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The estimation of live fish size from archaeological cranial bones of New Zealand Labridae

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ABSTRACT: Thirty measurements were taken on the otoliths, pharyngeal bones, and five of the paired cranial bones of a modern sample of labrids from New Zealand, consisting of 18 *Notolabrus celidotus* (spotty) and 122 *Pseudolabrus miles* (scarlet wrasse). Regression analysis was performed on these measurements to estimate 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. It was found that live fork length of this species can be estimated with a standard error of less than ± 21 mm, and live weight to less than ± 94 g. Coefficients are provided for 60 equations linking bone size to live characteristics. This is followed by a study of labrids from an archaeological site at Waihora in the Chatham Islands. Measurements were made on 3,096 archaeological bones with a Minimum Number of Individuals of 1,509. It was found that the labrid catch had non-normal characteristics with a mean fork length of 295 mm and SD of 59 mm. The non-normality is largely attributed to a mixture of three species of labrids in the archaeological collection, which could not be identified to species from bone anatomy. The size-frequency mixture was decomposed into three separate size-frequency diagrams using a recursive technique. This analysis suggested approximate proportions of 7% *Notolabrus celidotus* (spotty), 66% *Pseudolabrus miles* (scarlet wrasse), and 27% *Pseudolabrus fucicolia* (banded parrotfish).

KEYWORDS: NEW ZEALAND, ARCHAEOZOOLOGY, FISHES, LABRIDAE, REGRESSION ANALYSIS, LENGTH AND WEIGHT ESTIMATION

RESUMEN: Treinta mediciones se llevaron a cabo en otolitos, dientes faríngeos y cinco de los huesos craneales pares de una muestra reciente de lábridos neozelandeses formada por 18 *Notolabrus celidotus* y 122 *Pseudolabrus miles*. Sobre estos valores se llevó a cabo un análisis de regresión a fín de inferir la longitud corporal hasta la inflexión de la aleta caudal y el peso del pez sin eviscerar. Diferentes modelos de regresión (eg. linear, logarítmico, exponencial y curva exponencial) han sido valorados al objeto de seleccionar el mejor estimador para cada caso (hueso) específico. El estudio demuestra que la longitud y el peso en estas especies puede ser estimado con errores standard de ± 21 mm y ± 94 g respectivamente. Se ofrecen asimismo los coeficientes de 60 ecuaciones que conectan la talla de los diferentes elementos óseos con diversos rasgos de los animales. En la segunda parte del trabajo se estudian las muestras de lábridos del yacimiento de Waihora en el archipiélago de las Chatham. Se miden 3096 huesos procedentes de un número mínimo de individuos de 1509. Del análisis se desprende que la muestra de lábridos presenta rasgos que no se ajustan a una distribución normal con una longitud a la inflexión de la caudal de 295 mm y una DS de 59 mm. La ausencia de normalidad en la muestra puede deberse a la inclusión simultánea de tres especies de lábridos que no pueden diferenciarse osteológicamente. La agrupación de frecuencias de tamaños ha sido posteriormente subdividida en tres diagramas independientes de frecuencia de tallas con el concurso de una técnica recursiva. Tal desglose sugiere porcentajes del orden del 7% para *Notolabrus celidotus*, 66% para *Pseudolabrus miles* y 27% para *Pseudolabrus fucicolia*.

PALABRAS CLAVE: NUEVA ZELANDA, ARQUEOZOOLOGIA, PECES, LABRIDAE, ANÁLISIS DE REGRESIÓN, ESTIMACIÓN DE LONGITUD Y PESO

INTRODUCTION

The labridae family of fish comprises some 450 different species distributed widely throughout the world's seas. These fish are most diverse in the tropics, with 20 or more genera recognised in the Hawaiian archipelago, for example, but some species have become adapted to temperate seas – there are 7 genera in New Zealand waters. Labrids are solitary foraging carnivorous animals with sharp conical teeth. They possess a highly developed pharyngeal mill for crushing up shell and other food-bearing matter. Different species show distinct food preference patterns.

Fourteen labrid species are known in New Zealand, but most are found in northern offshore waters. The three most common species are the spotty *Notolabrus celidotus*, the scarlet wrasse *Pseudolabrus miles*, and the banded parrotfish *Pseudolabrus fucicolia*. Although these eat a wide variety of food, the spotty prefers bivalves, the scarlet wrasse hermit crabs, and the banded parrotfish crabs, hermit crabs, and molluscs such as limpets, small paua and mussels (Doak, 1972: 76, 82).

Observations by divers have shown that labrids are solitary, aggressive, home-ranging fishes that will defend a particular territory. They frequent rocky areas and are active during daylight hours. At night they hide in crevices and do not feed. Spotties, the smallest of the three main species (mean fork length about 210 mm), are found in greatest concentration in shallow water, tapering off at about 12 m. The scarlet wrasse, which is a medium-sized fish (mean fork length about 275 mm), starts to appear at about the depth at which spotties tail off, occurring from about 9m to 120m. The banded parrotfish (mean fork length about 350 mm) lives in amongst seaweed and at night rests in the upper 5 m depth range, covered in a protective mucous envelope. It is found down to about 36 m depth.

It is interesting that these fish are almost never eaten by modern European New Zealanders, who consider them fit only for use as bait. However, they were a very popular food item in pre-European times. In Appendix 1 we document the frequency of labrids in archaeological sites in New Zealand. Of 91 sites for which we have information, 40 contain labrids at greater than 10% of the total catch. The highest figures are from sites in Cook Strait, Foveaux Strait, and the Chatham Islands. This partly reflects variations in natural abundance, but it has been argued that it also reflects preferential fishing close inshore at times when sea conditions made it very difficult to use canoes for access to favoured deeper water fishing spots (Leach & Anderson, 1979).

Although it is easy to identify a live labrid to species from its colour and general external shape, they are far more difficult to identify from their osteology. The three common species, mentioned above, have the same spine formula (D. IX, 11; A. III, 10), fairly reflecting the difficulty confronting archaeologists. We believe that with a greatly improved modern comparative collection (multiple specimens from all 14 species) it may be possible to identify some species from some of the anatomy. However, it is unlikely that we will ever be able to identify species reliably from **all** five paired cranial bones which we routinely analyse from archaeological sites. The first step towards understanding ancient fishing behaviour is to establish the relative abundance of different types of fish. This is done, not on the basis of one part of the anatomy, but on the combined results from several parts of the bony skeleton. Unfortunately we have to accept that we cannot do this to species level for labrids. It may, in the future, be possible to establish the relative abundance of several, but not all, labrid types from the pharyngeal clusters. Another possibility, which we explore in this paper, is to examine the size-frequency diagram of the combined labrid fish catch and attempt to separate it into its constituent species on the basis of their different size distributions.

The biology and behaviour of the labrids can provide important clues about prehistoric human fishing behaviour. Although night-fishing is very popular amongst Pacific Island and New Zealand fishermen, the presence of labrids in archaeological sites indicates day-time fishing. The relative abundance of different species can also be a useful guide to the depth where fishermen were focusing their effort. Also, the solitary and home-ranging behaviour of these fish makes this family a useful one with which to explore issues of overfishing and environmental impact of prehistoric human communities over archaeological time. In order to examine such a possibility for any archaeological site, we must first have a method for reconstructing live fish length and weight from archaeological bone fragments, so that the size-frequency distribution of fish catches can be estimated for different periods. This is the focus of this paper.

BONE MEASUREMENT METHODOLOGY

The bones used for measurement are five paired cranial bones (the dentary, articular, quadrate, premaxilla, and maxilla), the otoliths, and three pharyngeal bones which contain teeth (a single inferior pharyngeal cluster, and a pair of superior pharyngeal clusters). The first-named five paired cranial bones have been used for many years to quantify prehistoric fish catches from archaeological sites in the Pacific and New Zealand (Leach & Davidson, 1977; Leach & Ward, 1981; Leach, 1986; Leach & Boocock, 1993). They do not always survive intact in labrids; therefore it is desirable to include measurements which are applicable to incomplete bones. For this reason more than one measurement was made on four of the five bones involved. Whenever possible the largest dimension is always taken, as this yields the most reliable estimate of the original fish size. Thus, there is a series of measurements appropriate to whole bones and another series appropriate to various forms of bone fragment. The dimensions chosen are illustrated in Figure 1. These closely parallel those employed by archaeozoologists on other species (Libois & Libois, 1988; Roselló-Izquierdo, 1988: 35; Sternberg, 1992; Wheeler & Jones, 1989: 139 ff.).

