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Hoki ageing: recommendation of which data to routinely record for hoki otoliths

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7. Executive Summary

This report presents the results of the second piece of work commissioned by the Ministry to look at refining the hoki ageing methodology. The first piece of work examined otolith ring measurements for hoki of known ages 1 or 2 years. The results of this work were presented to the Hoki Working Group at a meeting on 3 December 1999.

It was seen that the distributions of ring measurements and other features of these otoliths could be used to test hypotheses with regard to the age of otoliths from older hoki. It was noted that more powerful tests could be made if data were available from hoki of known age 3 years. Also, the question was asked whether there were any differences in hoki otoliths from spawning and non-spawning fish (if there were, then using otoliths from immature Chatham Rise fish to provide a ground-truth distribution of otolith characteristics might not be useful for testing hypotheses on the age of spawning fish).

Work was proposed to examine otolith data from hoki of known age 3 years (for hoki collected at spawning and non spawning grounds) and to determine a list of data to be routinely collected from hoki otoliths. The latter was needed so that the routine reading of hoki otoliths could resume (reading of hoki otoliths had been temporarily suspended pending refinements to the reading method).

Using appropriate length classes to ensure that 3 year old fish were almost exclusively selected, otoliths from the 1991 and 1992 cohorts from the four main fishing grounds were prepared and read. In addition to the total ring count, measurements were made to the outer edges of each ring, and clarity grades and the occurrence of split or multiple zones were recorded. Descriptive statistics were plotted and tabulated, a multiple regression analysis was done, and a hypothesis test was developed for choosing between alternative interpretations of an otolith. Average ring measurements were very similar between cohorts, areas, and gender. The regression analysis showed that the most important factor in explaining a ring measurement was the adjacent ring measurement. The addition of an area factor explained another 2–6% of the variation. For the 3rd ring, the combination of the 2nd ring measurement and area explained 69% of the variation.

For the 3 year old hoki, the proportions of otoliths for which the 2nd zone were split or multiple were not consistent with the data for hoki from the same cohort at age 2 years. It seems doubtful that consistent recording of whether a zone is split or multiple is possible. It does appear possible to maintain consistency for the clarity grades. It is recommended for routine reading of hoki otoliths that in addition to the total ring count, the measurements to the outer edges of the 1st, 2nd, and 3rd rings should be recorded, together with the clarity grades for the juvenile and 1st zones. This should be done for each reasonable interpretation of the rings on each otolith. The number of interpretations recorded for an otolith will then represent an overall clarity grade. Hypothesis tests should be developed and tested for choosing between the possible interpretations. In a trial of a proposed hypothesis test for choosing between two alternative sets of measurements, a success rate of 91% was achieved when the 3rd ring measurement was spuriously proposed as the 2nd ring measurement.

8. Objective:

To determine what data should be routinely collected from hoki otoliths when they are read for the purpose of age estimation

9. Introduction

A validated ageing method for hoki was determined by Horn and Sullivan (1996). This method has been used to provide estimates of age frequency for commercial catches and trawl surveys, which have been a crucial input into hoki stock assessment in the 1990s. However, in the most recent assessment the accuracy of some of the estimated age frequencies appeared questionable for some of the cohorts. Routine reading of hoki otoliths was temporarily suspended and some initial work aimed at ultimately refining the ageing method was commissioned by the Ministry. The results of this work were presented to a Hoki Working Group meeting on 3 December 1999.

The work considered otoliths from hoki of known ages 1 or 2 years for fish caught in the January Chatham Rise trawl surveys. It was seen that the distributions of ring measurements and other features of these otoliths could be used to test hypotheses with regard to the age of otoliths from older hoki. It was noted that more powerful tests could be made if data were available from hoki of known age 3 years. Also, the question was asked whether there were any differences in hoki otoliths from spawning and non-spawning fish (if there were, then using otoliths from immature Chatham Rise fish to provide a ground-truth distribution of otolith characteristics might not be useful for testing hypotheses on the age of spawning fish).

At the meeting it was decided that a detailed plan should be developed with regard to the development of ageing methodology for hoki. The Hoki Working Group sees the methodology ultimately involving the use of modelling techniques to estimate an age frequency from input data which includes ring measurements and other data from individual otoliths. The Ministry may commission the writing of this plan in the near future, but in the interim the routine "processing" of hoki otoliths needs to continue so that an undue backlog of otoliths does not develop. The processing of the otoliths will involve the normal preparation step and a modified "reading" process.

The "reading" of each otolith will involve the collection of ring measurements and other data in addition to the usual estimate of a total ring count. When more than one reasonable interpretation of the ring count for an otolith exists, then ring measurements for each interpretation will be recorded. From the results of the work presented at the 3 December 1999 meeting, it was reasonably apparent what measurements and other data should be collected. However, it was considered prudent to do some further work prior to finalizing the list of data to be recorded.

Work was proposed to examine otolith data from hoki of known age 3 years (for hoki collected at spawning and non spawning grounds) and to determine a list of data to be routinely collected from hoki otoliths. The latter was needed so that the routine reading of hoki otoliths could resume (reading of hoki otoliths had been temporarily suspended pending refinements to the reading method). This report presents the results of the analysis of the otolith data from hoki of known age 3 years and makes a recommendation on the list of data to be routinely collected from hoki otoliths.

10. Methods

Two key activities were proposed for this work and the methods are described for each activity below.

1. Prepare and read otoliths from hoki of probable age 3 years for fish of the same cohort collected from spawning and non-spawning grounds.

To obtain otoliths from hoki of known age 3 years is problematic because there is often an overlap in the length frequencies with age 2 years and invariably with age 4 years. However, if reasonably well defined modes are present in a length frequency then a careful choice of length class will maximize the proportion of otoliths from 3 year old hoki.

A comparison of otoliths for hoki collected in each of the four main fishing areas was considered desirable as it covers both stocks with spawning and non-spawning fish. An examination of trawl survey and commercial catch length frequencies showed that the 1992 cohort was present at age 3 years in samples from each of the four areas (Ballara *et al.* 1998, Colman 1996). It appeared to be the only cohort which was well represented at age 3 in all of the areas; the 1991 cohort was next best being well represented in each area except the Sub-Antarctic.

It was proposed to prepare and read up to 35 otoliths for each sex in length classes chosen to maximize the proportion of the 1992 cohort for each of the four areas:

Sub-Antarctic:	TAN9605 (March-April 1996)
Chatham Rise:	TAN9601 (January 1996)
WCSI:	Observer data (winter 1995)
Cook Strait:	Shed sampling data (winter 1995)

If it happened that there were not enough otoliths available for the 1992 cohort then consideration was to be given to using the 1991 cohort instead, or as well as the 1992 cohort (in any case, a total of about 280 otoliths were to be prepared and read for probable 3 year old fish).

Otoliths were baked whole until amber-coloured, embedded in blocks of epoxy resin, and sawn transversely through the nucleus using a diamond-tipped sectioning saw. The cross-sections were examined under a binocular microscope (x30), with illumination by reflected light just above the plane of the prepared surface.

