Tuhinga 12: 17–38

The Estimation of Live Fish Size from Archaeological Cranial Bones of New Zealand Red Cod *Pseudophycis bachus*

Foss Leach, Janet Davidson,
Meredith Robertshawe, and Penny Leach
Museum of New Zealand Te Papa Tongarewa, PO Box 467, Wellington, New Zealand

ABSTRACT: The New Zealand red cod (*Pseudophycis bachus*) is a common fish in archaeological bone collections from New Zealand. It is not a true cod (family Gadidae) but a member of the family Moridae. The Māori name is hoka.The species is present in 77 of 126 archaeological sites in which fish remains have been studied, with a strong southern bias in abundance. This paper establishes a method for reconstructing fish size and weight from archaeological bones. Twenty measurements were taken on five of the paired cranial bones of a modern sample of the New Zealand red cod (*Pseudophycis bachus*). Regression analysis was performed on these measurements to estimate total fish length and fish weight. A number of regression models were examined (linear, logarithmic, exponential, and power curve) to work out the optimal estimator for each bone measurement. It was found that total length of this species can be estimated with a standard error of less than 23 mm, and weight to less than ± 194 g. Coefficients are provided for 40 equations linking bone size to fish length and weight. This is followed by an example of how to apply the equations to a small bone collection of red cod from an archaeological site at Raumati Beach near Wellington in order to reconstruct the size-frequency of the original fish catch.

KEYWORDS: New Zealand, archaeozoology, Moridae, *Pseudophycis bachus*, regression analysis, length and weight estimation.

Introduction

The New Zealand fish commonly known as red cod (*Pseudophycis bachus*) is a member of the family Moridae. It is not a true cod of the family Gadidae. In New Zealand (as elsewhere) the name 'cod' has been given to various fish unrelated to true cod (see Leach *et al.* 2000), although there are also two species of Gadidae. Other examples besides red cod are the blue cod *Parapercis colias* (family Mugiloididae) and the black cod or Māori chief *Paranotothenia angustata* (family Nototheniidae). This apparently conflicting taxonomy is merely a reflection of the diverse ways in which humans classify familiar objects with different objectives in mind. It is common for European scientists involved in biosystematics to think that the only valid system of classifying animals and plants is the binomial system, whereas there is a large body of literature that shows this view to be naive (eg, Conklin 1962; Bulmer 1967, 1970).

The Māori name for the red cod is hoka, a word that, in various forms (such as hoka Paumotan

[Tuamotuan], so'aso'a Samoan, hoahoa Hawaiian), is widespread in Polynesia, referring to a variety of sharp pointed objects or activities associated with them. For example, the word okaoka in Mangarevan means to poke about with sticks amongst coral looking for fish (Tregear 1891: 78). The New Zealand red cod has a single barbel below the lower jaw, which functions in a very similar manner to okaoka amongst the Mangarevans, as the following passage makes clear:

> The barbel or feeler below the chin of Red Cod has special uses, which I have often observed in the Red Cod kept in captivity in the large outside ponds which have muddy bottoms. Lying flat on the ground, face downwards as near as possible to the pond, I have seen a Red Cod sink to the bottom and begin moving along the floor, using his barbel to feel and poke the mud. Again and again I saw him swim backwards and open-mouthed, and then swallow some creature he had evidently touched with his feeler. This barbel is an extra sense and very sensitive, for it no sooner feels some crab or worm than the Red Cod slips into reverse gear in a flash and the animal is not only in his shovel-shaped mouth but well down his gullet. (Graham 1956: 170).

Perhaps this New Zealand fish was named hoka because of its poking about looking for food with its barbel. Certainly, when the first Polynesians came to New Zealand, this fish would have been entirely new to them, as it is not found outside temperate waters. It is interesting that the Māori also named the ling hoka and hokarari (Williams 1975: 56). In one important respect a ling has a superficial resemblance to a red cod – it has slender pelvic fins set well forward beneath the lower jaw, where they are easily mistaken for barbels (Ayling & Cox 1982: 152).

Red cod are voracious carnivores, feeding on a wide variety of marine organisms. They average 30 to 50 cm in length, but very large specimens are known to reach 1 m in length and weigh over 6 kg (Ayling & Cox 1982: 142). They reach 25 cm in the first year, and 40, 50, and 55 cm in subsequent years. They are sexually mature at the age of two to three years (Annala *et al.* 2000: 338). They are found throughout New Zealand, but more commonly around the South Island. Ayling & Cox (1982: 143) suggest that there may be two distinct populations: one in rocky areas down to about 50 m depth, and the other over sandy and muddy bottoms in deeper water on the continental shelf from 50 to 550 m depth.

Red cod are schooling fish, migrating seasonally but irregularly from deeper to shallower waters, possibly in connection with their breeding activities and changes in food supply. Paul (1986: 57) states that spawning occurs about August, probably in offshore waters. Schools appear in the Canterbury Bight and Banks Peninsula around November, and are not found in any number in these waters after about June. Commercial catch data indicate that they move into deeper water at this time. Recruitment is highly variable, resulting in large variations in catches from one year to another (Annala *et al.* 2000: 338). In an interesting study of the types of fat present in red cod, Carter & Malcolm (1926: 649) argued that, in Otago waters at least, these fish gorge themselves on whale feed during summer and autumn, retiring to deep cold water in winter and basically living on their fat reserves until the whale-feed season occurs again.

These fish have a poor reputation amongst many modern fishermen. Doogue & Moreland, with their usual flair for getting straight to the point, comment: "It is doubtful if anyone would go out with the firm intention of seeking out these fish. As they do not have speed, stamina or particularly good eating qualities, they are easily caught – if you want them... Food qualities: little fat, a flaky rather flavourless flesh. Unsuitable for frying" (Doogue & Moreland 1966: 208). The comment about lack of fat contrasts with the observation of Carter & Malcolm noted above. Recent research suggests that some recreational fishermen do indeed target this species, particularly in the southern North Island and the South Island (Fisher & Bradford 1999: 24). Generally speaking, these fish are more easily caught in inshore waters during spring and summer, before moving into deeper water during winter.

Graham (1956) makes some fascinating observations about red cod, although his suggestion that the name hoka is appropriate because in Māori it means "to eat anything" (Graham 1956: 167), one of the characteristics of this fish, is not correct. This meaning is not recorded in any known source on the Māori language (Ray Harlow pers comm 2000). Graham considered that the bad reputation that red cod has for poor eating qualities was not well founded, but then it is hard to find a species in his volume that he does not consider good eating. He has much to say about the eating qualities of red cod and suggests adding salt to the flesh some hours before cooking to firm it up. He also notes that, although they can be caught in great abundance in some years, they can disappear completely from inshore waters for up to seven years at a time. His story that fishermen's wives refused to go into the harbour in rowing boats on account of the unnatural numbers of fish they had to pull through (Graham 1956: 168) stretches credulity, although very large quantities of red cod probably did come into the Otago harbour during this incident.

