TUHINGA

Records of the Museum of New Zealand Te Papa Tongarewa

The estimation of live fish size from archaeological cranial bones of the New Zealand kahawai *Arripis trutta*

Museum of New Zealand
Te Papa Tongarewa
PO Box 467
Wellington, New Zealand

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The estimation of live fish size from archaeological cranial bones of the New Zealand kahawai *Arripis trutta*

B.F. Leach[1], J.M Davidson[1], L.M. Horwood[2], S. Mallon[1]

ABSTRACT: Five paired cranial bones and the otoliths of a modern sample of 143 kahawai, *Arripis trutta*, were measured and regression analysis performed against live fork length and ungutted weight. A number of regression models were examined (linear, logarithmic, exponential and power curve) to work out the optimum estimator for each bone measurement. Coefficients are provided for 44 equations linking archaeological bone size to live characteristics. It was found that fork length could be estimated with a standard error of less than ±29 mm and weight to less than ±290 g.

INTRODUCTION

In some areas of New Zealand, particularly the southern North Island, kahawai was of moderate importance in pre-European Māori fish catches. This is indicated from a New Zealand-wide study, published by Leach and Boocock (1993). Kahawai is a pelagic species generally confined to inshore coastal waters, although they frequently enter shallow harbours, and are sometimes present in estuarine lagoons and the tidal reaches of large rivers (Paul 1986: 92). They are voracious carnivores feeding on a variety of

[1]Archaeozoology Laboratory, Museum of New Zealand Te Papa Tongarewa, P.O. Box 467, Wellington, New Zealand
[2] Whanganui Regional Museum, PO Box 352, Wanganui, New Zealand

pelagic animals, mainly crustaceans and small fish, and are therefore easily taken on a trolled lure.

The presence of this fish in prehistoric fish catches does not of itself provide much indication of its economic role — for this, it is necessary to be able to reconstruct the size frequency distribution of the original fish catch, and to estimate the meat weight derived from this species, and then compare this information with other sources of food. In order to do this we need reliable techniques for estimating the original fork length and ungutted weight from the typical bone fragments which we find in archaeological sites. In the past few years research has been carried out with this objective in mind in the Archaeozoology Laboratory at the Museum of New Zealand. The research is labour intensive and we are working on one species at a time, targeting those types of fish which were commonly caught by the pre-European Māori.

A large study of snapper (*Pagrus auratus*) has been completed (Leach and Boocock, 1995), and the barracouta (*Thyrsites atun*) has also been subjected to intensive study (Leach *et al*, 1996). This present study is a continuation of this ongoing research project.

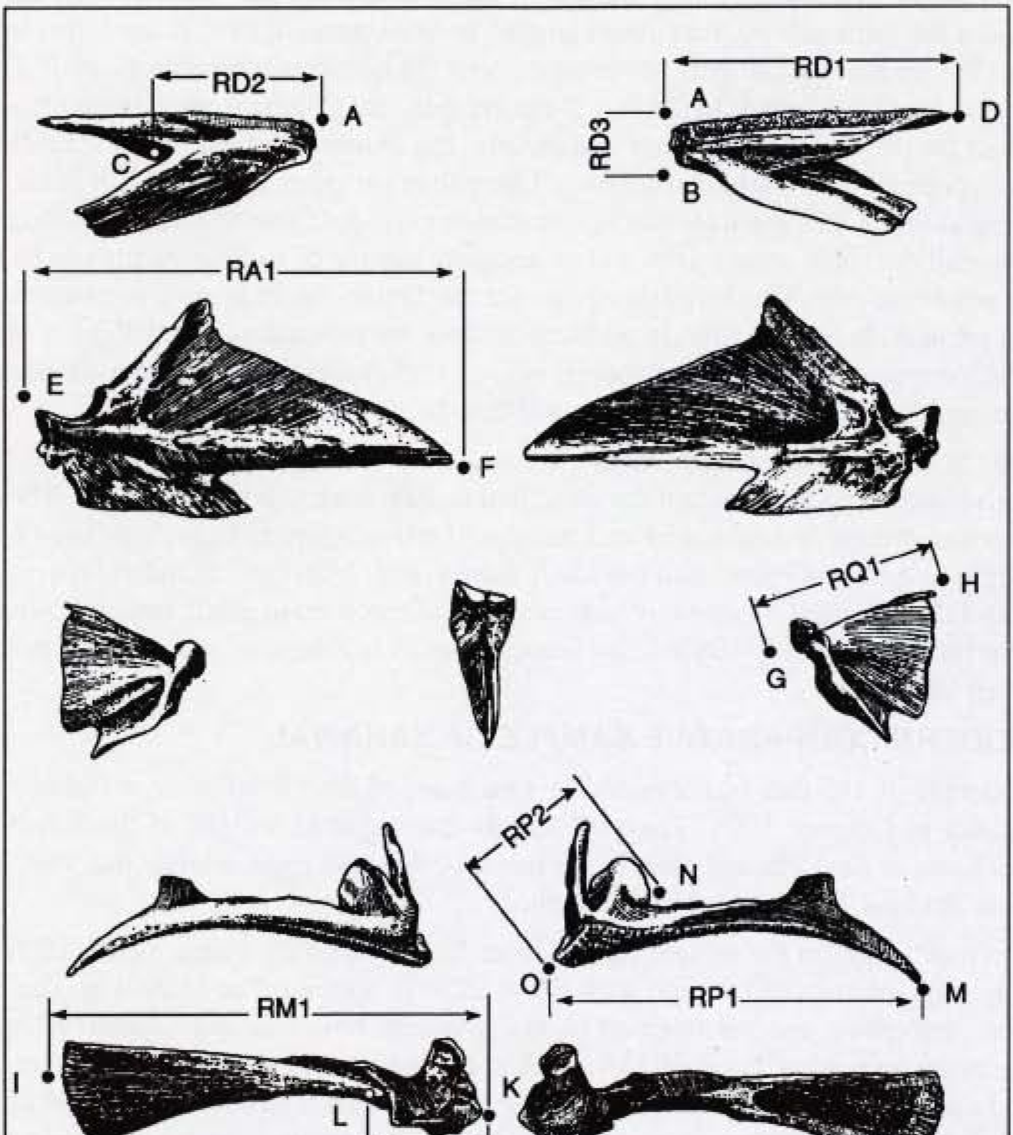
BONE MEASUREMENT METHODOLOGY

The method we use to quantify prehistoric fish catches from New Zealand and the Pacific islands focuses on five paired cranial bones — the dentary, articular, quadrate, premaxilla, and maxilla (Leach and Davidson, 1977; Leach and Ward, 1981; Leach, 1986; Leach and Boocock, 1993). In this present study these bones, together with the otoliths, are used for measurement.