For each otolith, the following data were recorded (this was also the tentative list of data to be routinely recorded for hoki otoliths):

- Total number of annual zones
- Radius to outer edge of juvenile zone
- Radius to outer edges of annual zones 1, 2, & 3, and to otolith margin
- For each of annual zones 1, 2, & 3, whether they are "split/multiple" or not
- Clarity grade for the juvenile zone
- Clarity grade for the 1st annual zone

Measurements were made, using a micrometer eyepiece, of the distances from the nucleus to the otolith margin, and to the outer edges of the translucent parts of the juvenile, 1st, 2nd and 3rd zones. (The translucent zones appeared dark when using the examination method described above.) All measurements were made on the longest axis of the ventral part of the otolith cross-section. The clarity of the juvenile and first annual zones were graded on a 4 point scale: 1=good, 2=ok, 3=poor, 4=unreadable. A zone was considered to be "split/multiple" when it comprised, in part, at least two distinct, dark "sub-zones". Sub-zones were distinguished from "true" zones in that they merged at some point into a single zone. The translucent (dark) parts of the juvenile, 1st, 2nd and 3rd "true" zones were almost always separated along their entire lengths by a band of opaque (light) material.

2. <u>Analyse the results of the otolith readings with regard to whether the proposed data list is appropriate.</u>

The analysis was aimed at determining whether the tentative list of data was appropriate for routine reading of hoki otoliths, given the plans to move toward some form of hypothesis testing using a ground-truth set of otolith measurements and features, and ultimately a model based estimation approach.

For the otoliths read in Activity 1, which were considered to be from 3 year old fish, the otolith data were explored with descriptive analyses. Primary consideration was given to the distributions of the ring measurements, and in particular the average ring measurements for different categories of otoliths (area of capture, cohort, and sex). The relative proportions of clarity grades and the occurrence of split/multiple zones were also considered. Comparisons were also made with the existing data from the Chatham Rise for the 1991 and 1992 cohorts when they were aged 1 or 2 years.

In addition to the descriptive analysis, multiple regression analyses were done to determine which factors were most important in explaining variation in ring measurements and, based on the regression results, some hypothesis tests were developed and tested (for effectiveness).

Multiple regression

The standard multiple stepwise forward regression technique was used with a cutoff of 0.5% in R^2 to determine which of the following factors and their first order interactions to use in explaining the variation in R3 (the 3rd ring measurement):

- RJ, RJ^2 — juvenile ring measurement and its square
- R1, $R1^2$ — 1st ring measurement and its square
- R2, $R2^2$ — 2nd ring measurement and its square
- Split1 — split/multiple 1st zone
- Split2 — split/multiple 2nd zone
- Split3 — split/multiple 3rd zone
- CJ — juvenile zone clarity grade
- C1 — 1st zone clarity grade
- Area — area of capture
- Cohort — 1991 or 1992
- Sex — male or female

The same approach was taken to determine a linear relationship to explain the variation in R2 (using the above factors with the exclusion of R2 and $R2^2$).

Additional regressions were also done using just the ring measurements (rather than their squares), the area of capture, whether the capture area was a spawning ground or not, and whether the capture area contained only eastern hoki (Cook Strait), only western hoki (WCSI and Sub Antarctic), or a mixture (Chatham Rise).

Hypothesis tests

In the regression analysis, functional linear relationships for R3 and R2 were established:

$$R2 = f(x) + \varepsilon$$

$$R3 = g(y) + \beta$$

where x and y denote the factors used and ε and β are random errors. The residuals from the regression analyses should approximate the probability distributions of ε and β. Since the distributions are obtained from hoki of known age then the relationships and the error distributions should at some level capture the true relationships and error distributions. Further, if the error distributions are sufficiently tight it may be that if incorrect values are used in a relationship then the residual will be atypical of the error distribution. This is the rationale for one of the proposed hypothesis tests. Another test is proposed for when more than one alternative interpretation of an otolith is offered.

When an otolith is read (with measurements and other characteristics) and only one interpretation is recorded, the interpretation can be tested to see if it is reasonable. We illustrate the type of test proposed using the R2 relationship (as defined above).

Let r2 be a proposed 2nd ring measurement and v be a proposed vector of corresponding factors. A test of r2 and v at the α level is to reject them as reasonable if $p < \alpha$ where

$$p = \text{Prob}(\ \varepsilon < -|f(v)-r2| \text{ or } \varepsilon > |f(v)-r2|\ )$$

This is a two-sided test which simply stated says if the residual is too extreme then r2 and v do not constitute a reasonable interpretation of the otolith (which in practice would mean that the interpretation would be checked rather than necessarily being rejected). To examine the effectiveness of this test, the data in the study were used to see how often a true 3rd ring when spuriously proposed as a 2nd ring caused the test to reject the proposal. This was done at levels of α from 0.01 to 0.15 (note, α is the probability that a true proposal will be rejected).

When more than one interpretation of an otolith is recorded then a comparison of p-values can be used to choose a single interpretation. We illustrate the type of test proposed using the R2 and R3 relationships (as defined above) for an otolith which can either be interpreted as age 2 or age 3.

Let r2 be a proposed 2nd ring measurement and v be a proposed vector of corresponding factors. For the same otolith, in the alternative interpretation, let r3 be the proposed 3rd ring measurement and w be the proposed vector of corresponding factors. A choice between the two alternatives can be made as follows:

If $p_2 > p_3$ choose age = 2 otherwise choose age = 3, where

$$p_2 = \text{Prob}(\ \varepsilon < -|f(v)-r2| \text{ or } \varepsilon > |f(v)-r2|\ )$$

$$p_3 = \text{Prob}(\ \beta < -|g(w)-r3| \text{ or } \beta > |g(w)-r3|\ )$$

For an otolith where both alternatives propose ages of 3 or more years, the alternative with the lowest p-value from the R3 relationship will be chosen. If more than two alternatives are proposed the choice could still be made using the lowest p-value.

To examine the effectiveness of this type of test, the data in the study were used to see how often a true 3rd ring when spuriously proposed as a 2nd ring would be chosen ahead of the true interpretation.

11. Results

Otolith selection and reading

There were not an adequate number of otoliths from the 1992 cohort in the specified length classes so additional otoliths from the 1991 cohort were also used. The length classes chosen for each cohort varied depending on the shape of surrounding modes in the length frequency and the modal length of the target cohort (Figure 1). In total 269 otoliths were used in the analysis with 203 from the 1992 cohort and 66 from the 1991 cohort. The only survey for which the target of 35 otoliths from each sex was achieved was in the Sub Antarctic survey TAN9605 (Table 1). In the previous study (Chatham Rise hoki aged 1 or 2 years) otoliths from the 1991 and 1992 cohorts were also used (with measurements of the 1st and 2nd rings but not the juvenile ring). A list of all cohorts used in the two studies is given in Table 2. A total of 782 otoliths have been used in the two studies combined.

There were an additional 16 otoliths selected which were in the length classes but which were not used in the analysis. The most common reason (7 out of the 16) was that there was a suspected recording or embedding error as the otolith clearly had an age greater than 3 (often much greater). Other causes were: the otolith was believed to be from a 2 year old hoki (2/16); the otolith was unreadable (5/16); and the otolith had been sectioned too far from the nucleus (2/16). None of the otoliths in the study were aged at 4 years as the reader could always see a valid interpretation which gave an age of 3 years. However, had the otoliths been from a random sample he probably would have assigned 3 or 4 of them an age of 4 years.