Red cod bones have been identified in 77 of 126 archaeological sites for which there is information in the database at the Archaeozoology Laboratory in the Museum of New Zealand. The sites where red cod are most abundant (measured as a percentage of MNI)[1] are listed in Appendix 1. There is a strong southern bias to these occurrences. This is evident in Figures 1 and 2, which plot out the relative abundance by region. Up until now, it has not been possible to describe the size distribution of the red cod represented in these sites because the basic background research linking bone size to total fish length and fish weight had not been carried out. The present paper seeks to remedy this. It is one of a series of papers on the analysis of fish species important in the New Zealand archaeological record (Leach & Boocock 1995; Leach *et al.* 1996a, 1996b, 1997a, 1997b). Using the methodology described here, it will be possible to re-examine archaeological collections of red cod to reconstruct the original catch characteristics. This is the fundamental knowledge from which changes through time and space can be traced. Such changes reflect the interplay between human and environmental history over the last thousand years in New Zealand.

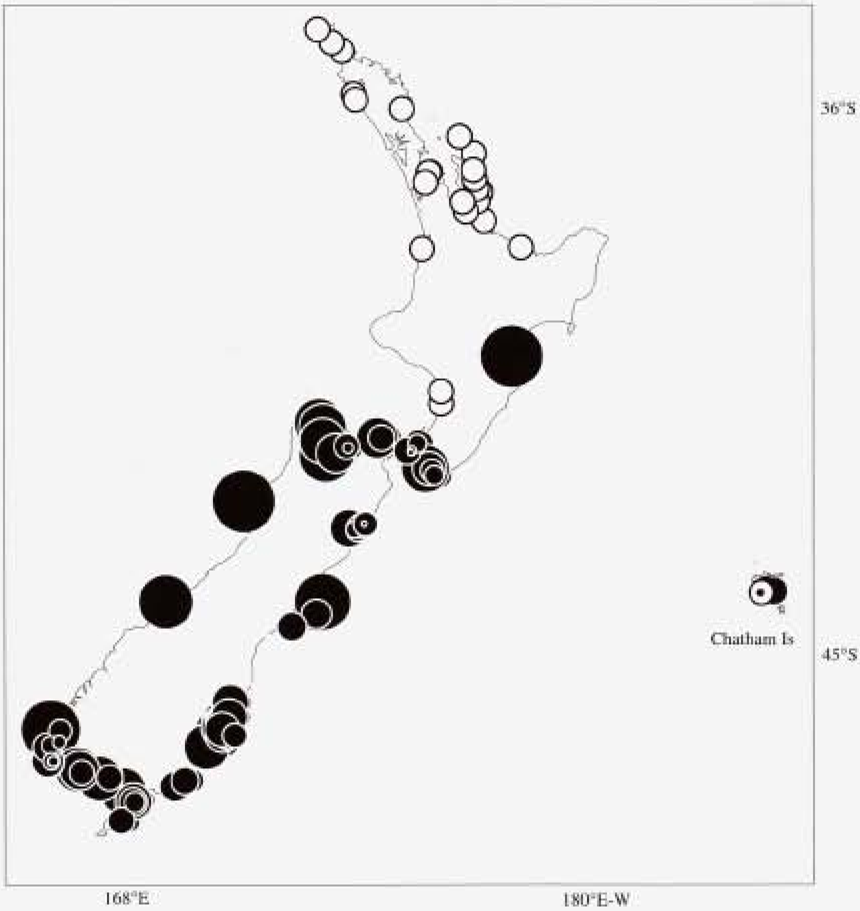


Fig. 1. Map of New Zealand showing the presence of *Pseudophycis bachus* (red cod) in 126 archaeological sites for which good information is available. The plain white circles are sites where red cod is unknown. The size of the black circles indicates the relative abundance of red cod on a logarithmic scale.

---

[1] The term MNI means Minimum Number of Individuals, and is a basic unit of abundance used in archaeozoological research (Chaplin 1971; Leach 1986).

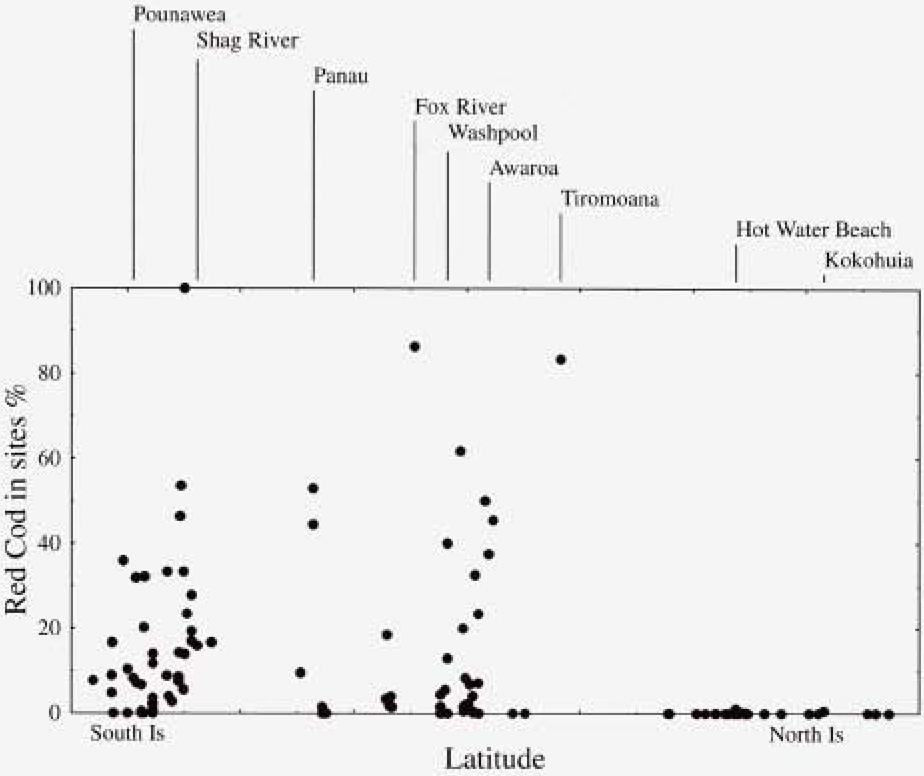


Fig. 2. The abundance of *Pseudophycis bachus* (red cod) as a percentage of total MNI in each of the New Zealand archaeological sites in the fishbone data base at the Archaeozoology Laboratory of the Museum of New Zealand, organised by latitude. The dominance in more southern waters is evident.