As these bones in kahawai do not always survive intact in archaeological sites it is necessary to define measurements that can be made on bone fragments as well as on the whole bones. Wherever possible the largest dimension is always taken, as this yields the most reliable estimate of the original fish size. The dimensions chosen for measurement for this species are illustrated in Figure 1. These closely parallel those employed by archaeozoologists on other species (Rosello-Izquierdo, 1986:35; Libois and Libois 1988; Sternberg, 1992; Wheeler and Jones, 1989:139 ff.). However, it must be noted that there are subtle differences in the anatomy from one species to another, requiring careful definition of exactly what is being measured in each case.

In Figure 1, the anatomical landmarks used for measurements are indicated by a small dot and given a letter A to Q. Each measurement is given a code with three characters, which are listed in Table 1 together with the anatomical landmark definitions. Thus,

Figure 1: Cranial elements of *Arripis trutta* (kahawai) used for measurements. The right bones are illustrated. Measurements are made between landmarks A-B, A-C, and A-D on the dentary; between E-F on the articular; between G-H on the quadrate; between O-M and O-N on the premaxilla; between K-I and K-L on the maxilla; and between P-Q on the otolith.


RD2
A
C
RD1
A
D
RD3
B
RA1
E
F
RQ1
H
G
RP2
N
O
M
RP1
RM1
I
K
L
RM2

LD1 refers to the left dentary and the first measurement made on that bone. In cases where the terminology 'maximum length' or 'maximum height' is used, this implies that the measuring callipers are rotated about the nominated landmarks until a maximum value is obtained. In Table 1 it can be seen that fragment measurements are not taken for the articular, quadrate and otolith. The number of these bones identified for this species is generally considerably lower than for other bones, and in particularly large assemblages the quadrate is sometimes excluded from the analysis altogether. The otolith is also quite robust and an adequate sample of measurements can be taken on whole otoliths. Three measurements for the dentary are indicated, and two each for the premaxilla and maxilla. In addition to these measurements, the weight of otoliths was measured. Otoliths are of special interest to fisheries scientists for estimating fish age, and it was considered useful to add this dimension to the study.

This three character measurement code is a simple method of coding measurements onto plastic bags that contain the identified archaeological bone fragments. These are later entered into a database by archaeological provenance, and equations used for live length and weight estimation based on these codes. Mitutoyo digital callipers model 500-322 were used for linear measurements and recorded to ±0.01 mm precision, and a Sartorius model BA310S balance was used for weight measurements with a precision of ±0.001 g.

MODERN COMPARATIVE SAMPLE OF KAHAWAI

A sample of 143 fish was obtained by Leach and Mallon from Sealord Fisheries Ltd. Nelson in October 1993. The fork length and ungutted weight of these fish were measured at Sealords and their heads removed for later processing at the Museum of New Zealand Archaeozoology Laboratory.

The fork length in the sample ranged from 289 to 625 mm, with a mean of 522 mm. The range of ungutted weight was 379 to 2920 g, with a mean of 1991 g. The heads were macerated and the relevant cranial anatomy removed and measured in 1994. Measurements were made of 24 variables, consisting of the fork length, the ungutted body weight, and 22 measurements on the bones. Some bones were broken or missing (in the case of a number of otoliths), so not all measurements were able to be taken. The final data matrix of 3432 entries had 378 missing values. In carrying out regression analysis, missing values were not estimated, but arrays were concatenated in pairs as appropriate.

LEAST-SQUARES ANALYSIS OF MODERN COMPARATIVE MATERIAL

The main objective of this study was to establish reliable regression relationships between bone dimension and live fork length and ungutted weight for modern kahawai which could then be used for archaeological bones. This involves seeking best fit relationships directly between the bones of individual fish and the live fork length. In the case of estimating live weight, there are two possible approaches — a one or two step procedure.

Method 1 — One Step Procedure
Establish the relationship between a bone dimension and ungutted weight (equation 1)
Step 1: Using equation 1 estimate the live ungutted weight from the bone measurement.

Method 2 — Two Step Procedure
Establish the relationship between a bone dimension and the fork length (equation 2).
Establish the relationship between fork length and body weight (equation 3).
Step 1: Using equation 2 estimate the live fork length from the bone measurement.
Step 2: Using equation 3 estimate the live ungutted weight from the estimated fork length.

The reason why a possible two step procedure is envisaged is that it is a relatively simple matter to get a very large sample of fish from which to calculate equation 3. On the other hand, extracting the necessary bones from modern specimens is much more difficult and time consuming, and samples are very small. Thus, the one step procedure may be based on a small and biassed sample. Whether a one or two step procedure should be followed depends on the samples available for study and the standard errors which can be achieved in their analysis. These two methods were examined to establish the most reliable regression relationships.

First, various types of curves were fitted to the comparative collection data using the least squares method to determine the metrical relationship between bone dimensions and fork length and live weight. The equations for estimating Y from X are as follows (A = constant, B = slope):

Linear Fit	$Y = A + B * X$
Exponential Fit	$Y = A * \exp(B * X)$
Logarithmic Fit	$Y = A + B * \ln(X)$
Power Curve Fit	$Y = A * X^B$
Cubic Fit	$Y = A + B * X^3$

Using the left dentary maximum length as an example, the statistics for these relationships are presented in Table 2 and illustrated in Figures 2 and 3.

