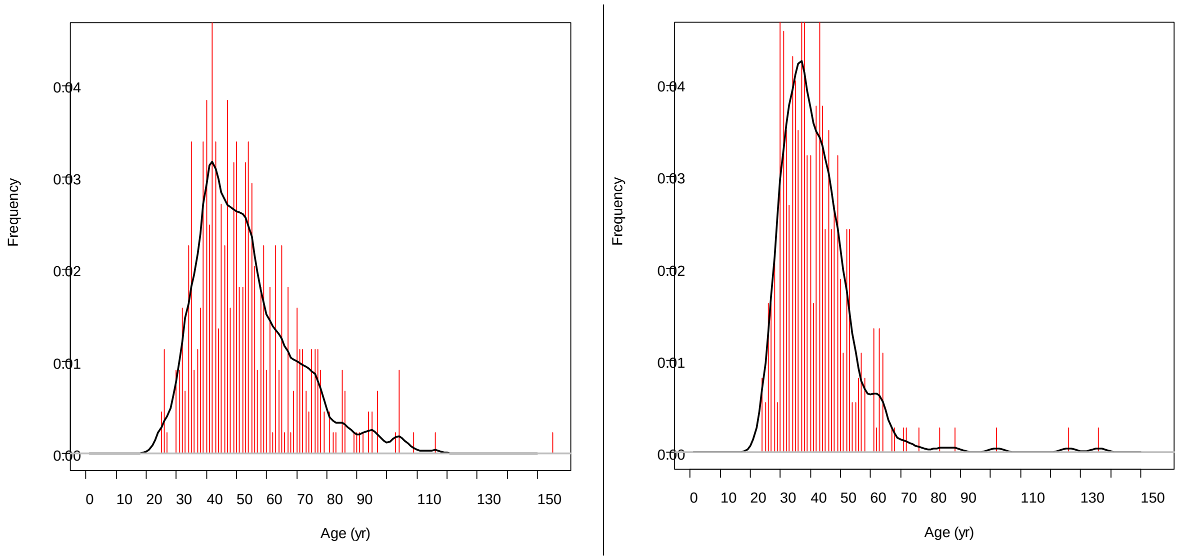

Figure 3: Smoothed age frequency (black curve) and the raw frequency (vertical lines) for the Main Plume (left panel) and Rekohu Plume (right panel).

The 95% pointwise confidence intervals (CI) only overlap greatly between ages 40 and 55 (Figure 4) so the pattern looks highly significant even though the weighted CV for each age frequency is about 50% (Table 1). The difference between the plumes is so great that the actual test statistic is a long way beyond the range of the randomisation test statistic distribution (Figure 5).