Descriptive analysis

The average ring measurements showed little variation across the six samples (Table 3, Figure 2). When the otoliths were grouped by cohort and combined by sex there was almost no variation in the average ring measurements between cohorts (Table 4). There is little overlap in the distributions of adjacent ring measurements except for the 2nd and 3rd rings (Figure 3). For the 2nd and 3rd rings the range of the distribution generally includes the mean of the other distribution (Figure 3). That is, there is a substantial overlap and therefore some potential for confusing 2nd and 3rd rings when an otolith is read.

When ring measurements for the 1st, 2nd, and 3rd rings for Chatham Rise hoki are compared across the two studies their distributions are seen to be very similar (Figure 4). There is perhaps an indication that the distribution of the 1st ring in the second study has less range and a lower mean than the distribution of the 1st ring in the first study. This effect, if real, is not unexpected as in the second study the selected hoki had a length distribution truncated at the high end to avoid the selection of 4 year old fish (*see* Figure 1). In the first study, for fish aged 1 year, any truncation in fish lengths at the high end would have been minimal because of the larger separation of 1 and 2 year old length distributions.

The 1st and 3rd zones were typically classified as split/multiple but the 2nd zone was just as often split/multiple as not (Table 5). There was little difference between the sexes, but there were some minor variations between samples (Table 5). When the samples were grouped by cohort it was seen that the 1st and 3rd zones were split/multiple in almost the same proportions for each cohort, but for the 2nd zone the 1992 cohort was less often split/multiple while the 1991 cohort was split/multiple about 50% of the time (Tables 6a & 6b). However, it appears that consistency in making these classifications may not be possible as in the previous study the 1991 cohort had no otoliths classified with a split/multiple 2nd zone and the 1992 cohort was more often split/multiple than not for the 2nd zone (Table 7).

The clarity of the juvenile zone was generally graded "ok" or "poor" for each of the samples, but the clarity of the 1st zone was typically "good" and hardly ever "poor" and never "unreadable" (Table 8a). There was some variation between the sexes, but more between the samples. When the samples were grouped by cohort, it was seen that the 1991 cohort had much better juvenile clarity than the 1992 cohort and also slightly better 1st zone clarity (Table 8b). Consistent grading of these zones may be possible as in the first study it was noted that "the 1991 cohort generally exhibited a strong and clear juvenile zone".

Regression analysis

In the stepwise regression to explain R3 (the 3rd ring measurement) the following factors entered the model:

- $R2^2$
- Area
- Split3
- Sex

$R2^2$ explained 67% of the variation and the addition of the other factors brought the explanatory power up to 71% before the 0.5% cutoff prevented the addition of any other factors.

In the stepwise regression to explain R2 the following factors entered the model:

- $R1^2$
- Area
- Split2
- Area:Split2

where the colon denotes a 1st order interaction. In this model 36% of the variation was explained by $R1^2$ and the addition of the other factors increased this to 41%.

These results suggest that it might be appropriate to record the occurrence of split/multiple 2nd and 3rd zones when routinely reading hoki otoliths. However, because of the earlier evidence that the 2nd zone cannot be consistently classified it would be inappropriate to routinely record it. It seems likely that the 3rd zone classification may also be difficult to apply consistently so its use would also seem unnecessary.

The presence of the squared terms prompted more regressions to be done to see how much variation could be explained if single powered terms were used instead. It happened that the single powered termed by themselves explained almost exactly the same amount of variation as the squared terms. When the "Area" factor was included the explanatory power was only slightly less than that of the original models. A plot of the data shows that the relationships look just as likely to be linear as quadratic (Figure 5) and because single powers have a much simpler interpretation it was decided to exclude the squared terms from the models. Two alternatives to the "Area" factor were also considered: "Spawning flag" (spawning ground or not), and "Stock" (East, West, or mixed; the mixed area being the Chatham Rise). The additional regressions also considered R1 in terms of Rjuv (the juvenile ring measurement) and in this case the "C1" factor (1st zone clarity) was sometimes included.

When the adjacent inside rings were used in the regressions with the "Area" factor the percentages of R^2 explained for R1, R2, and R3 respectively were 27%, 39%, and 69% (Table 9a). (The percentages for R3 and R2 are only 2% less than the stepwise regression models.) The "Area" factor added a decreasing amount as the ring age increased: 6%, 3%, and 2% (Table 9a). When the "Spawning flag" was used instead of "Area" the model for R1 did only a little better than when only Rjuv was used; for R2 the model was almost as good as for "Area"; and for R3 it was just as good (Table 9b).

When the "Stock" factor is used instead of "Area", the variations in R1 and R2 are explained as well as with "Area", but for R3 the model did no better than when only R2 was used (Table 9c). An interesting feature of the regression for R1 is the consistency of the estimated coefficients for "Stock". The interpretation is that, on average, eastern hoki have their 1st ring closer to their juvenile ring than western hoki, and the average difference in the "Mixed stock" falls in between (which makes sense as the "Mixed stock" includes both eastern and western hoki). If such a relationship exists then it should be possible to reliably estimate the relative proportions of eastern and western hoki in any sample of sufficient size. The key to doing such an estimation reliably would be to first establish a relationship which incorporated the "Stock" factor and accounted for any other significant factors, which may well include cohort (if data from a larger number of cohorts were considered). Another factor which is likely to be important is the clarity of the 1st zone. When this was included in the R1 regression (with Rjuv and either "Area" or "Stock") then the percentage of R^2 explained increased from 27% to 30% (with increasing clarity corresponding to smaller 1st rings).

Hypothesis tests

Using all of the samples from this study combined, the 3rd ring measurements were spuriously presented as the 2nd ring measurements (together with the correct 1st ring measurements and the correct "Area" factors) and the single option hypothesis test was done at various levels of α with the following results:

α	%rejected
0.01	37
0.05	67
0.10	81
0.15	88

Hence, if a 3rd ring is presented as a second ring and only one option is offered then the hypothesis test struggles to distinguish between valid readings and false readings (α is the probability of rejecting a valid reading).

When the true readings were offered as alternatives to the 3rd rings spuriously presented as the 2nd rings, the correct readings were selected in 91% of the 269 cases. This is an encouraging result, but more work needs to be done to determine how well such tests will perform under other error conditions and over a much wider range of cohorts. Of course, with more ground truth data, better tests could be developed which could account for cohort differences which might cause a test without a cohort factor to perform badly (i.e., badly with a non average cohort).

12. Conclusions and recommendations

The classification of zones into "split/multiple" or "not split/multiple" should not be done for routine readings of hoki otoliths because it is unlikely to be done in a consistent fashion over time (the results may be dependent on the age of the otolith, or it may simply be too subjective to allow consistency).

The clarity grades for the juvenile and 1st zones may provide some differentiation between cohorts. For this reason they should be included in the routine reading of hoki otoliths (at least in the medium term).

Hypothesis tests using the 1st, 2nd, and 3rd ring measurements appear to hold some promise for detecting errors and choosing correctly between alternative interpretations. Their collection should be routinely done for hoki otoliths.