The anatomical landmarks used in this study are indicated on Figure 1 by a small dot and given a letter code from A to Z´. Each measurement was given a computer code with three characters. Thus, LD1 refers to the Left Dentary and the first measurement made on that bone. Where the terminology

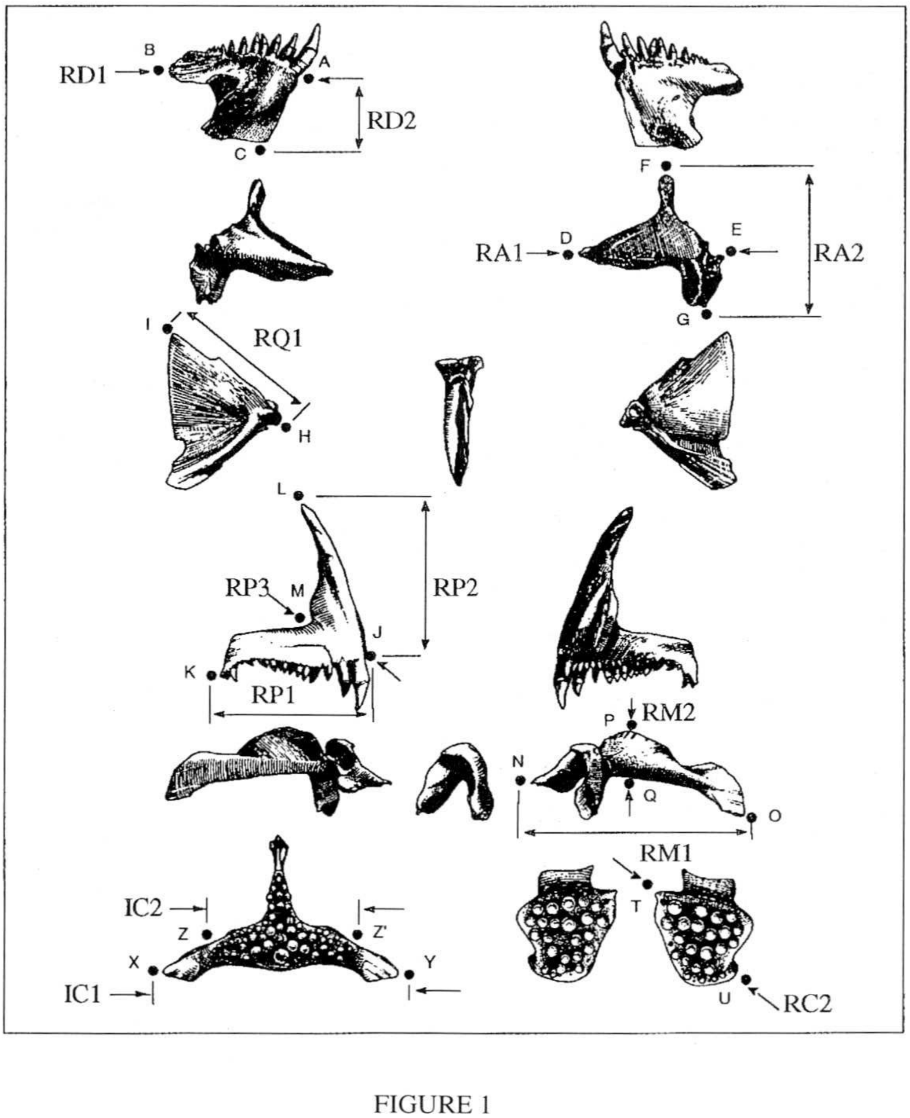

FIGURE 1

Cranial elements of *Notolabrus celidotus* (spotty) used for measurements. The right bones are illustrated. Measurements are made between landmarks A-B and A-C on the dentary; between D-E and F-G on the articular; between I-H on the quadrate; between J-K, J-L and J-M on the premaxilla; between N-O and P-Q on the maxilla; R-S (not shown, see Appendix 2) and T-U on the superior pharyngeal cluster; the maximum length of the otolith V-W (not shown); and between X-Y and X-Z´ on the inferior pharyngeal cluster.

«maximum length» or «maximum height» is used, the measuring callipers were rotated about the nominated landmarks until a maximum value was obtained. The definition of each measurement is provided in Appendix 2. It will be seen in Table 1 that fragment measurements were not taken on the quadrate and otolith. The number of these bones identified for any one species is generally considerably lower than for other bones. Moreover, in particularly large assemblages the quadrate is sometimes excluded from the analysis, because of difficulties in distinguishing between some species. The quadrate and the otolith are quite robust and an adequate sample of measurements can be taken on whole bones. Three measurements are indicated for premaxillae, and two each for the dentary, articular, maxilla, superior and inferior pharyngeal clusters.

Modern Comparative Collection

Left	Missing	Right	Missing	Landmarks	Bone	Dimension	Units
LD1	3	RD1	1	A-B	Dentary	Length	mm
LD2	2	RD2	1	A-C	Dentary	Fragment Height	mm
LA1	1	RA1	7	D-E	Articular	Length	mm
LA2	24	RA2	29	F-G	Articular	Maximum Height	mm
LQ1	3	RQ1	6	H-I	Quadrate	Length	mm
LP1	2	RP1	3	J-K	Premaxilla	Maximum Length	mm
LP2	1	RP2	2	J-L	Premaxilla	Height	mm
LP3	1	RP3	2	J-M	Premaxilla	Fragment Width	mm
LM1	8	RM1	1	N-O	Maxilla	Maximum Length	mm
LM2	2	RM2	2	P-Q	Maxilla	Height	mm
LC1	4	RC1	3	R-S	Sup. Pharyngeal	Height	mm
LC2	4	RC2	3	T-U	Sup. Pharyngeal	Maximum Width	mm
LO1	21	RO1	25	V-W	Otolith	Maximum Length	mm
LOW	22	ROW	25	–	Otolith	Weight	g
Totals	**98**		**110**				
Mid-Line Bones							
IC1	4			X-Y	Inf. Pharyngeal	Maximum Width	mm
IC2	4			Z-Z′	Inf. Pharyngeal	Fragment Width	mm
Total Missing	**216**						

Total Number of possible measurements (140 fish x 32 variables) 4480
Total Number of measurements missing 216
Nett Measurements available 4264

Archaeological Bones - Waihora Site Chatham Islands

Anatomy	Measurements	Anatomy	Measurements	Total
LD1	127	RD1	118	245
LD2	105	RD2	95	200
LA1	165	RA1	153	318
LA2	4	RA2	7	11
LQ1	0	RQ1	0	0
LP1	95	RP1	101	196
LP2	63	RP2	77	140
LP3	53	RP3	69	122
LM1	73	RM1	70	143
LM2	100	RM2	77	177
LC1	500	RC1	480	980
LC2	11	RC2	23	34
LO1	0	RO1	0	0
LOW	0	ROW	0	0
Sub-Totals	**1296**		**1270**	
IC1				367
IC2				163
Total				**3096**

TABLE 1
Measurements made on cranial bones.

The purpose of the three character code is to permit simple coding of measurements on plastic bags which contain identified fish bones from archaeological sites. These are later entered into a database according to the original archaeological provenance. The appropriate equation for estimating live fork length and weight is selected using these three character codes. Mitutoyo digital callipers model 500-322 were used for linear measurements which are recorded to ± 0.01 mm precision. A Sartorius model BA310S balance was used for weight measurements with a precision of ± 0.001 g.

In our experience, even with the benefit of an annotated illustration (Figure 1) and formal definitions (Appendix 2), it is not a simple matter for a new research assistant to make the correct measurements on archaeological bones. It is desirable for a newcomer to learn the correct methods by re-measuring bones in the modern comparative collection and cross-checking measurements against those taken earlier. Subtle differences in the orientation of callipers, even when placed on the correct landmarks, can cause substantial percentage errors.