Bone Measurement Methodology

The bones used for measurement in this and in our previous studies are five paired cranial bones (the dentary, articular, quadrate, premaxilla, and maxilla). These 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 and it is therefore desirable to include measurements that are applicable to incomplete bones. For this reason, more than one measurement is usually made on each bone in the modern comparative collection. Whenever possible, the largest dimension is measured on an archaeological bone, 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 used in our studies of New Zealand fish species closely parallel those employed by archaeozoologists on other species (Rosello-Izquierdo 1986: 35; Libois & Libois 1988; Sternberg 1992; Wheeler & Jones 1989: 139 ff).

Each measurement is given a computer code with three characters. Thus, LD1 refers to the Left Dentary and the first measurement defined for that bone. The purpose of the three character code is to permit simple coding of measurements on plastic bags that 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 total fish length and fish weight is selected using these three character codes. Mitutoyo digital callipers model 500-322 are used for linear measurements, which are recorded to ± 0.01 mm precision.

The dimensions chosen in this study of red cod are illustrated in Figure 3. The anatomical landmarks used are indicated on Figure 3 by a small dot and given a letter code from A to R. Anatomical land-

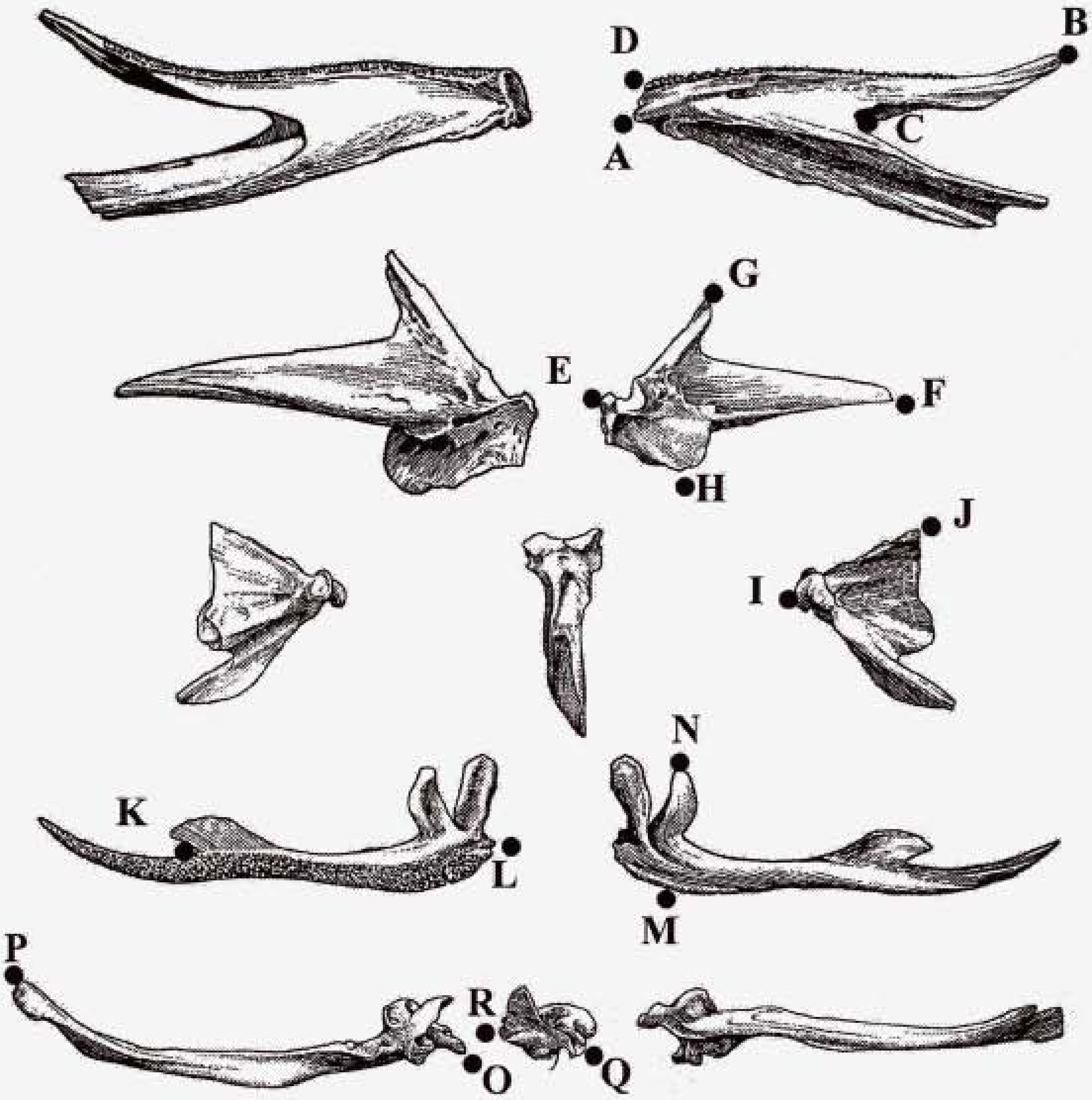


Fig. 3. Cranial elements of *Pseudophycis bachus* (red cod) used for measurements. The left bones are illustrated. Measurements are made between landmarks A–B, A–C, and A–D on the dentary; between E–F and G–H on the articular; between I–J on the quadrate; between K–L and M–N on the premaxilla; and between O–P and R–R on the maxilla.

marks are points on a bone, such as the junction of separate sutures, which can be defined very accurately in three dimensions (Buranarugsa & Leach 1986, 1993). In cases where the terminology 'maximum length' or 'maximum height' is used, this implies that 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 for the quadrate. 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 is quite robust, and an adequate sample of measurements can be taken on whole bones. Three measurements are indicated for the dentary, and two each for the articular, premaxilla, and maxilla.