The total otolith radius depends on the time of capture and would need to be standardised for this before it could be useful in hypothesis testing. It may or may not be useful, but its collection would add to the overall cost of reading hoki otoliths so it is not recommended for routine collection.

The juvenile ring measurement will be extremely important if it can be established that it has a stock-dependent relationship with the 1st ring measurement. However, its routine collection is not recommended because it appears that it will be of little use in hypothesis testing of otolith readings made for the purpose of constructing age length keys.

13. Publications

Nil.

14. Data Storage

The otoliths are stored by the Ageing Unit at NIWA. The data sets resulting from this study and the previous study are currently stored in text files and S objects on individuals PCs and on NIWAs computer *muscle* (for which backup tapes/disks are regularly made). A request will be made to the Ministry to modify the *age* database to allow the storage of these data and future hoki otolith data which includes measurements and clarity grades.

15. References

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Table 1: Number of otoliths read by area and data set, cohort and sex

			Males		Females	
Area	Data	Cohort	Length range (cm)	Number measured	Length range (cm)	Number measured
Chatham Rise	tan9501	1991	59-63	25	60-64	17
	tan9601	1992	56-60	14	57-61	23
Sub-Antarctic	tan9605	1992	59-64	35	61-66	35
Cook Strait	ms* 1994	1991	51-58	15	51-58	9
	ms* 1995	1992	51-57	21	52-57	7
WCSI	observer 1995	1992	51-58	42	51-58	26

* ms = market sampling data

Table 2: List of all areas and cohorts used in the two ageing studies

Area	Data set	Cohort	Age
Chatham Rise	tan9106	1990	1+
	tan9212	1991	1+
	tan9401	1992	1+
	tan9401	1991	2+
	tan9501	1993	1+
	tan9501	1991	3+
	tan9601	1992	3+
	tan9701	1995	1+
	tan9701	1994	2+
	tan9801	1996	1+
	tan9901	1997	1+
	tan9901	1996	2+
Sub-Antarctic	tan9605	1992	3+
Cook Strait	ms* 1994	1991	3+
	ms* 1995	1992	3+
WCSI	obs+ 1995	1992	3+

* market sampling data
+ observer data

Table 3: Mean otolith length measurements for each data set by males, females and all fish. Juvenile, Radius 1, 2 and 3 are measurements from the nucleus to the outside of the juvenile, first, second and third zones

Measurement type	Data	Cohort	Mean otolith measurement (mm)		
			Males	Females	All fish
Juvenile	Chat 1995	1991	1.51	1.52	1.51
	Chat 1996	1992	1.63	1.56	1.59
	Suba 1996	1992	1.49	1.52	1.50
	Cstr 1994	1991	1.45	1.61	1.51
	Cstr 1995	1992	1.46	1.54	1.48
	WCSI 1995	1992	1.55	1.42	1.50
	All combined	-	1.52	1.51	1.51
Radius 1	Chat 1995	1991	2.33	2.34	2.33
	Chat 1996	1992	2.24	2.24	2.24
	Suba 1996	1992	2.34	2.33	2.33
	Cstr 1994	1991	2.16	2.30	2.21
	Cstr 1994	1992	2.19	2.26	2.21
	WCSI 1995	1992	2.30	2.33	2.31
	All combined	-	2.28	2.31	2.29
Radius 2	Chat 1995	1991	3.11	3.10	3.11
	Chat 1996	1992	3.04	3.05	3.04
	Suba 1996	1992	3.10	3.12	3.11
	Cstr 1994	1991	3.07	3.21	3.12
	Cstr 1994	1992	3.08	3.19	3.11
	WCSI 1995	1992	3.12	3.10	3.12
	All combined	-	3.11	3.11	3.10
Radius 3	Chat 1995	1991	3.46	3.48	3.47
	Chat 1996	1992	3.42	3.49	3.46
	Suba 1996	1992	3.48	3.53	3.51
	Cstr 1994	1991	3.40	3.59	3.47
	Cstr 1994	1992	3.41	3.63	3.46
	WCSI 1995	1992	3.46	3.44	3.44
	All combined	-	3.45	3.51	3.47

Table 4: Mean otolith length measurements for each cohort by males, females and all fish. Juvenile, Radius 1, 2 and 3 are measurements from the nucleus to the outside of the juvenile, first, second and third zones

Measurement type	Cohort	Mean otolith measurement (mm)		
		Males	Females	All fish
Juvenile	1991	1.49	1.55	1.51
	1992	1.53	1.50	1.51
Radius 1	1991	2.27	2.33	2.29
	1992	2.29	2.30	2.29
Radius 2	1991	3.10	3.14	3.11
	1992	3.10	3.11	3.10
Radius 3	1991	3.44	3.51	3.47
	1992	3.45	3.50	3.47

Table 5: Number of otoliths which have split/multiple zones for zones 1, 2 and 3

(a) Males

Data	Cohort	Zone 1		Zone 2		Zone 3	
		Split	Not	Split	Not	Split	Not
Chatham 1995	1991	17	8	13	12	23	2
Chatham 1996	1992	13	1	2	12	10	4
Sub-Antarctic 1996	1992	27	8	9	26	32	3
Cook Strait 1994	1991	15	0	7	8	12	3
Cook Strait 1995	1992	19	2	5	16	21	0
WCSI 1995	1992	42	0	26	16	40	2

(b) Females

Data	Cohort	Zone 1		Zone 2		Zone 3	
		Split	Not	Split	Not	Split	Not
Chatham 1995	1991	16	1	11	6	14	3
Chatham 1996	1992	20	3	2	21	19	4
Sub-Antarctic 1996	1992	27	8	12	23	29	6
Cook Strait 1994	1991	9	0	3	6	8	1
Cook Strait 1995	1992	5	2	1	6	5	2
WCSI 1995	1992	22	4	13	13	26	0

(c) All data

Data	Cohort	Zone 1		Zone 2		Zone 3	
		Split	Not	Split	Not	Split	Not
Chatham 1995	1991	33	9	24	18	37	5
Chatham 1996	1992	33	4	4	33	29	8
Sub-Antarctic 1996	1992	54	16	21	49	61	9
Cook Strait 1994	1991	24	0	10	14	20	4
Cook Strait 1995	1992	24	4	6	22	26	2
WCSI 1995	1992	64	4	39	29	66	2

Table 6a: Number of otoliths by cohort which have split/multiple zones for zones 1, 2 and 3

	Cohort	Zone 1		Zone 2		Zone 3	
		Split	Not	Split	Not	Split	Not
Males	1991	32	8	20	20	35	5
	1992	101	11	42	70	103	9
Females	1991	25	1	14	12	22	4
	1992	74	17	28	63	79	12
All data	1991	57	9	34	32	57	9
	1992	175	28	70	133	182	21

Table 6b: Proportions of otoliths by cohort which have split/multiple zones for zones 1, 2 and 3

	Cohort	Zone 1		Zone 2		Zone 3	
		Split	Not	Split	Not	Split	Not
Males	1991	0.80	0.20	0.50	0.50	0.88	0.12
	1992	0.90	0.10	0.38	0.62	0.92	0.08
Females	1991	0.96	0.04	0.54	0.46	0.85	0.15
	1992	0.81	0.19	0.31	0.69	0.87	0.13
All data	1991	0.86	0.14	0.52	0.48	0.86	0.14
	1992	0.86	0.14	0.34	0.66	0.90	0.10