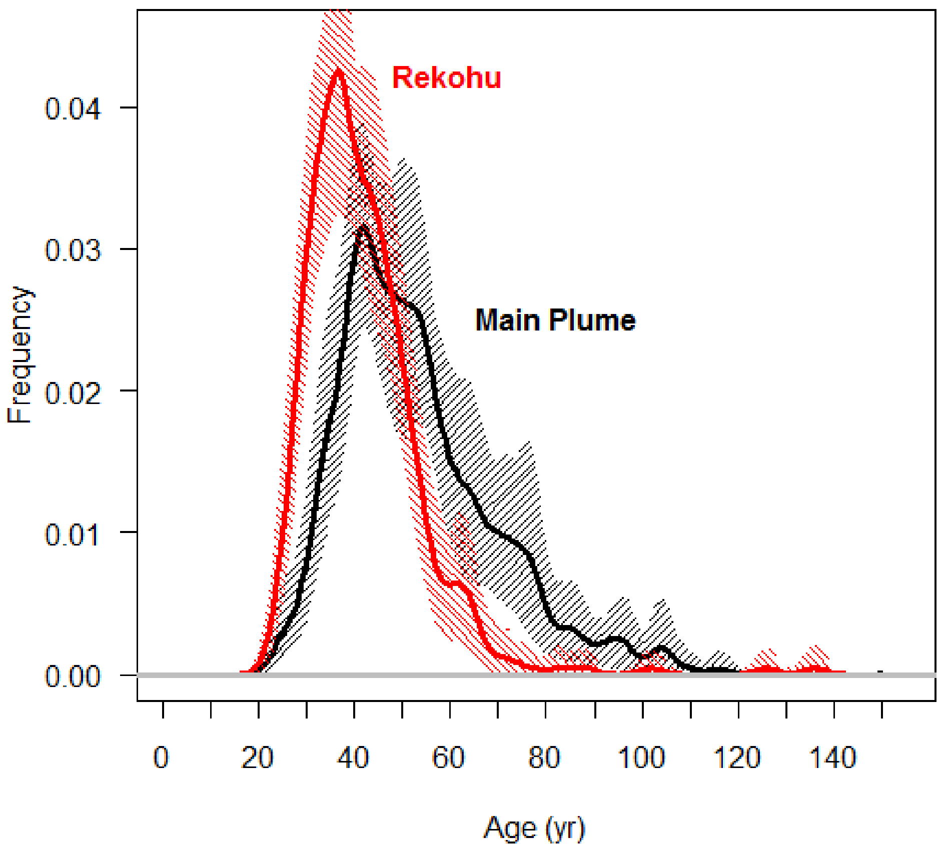

Figure 4: Comparison of age frequencies (curved lines) for the Main Plume and Rekohu Plume with the pointwise 95% confidence interval (slanted lines; for Rekohu, downwards left to right. for Main Plume, upwards left to right).

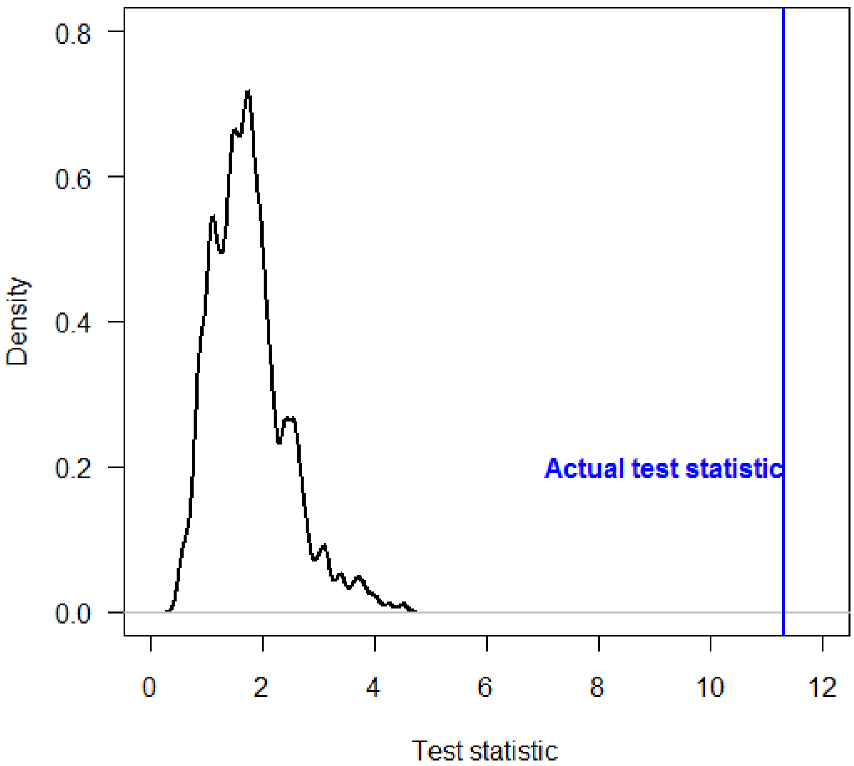

Figure 5: Test statistic for the randomisation test of the age frequencies with the actual test statistic indicated by the vertical line.

3.2 MEC fishery age data

Otolith samples were available from three landings in 1989 (*n* = 150), four in 1990 (*n* = 200), and five in 1991 (*n* = 249). The number of otoliths for each landing was 50, except for one landing with 49. The numbers of otoliths with readability codes less than 5 were 134, 185, and 231 for 1989 to 1991, respectively. For 2010, there were 239 otoliths of which 237 were readable.

Estimated ages where two readings were available for a single otolith are plotted against each other in Figure 6 and mostly show no bias. Within-reader CV was 5% which compares favourably to the 15% obtained in the protocol testing study which used four readers (Tracey et al. 2007).

The growth for both year groups was similar, particularly in the interval where the ages from each sample overlap strongly (Figure 7).