In our experience, even with the benefit of an annotated illustration (Fig 3) and formal definitions (Appendix 2), it is not a simple matter for a new research assistant to make the correct measurements

Table 1

Measurements made on Cranial Bones of Red Cod
from modern material and from an archaeological site

Modern Comparative Collection

Left Bone Meas.	No. Missing Meas.	Right Bone Meas.	No. Missing Meas.	Landmarks	Bone	Dimension	Units
LD1	0	RD1	0	A-B	Dentary	Maximum Length	mm
LD2	1	RD2	1	A-C	Dentary	Fragment Length	mm
LD3	0	RD3	0	A-D	Dentary	Symphysis Height	mm
LA1	3	RA1	2	E-F	Articular	Maximum Length	mm
LA2	2	RA2	1	G-H	Articular	Maximum Height	mm
LQ1	1	RQ1	2	I-J	Quadrate	Length	mm
LP1	0	RP1	0	K-L	Premaxilla	Fragment Length	mm
LP2	0	RP2	0	M-N	Premaxilla	Maximum Height	mm
LM1	2	RM1	2	O-P	Maxilla	Maximum Length	mm
LM2	1	RM2	0	Q-R	Maxilla	Width	mm
Totals	**10**		**8**				
Total Missing	**18**						

Total number of possible measurements (150 fish x 20 variables)	3000
Total number of measurements missing	18
Nett measurements available	2982

Archaeological Bones — Raumati Beach Site, near Wellington

Left Bone Meas.	Number of Measurements	Right Bone Meas.	Number of Measurements	Total
LD1	1	RD1	0	1
LD2	1	RD2	0	1
LD3	4	RD3	8	12
LA1	3	RA1	3	6
LA2	2	RA2	4	6
LQ1	2	RQ1	2	4
LP1	0	RP1	0	0
LP2	11	RP2	13	24
LM1	0	RM1	2	2
LM2	4	RM2	9	13
Totals	**28**		**41**	**69**

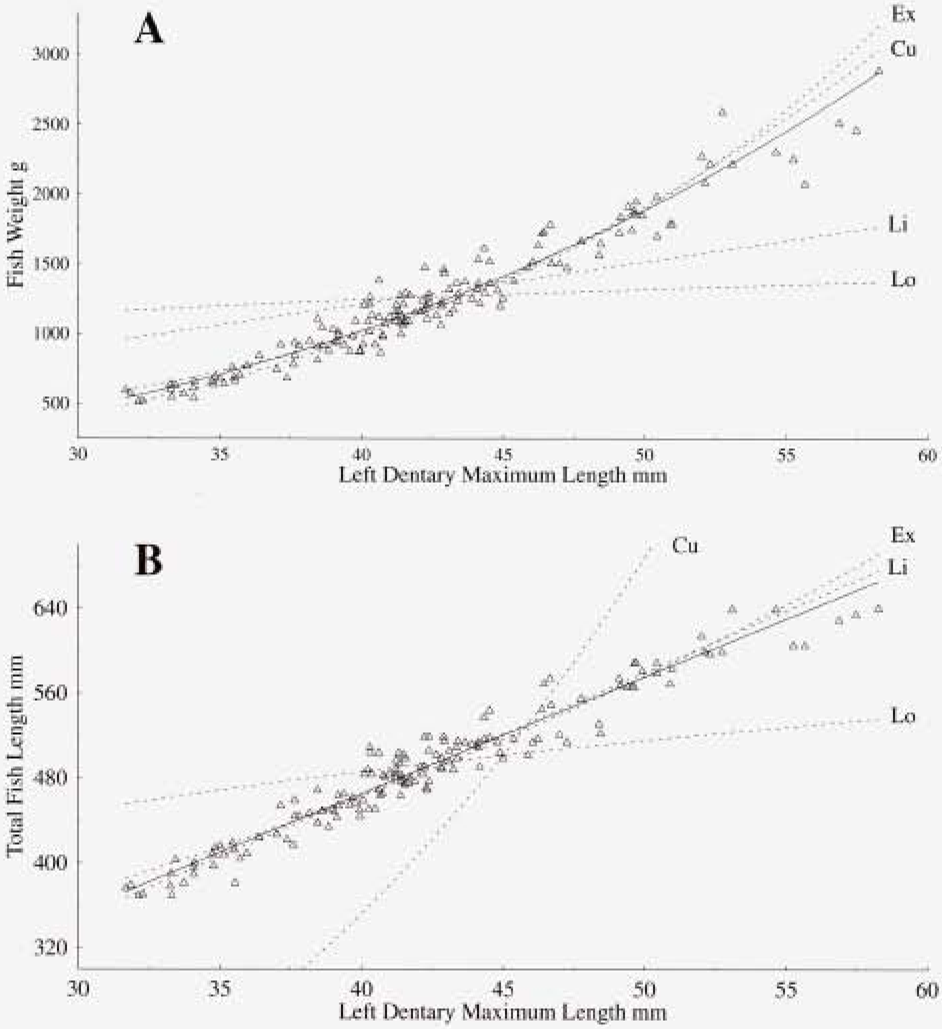


Fig. 4. Several regression models were applied to the measurement of left dentary length and total fish length and weight (N=150). Note that some of the lines of best fit are reasonable approximations of the relationships, while others are quite inappropriate. The solid line is the power curve fit in each case and is an excellent model. Other lines are Ex=Exponential, Cu=Cubic, Li=Linear, Lo=Logarithmic.

on archaeological bones. It is desirable for a newcomer to learn the correct methods by remeasuring 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. A person learning to take the measurements must be able to repeat any one measurement within ± 0.05 mm. That is, the precision is ± 0.01 mm and the accuracy must be ± 0.05 mm. This accuracy is equivalent to ± 5 mm in estimating the total fish length from the dentary length on the largest specimens of red cod in the comparative collection. This can be compared with the standard error of the estimate of ± 15.1 mm for this measurement (see below Table 3).

Modern Comparative Sample of Red Cod

A sample of 150 red cod was used in this study. They were obtained from the Sealords fish factory in Dunedin. It is always very difficult to get specimens of exceptionally large size. There are occasions when fish bones from New Zealand archaeological sites are very large, reflecting relatively unexploited inshore stocks. Wherever possible, it is important to develop equations for estimating fish size that do not involve extrapolation