Table 7: Number of otoliths from previously read Chatham Rise data which have a split second zone

		males		females		total	
Data	Cohort	Split	Not	Split	Not	Split	Not
Chatham 1994	1991	0	30	0	30	0	60
Chatham 1995	1992	21	9	24	6	45	15
Chatham 1997	1994	9	5	10	10	19	15
Chatham 1999	1996	0	21	0	22	0	43

Table 8a: Number of otoliths by area and clarity of juvenile and first zones. (1 = good, 2=ok, 3 = poor, 4 = unreadable)

(i) Clarity of juvenile zone

Data	Males				Females				Total			
	1	2	3	4	1	2	3	4	1	2	3	4
Chat 1995	5	13	7	0	4	7	5	1	9	20	12	1
Chat 1996	1	5	8	0	3	9	10	1	4	14	18	1
Suba 1996	6	12	17	0	5	16	14	0	11	28	31	0
Cstr 1994	3	9	2	1	1	7	1	0	4	16	3	1
Cstr 1995	2	9	9	1	1	1	5	0	3	10	14	1
Wcsi 1995	5	12	23	2	3	10	13	0	8	22	36	2

(ii) Clarity of first zone

Data	Males			Females			Total		
	1	2	3	1	2	3	1	2	3
Chat 1995	21	3	1	12	5	0	33	8	1
Chat 1996	6	7	1	18	5	0	24	12	1
Suba 1996	21	10	4	23	10	2	44	20	6
Cstr 1994	11	4	0	6	3	0	17	7	0
Cstr 1995	17	3	1	4	2	1	21	5	2
Wcsi 1995	24	16	2	18	7	1	42	23	3

Table 8b: Proportion by clarity for 1991 and 1992 cohorts

	Juvenile clarity				First zone clarity		
	1	2	3	4	1	2	3
1991	0.20	0.55	0.23	0.03	0.76	0.23	0.02
1992	0.13	0.36	0.49	0.02	0.65	0.30	0.06

Table 9a: Estimated coefficients and explanatory power for the additional regressions which used the "Area" factor (CKST = Cook Strait, CR = Chatham Rise, SA = Sub Antarctic). "Adj. R" denotes Rjuv for R1, R1 for R2, and R2 for R3

Dependent	Coefficients						%R^2	
variable	Intercept	Adj. R	CKST	WCSI	CR	SA	Adj. R	+ Area
R1	1.71	0.41	–0.13	–0.03	–0.07	0.00	21	27
R2	1.68	0.61	+0.08	+0.02	–0.01	0.00	36	39
R3	0.70	0.90	–0.05	–0.07	–0.01	0.00	67	69

Table 9b: Estimated coefficients and explanatory power for the additional regressions which used the "Spawning flag". "Adj. R" denotes Rjuv for R1, R1 for R2, and R2 for R3

Dependent	Coefficients				%R^2	
variable	Intercept	Adj. R	Spawn	Non Sp.	Adj. R	+ Sp. flag
R1	1.71	0.39	–0.04	0.00	21	22
R2	1.72	0.59	+0.05	0.00	36	38
R3	0.69	0.91	–0.06	0.00	67	69

Table 9c: Estimated coefficients and explanatory power for the additional regressions which used the "Stock" factor (East = Cook Strait, West = WCSI or Sub Antarctic, Mix = Chatham Rise). "Adj. R" denotes Rjuv for R1, R1 for R2, and R2 for R3

Dependent	Coefficients					%R^2	
variable	Intercept	Adj. R	East	West	Mix	Adj. R	+ Stock
R1	1.65	0.41	–0.06	+0.05	0.00	21	27
R2	1.68	0.61	+0.09	+0.02	0.00	36	39
R3	0.69	0.90	–0.03	–0.02	0.00	67	67