MODERN COMPARATIVE SAMPLE OF LABRIDS

A comparative sample of 140 labrids was used in this study, consisting of 18 *Notolabrus celidotus* (spotty) and 122 *Pseudolabrus miles* (scarlet wrasse). Most were obtained by ourselves during regular collecting expeditions in the Marlborough Sounds. A few large specimens were obtained by request from local fishermen. It was very difficult obtaining specimens of exceptional size. There are occasions when fish bones from New Zealand archaeological sites are of very large size, reflecting relatively unexploited inshore stocks. Wherever possible it is important to develop equations for estimating live dimension which do not involve extrapolation beyond the limits of modern comparative collections.

Regression analysis was performed on these measurements to estimate live fork length and ungutted weight. The modern sample of 140 fish had fork lengths ranging from 133 to 375 mm with a mean of 276.3 mm. The ungutted weights ranged from 29 to 1022 g with a mean of 445.3 g. Information was collated for 32 variables, consisting of fork length, ungutted body weight, and 30 bone measurements. Some bones were broken or lost (many of the otoliths were not retrieved), and therefore not all measurements could be taken. The final data matrix of 4,480 entries had 230 missing values (Table 1). In cases where pairs of variables were being used for covariance calculations, arrays were concatenated by deletion of examples with missing values. It will be seen in Table 1 that otolith measurements stand out as having a sizeable number of missing values. These could not be taken because the otoliths were lost during maceration of specimens.

Some preliminary results are also presented in Table 1 from a study of archaeological bones of labrids from an archaeological site in the Chatham Islands. It will be noticed that no otolith measurements are presented. The ratio of number of measurements of whole bones to fragments is relatively high compared with other fish types. This unusual feature attests the relatively robust anatomy of labrid bones. These ratios vary from 28.9 for the articular to 0.75 for the premaxilla. Low ratios for premaxilla and maxilla demonstrate the importance of defining measurements which are appropriate to bone fragments. It must be remembered, however, that if bones are complete, the largest dimension should always be measured as this is invariably the most reliable estimator of original fish size.

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 which could then be used for studying archaeological bones. To this end, regression analysis was carried out on the measurements of the osteological collection taking each bone dimension individually, and testing various types of curve fitting procedures to the data using the least-squares method. The general 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 * In(X)
Power Curve Fit	Y = A * X**B
Cubic Fit	Y = A + B * X**3

The various curve fitting procedures are shown in Figure 2 using the example of the left dentary length. The statistics for the regression analysis estimating live fork length and ungutted weight from the left dentary length are given in Table 2.

Inspection of Table 2 will reveal that in estimating live fish weight the power curve fit is by far the best model. This is evident from both the value of the correlation coefficient (0.983) and the standard error of the estimate (± 45 g). The cubic fit is a close second (correlation coefficient = 0.965 and the standard error of the estimate = ± 63 g). The residuals are by far the lowest in the case of the power curve fit.

In the estimation of live fish length very good fits were obtained for both the power curve fit and linear model. The correlation coefficients are 0.977 and 0.974, and the standard errors of the estimate are ± 11 mm and ± 12 mm respectively. The residuals for the power curve fit are less than half those of the linear model.

In Figure 2 the various models are plotted out. The solid line is the power curve fit in both cases. In some previous regression studies of bone dimensions against live length and weight, we have taken the view that the best equation is the one which produces the lowest standard error of the estimate. Unfortunately, however, we have found cases where an exponential curve produces the lowest standard error of the estimate for weight, but for the few very large specimens in our collection the curve does not follow the data very well at all, producing less acceptable error margins at this end of the distribution. We think the best approach is to use the power curve model. In estimating fork length from bone dimension we have found cases of non-linearity and a power curve fit is a better option here too.

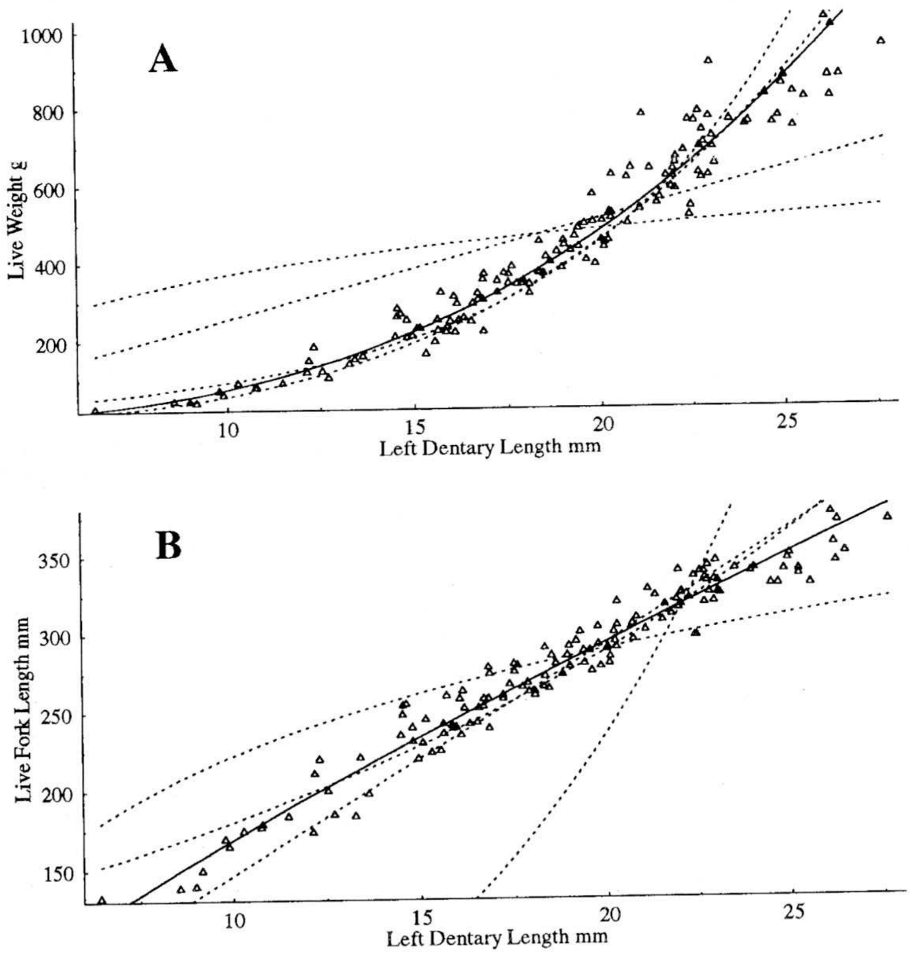

FIGURE 2

Several regression models were applied to the measurement of left dentary length and live fork length and weight (N=140). Note that some of the lines of best fit are reasonable approximations of the relationships, while others are quite inappropriate. The solid line is the power curve fit in each case, and is an excellent model.

Several regression models were applied to these data, and the results are presented below. In each case, it was assumed that the various curves passed through the origin.

A	=	regression constant
B	=	regression slope
R	=	correlation coefficient
SEE	=	standard error of estimate of fork length or weight
SER	=	standard error of R
t	=	Student's t value for R

Live Fork Length mm

Fit	A	B	R	SEE	SER	t	DF	Residuals	DF
Linear	0.0	14.64234	.974	12.1	.00443	49.7	135	160	136
Exponential	112.6091	0.04695165	.957	15.5	.00722	38.3	135	134	136
Logarithmic	0.0	96.43709	.970	13.0	.00508	46.2	135	524	136
Power Curve	27.07779	0.795092	.977	11.4	.00390	53.1	135	71	136
Cubic	0.0	0.02942409	.914	21.6	.01409	26.1	135	6031	136

Live Weight g

Fit	A	B	R	SEE	SER	t	DF	Residuals	DF
Linear	0.0	25.46092	.958	69.0	.00698	38.9	135	12524	136
Exponential	19.01098	0.1581631	.962	66.0	.00639	40.9	135	2319	136
Logarithmic	0.0	160.5138	.911	99.4	.01451	25.7	135	28566	136
Power Curve	0.1552353	2.680729	.983	44.5	.00291	61.9	135	897	136
Cubic	0.0	0.05662374	.965	62.9	.00580	43.1	135	1267	136

TABLE 2

Least squares analysis of left dentary length with both fork length and live weight.