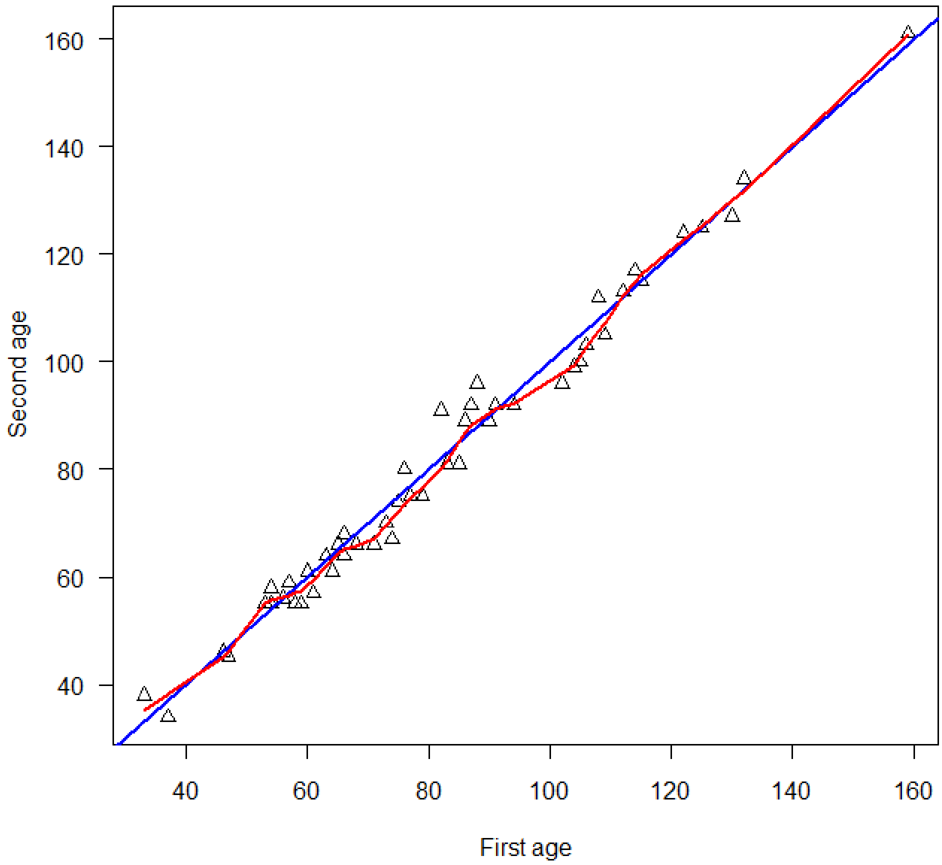

Figure 6: Comparison of ages from two readings of the same MEC otolith. Also shown are the 1:1 line (blue) and a smoothed curve (red).