In the case of fork length estimates the standard errors of the estimates are 18.9, 19.1, 18.1, 17.0 and 23.1 for linear, exponential, logarithmic, power curve and cubic fits respectively. The power curve fit is the best fit on this basis. Thus, the best equation is:

$$\text{Fork Length} = 9.6 * LD1^{1.038} \pm 17 \text{ (units mm/mm)}$$

Similarly, for the weight estimates the standard errors of the estimates are 197, 199, 196, 179, and 213 g for the linear, exponential, logarithmic, power curve and cubic fits respectively. Once again, the smallest standard error is the power curve fit. Thus, the best equation would be:

$$\text{Weight} = 0.166 * \text{LD1}^{2.433} \pm 179 \text{ (units mm/g)}$$

This procedure was carried out for all measurements listed in Table 1. The final choices for estimating length and weight from all bone dimensions are listed in Table 3, and are based on the smallest standard error of the estimate in each case. Figure 4 shows the best and worst cases of estimating fork length from bone measurements, and Figure 5 shows the best and worst cases for estimating ungutted weight from bone measurements. In both these illustrations the regression relationship is bounded by curves showing the 95% confidence limits, based on the standard error of the estimate of Y on X (Schefler, 1969:155-157; Snedecor and Cochran, 1967:155).

It is useful to follow a worked example. For this purpose, a modern fish in the comparative collection of medium size is chosen, catalogued as specimen AB356. This fish had a live fork length of 495 mm, and an ungutted weight of 1640 g. The left dentary maximum length LD1 was 42.77 mm.

From Table 3 it will be seen that the best fit model for estimating fork length from the LD1 bone measurement was found to be a power curve fit, and this can be extracted from the Table as follows:

$$\text{Fork Length} = 9.600739 * \text{LD1}^{1.038067} \pm 17.0 \text{ (units mm/mm)}$$

Again, in Table 3 it will be observed that the best fit model for estimating live weight from the LD1 bone measurement was also found to be a power curve fit, and this can be extracted from the Table as follows:

$$\text{Weight} = 0.166353 * \text{LD1}^{2.433992} \pm 179.3 \text{ (units mm/g)}$$

By substituting the value of LD1 of 42.77 into these two equations, we derive estimates for the fork length of 474 mm, and for the weight of 1553 g. The error in estimating the fork length is therefore 21 mm (495-474), and of estimating the weight 87 g (1640-1553).

There are two methods by which an estimate can be obtained of the original weight of the fish directly from the bone to the weight, using the comparative material assembled for this present study, or one could adopt a two-step process; firstly estimating the fork length from the bone dimension, and then secondly estimating the weight from the fork length. There is a potential shortcoming in the first approach, in that this present osteological sample of 143 fish is only relatively small and does not contain many very small specimens or very large ones. Thus, with archaeological material we may sometimes be obliged to extrapolate beyond the size limits of the osteological collection. This is not a serious problem in the case of regression equations which are close to linear; however, it could produce significant errors when a regression relationship is close to a cubic function. Fortunately, MAF Fisheries scientists have studied the relationship between fork length and body weight for very large samples of fish, and also for different sexes, at different seasons, and at different localities. The equation for both sexes combined published by Drummond and Wilson (1993: 38) is:

$$\text{Weight} = 0.000034 * \text{Fork Length}^{2.8051} \text{ (units cm/kg)}$$

In our own study of 143 kahawai, our equation was found to be:

$$\text{Weight} = 0.001095056 * \text{Fork Length}^{2.299728} \pm 148 \text{ (units mm/g)}$$

The former equation is preferred here because it is based on a much larger sample of kahawai. One way of trying to evaluate the relative merits of the one step and two step approaches is to examine the residuals. That is, the difference between observed and estimated fork length and weight, using estimates from the two models. This was carried out, and the results are graphed in Figure 7. The mean of the residuals is close to zero for estimates of fork length. In the case of weight estimates, the one step model had a mean residual of -0.09%, compared with -16.2% for the two step model. Despite the apparently lower mean figure for the one-step model, this is only based on a small modern sample of fish, and is therefore slightly suspect. Moreover, archaeological fish are sometimes larger than easily obtained modern osteological collections, which would require extrapolation beyond the limits of the available material. In the case of near cubic functions, it is best to use those based on the largest possible sample. For this reason the two step model based on Drummond and Wilson's equation is the preferred option.

PUTTING THE ALGORITHMS TO WORK

During the analysis of fish bone from an archaeological site, the bones are sorted by anatomy and identified to species. Wherever possible one of the bone dimensions described in Table 1 is measured on each bone. These measurements are then entered onto a computer file by provenance, for example:

```
Paremata Site N160/50 Kahawai Archaeological Bone Measurements
PARE Layer 6
LD3 05.22 03.09 04.81
RD3 05.13 05.37 05.99 05.68 07.76
LP2 09.16
LM2 09.00 09.18
RM2 10.83 09.37 08.82 08.46 09.43 06.88 09.43
RA1 30.33
LQ1 11.86
RQ1 19.48
```

A simple computer program is then used to convert these measurements into estimates of live fork length and ungutted weight. For example, the first measurement LD3 is one of the fragment measurements for the left dentary. The equations for estimating live fork length and ungutted weight are given in Table 3, viz:

$$\text{Fork Length} = 113.2251 * \text{LD3}^{0.7773609} \pm 28 \text{ (units mm/mm)}$$

Since LD3 = 5.22 mm in the first specimen, the estimated fork length is therefore 409.1 mm. The two possible equations for estimating the ungutted weight are:

$$\text{Weight} = 51.25237 * \text{LD3}^{1.850353} \pm 230 \text{ (units mm/g) — one step model}$$

$$\text{Weight} = 0.000034 * \text{Fork Length}^{2.8051} \text{ (units cm/kg) — two step model}$$

Using the LD3 measurement of 5.22 mm and the estimated Fork Length of 40.91 cm, the two estimates of ungutted weight are therefore 1090.6 g and 1.1293 kg. The difference between the two models is 38.7 g, well within the ±230 g range given for the one step equation.

CONCLUSIONS

This analysis of modern kahawai bones has shown that it is feasible to estimate the live fork length and ungutted weight from the cranial bones of kahawai in archaeological sites within acceptable margins of error. Fork length can be estimated with a standard error of better than 30 mm in all cases of bone measurements described in this paper, and the ungutted weight to better than 290 g. This latter error is large compared with most estimates, and is obtained from measurement of the otoliths. Typical cranial bones, such as the dentary, provide standard errors of about ±180 g.