Figure 3 shows the final two choices of regression model for the left dentary length, with all fish in the comparative collection plotted against the regression curves with 95% confidence bands. The two solutions are very satisfactory.

The power curve model was chosen for all 30 bone measurements, enabling best fit regression equations to be calculated, and thereby completing the tabulations given in Tables 3 and 4. Figures 4 and 5 illustrate the best and worst fits for estimating fork length and weight respectively. The otolith weight in both cases gives the worst results. This is partly due to the much smaller sample size in the case of otoliths (see Table 1). The range of errors associated with the final choice of regression models is illustrated in Figure 6. Fork length errors range from ± 10.9 to 20.8 mm, and weight errors range from ± 44.2 to 93.5 g. These are very reasonable.

It is useful to follow a worked example. For this purpose, a modern fish of medium size in the comparative collection was chosen, catalogued as specimen AG950. This fish had a live fork length of 275 mm and an ungutted weight of 366 g. The left dentary length LD1 was 17.51 mm.

From Table 3 it will be seen that the best fit equation for estimating fork length from the LD1 bone measurement is the power curve fit, with coefficients in the Table as follows:

$$\text{Fork Length mm} = 27.07779 * \text{LD1}^{0.795092} \pm 11 \text{ mm}$$

In Table 4 it will be observed that the best fit equation for estimating live weight from the LD1 bone measurement is the power curve fit, with coefficients in the Table as follows:

$$\text{Weight g} = 0.1552353 * \text{LD1}^{2.680729} \pm 45 \text{ g}$$

By substituting a value for LD1 of 17.51 into these two equations we derive estimates of 264 mm for the fork length and 334 g for the weight. The error in estimating the fork length is therefore 11 mm (275-264), and in estimating the weight 32 g (366-334). The error in the estimated fork length is on the boundary of the 68% confidence limits of ± 11 mm, and the error in the estimated ungutted weight is within the confidence limits of ± 45 g.

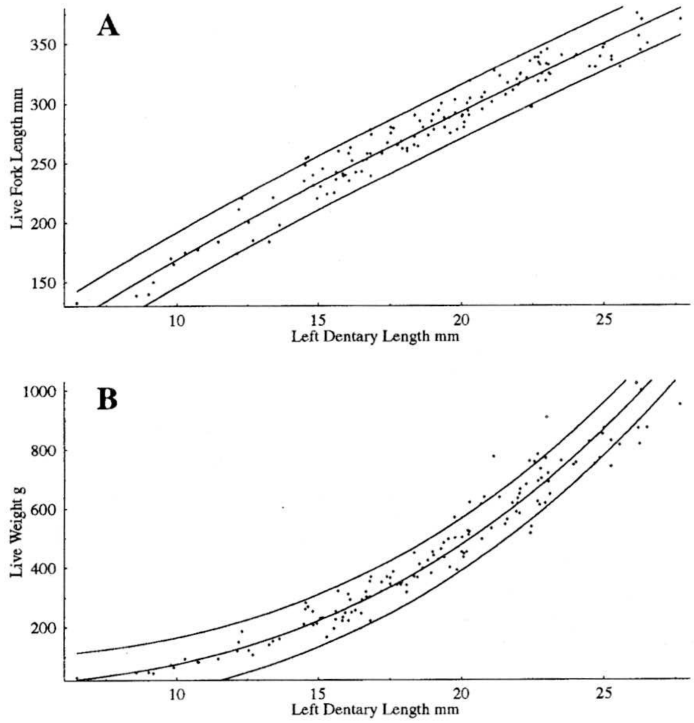

FIGURE 3

The regression model which best fits the data when estimating fork length (A) and ungutted weight (B) from the left dentary 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 ± 11 mm for the fork length, and ± 45 g for the weight. The powers are 0.80 and 2.68 for fork length and weight respectively. These values are close to linear and cubic (see Table 2).

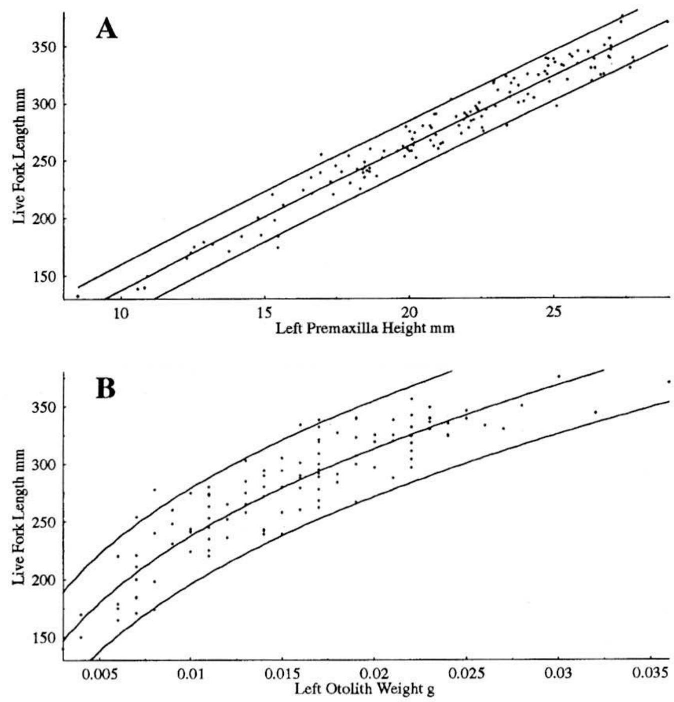

FIGURE 4

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 premaxilla height, which has a standard error of the estimate of ± 11 mm; and the worst is the left otolith weight with ± 21 mm.

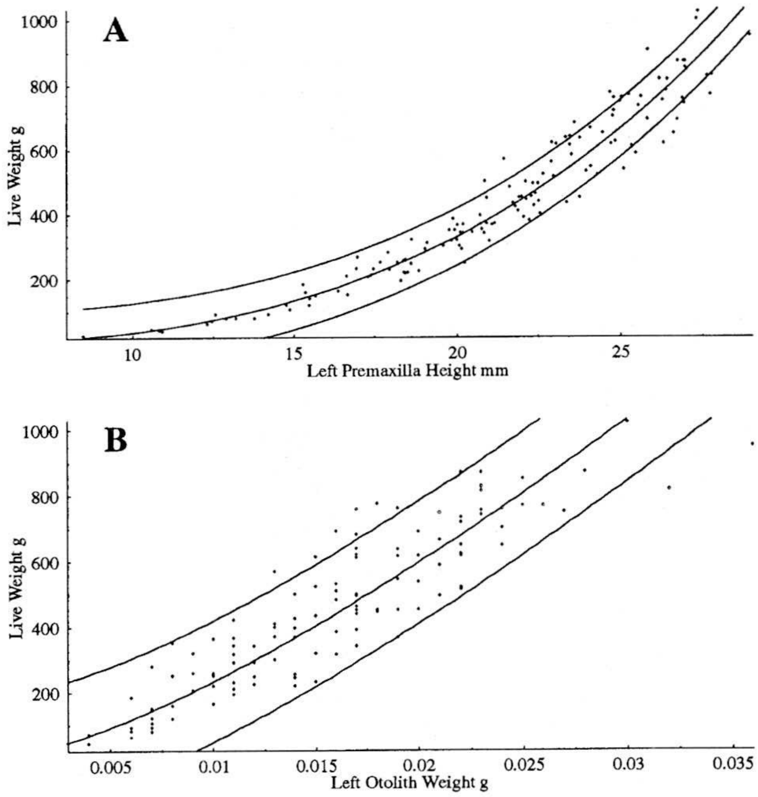

FIGURE 5

This shows the best (A) and the worst (B) fit regression lines for estimating ungutted weight from bone measurements. The best measurement is the left premaxilla height, which has a standard error of the estimate of ± 44 g; and the worst is the left otolith weight with ± 94 g.