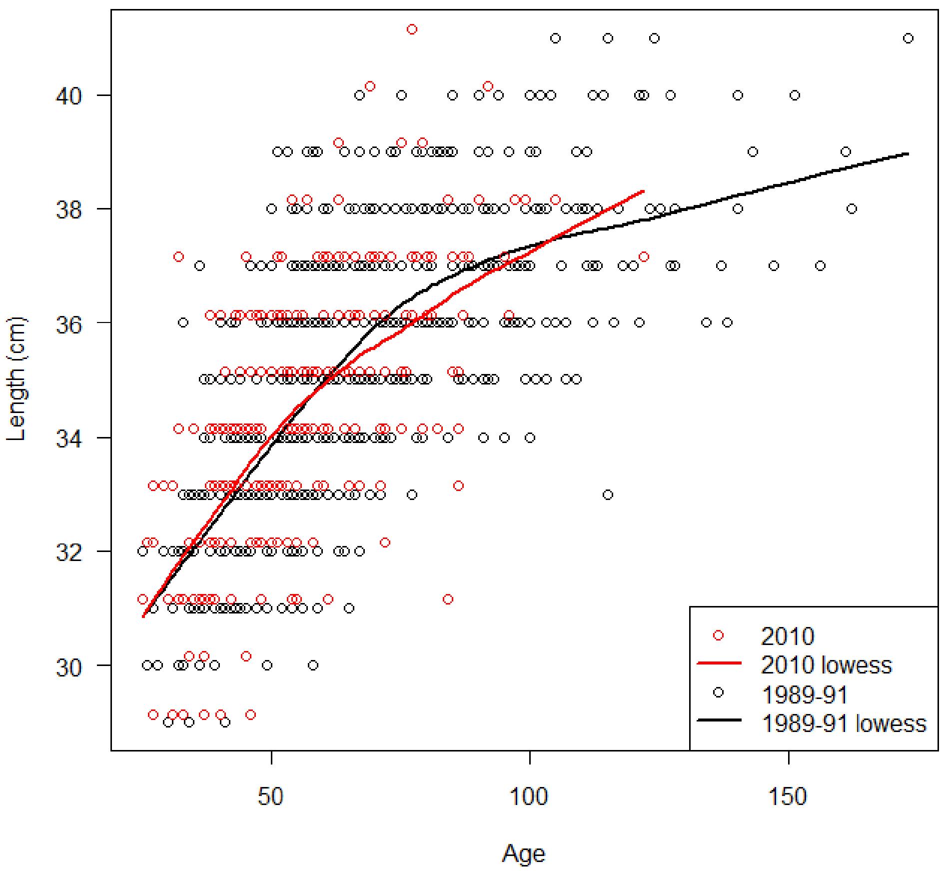

Figure 7: Length versus age for the MEC fishery data, showing raw data points and lowess fits to the data. The 2010 lengths were plotted with an offset of 0.2 cm to make comparisons easier. The 1989–91 data do not have the offset applied.

Figure 8 shows the raw age frequencies for the MEC landing data. The 2012 frequency has more younger fish and the tail of older fish has largely disappeared. The 2012 mean age is statistically significantly younger than the earlier samples by 8 to 16 years depending on the year compared (Table 2).

Table 2: Mean age of raw data for the MEC fishery data.

Year	Mean age (yr)	s.d.
1989	73	2.3
1990	71	1.9
1991	65	1.6
2010	57	1.1

Figure 9 shows the age frequency results weighted by catch. There are only minor differences from the raw age frequencies.

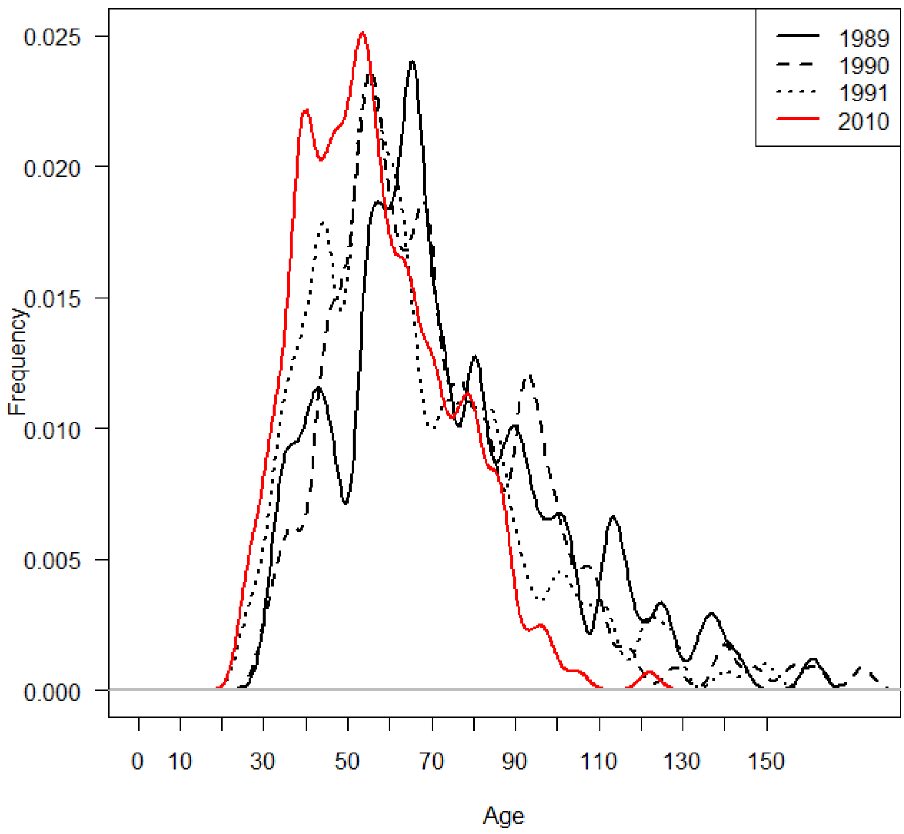

Figure 8: Raw age frequencies for the MEC fishery data: 1989 to 1991, and 2010.