Equations are provided in this paper for estimating fork length and weight for 22 bone measurements. These cover the range of whole bones and bone fragments of kahawai which commonly occur in archaeological sites in New Zealand.

ACKNOWLEDGEMENTS

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Figure 2: Several regression models were applied to the measurement of left dentary maximum length and live fork length and weight (N=143). Note that some of the lines of best fit are difficult to distinguish. The solid lines show the equations chosen as the most satisfactory fit (power curve fit in both cases).

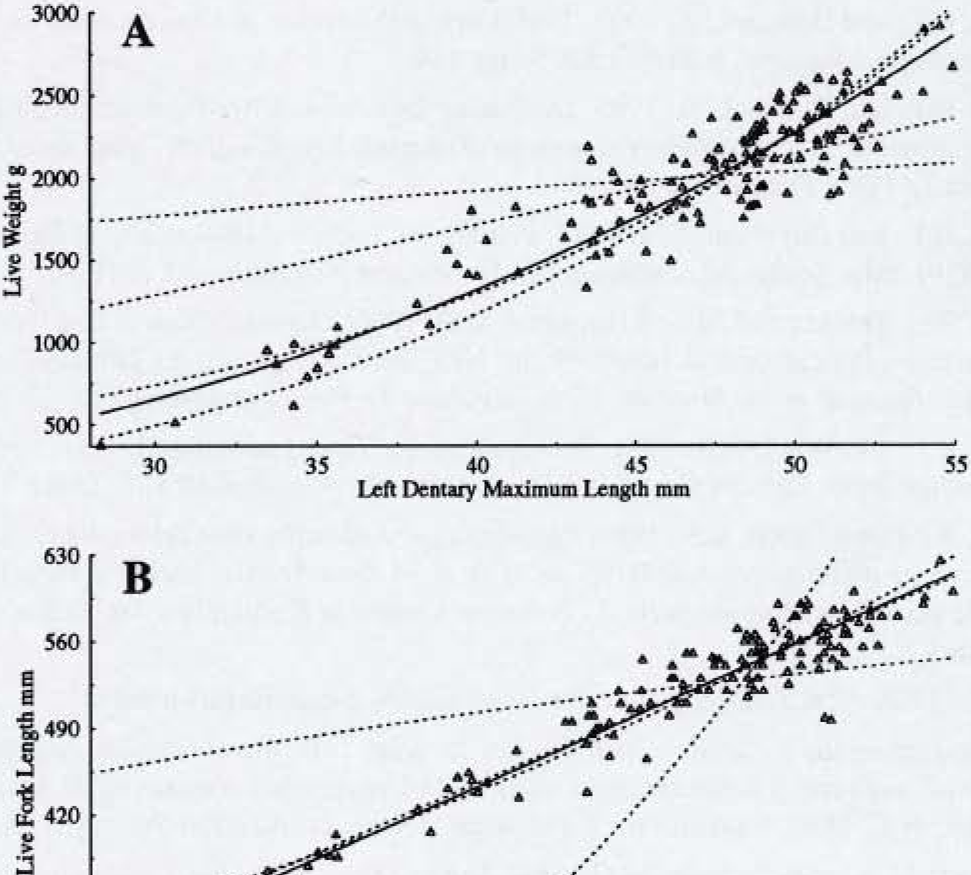


Figure 3: The regression model which best fits the data when estimating fork length (A) and ungutted weight (B) from the left dentary maximum length is a power curve fit in both cases. The 95% confidence boundaries for the regression line of y on x are shown. The standard errors are ±17 mm for the fork length, and ±179 g for the weight. The powers are 1.04 and 2.43 for fork length and weight respectively. These values are close to linear and cubic.