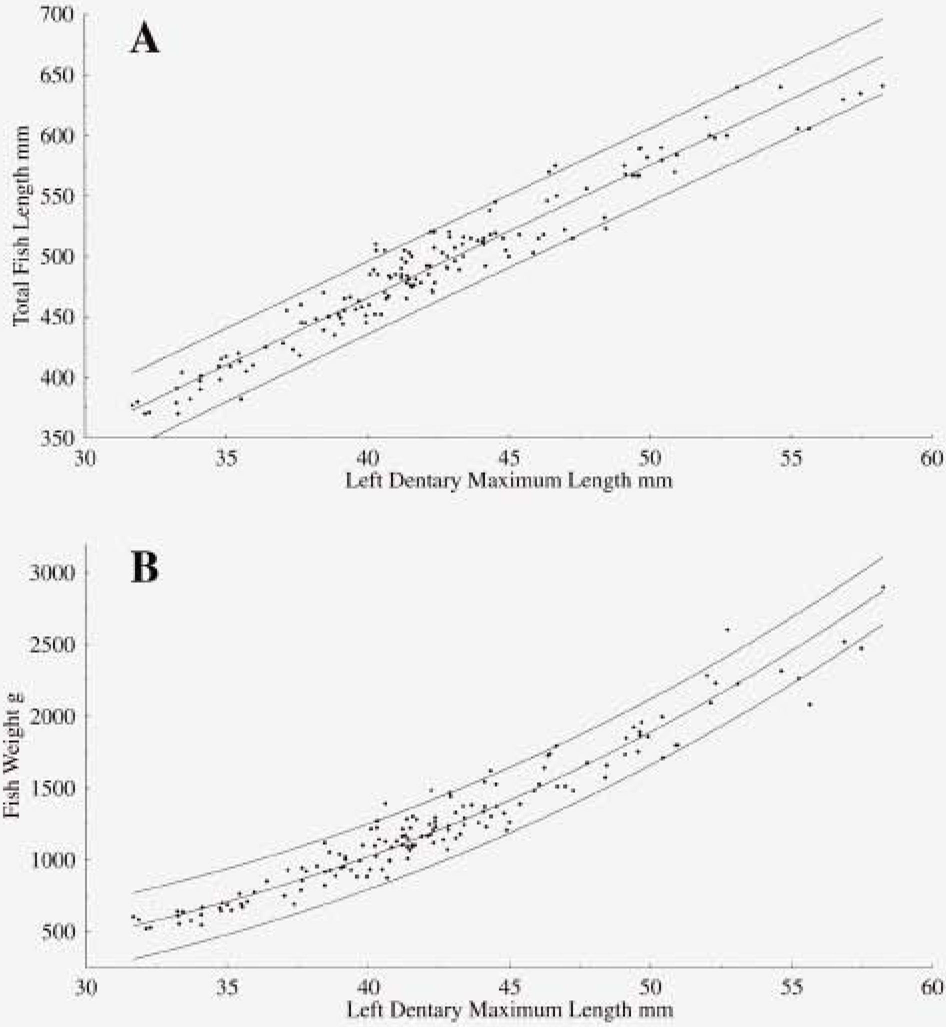


Fig. 5. The regression model that best fits the data when estimating total fish length (A) and fish weight (B) from the left dentary length is a power curve fit in both cases. The 95% confidence boundaries for the regression line of y on x are shown. The standard errors are ± 15 mm for the total length and ± 115 g for the weight. The powers are 0.95 and 2.75 for total fish length and fish weight respectively. These values are close to linear and cubic (see Table 2).

beyond the limits of modern comparative collections. Unfortunately, archaeological fish specimens are frequently much larger than those available in the modern New Zealand fishery, following massive exploitation in the post-European era (Leach & Davidson 2000: 521). Therefore, every effort must be made to find as many specimens as possible at the upper end of the size range when building comparative material for these metrical studies. In the case of very small specimens, there is not the same problem in acquiring specimens; moreover, the regression techniques employed are forced to pass through the origin.

This modern sample of 150 fish had total lengths ranging from 370 to 641 mm with a mean of 490 mm. The fish weights (whole ungutted weight) ranged from 521 to 2897 g with a mean of 1247 g. The heads were removed and frozen, and then boiled down one by one and the five paired cranial bones removed, cleaned, and air dried. Information was collated for 22 variables, consisting of total fish length, fish weight, and 20 bone measurements. Some bones were broken or missing, and therefore not all measurements were able to be taken. The final data matrix of 3,000 entries had 18 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.

Table 2

Least-squares Analysis of Left Dentary Length with both Total Fish Length and Fish Weight

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 total length or weight
SER = standard error of R
t,DF = Student's t value for R and degrees of freedom
Resid,DF = Residuals and degrees of freedom

Total Fish Length mm

Fit	**A**	**B**	**R**	**SEE**	**SER**	**t**	**DF**	**Resid**	**DF**
Linear	.00	11.59	.97	15.4	.005	48.3	148	74	149
Exponential	192.48	.02	.96	17.2	.006	43.0	148	90	149
Logarithmic	.00	131.79	.97	15.0	.005	49.7	148	662	149
Power Curve	13.97	.95	.97	15.2	.005	49.2	148	69	149
Cubic	.00	.01	.94	20.8	.009	34.9	148	5625	149

Fish Weight g

Fit	**A**	**B**	**R**	**SEE**	**SER**	**t**	**DF**	**Resid**	**DF**
Linear	.00	30.36	.97	122.1	.005	45.3	148	12417	149
Exponential	79.44	.06	.96	129.3	.006	42.6	148	2028	149
Logarithmic	.00	337.45	.95	140.9	.007	38.8	148	22904	149
Power Curve	.04	2.75	.97	114.9	.005	48.4	148	1508	149
Cubic	.00	.02	.97	121.6	.005	45.5	148	1855	149

Table 3

Best Fit Coefficients for Total Fish Length Estimates

All are power curve equations of the form:
Total length = A * Bone Measurement^B (units mm)

Bone Measurement	**Constant**	**Slope**	**Standard Error**
LD1	13.97309	.95039	15.1
LD2	25.28635	.97784	24.7
LD3	154.37830	.76265	22.6
LA1	17.58462	.91693	15.8
LA2	38.98862	.84050	16.4
LQ1	58.92426	.83053	21.7
LP1	21.14239	.94477	18.0
LP2	48.24505	.98795	19.3
LM1	12.51169	.94955	13.3
LM2	70.91583	.92372	18.5
RD1	13.91110	.95108	15.0
RD2	22.31893	1.01885	22.6
RD3	155.50670	.75995	23.5
RA1	17.02400	.92505	15.8
RA2	39.91954	.83287	16.3
RQ1	57.33204	.84259	19.6
RP1	22.09695	.93059	18.3
RP2	47.26055	.99740	20.1
RM1	12.65487	.94575	13.0
RM2	68.50343	.93899	17.3

Least-squares Analysis of Modern Comparative Material

The main objective of this study was to establish reliable regression relationships between bone dimension and total fish length and fish weight, which can be used for interpreting 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 4, using the left dentary length as an example. The statistics for the regression analysis estimating total fish length and fish weight from the left dentary length are given in Table 2.

Inspection of this table will reveal that, in estimating fish weight, the power curve fit is the best model, closely followed by the cubic function. This is evident from both the standard errors of the estimate

Table 4

Best Fit Coefficients for Weight Estimates

All are power curve equations of the form:
Weight = A * Bone Measurement^B (units g, mm)

Bone Measurement	Constant	Slope	Standard Error
LD1	.04032	2.74900	114.8
LD2	.23240	2.81683	193.4
LD3	42.52544	2.19787	174.2
LA1	.07494	2.66454	111.3
LA2	.78456	2.43093	124.9
LQ1	2.55277	2.40851	159.3
LP1	.13980	2.71913	142.5
LP2	1.41662	2.86847	140.9
LM1	.03016	2.73898	108.5
LM2	4.42988	2.67131	141.8
RD1	.03990	2.75042	114.2
RD2	.16684	2.92564	178.7
RD3	42.51634	2.20422	174.0
RA1	.07236	2.67221	118.8
RA2	.86067	2.40119	132.6
RQ1	2.44887	2.42798	150.4
RP1	.15754	2.68062	144.8
RP2	1.32285	2.89959	144.4
RM1	.03116	2.72801	106.2
RM2	4.11571	2.70303	138.5

(± 115 and 121 g respectively) and the residuals.