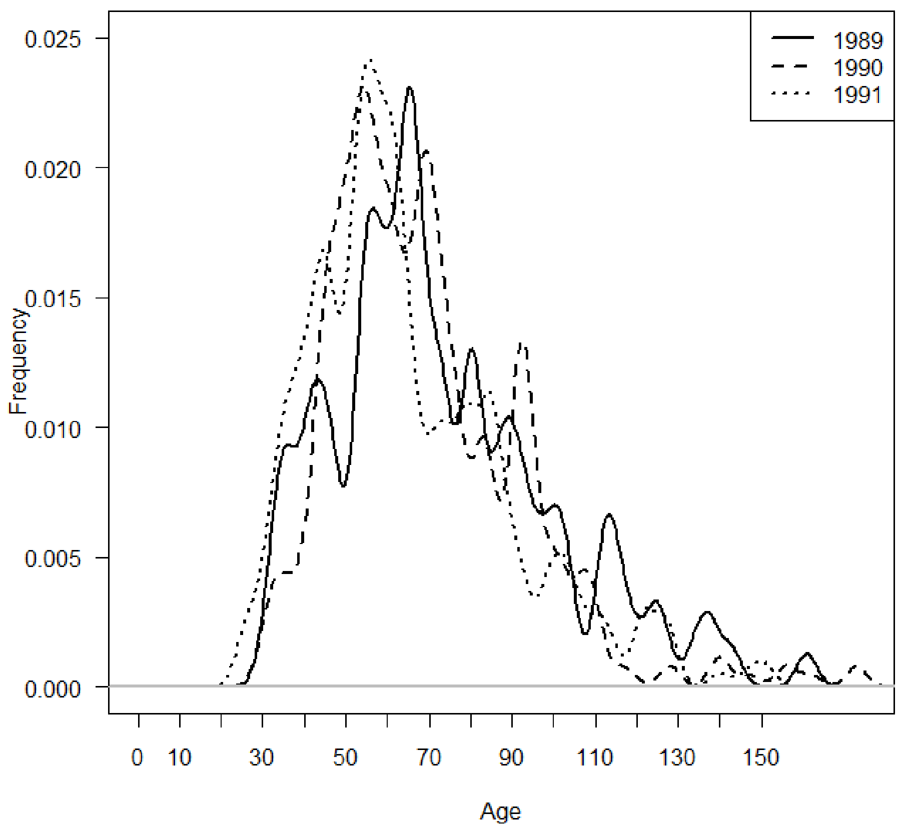

Figure 9: Age frequencies for the 1989 to 1991 fishery data, weighted by catch weight.

There were 483 of the 1989–91 MEC otolith sections that had both CAF and NIWA age estimates. The age-frequency distributions of these two comparable data sets are shown in Figure 10. The NIWA estimates are, on average, greater than those produced by CAF. However, the raw age-frequency distributions had different shapes (i.e., the NIWA distribution was not simply shifted to the right of the CAF one by a constant value), so the differences in otolith interpretation between the two reading methods varied with age. It was apparent that the NIWA reader recognised a TZ in many (i.e., 28% of comparisons) otolith sections where the CAF reader did not (Table 3). For these otoliths, the NIWA estimated age was, on average, 10 years higher than the CAF estimated age. However, in situations where both readers either did, or did not, recognise a TZ, the differences in age estimates were smaller at about 3–5 years (Table 3).

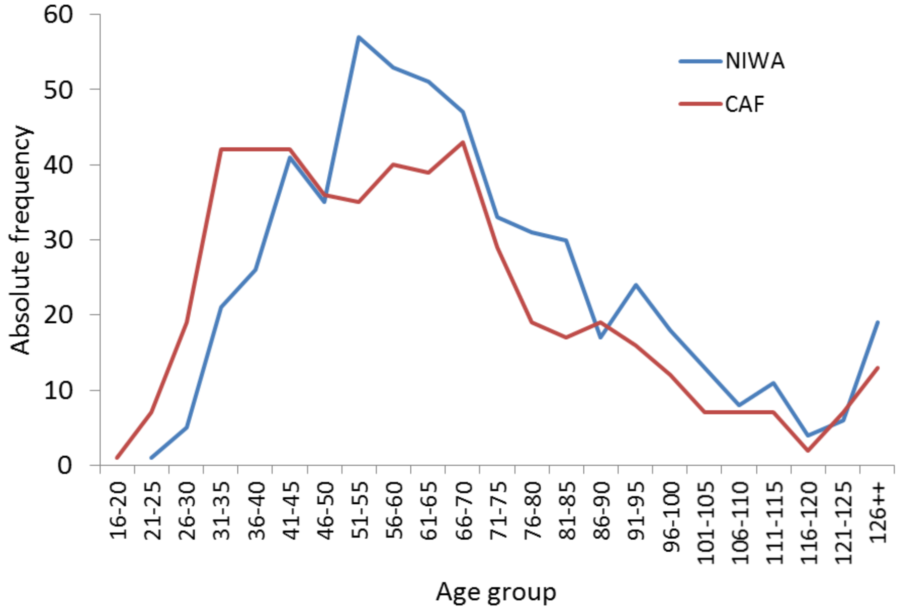

Figure 10: Age frequencies for the 1989–91 landing data, when both NIWA and CAF readings were available for individual otolith sections.