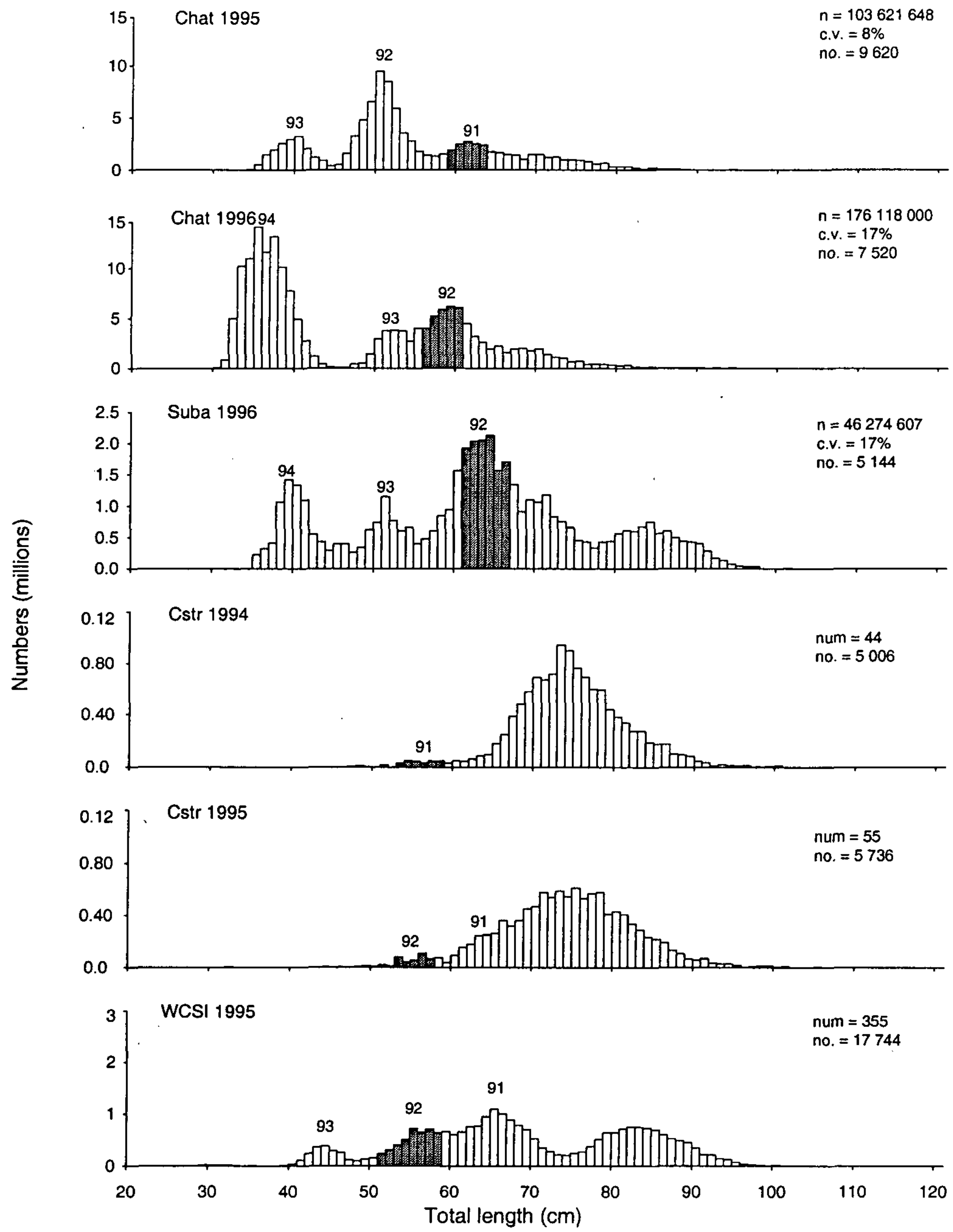

Figure 1a: Scaled length frequency of male hoki caught in the trawl surveys of the Chatham Rise and Sub-Antarctic (Chat 1995, Chat 1996, Suba 1996); sampled from commercial catches in sheds by the Cook Strait Stock monitoring program (Cstr 1994, Cstr 1995), and sampled from the WCSI observer program (WCSI 1995). Shaded areas are the length ranges from which otoliths were reaged. (n is the scaled number of fish; no. is the number of fish sampled, and num is the number of landings (Cook Strait) or tows (WCSI) sampled).

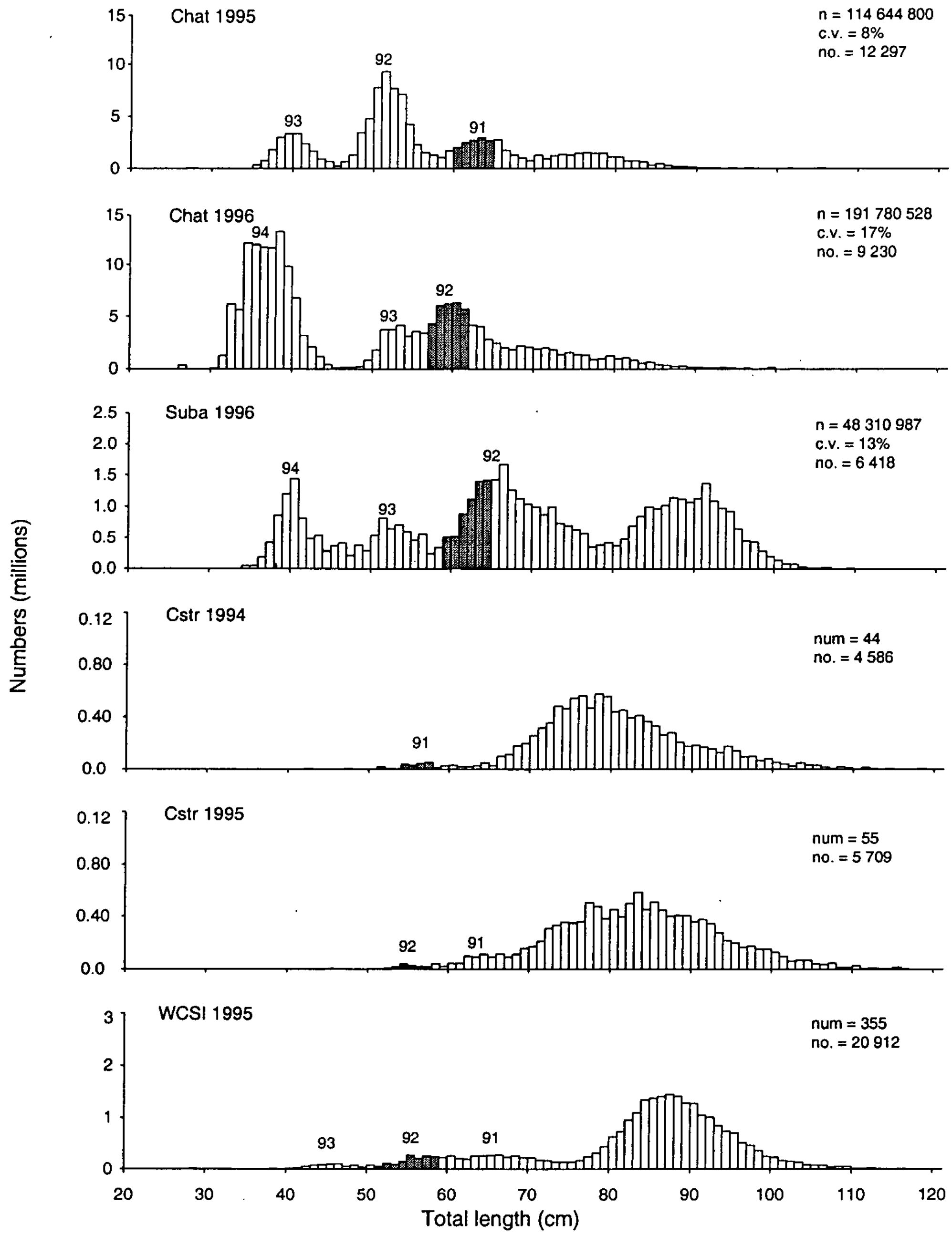

Figure 1b: Scaled length frequency of female hoki caught in the trawl surveys of the Chatham Rise and Sub-Antarctic (Chat 1995, Chat 1996, Suba 1996); sampled from commercial catches in sheds by the Cook Strait Stock monitoring program (Cstr 1994, Cstr 1995), and sampled from the WCSI observer program (WCSI 1995). Shaded areas are the length ranges from which otoliths were reaged. (n is the scaled number of fish; no. is the number of fish sampled, and num is the number of landings (Cook Strait) or tows (WCSI) sampled).