In estimating the total fish length, very good fits were obtained for both the power curve fit and linear model. The standard errors of the estimate are ± 15 mm in both cases, while the residuals are slightly better for the power curve fit than the linear model.

The various models are plotted out in Figure 4 . The solid line is the power curve fit in both cases. In some previous regression studies of bone dimensions against total fish length and weight, we have taken the view that the best equation is the one that 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. We have found cases of non-linearity in estimating total fish length from bone dimension, and a power curve fit is a better option here too.

Figure 5 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 confidence interval in estimating y from x increases as we move away from the mean value, and a correction is needed. The 95% confidence boundary for the standard error

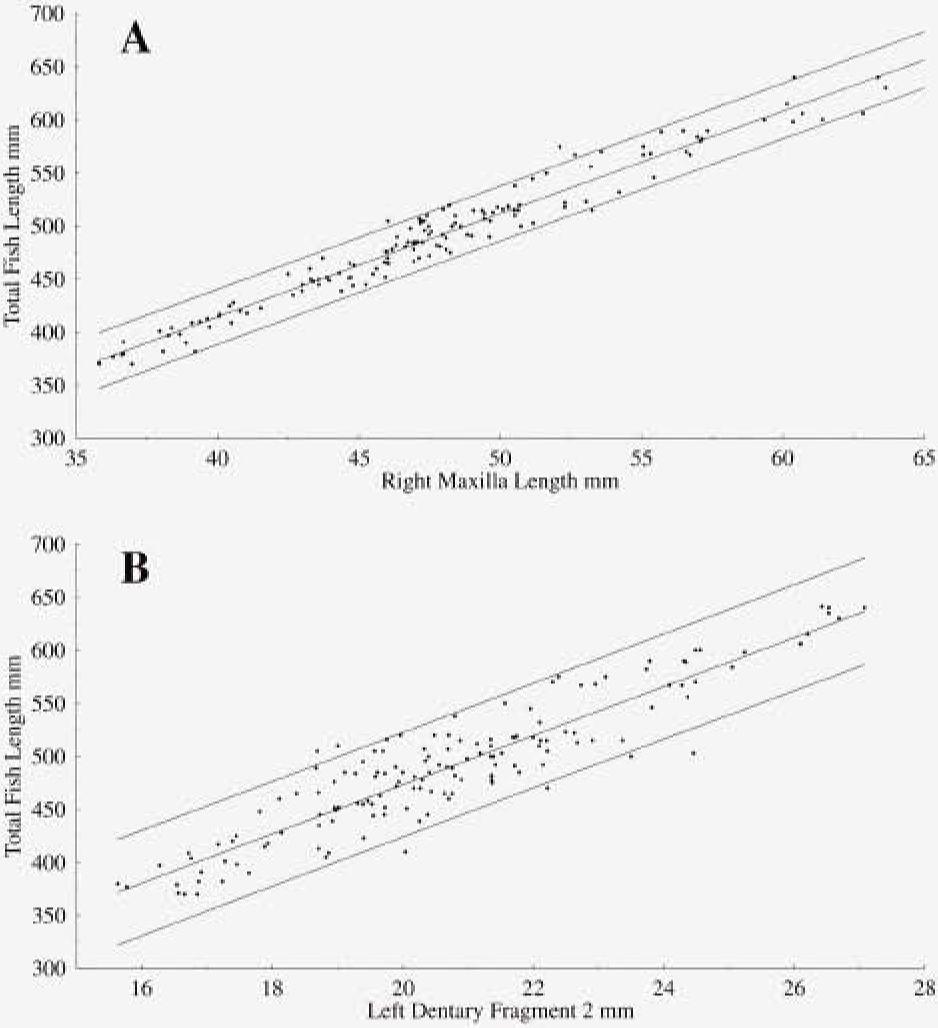


Fig. 6. This shows the best (A) and the worst (B) fit regression lines for estimating total fish length from bone measurements. The best measurement is the right maxilla length, which has a standard error of the estimate of ± 13 mm; and the worst is the left dentary fragment 2 measurement with ± 25 mm (see Table 3).

of the estimate for Y on X is therefore calculated (Schefler 1969: 155–157; Snedecor & Cochran 1967: 155). These are the boundaries shown in Figures 5–7.

The power curve model was chosen for all 20 bone measurements, enabling best fit regression equations to be calculated and thereby completing the tabulations given in Tables 3 and 4. Figures 6 and 7 illustrate the best and worst fits for estimating total fish length and fish weight respectively. The Dentary Fragment Length measurement in both cases gives the worst results. The range of errors associated with the final choice of regression models is illustrated in Figure 8. Total length errors range from ± 13.0 to 22.6 mm, and weight errors range from ± 106.2 to 193.4 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 AJ186. This fish had a total length of 505 mm and a weight of 1171 g. The left dentary length LD1 was 41.31 mm.