Table 3: A comparison of numbers of otolith sections where a TZ was or was not recognised by the NIWA and CAF readers, and the average age differences resulting from these different interpretations.

Sample size

		NIWA TZ	
		No	Yes
CAF TZ	No	10	137
	Yes	1	335

Average age difference (yrs)

		NIWA TZ	
		No	Yes
CAF TZ	No	3	10
	Yes	-24	5

4. CONCLUSIONS

The two plumes on the northeast Chatham Rise (ORH 3B) have significantly different age frequencies such that Rekohu Plume fish were 12 years younger on average than those in the Main Plume. Growth rates were similar in the two plumes. Both spawning plumes were assumed to be part of the same population. It is not known if the Rekohu Plume existed before 2010.

The ageing protocol for orange roughy developed by Tracey et al. (2007) can make a difference in the interpretation of age frequencies used in stock assessments. Using the age readings produced originally by CAF for the 1989–91 MEC samples produced a double mode in the age frequencies, which was interpreted as two good periods of recruitment in the stock assessment (Patrick Cordue, pers. comm.). When the age data produced using the 2007 protocol (as reported here) are used in the assessment, the age frequencies are unimodal and the stock assessment changed as a result (Patrick Cordue, pers. comm.). The main change between the two age readings results from a tighter definition to determine the presence or absence of a TZ, which affected original age estimates predominately in the 20 to 40 year age range. It was found in previous studies that recognition of a TZ in an otolith section will produce an age estimate about 30% higher than an estimate from the same section when no TZ is recognised (Tracey et al. 2009). Since the earlier CAF readings of the MEC otoliths frequently did not recognise the TZ, many otoliths in the younger mode (centred on 30–35) were subsequently recognised to have a TZ, and so ages increased by about 10, which reduced the size of that younger mode and produced an essentially unimodal distribution centred around the older second mode.

The new readings reported here for the MEC samples were produced using the accepted protocol developed in 2007 so these data must take precedence over the previously produced CAF age data. The mean age of orange roughy taken by this fishery declined by about 12 years between 1989–91 and 2010.

5. ACKNOWLEDGMENTS

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APPENDIX 1: STATIONS USED IN THE CHATHAM RISE ANALYSIS

Table 1.1: Main Plume stations, catch, relative population by station used to randomly sample otoliths, number of otoliths collected, probability to select one otolith (= relative station population divided by the number of otoliths sampled at the station), and number of unique otoliths sampled for reading.

Station	Catch (kg)	Relative station population	Number of otoliths	Probability to select one otolith	Number of unique otoliths
SP20	29 076	0.0837	40	0.0021	30
SP22	14 500	0.0418	20	0.0021	14
SP23	19 360	0.0558	20	0.0028	14
SP24	35 065	0.1010	40	0.0025	27
SP25	29 573	0.0852	40	0.0021	24
SP26	18 242	0.0525	20	0.0026	13
SP27	25 806	0.0743	40	0.0019	25
SP28	28 796	0.0829	40	0.0021	23
SP29	20 858	0.0601	20	0.0030	17
SP30	25 053	0.0722	40	0.0018	18
SP31	24 885	0.0717	40	0.0018	26
SP32	23 812	0.0686	20	0.0034	18
SP33	21 208	0.0611	20	0.0031	18
SP34	30 983	0.0892	40	0.0022	29

Table 1.2: Rekohu Plume stations, catch, relative population by station used to randomly sample otoliths, number of otoliths collected, probability to select one otolith (= relative station population divided by the number of otoliths sampled at the station), and number of unique otoliths sampled for reading.