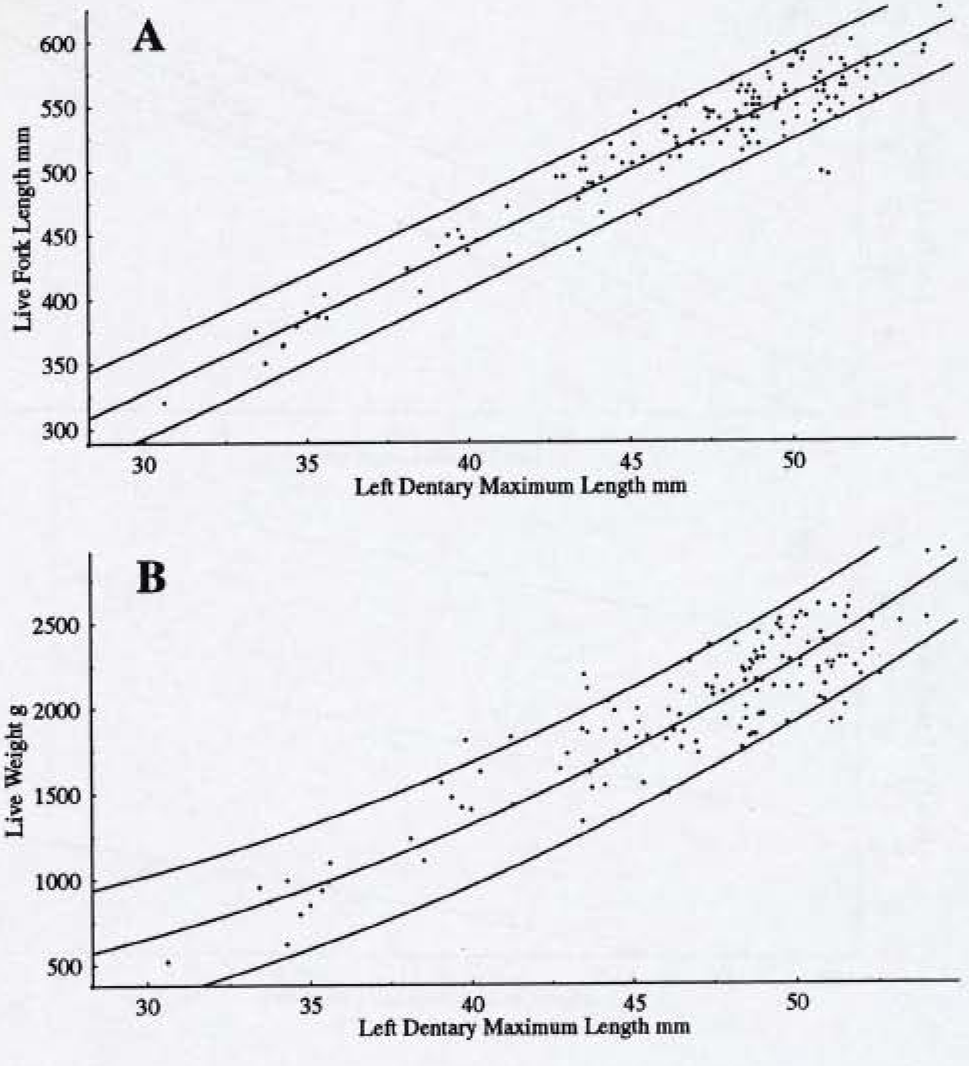


Figure 4: This shows the best (A) and the worst (B) fit regression lines for estimating fork length from bone measurements. The best measurement is the left maxilla maximum length, which has a standard error of the estimate of ±17 mm; and the worst is the right otolith maximum length with ±28 mm.

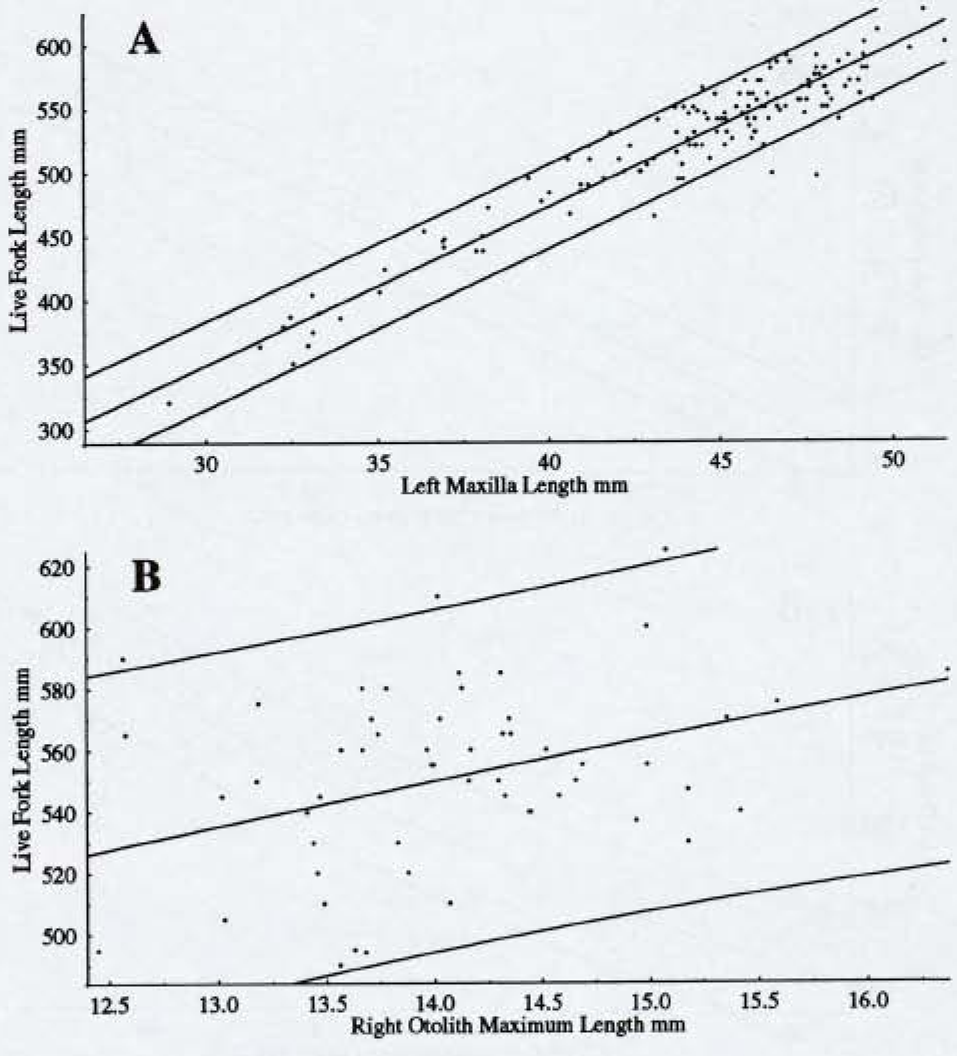
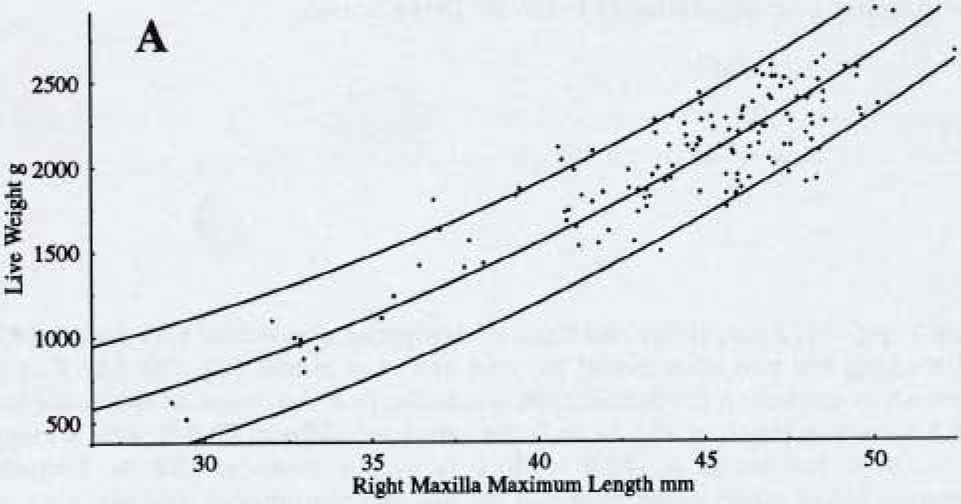


Figure 5: This shows the best (A) and the worst (A) fit regression lines for estimating ungutted weight from bone measurements. The best measurement is the right maxilla maximum length, which has a standard error of the estimate of ±177 g; and the worst is the right otolith maximum length with ±288 g.