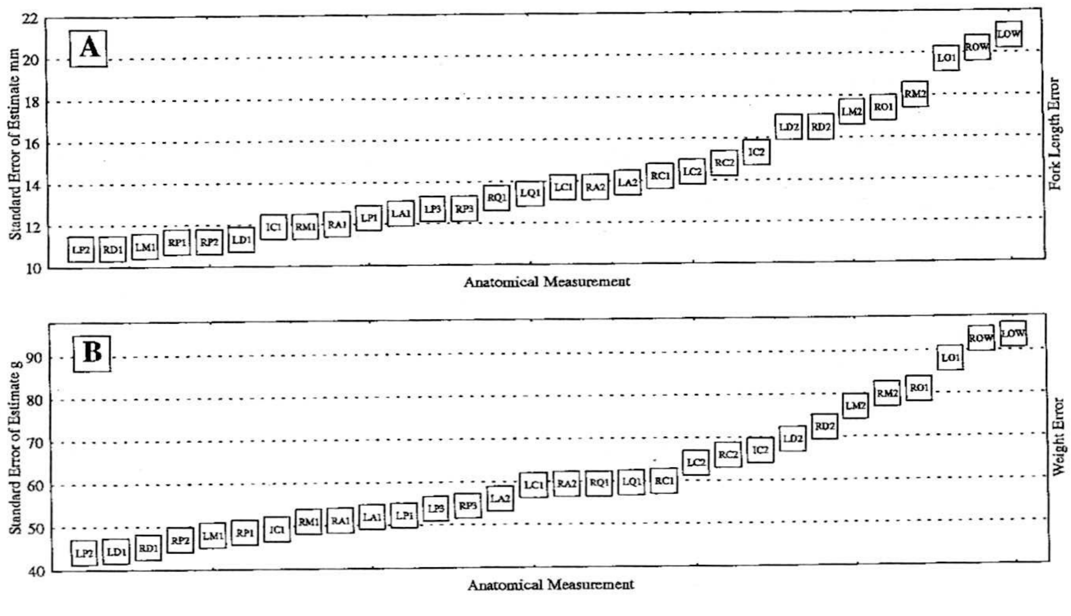

FIGURE 6

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 11 to 21 mm and 44 to 94 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 low number of measurements made on these bones.

Measurement	Constant	Slope	Standard Error
LD1	27.07779	.7950920	11.3
LD2	64.07246	.6762176	16.5
LA1	17.53880	.9814655	12.5
LA2	23.92110	.9403583	13.9
LQ1	38.80244	.8005717	13.4
LP1	26.99170	.8006946	12.3
LP2	16.02125	.9336320	10.9
LP3	48.05389	.7621238	12.7
LM1	20.77790	.8635429	11.0
LM2	72.39370	.8520375	17.2
LC1	58.83652	.7437941	13.7
LC2	53.10122	.7351247	14.4
LO1	45.73420	1.0168180	19.7
LOW	1495.97800	.3996890	20.8
IC1	27.41369	.7382151	11.9
IC2	42.15550	.6962584	15.3
RD1	24.44313	.8309122	10.9
RD2	62.50561	.6884733	16.5
RA1	16.51440	1.0031440	12.0
RA2	22.23371	.9677413	13.7
RQ1	37.61079	.8131332	13.2
RP1	27.14506	.7979931	11.2
RP2	16.25578	.9290395	11.2
RP3	48.40667	.7590269	12.7
RM1	20.77823	.8625634	11.9
RM2	72.50062	.8546013	18.0
RC1	59.39358	.7374048	14.2
RC2	53.05075	.7344244	14.8
RO1	41.87877	1.0681640	17.4
ROW	1439.39400	.3891799	20.2

TABLE 3

Best fit coefficients for fork length estimates all are power curve equations.

There are two methods by which an estimate of the original weight of the fish can be obtained. One could work directly from the bone length to the weight, using the comparative material assembled for this present study, or one could adopt a two-step process, first estimating the fork length from the bone dimension, and then estimating the weight from the fork length. There is a potential shortcoming in the first approach, in that this present osteological sample of 140 fish is relatively small and does not contain many very small or very large specimens. 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 with a regression relationship which is close to a cubic function.

For economically important species MAF Fisheries scientists usually have well established relationships between fork length and body weight for very large samples of fish, and also for different sexes, at different seasons, and at different localities. However, authoritative information is not available for labrids and probably never will be. Labrid fish are not taken commercially and are not sought after by recreational fishermen except as bait.

The sample of 140 fish specimens in our own comparative collection has the following relationship:

$$\text{weight} = 0.0000032117 * \text{fork length}^{3.311703}$$
$$\text{(fork length in mm, weight in g)}$$

The medium-sized fish AG950 mentioned above had a fork length of 275 mm and weighed 366 g. Using this equation on the fork length we would obtain an estimate of the weight for this fish of 385 g, an error of 19 g.

Measurement	Constant	Slope	Standard Error
LD1	.1552353	2.680729	44.5
LD2	2.8300790	2.280579	69.5
LA1	.0365252	3.302506	52.0
LA2	.1040942	3.162827	56.0
LQ1	.5507523	2.677320	59.6
LP1	.1573348	2.690746	52.3
LP2	.0272161	3.138102	44.2
LP3	1.0945480	2.560597	53.8
LM1	.0629958	2.913798	48.0
LM2	4.2455290	2.876209	77.0
LC1	2.1216140	2.507122	59.1
LC2	1.5194230	2.472552	64.1
LO1	.8684444	3.451381	88.0
LOW	118856.5	1.353719	93.5
IC1	.1592722	.2.493045	49.3
IC2	.6892375	2.346967	66.9
RD1	.1175722	2.778496	45.3
RD2	2.7064710	2.303726	72.3
RA1	.0322077	3.348347	51.2
RA2	.0915900	3.210168	59.4
RQ1	.5168062	2.703086	59.4
RP1	.1621199	2.678413	48.6
RP2	.0288996	3.119479	47.0
RP3	1.1291780	2.547966	54.4
RM1	.0659037	2.896050	51.0
RM2	4.3941800	2.867009	79.9
RC1	2.1580850	.2.492484	59.9
RC2	1.5037890	2.473171	65.9
RO1	.6936846	3.583349	81.0
ROW	100526.3	1.309758	92.5

TABLE 4

Best fit coefficients for weight estimates all are power curve equations.

Deciding whether to estimate the ungutted weight in a single step from the bone measurement, or by a two-step procedure from the bone to the fork length and then from the fork length to the weight, is not a simple matter. One way of trying to evaluate the relative merits of these two 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 (+0.1%) for estimates of fork length from bone measurements. The mean residual for the one-step model of weight estimation is also close to zero (+1.6%), but is slightly higher for the two-step weight model (+1.7%). The range of residuals is similar in both cases. Despite the small apparent advantage of the one-step model, it is suggested that in cases where archaeological bones are either very small or very large, the two-step procedure is the preferable model to use. The dangers of extrapolation are well known.

PUTTING THE ALGORITHMS TO WORK

Following the identification of anatomy and species of archaeological fish bone collections, wherever possible one, **and only one**, of the dimensions described in Table 1 is measured on each bone. The measurements are then entered into a computer file by provenance and bone code. As an example of the procedure, we chose measurements we have made of bones from the site at Waihora in the Chatham Islands (Sutton, 1979, 1980, 1989). A typical selection of coded measurements from this site appears below:

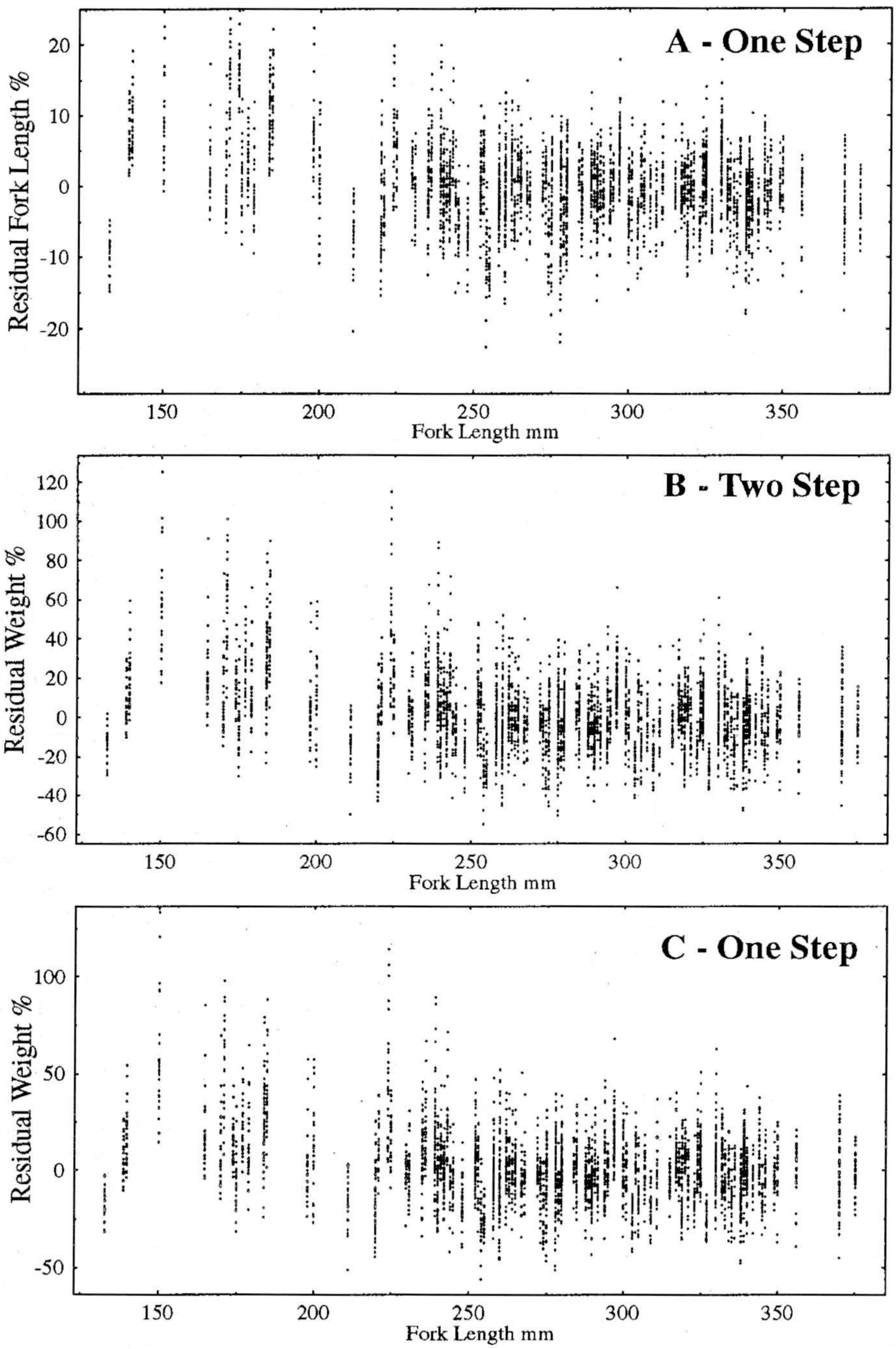

FIGURE 7

Analysis of residuals of estimated and actual fork length (A), and weight using the two step-model (B) and one step model (C). The 140 fish in the comparative collection produced 4264 measurements which are used in this analysis. In A the range of residuals is -29.3 to 24.8%, with a mean of +0.10%. In B the range is -64.3 to +136.3% with a mean of +1.70%. In C the range is -65.1 to +133.7% with a mean of +1.60%. The two step model is preferred in cases of archaeological bones that are very small or very large.

Labrid measurements from Waihora Site Chatham Islands

Layer 1	I/13	RC108.76 LD112.24 LD115.10 RP111.68 RP118.62
Layer 1	I/14	LC109.79 IC132.81 IC130.87 RD218.31
Layer 1	I/18	IC138.37 IC124.75 IC123.41 IC227.55 IC221.10 LC108.88
Layer 1	I/19	LC115.57 LC108.34 LC107.90 RC110.81 IC137.00 IC134.99 IC120.99 IC121.66 IC121.87 IC133.18 LD208.50 LD207.99 RD210.18 LP229.31 RA120.51
Layer 1 ash lens	Vb/9	LC108.60
Layer 1 lens 1	VI/22	RP119.68
Layer 1 lens A	VI/13	RC107.65
Layer 1 lens A	VI/22	LC112.21 LA121.81 LM204.20
Layer 2	II/22	LD214.08 LP115.93 LP310.00 RP128.04 LM203.74
Layer 2	IV/1	IC138.74 RC108.62 RM206.40
Layer 2	IV/9	IC127.96 IC133.52 IC133.70 IC122.23 IC117.92 IC120.81 IC117.52 IC124.01 IC124.46 IC136.22 IC132.02 IC130.58 LC111.96 LC112.61 LC112.80 LC110.06 LC106.99 LC108.22 RC113.33 RC111.03 RC111.23 RC108.20 RC108.04 RC106.97 LD118.47 LD211.14 RD205.48 LP127.44 LP121.65 LP118.22

We have recently re-analysed all the fish bones from the Waihora site and have identified a number of species in addition to those on the original list of MNI obtained by Sutton (1989). Of the 22,249 fish bones we identified to species (MNI = 6,907 fish) we were able to measure 3,096 bones of labrids. These gave an MNI of 1,509 fish. Thus, we measured 2.05 times the amount of labrid MNI. This may initially appear a somewhat strange approach to obtaining a size-frequency distribution of the original fish catch. For example, an alternative might be to take one measurement on the most numerous bone in the collection. In this way the number of measurements taken would be the same as the MNI. However, it should be remembered that the MNI represents only the **minimum** number of individuals in the site, and since our technique of obtaining the MNI does not take into account bones which are mismatched by size, measurements taken only on the most numerous bone may produce a biased size-frequency histogram.

This issue has been the subject of formal theoretical analysis by Leach & Boocock (1995: Appendix 1) using a computer simulation model. This involved taking a large sample of bones from a fish catch where the size-frequency diagram and associated dispersion statistics were known, and carrying out recursive simulated breakage of bones so they could not be measured. It was concluded that estimating the size-frequency diagram on the basis of all possible measurements did not produce bias. This approach was therefore adopted in this present study.

With the aid of a simple computer program, the 3,096 labrid bone measurements were converted into estimates of fork length using the coefficients listed in Table 3, and estimates of ungutted weight, using the two-step model referred to above. The resulting histogram of fish length is illustrated in Figure 8, together with the dispersion statistics. The histogram displays shape characteristics which are only approximately normal. There is significant positive skewness and negative kurtosis (g1 and g2 depart from 0.0 and 3.0 respectively). The reason for this non-normal shape is bound to be the existence of more than one species in the assemblage of labrids.

It is possible to decompose a size-frequency diagram where there is a mixture of components. A considerable amount has been published on the subject (Everitt & Hand, 1981; MacDonald, 1987; MacDonald & Pitcher 1979; McLachlan & Basford, 1988; Schnute & Fournier, 1980; Titterington *et al.*, 1985). Peter MacDonald at McMaster University, Canada has developed an algorithm which is now widely used for separating age grades of fish from trawl catch data. We used his program MIX (version 3.0) to separate out the different species in the catch diagram from the Waihora site.

For a number of reasons we can be fairly confident that there are three main species in the archaeological collection, *Notolabrus celidotus* (spotty), *Pseudolabrus miles* (scarlet wrasse), and *Pseudolabrus fucicolia* (banded parrotfish). These are by far the most common species in the region, and although not all of the labrid anatomy in the collection can be sorted into different species, the inferior pharyngeal clusters do appear to belong to three species. One of these is consistent with spotty in our comparative collection, another with the scarlet wrasse, and the third is not present in the comparative collection. Since it is much larger than the other two, it is almost certainly the banded parrotfish.