Station	Catch (kg)	Relative station population	Number of otoliths	Probability to select one otolith	Number of unique otoliths
RP01	18 987	0.0317	20	0.0016	9
RP02	26 428	0.0442	40	0.0011	14
RP03	19 940	0.0333	30	0.0011	8
RP04	28 142	0.0470	40	0.0012	12
RP05	25 381	0.0424	40	0.0011	13
RP06	32 472	0.0543	40	0.0014	18
RP07	33 960	0.0568	40	0.0014	19
RP08	36 801	0.0615	40	0.0015	18
RP09	34 000	0.0568	40	0.0014	17
RP10	30 307	0.0507	40	0.0013	19
RP11	32 000	0.0535	40	0.0013	15
RP12	38 064	0.0636	40	0.0016	18
RP13	28 610	0.0478	40	0.0012	13
RP14	40 319	0.0674	40	0.0017	17
RP15	26 000	0.0435	40	0.0011	17
RP16	39 868	0.0666	40	0.0017	18
RP17	35 854	0.0599	40	0.0015	13
RP18	38 966	0.0651	40	0.0016	21
RP19	32 246	0.0539	40	0.0013	19

APPENDIX 2: CHATHAM RISE ESTIMATED AGE FREQUENCIES

Table 2.1: Estimated age frequencies for the Main Plume and Rekohu Plume.

	Main Plume		Rekohu Plume	
Age (yr)	Frequency	Smoothed frequency	Frequency	Smoothed frequency
1	0	1.419259e-05	0	2.001335e-05
2	0	1.419259e-05	0	2.001335e-05
3	0	1.419259e-05	0	2.001335e-05
4	0	1.419259e-05	0	2.001335e-05
5	0	1.419259e-05	0	2.001335e-05
6	0	1.419259e-05	0	2.001335e-05
7	0	1.419259e-05	0	2.001335e-05
8	0	1.419259e-05	0	2.001335e-05
9	0	1.419259e-05	0	2.001335e-05
10	0	1.419259e-05	0	2.001335e-05
11	0	1.419259e-05	0	2.001335e-05
12	0	1.419259e-05	0	2.001335e-05
13	0	1.419259e-05	0	2.001335e-05
14	0	1.419259e-05	0	2.001335e-05
15	0	1.419259e-05	0	2.001335e-05
16	0	1.419259e-05	0	2.001335e-05
17	0	1.419259e-05	0	3.691439e-05
18	0	2.869035e-05	0	0.0001112607
19	0	7.407094e-05	0	0.0002979343
20	0	0.0002196503	0	0.0006945814
21	0	0.0004410441	0	0.001441983
22	0	0.0009386995	0	0.002670266
23	0	0.001471761	0	0.004471783
24	0	0.002297998	3	0.006859371
25	2	0.002904013	2	0.00978134
26	5	0.003597386	6	0.01319104
27	1	0.004080232	6	0.01704217
28	0	0.004922949	8	0.02126661
29	0	0.006289458	2	0.02562238
30	4	0.007768869	19	0.02970348
31	4	0.01020754	17	0.03312978
32	7	0.01219730	13	0.03575469
33	3	0.01471273	10	0.03779114
34	10	0.01633250	16	0.03955224
35	15	0.01814728	15	0.04114184
36	4	0.01948513	13	0.04229812
37	5	0.02170932	23	0.04255616
38	7	0.02386095	21	0.04129578
39	15	0.02711995	12	0.03936585
40	17	0.02936575	12	0.03736297
41	11	0.03132940	6	0.03585929
42	25	0.03170279	14	0.03494055
43	15	0.03093543	18	0.03425792
44	6	0.02981563	14	0.03336782
45	12	0.02834631	9	0.03205550
46	10	0.02756686	13	0.03036314
47	17	0.02700569	9	0.02845067
48	7	0.02678937	10	0.02641887
49	14	0.02655836	12	0.02430886
50	15	0.02632116	7	0.02213005
51	8	0.02617200	4	0.01988981
52	8	0.02597549	9	0.01758555
53	14	0.02567860	9	0.01524168
54	15	0.02476501	2	0.01295235