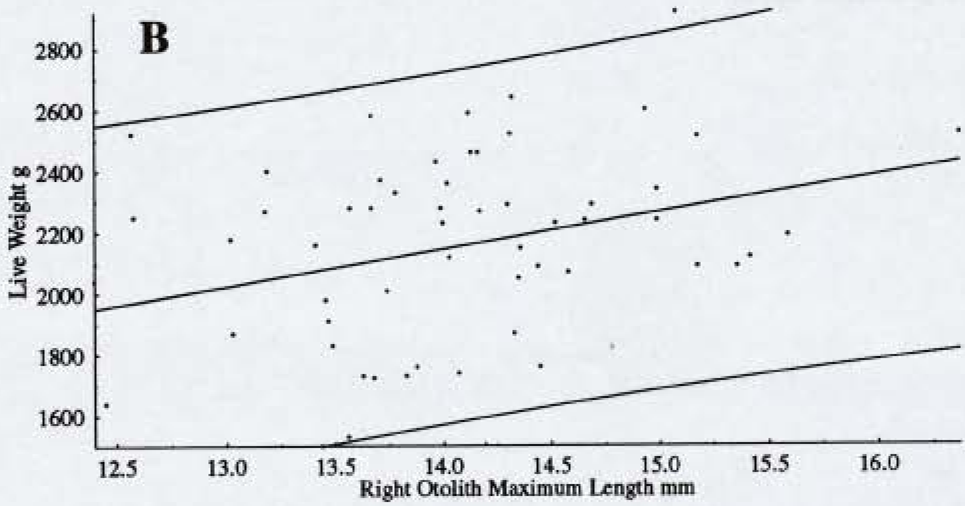
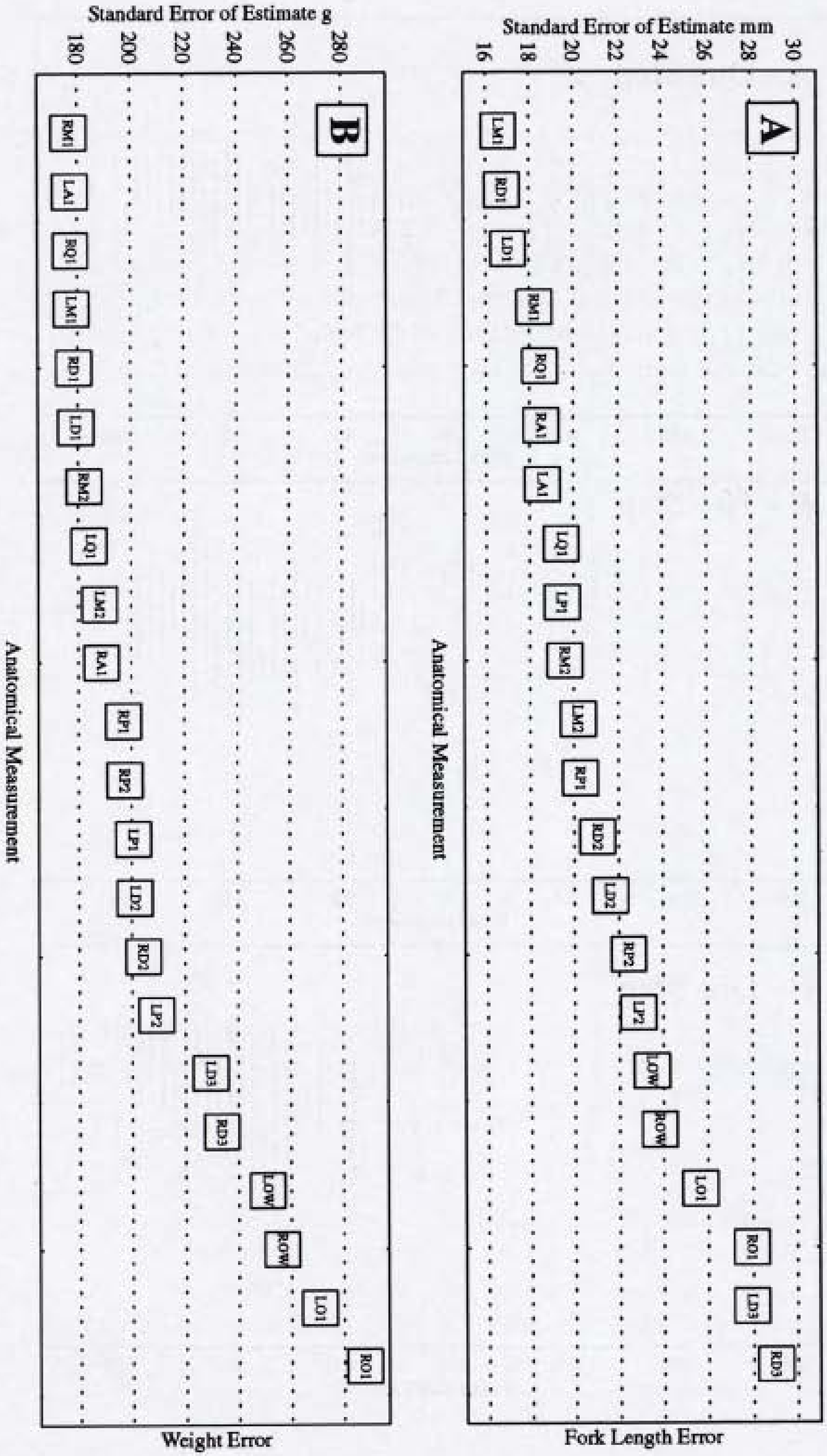


Figure 6 (right): These two graphs show the range of standard errors of the estimate for both fork length (A) and ungutted weight (B) for all bone measurements taken. These range from 17 to 28 mm and 177 to 288 g. The general pattern of errors is similar for any one measurement between the two graphs. Note that the comparatively poor performance of the otolith measurements is partly due to the lower number of measurements made on these bones.