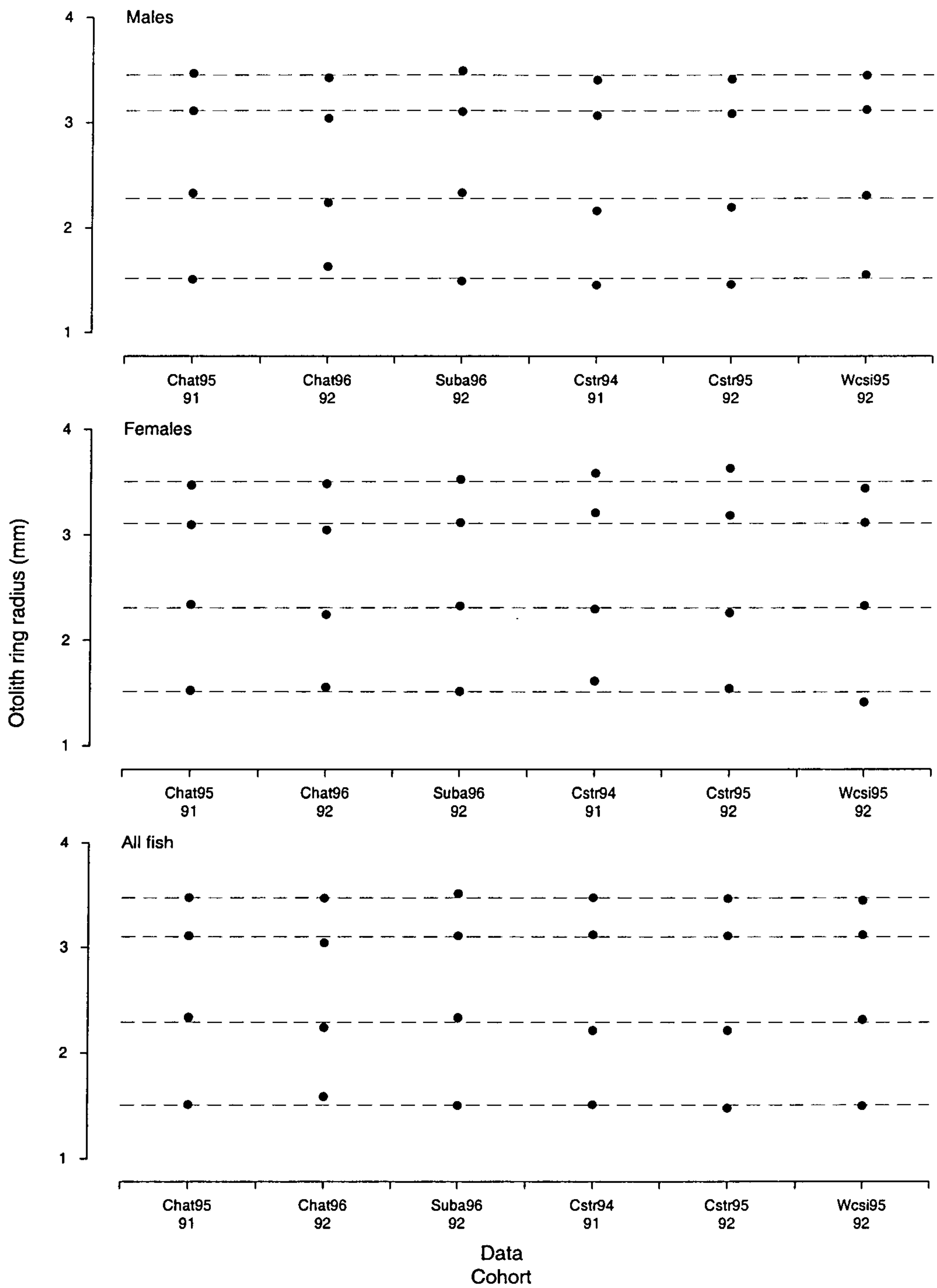

Figure 2: Mean otolith ring radius by cohort and data set. Dotted lines are mean of means for Rjuv, R1, R2, and R3.

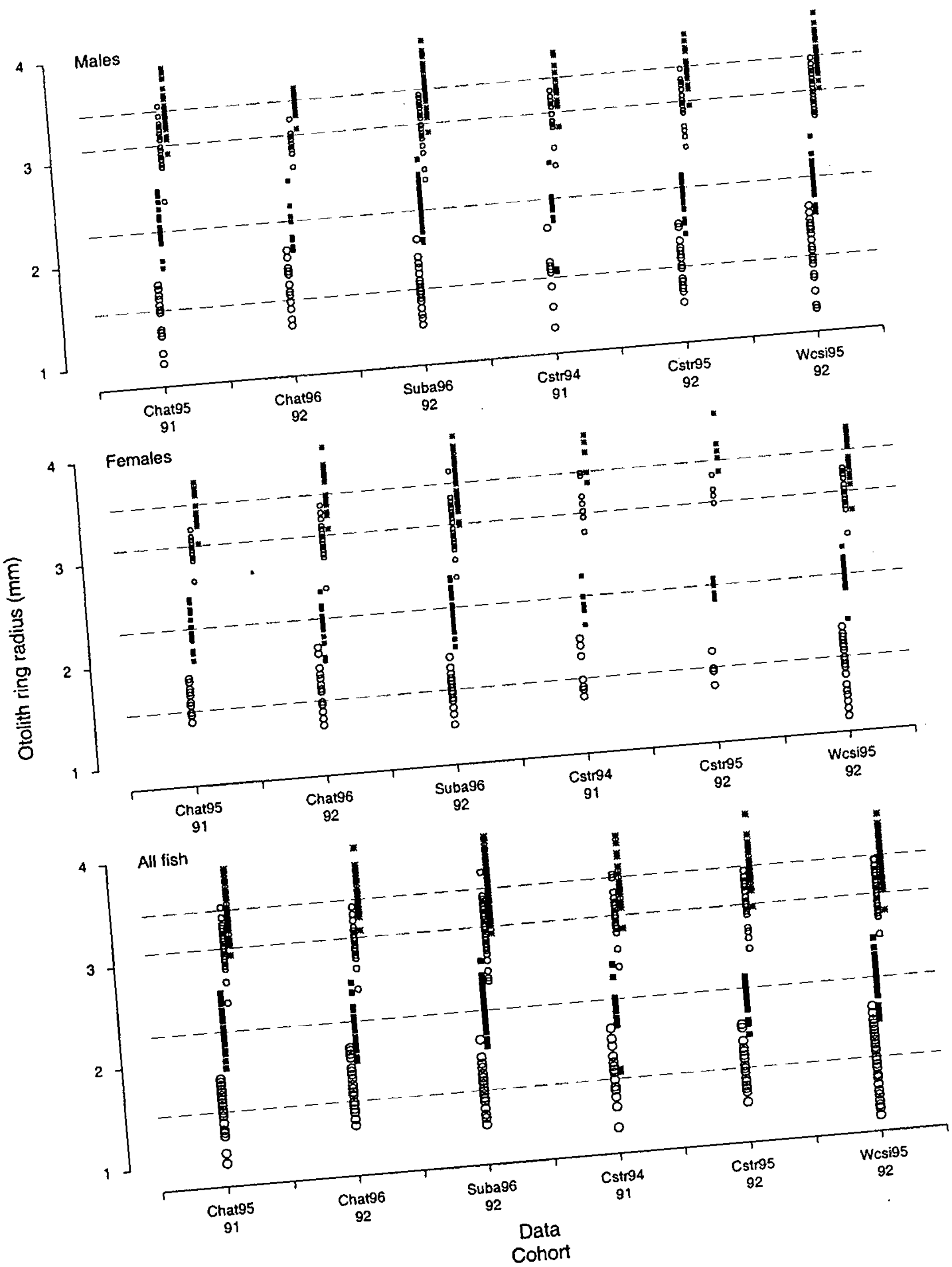

Figure 3: Otolith ring radius (Rjuv, R1, R2, and R3) for each fish. Dotted lines are the mean otolith radius for Rjuv, R1, R2, and R3.