We can estimate an approximate mean and standard deviation for the fork lengths of spotty (210 ± 30 mm) and scarlet wrasse (275 ± 45 mm) from our comparative collection of 140 fish, and for the banded parrotfish by using the MIX software iteratively until the χ^2 value is lowest, indicating the best fit (350 ± 50 mm). The results are shown in the lower part of Figure 8. In this way, the proportions of the three species in the collection may be estimated as:

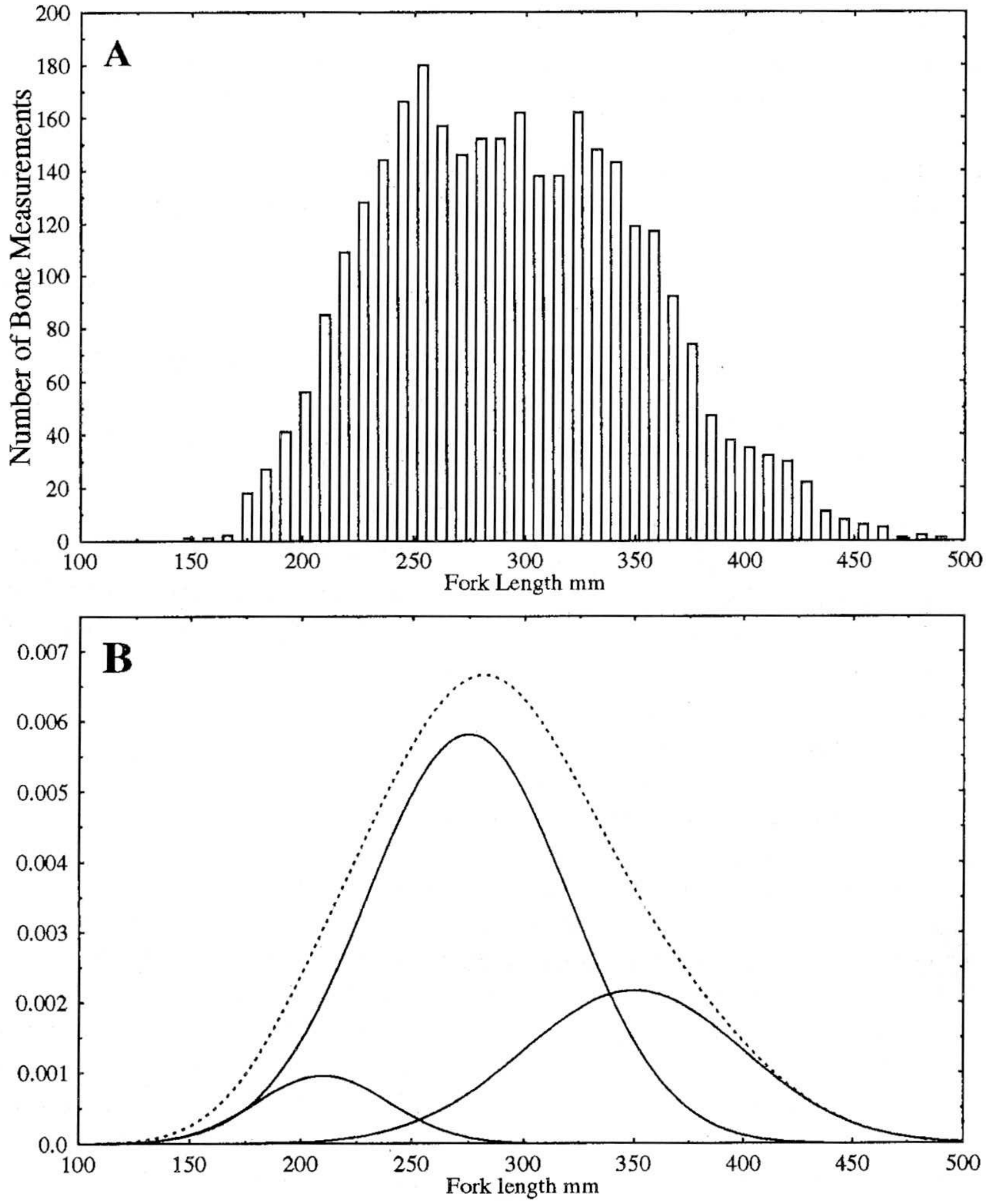

FIGURE 8

Size-frequency histogram of labrid lengths from the Waihora Site in the Chatham Islands. This is based on 3,096 bone measurements (A). The fork length range is 149 to 489 mm; with a mean of 294.8 ± 0.6 mm; SD = 58.7 ± 0.8 mm; g1/W1 = +0.28, 12.0; g2/W2 = +2.55, 5.1. Three species are believed to make up the labrid catch. The size-frequency distribution is decomposed into three components (B), with approximate proportions of 7% *Notolabrus celidotus* (spotty), 66% *Pseudolabrus miles* (scarlet wrasse), and 27% *Pseudolabrus fucicolia* (banded parrotfish). The dotted line is the combined curve.

Species	Common Name	Percentage of Catch
Notolabrus celidotus	spotty	7.2% ± 1.0
Pseudolabrus miles	scarlet wrasse	65.5% ± 1.8
Pseudolabrus fucicolia	banded parrotfish	27.2% ± 1.3

The mean weight of the fish represented by these bones was estimated to be 559.5 ± 6.6 g (that is, ± 1.19%). From this, we can calculate the total weight of labrids, using the MNI value for the species. Of the total MNI of 6,907 fish identified from this site, 1,509 were labrids (21.9 %). The total weight of these labrids can be calculated as:

Mean Body Weight	x	MNI		Total Body Weight	Usable Meat Weight
560 g	x	1509	=	845 ± 10 kg	592 kg

Smith (1985: 487-488) recommends using a figure of 70% for the amount of usable meat weight per total body weight for the common species of New Zealand fishes. At Waihora, this is therefore estimated to be about 0.6 metric tonnes of labrid meat. The stated error of ± 10 kg for the total body weight is based on the standard error of the mean weight of fish, which is ± 1.19%.

CONCLUSIONS

This study was aimed at finding the most reliable means of estimating live fork length and ungutted weight of New Zealand labrid fishes from bones and bone fragments. Using a modern sample of 140 fish, it was established that live fork length of this species can be estimated with a standard error of less than ± 21 mm and weight with a standard error of less than 94 g.

Two methods of estimating live weight were explored: a one-step method directly from the bone to the weight, and a two step method, estimating fork length from bone measurement, and then estimating weight from fork length. Although results using the one step method on this sample seemed slightly better, it is suggested that the two step method should be used when archaeological bones are either very large or very small.

The ultimate aim of this study is, of course, to improve understanding of the nature of pre-European catches of labrids. The methodology developed here was applied to 3,096 labrid bones, with a Minimum Number of 1,509 Individuals from an archaeological site at Waihora in the Chatham Islands. This labrid catch showed non-normal characteristics indicating a mixture of several species. We decomposed this mixture into three species using a recursive technique. This analysis suggested approximate proportions of 7% *Notolabrus celidotus* (spotty), 66% *Pseudolabrus miles* (scarlet wrasse), and 27% *Pseudolabrus fucicolia* (banded parrotfish).

The mean fork length of all species combined was 295 ± 1.1 mm and the mean body weight was 560 ± 6.6 g. The usable meat weight represented by these fish was estimated to be 0.6 metric tonnes.

Application of the methodology to other archaeological remains of labrids will enhance our understanding of past Māori use of this important resource.

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APPENDIX 1

LABRIDS IN NEW ZEALAND ARCHAEOLOGICAL SITES

The relative abundance of labrids in New Zealand archaeological sites can be documented from the fish bone database maintained by the Archaeozoology Laboratory, Museum of New Zealand. This database has grown over many years and at present contains information from 91 sites throughout New Zealand, with a total MNI of 32,713 fish. Of these sites, 40 contain labrids with a frequency greater than 10% of the total fish recovered in the excavation. These are listed below.