Figure 7 (pg 16): Analysis of residuals of estimated and actual fork length (A), and weight using the two step-model (B) and one step model (C). The 143 fish in the comparative collection produced 2768 residuals. In A the range of residuals is -32.1 to 28.3 %, with a mean of -0.1 %. In B the range is -135.6 to 50.0 % with a mean of -16.2 %. In C the range is -72.8 to 40.4 % with a mean of -0.8 %. Despite the apparently lower mean value obtained for the one step model, the two step model is the preferred option.


Standard Error of Estimate g
180 200 220 240 260 280
B
RM1 LA1 RQ1 LM1 RD1 LD1 RM2 LQ1 LM2 RA1 RP1 RP2 LP1 LD2 RD2 LP2 LD3 RD3 LOW ROW LO1 RO1
Anatomical Measurement
Weight Error
Standard Error of Estimate mm
16 18 20 22 24 26 28 30
A
LM1 RD1 LD1 RM1 RQ1 RA1 LA1 LQ1 LP1 RM2 LM2 RP1 RD2 LD2 RP2 LP2 LOW ROW LO1 RO1 LD3 RD3
Anatomical Measurement
Fork Length Error

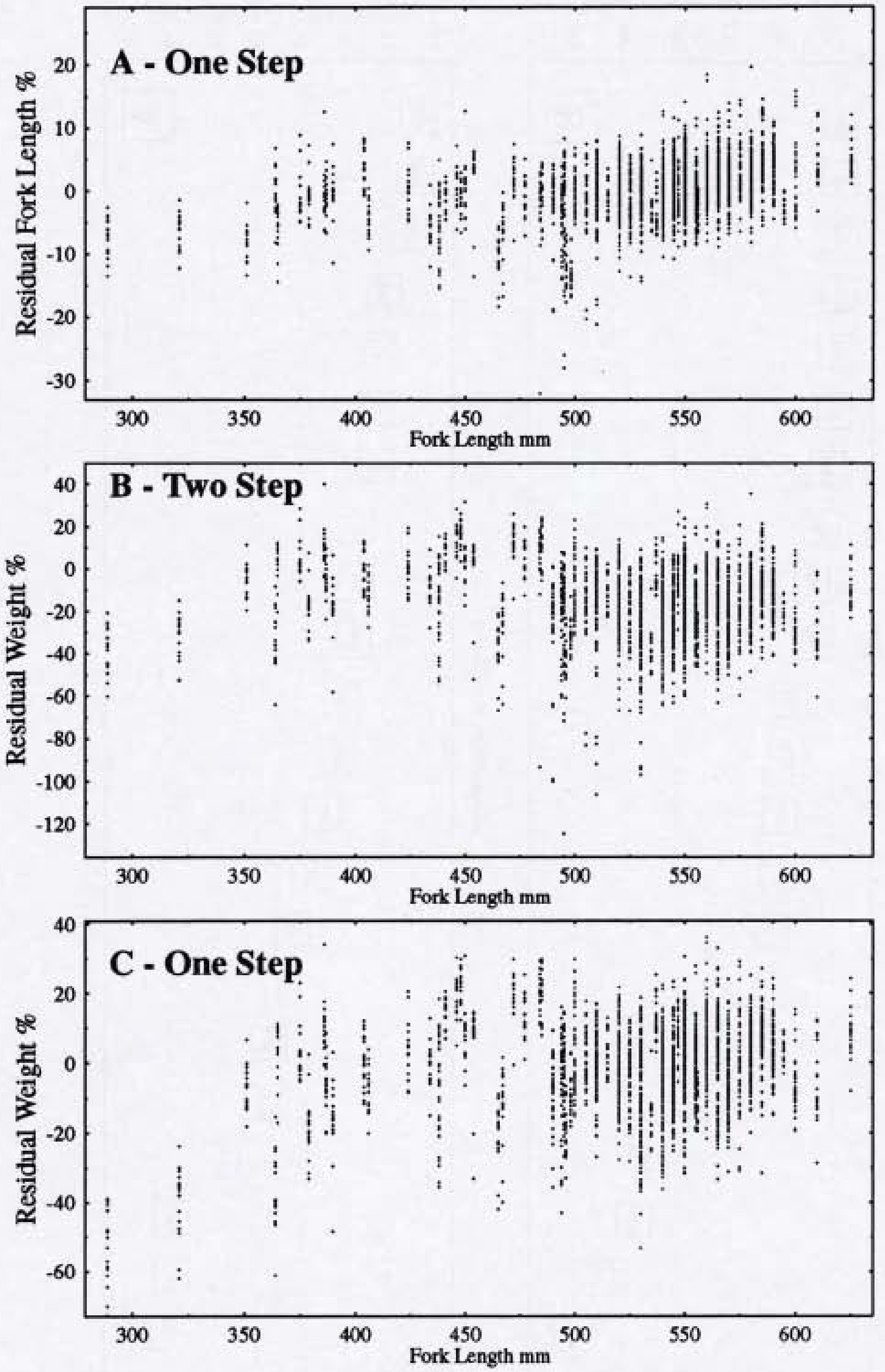

A - One Step
Residual Fork Length %
20
10
0
-10
-20
-30
300
350
400
450
500
550
600
Fork Length mm
B - Two Step
Residual Weight %
40
20
0
-20
-40
-60
-80
-100
-120
Fork Length mm
C - One Step
Residual Weight %
40
20
0
-20
-40
-60
Fork Length mm

Table 1. Measurements made on Cranial Bones

See Appendix 1 and Figure 1 for a full description.