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

Total Fish Length mm = 13.97309 * $\mathrm{LD1}^{0.95039}$ ± 15.1 mm

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

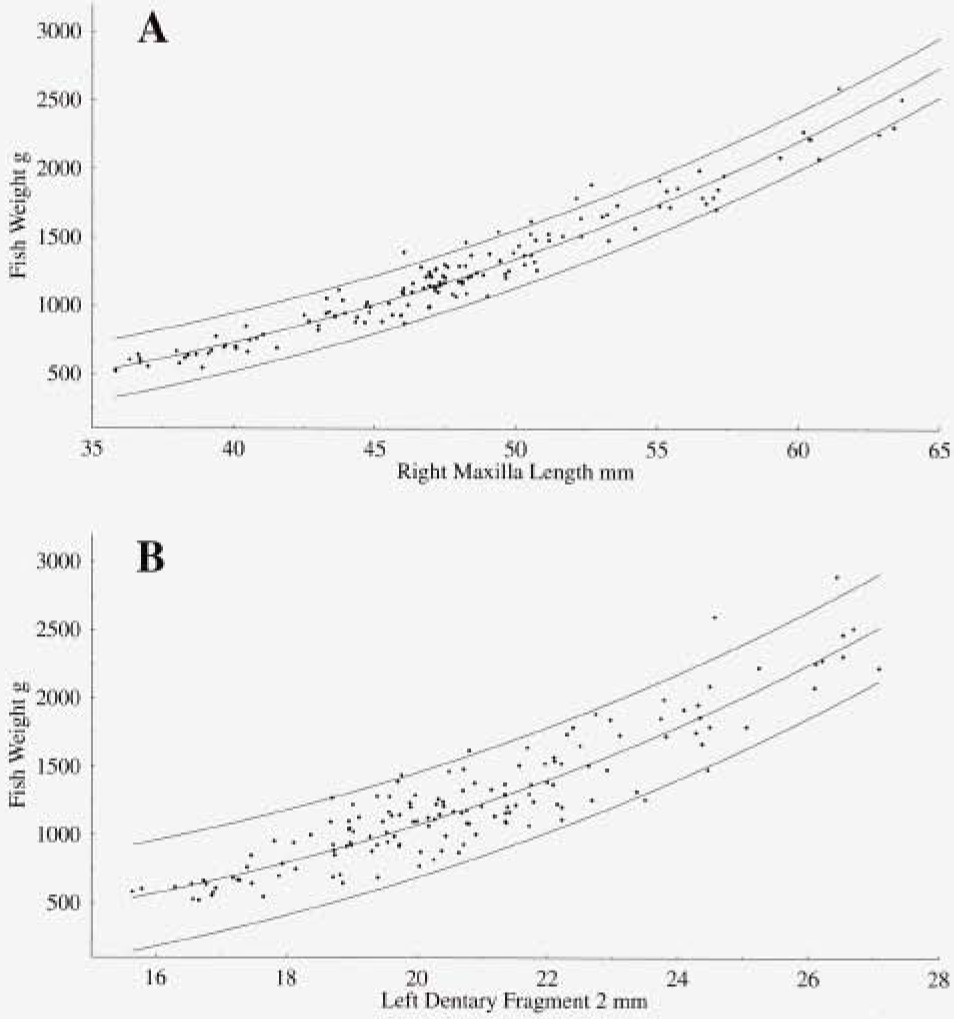


Fig. 7. This shows the best (A) and the worst (A) fit regression lines for estimating fish weight from bone measurements. The best measurement is the right maxilla length, which has a standard error of the estimate of ± 106 g; and the worst is the left dentary fragment 2 measurement with ± 193 g (see Table 4).

$\text{Weight g} = 0.04032 * \text{LD1}^{2.749} \pm 114.8 \text{ g}$

By substituting the value of 41.31 for LD1 into these two equations, we derive an estimate for the total fish length of 480 mm, and for weight of 1117 g. The error in estimating the total fish length is therefore 25 mm (505–480), and in estimating the weight 54 g (1171–1117). The error in the estimated total length is between the 68% and 95% confidence limits of ± 15.1 and ± 30.2 mm, and the error in the estimated fish weight is less than the 68% confidence limits of ± 114.8 g.

There are two methods by which an estimate of the original weight of the fish can be obtained. One can work directly from the bone to the weight using the comparative material assembled for this present study, or one can adopt a two-step process by first estimating the total fish length from the bone dimension and then estimating the weight from the total length. There is a potential shortcoming in the first approach, namely that this present osteological sample of 150 fish is relatively small and does not contain many very small or very large specimens. Thus, sometimes we may be obliged to extrapolate beyond the size limits of the osteological collection with archaeological material. This is not a serious problem in the case of regression equations that are close to linear; however, it could produce significant errors when a regression relationship is close to a cubic function.

For economically important species, fisheries scientists usually have well established relationships

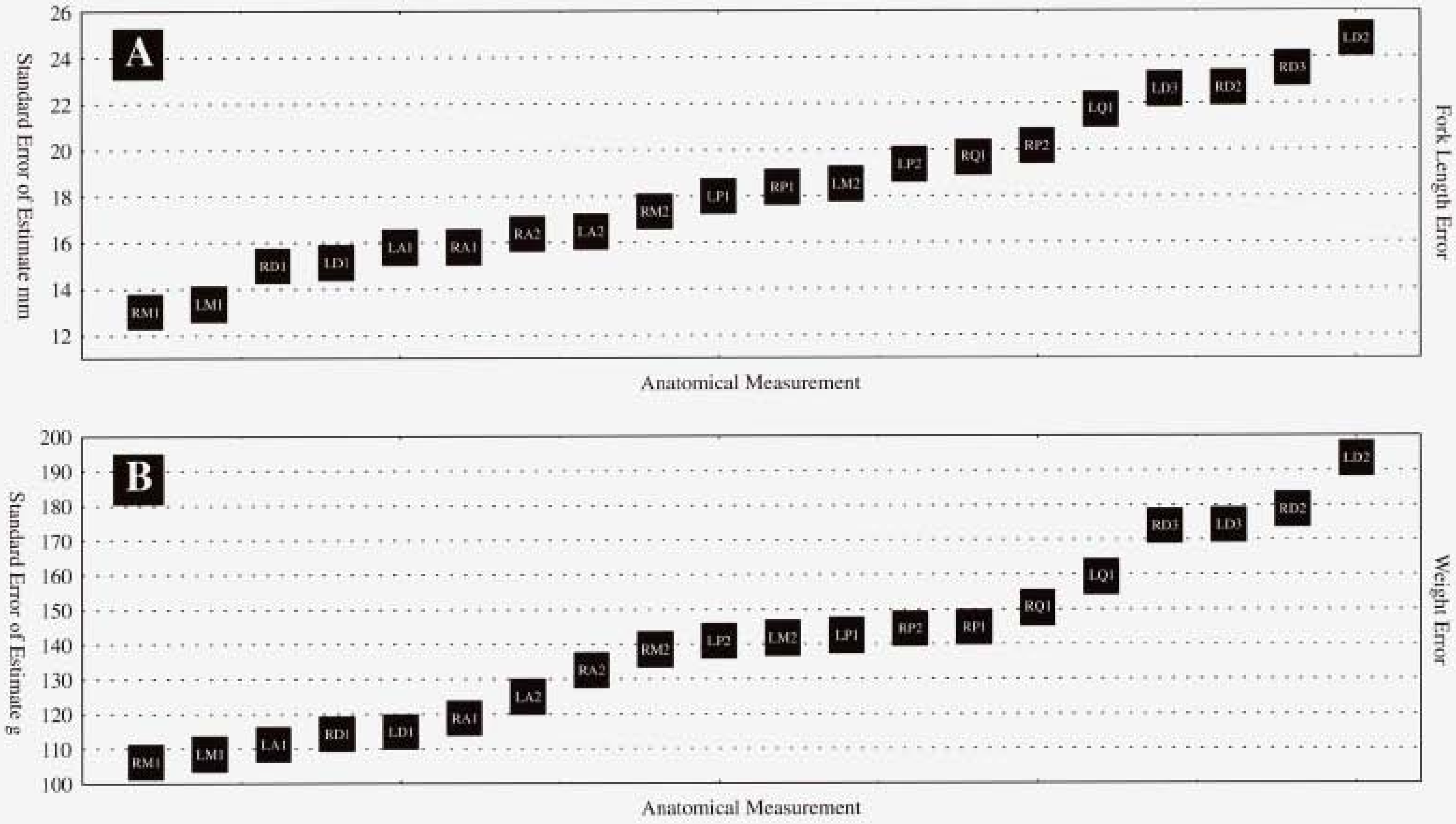


Fig. 8. These two graphs show the range of standard errors of the estimate for both total fish length (A) and fish weight (B) for all bone measurements taken. These range from 15 to 25 mm and from 106 to 193 g. The general pattern of errors is similar for any one measurement between the two graphs.

between total fish length and body weight for very large samples of fish, for different sexes, at different seasons, and at different localities. Several equations have been suggested in the case of red cod (total length in mm and weight in g for each case).