	Main Plume		Rekohu Plume	
Age (yr)	Frequency	Smoothed frequency	Frequency	Smoothed frequency
55	13	0.02358711	2	0.01086954
56	9	0.02148564	3	0.009123946
57	4	0.01978159	4	0.007786628
58	8	0.01770423	3	0.006866013
59	10	0.01642337	0	0.006378630
60	4	0.01512478	0	0.006266148
61	8	0.01443454	5	0.006379669
62	1	0.01380792	1	0.006448785
63	10	0.01346209	5	0.006211151
64	4	0.01296880	4	0.005564545
65	10	0.01247655	0	0.004607121
66	1	0.01167528	0	0.003571143
67	8	0.01107592	1	0.002676591
68	1	0.01047133	1	0.002037434
69	3	0.01020727	0	0.001641657
70	7	0.01002545	0	0.001419286
71	5	0.00985326	1	0.001277386
72	5	0.00967065	1	0.001153125
73	3	0.009401692	0	0.001020452
74	2	0.009221780	0	0.0008840106
75	5	0.008963572	0	0.0007549181
76	5	0.008647250	1	0.0006342882
77	5	0.007885601	0	0.0005186620
78	4	0.007056544	0	0.0004158284
79	2	0.005765973	0	0.0003481869
80	0	0.004849379	0	0.0003346831
81	2	0.003931752	0	0.0003895880
82	1	0.003546256	0	0.0004544907
83	1	0.003368803	1	0.0005025609
84	0	0.003370679	0	0.0005223074
85	4	0.003337480	0	0.0005246997
86	3	0.003191725	0	0.0005238760
87	0	0.002842129	0	0.0005171014
88	0	0.002543488	1	0.0004855518
89	1	0.002236656	0	0.0004160836
90	1	0.002123253	0	0.0003148239
91	1	0.002131701	0	0.0002070149
92	1	0.002260830	0	0.0001175722
93	0	0.002388420	0	5.768055e-05
94	2	0.002517148	0	2.653496e-05
95	2	0.002524843	0	1.750705e-05
96	0	0.002354734	0	2.780569e-05
97	3	0.002100417	0	6.074260e-05
98	0	0.001679969	0	0.0001220528
99	0	0.001408655	0	0.0002118483
100	0	0.001248448	0	0.0003142299
101	0	0.001313827	0	0.0003979350
102	0	0.001568020	1	0.0004314211
103	1	0.001759436	0	0.0003985763
104	4	0.001842551	0	0.0003151504
105	0	0.001720771	0	0.0002128008
106	0	0.001389450	0	0.0001227292
107	0	0.001103929	0	6.049500e-05
108	0	0.0007824551	0	2.550259e-05
109	1	0.0006063809	0	9.140398e-06
110	0	0.0004414819	0	2.827384e-06
111	0	0.0003312262	0	7.323755e-07
112	0	0.0002865101	0	1.671278e-07

	Main Plume		Rekohu Plume	
Age (yr)	Frequency	Smoothed frequency	Frequency	Smoothed frequency
113	0	0.0002814025	0	3.178391e-08
114	0	0.0003107150	0	9.318833e-09
115	0	0.0003564831	0	2.551467e-08
116	1	0.0003676548	0	1.340993e-07
117	0	0.0003286406	0	6.046284e-07
118	0	0.0002665395	0	2.357084e-06
119	0	0.0001688306	0	7.826556e-06
120	0	0.0001048416	0	2.216700e-05
121	0	4.649504e-05	0	5.390624e-05
122	0	2.210562e-05	0	0.0001115167
123	0	6.805995e-06	0	0.0002228328
124	0	2.491729e-06	0	0.0003246235
125	0	5.279646e-07	0	0.0004040427
126	0	1.495754e-07	1	0.0004302144
127	0	2.229850e-08	0	0.0003920042
128	0	4.745961e-09	0	0.0003071030
129	0	5.048572e-10	0	0.0002116906
130	0	7.845637e-11	0	0.0001414796
131	0	6.102577e-12	0	0.0001179561
132	0	3.388183e-13	0	0.0001492249
133	0	3.908658e-14	0	0.0002248912
134	0	1.550973e-15	0	0.0003213454
135	0	1.354855e-16	0	0.0004016682
136	0	1.880506e-16	1	0.0004306629
137	0	2.073169e-15	0	0.0003953405
138	0	5.229232e-14	0	0.0003101415
139	0	4.605755e-13	0	0.0002079269
140	0	7.781355e-12	0	0.0001190514
141	0	5.477738e-11	0	5.839640e-05
142	0	6.174113e-10	0	2.430634e-05
143	0	3.396233e-09	0	8.755163e-06
144	0	2.627124e-08	0	4.918971e-06
145	0	1.114683e-07	0	4.918971e-06
146	0	6.083475e-07	0	4.918971e-06
147	0	1.952293e-06	0	4.918971e-06
148	0	7.579779e-06	0	4.918971e-06
149	0	1.832150e-05	0	4.918971e-06
150	0	5.001618e-05	0	4.918971e-06