Left	Right	Landmarks	Bone	Dimension	Units
LD1	RD1	A-D	Dentary	Maximum Length	mm
LD2	RD2	A-C	Dentary	Fragment 1	mm
LD3	RD3	A-B	Dentary	Fragment 2	mm
LA1	RA1	E-F	Articular	Maximum Length	mm
LQ1	RQ1	G-H	Quadrate	Length	mm
LP1	RP1	O-M	Premaxilla	Maximum Length	mm
LP2	RP2	O-N	Premaxilla	Fragment 1	mm
LM1	RM1	K-I	Maxilla	Maximum Length	mm
LM2	RM2	K-L	Maxilla	Fragment 1	mm
LO1	RO1	P-Q	Otolith	Maximum Length	mm
LOW	ROW	-	Otolith	Weight	g

Table 2. Least Squares Analysis statistics of left dentary maximum length against live fork length and ungutted weight

Least squares analysis was performed on the data described in the text, assuming that the various curves pass through the origin. The data for the left dentary maximum length (LD1) dimension is presented in this table. A = constant, B = slope, R = correlation coefficient, SER = standard error of R, SEEy = standard error of the estimate of Y, t=Student's t (with 103 degrees of freedom), Residuals (Chi-Square, with 104 degrees of freedom).

		Live Fork Length mm					
Fit	A	B	R	SEEy	SER	t	Residuals
Linear	.000	11.125	.951	18.9	.007	36.4	98
Exponential	167.293	.024	.950	19.1	.008	36.0	122
Logarithmic	.000	136.155	.955	18.1	.007	38.2	712
Power Curve	9.600	1.038	.961	17.0	.006	40.9	98
Cubic	.000	.004	.927	23.1	.011	29.1	2560
		Live Weight g					
Fit	A	B	R	SEEy	SER	t	Residuals
Linear	.000	42.943	.911	196.6	.014	26.1	10672
Exponential	138.153	.056	.909	199.0	.014	25.7	3981
Logarithmic	.000	521.272	.912	196.2	.014	26.1	24367
Power Curve	.166	2.433	.927	179.4	.011	29.1	3372
Cubic	.000	.018.	895	212.9	.016	23.6	4576

Table 3. Best Fit Coefficients for length and weight estimates from bone fragments

Least squares analysis was performed on the data described in the text, assuming that the various curves pass through the origin. The coefficients are given for the best method of fitting a line to the data based on the smallest Standard Error of the Estimate of Y.

Estimation of Kahawai Live Fork Length mm

Fit	Bone	Constant	Slope	SEEy
Power	LD2	23.200420	.9578835	21.6
Power	LD3	113.225100	.7773609	27.9
Power	LM2	41.904720	.9890722	20.1
Power	LP2	61.616120	.8749795	22.8
Power	RD2	23.278680	.9571580	21.0
Power	RD3	111.650100	.7853177	28.9
Power	RM2	43.290210	.9778192	19.5
Power	RP2	58.655060	.8954408	22.4
Power	LA1	7.891983	1.0850010	18.5
Power	LD1	9.600739	1.0380670	17.0
Power	LM1	9.854971	1.0490260	16.6
Power	LO1	233.434500	.3239004	25.6
Power	LP1	18.059980	.9224114	19.4
Power	LQ1	22.484210	1.0910290	19.4
Power	RA1	8.053404	1.0792090	18.5
Power	RD1	9.416229	1.0429240	16.7
Power	RM1	10.503180	1.0322360	18.2
Power	RO1	211.625600	.3617831	27.9
Power	RP1	20.349240	.8894034	20.2
Power	RQ1	21.434240	1.1087880	18.4
Logarithmic	LOW	.000000	-253.6056000	23.4
Logarithmic	ROW	.000000	-253.0524000	23.8

Table 3 continued

Estimation of Kahawai Live Ungutted Weight g

Fit	Bone	Constant	Slope	SEEy
Power	LD2	1.316889	2.2455770	201.1
Power	LD3	51.252370	1.8503530	229.5
Power	LM2	5.133572	2.3287440	188.1
Power	LP2	13.037030	2.0501350	209.0
Power	RD2	1.396610	2.2281950	204.2
Power	RD3	48.679220	1.8786250	233.5
Power	RM2	5.436222	2.3097530	182.3
Power	RP2	11.054830	2.1177990	197.4
Power	LA1	.099410	2.5580790	177.3
Power	LD1	.166353	2.4339920	179.3
Power	LM1	.185598	2.4459710	177.8
Power	LO1	179.370400	.9354017	270.6
Power	LP1	.827350	2.1291570	200.5
Power	LQ1	1.341307	2.5262390	184.2
Power	RA1	.116623	2.5154040	188.8
Power	RD1	.166461	2.4330630	178.6
Power	RM1	.208700	2.4158070	176.9
Cubic	RO1	.000000	.7567568	287.7
Power	RP1	1.234735	2.0180420	197.0
Power	RQ1	1.062455	2.6096260	177.4
Power	LOW	5736.770000	.4585528	251.0
Linear	ROW	.000000	18561.7600000	256.5

Appendix 1

Description of bone measurements - See Figure 1

Dentary Maximum Length LD1,RD1 maximum length from the superior margin of the dentary symphysis to the most posterior point of the dorsal transverse process (A-D).

Dentary Fragment 1 LD2,RD2 length from the superior margin of the dentary symphysis to the lateral anterior angle between the two transverse processes (A-C).

Dentary Fragment 2 LD3,RD3 maximum height of the dentary symphysis (A-B).

Articular Maximum Length LA1,RA1 maximum length from the most posterior point of the articulating surface to the most anterior point (E-F).

Quadrate Length LQ1,RQ1 length along the dorsal margin from the lateral anterior edge of the articulating head to the most posterior point of the dorsal margin (G-H).

Premaxilla Maximum Length LP1,RP1 maximum length from the most anterior point of the symphysial margin to the most posterior point of the transverse body (O-M).

Premaxilla Fragment 1 LP2,RP2 width from the most anterior point of the symphysial margin to the point of intersection between the anterior process and the transverse body (O-N).

Maxilla Maximum Length LM1,RM1 - maximum length (K-I).

Maxilla Fragment 1 LM2,RM2 width from the most anterior point of the medial surface of the body to the point of intersection of the posterior part of the lateral process with the body of the maxilla (K-L).

Otolith Maximum Length LO1,RO1 maximum length (P-Q).

*Otolith Weigh*t weight.

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TE PAPA TONGAREWA
MUSEUM
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