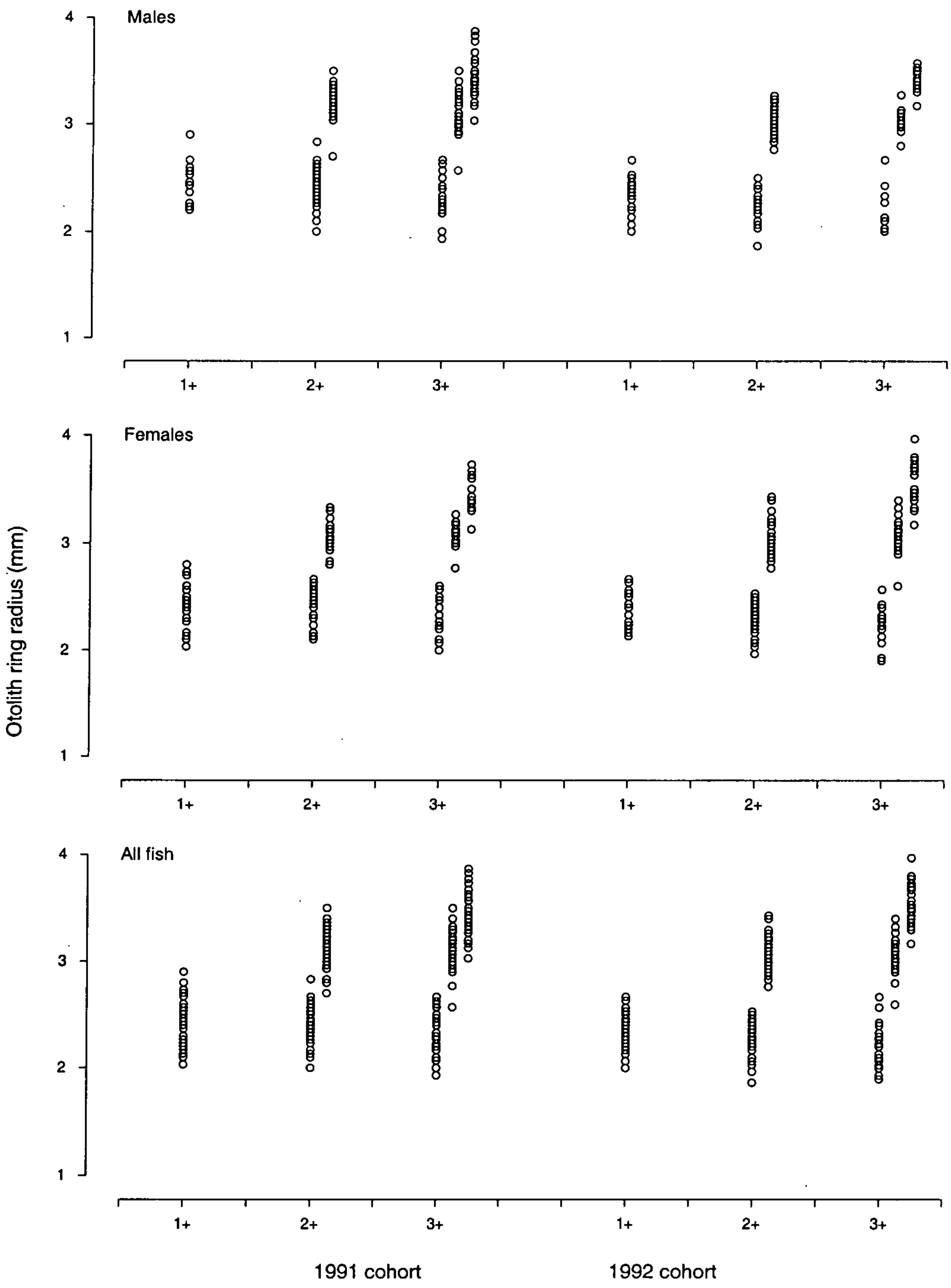

Figure 4: Comparison of Chatham Rise otoliths from the 1991 and 1992 cohort at ages 1+, 2+, and 3+.

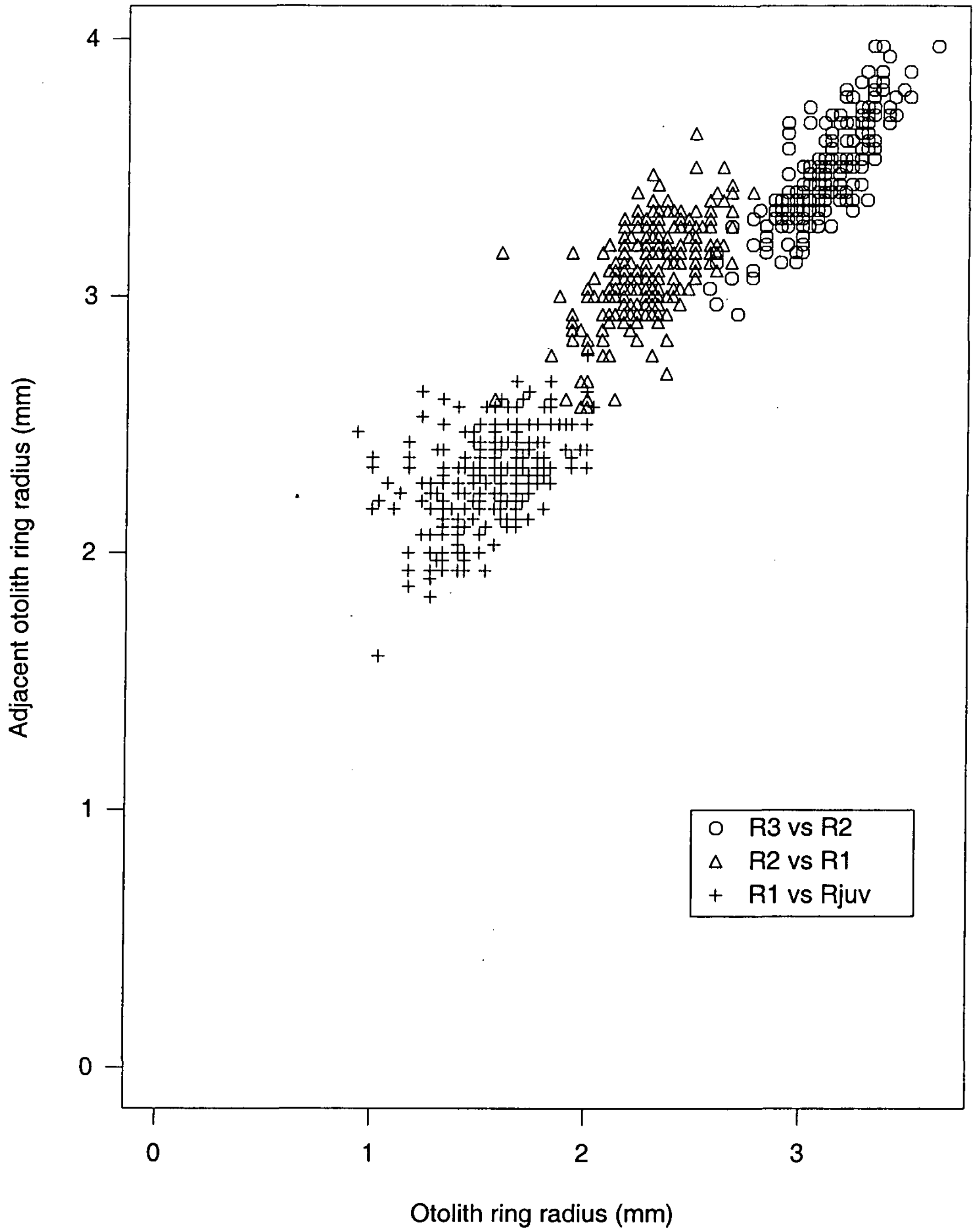

Figure 5: Plots of the 1st, 2nd, and 3rd ring measurements vs the adjacent ring measurements.