Site No	Site Name	% of MNI	Site MNI
C46/18	Port Craig Dry Rock Shelter 2 Site3	100.00	1
B45/19	Southport, Site 9	100.00	1
B45/16	Southport, Site 6	74.59	185
C46/31	Sandhill Point, Site 4	64.76	105
B45/17	Southport, Site 7	63.96	111
B46/12	Andrewburn, Fiordland	55.56	9
B45/11	Southport, Site 1	54.18	443
C240/277	Te Ngaio, Chatham Islands	50.00	4
C46/17	Port Craig Dry Rock Shelter 1 Site2	50.00	2
B45/23	Milford and Garden Island	50.00	8
B45/18	Southport, Site 8	50.00	10
B45/22	Chalky Island	46.67	45
B45/15	Southport, Site 5	45.83	120
Q27/36	Te Ika a Maru, Western Midden	40.20	199
B45/14	Southport, Site 4	36.05	86
B44/41	Breaksea Sound, Site 1	34.87	1153
C240/689	CHC, Chatham Islands	33.33	3
B44/22	Coopers Island	30.14	219
R27/41	Makara Beach Midden	24.00	50
O31/30	Avoca Point, Kaikoura	24.00	25
C46/31	Sandhill Point, Site 1	23.83	214
C240/273	Ohinemamao, Chatham Islands	23.53	17
T8/5	Harataonga Bay Western Midden	23.08	26
B44/1	Long Island	22.62	252
D46/35	Riverton, Southland	21.43	14
R27/42	Makara Terrace Midden	20.83	24
S28/49	Washpool Midden Site, Palliser Bay	20.39	363
C240/277	Te Ngaio, Petrie Bay, Chatham Is	20.00	5
B45/1	Cascade Cove	20.00	125
C240/283	Waihora, Chatham Islands	19.09	4197
T11/62	Tairua	17.14	70
R26/122	Paremata	17.01	147
I43/22	Ross's Rocks	16.67	144
E48/30	Te Kiri Kiri	16.07	56
T8/3	Harataonga Bay Pa	14.29	7
Q27/30	Te Ika a Maru, Eastern Midden	11.11	63
N36/72	Panau Site	11.11	45
T11/115	Hot Water Beach	10.67	178
O27/1	Rotokura, Tasman Bay	10.26	585
C240/681	CHA, Chatham Islands	10.07	884

APPENDIX 2
DEFINITION OF MEASUREMENTS MADE ON CRANIAL BONES

The landmarks are illustrated for the right bone in Figure 1 and described below.

Abbreviation and Landmarks		**Dimension**	**Description**
RD1	A-B	Dentary Length	The length from the most dorsal part of the dentary symphysis (A) to the most posterior margin of the superior transverse process (B) (do not rotate callipers). This can be a difficult measurement because of the large anterior tooth. Landmark A is at the base of this tooth at the anterior socket edge.
RD2	A-C	Dentary Fragment Height	The height of the dentary symphysis.
RA1	D-E	Articular Length	The length from the most posterior point of the articular notch (E) to the most anterior point of the body (D).
RA2	F-G	Articular Maximum Height	The maximum height of the articular including the vertical process (rotate callipers).
RQ1	H-I	Quadrate Length	The length from the most anterior lateral edge of the articulating surface (H) to the most posterior point of the superior margin (I).
RP1	J-K	Premaxilla Maximum Length	The maximum length along the body of the premaxilla from the most ventral point of the symphysis (J) to the most posterior point of the body (K) (rotate callipers).
RP2	J-L	Premaxilla Height	The height from the most ventral point of the symphysis (J) to the most superior point of the vertical process (L).
RP3	J-M	Premaxilla Width	The minimum width from the most ventral point of the symphysis (J) to the point of intersection (M) between the transverse and vertical bodies.
RM1	N-O	Maxilla Maximum Length	The maximum length of the body (rotate callipers).
RM2	P-Q	Maxilla Height	The height of the maxilla body.
RC1	R-S	Superior Pharyngeal Cluster Height	Height from ventral surface (S) to the medial surface including teeth (R), taken parallel to the ventral surface.
RC2	T-U	Superior Pharyngeal Cluster Maximum Width	Maximum width of the pharyngeal plate in the medial plane (rotate callipers).
RO1	V-W	Otolith Maximum Length	The maximum length of the otolith (rotate callipers).
ROW	-	Otolith Weight	The weight.
IC1	X-Y	Inferior Pharyngeal Cluster Maximum Width	The maximum width across the body (rotate callipers).
IC2	Z-Z′	Inferior Pharyngeal Cluster Fragment Maximum Width	The maximum width of the pharyngeal plate in the medial plane, between the most lateral points of the teeth edges (rotate callipers).

REFERENCES

DOAK, W. 1972: *Fishes of the New Zealand region*. Hodder and Stoughton, Auckland.

EVERITT, B. S. & HAND, D. J. 1981: *Finite Mixture Distributions*. Chapman and Hall, London.

LEACH, B. F. 1986: A method for analysis of Pacific island fishbone assemblages and an associated data base management system. *Journal of Archaeological Science* 13(2): 147-159.

LEACH, B. F. & ANDERSON, A. J. 1979: The role of labrid fish in prehistoric economics in New Zealand. *Journal of Archaeological Science* 6(1): 1-15.

LEACH, B. F. & BOOCOCK, A. 1993: *Prehistoric fish catches in New Zealand*. British Archaeological Reports (International Series) 584, Oxford.

LEACH, B. F. & BOOCOCK, A. 1995: Estimating live fish catches from archaeological bone fragments of snapper, *Pagrus auratus*. *Tuhinga: Records of the Museum of New Zealand* 3: 1-28.

LEACH, B. F. & DAVISON, J. M. 1977: Fishing methods and seasonality at Paremata (N160/50). *New Zealand Archaeological Association Newsletter* 20(3): 166-175.

LEACH, B. F. & WARD, G. K. 1981: *Archaeology on Kapingamarangi Atoll: a Polynesian outlier in the Eastern Caroline Islands*. Privately published by B.F. Leach.

LIBOIS, R. M. & LIBOIS, C. H. 1988: *Elements pour l'identification des restes craniens des poissons dulcaquicoles de Belgique et du nord de la France*. Fiches d'osteologie animale pour l'archeologie Serie A: Poissons. Centre de Reserches Archeologiques du CNRS.

MACDONALD, P. D. M. 1987: Analysis of length-frequency distributions. In: Summerfelt, R.C. & Hall, G.E. (eds): *Age and growth of fish*: 371-384. Iowa State University Press, Ames, Iowa.

MACDONALD, P. D. M. & PITCHER, T. J. 1979: Age-groups from size-frequency data: a versatile and efficient method of analysing distribution mixtures. *Journal of the Fisheries Research Board of Canada* 36: 987-1001.

MCLACHLAN, G. J. & BASFORD, K. E. 1988: *Mixture Models: Inference and Applications to Clustering*. Marcel Dekker, New York.

ROSELLÓ-IZQUIERDO, E. 1988: *Contribución al atlas osteológico de los Teleósteos Ibéricos I. Dentario y articular.* Colección de Estudios nº 14. Ediciones de la Universidad Autónoma de Madrid. 308 pp., Madrid.

SCHNUTE, J. & FOURNIER, D. 1980: A new approach to length-frequency analysis: growth structure. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1337-1351.

SMITH, I. W. G. 1985: Sea mammal hunting and prehistoric subsistence in New Zealand. Unpublished PhD Thesis, Anthropology, University of Otago.

STERNBERG, M. 1992: *Osteologie du loup. Dicentrachus labrax* (Linnaeus, 1758) *Labrax lupus* (Cuvier, 1828). Fiches d'osteologie animale pour l'archeologie Serie A: Poissons. Centre de Reserches Archeologiques du CNRS.

SUTTON, D. G. 1979: Polynesian coastal hunters in the Chatham Islands. Unpublished PhD Thesis, Anthropology Department, University of Otago.

SUTTON, D. G. 1980: A culture history of the Chatham Islands. *Journal of the Polynesian Society* 89(1): 67-93.

SUTTON, D. G. 1989: Moriori fishing: intensive exploitation of the inshore zone. In: Sutton, D.G. (ed.): *Saying So Doesn't Make it So: Papers in Honour of B.Foss Leach*: 116-131. New Zealand Archaeological Association Monograph 17.

TITTERINGTON, D. M.; SMITH, A. F. M. & MAKOV, U. E. 1985: *Statistical Analysis of Finite Mixture Distributions*. Wiley, New York.

WHEELER, A. & JONES, A. K. G. 1989: *Fishes*. Cambridge Manuals in Archaeology. Cambridge University Press.