1: $\text{weight} = 0.0000265 * (\text{total length}/1.0)^{2.843983} \pm 89$ g
2: $\text{weight} = 0.0074 * (\text{total length}/10.0)^{3.059} \pm ?$
3: $\text{weight} = 0.0145 * (\text{total length}/10.0)^{2.892} \pm ?$

Equation 1 is derived from our own study of the 150 red cod in our sample. Equations 2 and 3, for females and males respectively, are those suggested by NIWA (National Institute of Water and Atmospheric Research), based on a study by Beentjes (Annala *et al.* 2000: 338; Beentjes 1992). We have no means of establishing the sex of fish from archaeological bones, so choosing between these alternative recommended equations is difficult. The medium-sized specimen of 505 mm total length mentioned above yields the following estimates:

equation 1	1292 g (error = +121 g)
equation 2	1201 g (error = +30 g)
equation 3	1223 g (error = +52 g)

In the meantime, equation 1 is preferred until a mixed sex equation is available for a much larger sample than that used in the present study.

Deciding whether to estimate the fish weight in a single step from the bone measurement or as a two-step procedure from the bone to the total fish length and then from the total 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 (ie, the difference between observed and estimated total length and weight), using estimates from the two models. This was carried out, and the results are graphed in Figure 9. The mean of the residuals is +1.01% for estimates of total length from bone measurements (a one-step procedure). The mean residual for the one-step model in estimating weight directly from bone measurements is +4.04%; for the two-step weight model, it is +4.56%. Although the range of residuals is similar in both latter cases, we suggest 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

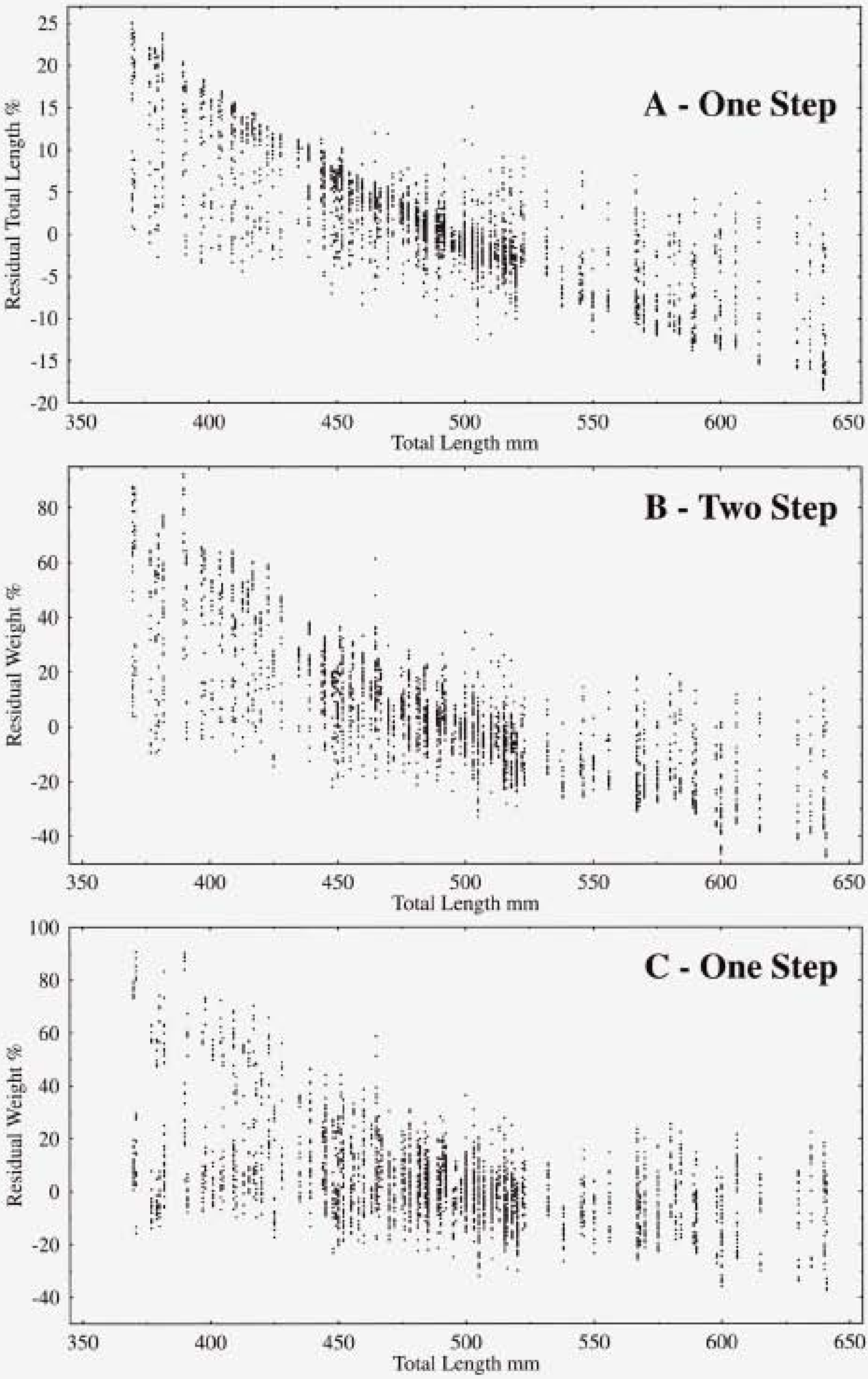
Following the identification of anatomy and species of archaeological fish bone collections, wherever possible one, *and only one*, of the bone dimensions described in Table 1 is measured on each bone. All available bones are measured, and this number usually exceeds the MNI value. This may initially appear somewhat curious; however, a careful examination of this matter showed that this is indeed the best approach to use (Leach & Davidson 2000: 516; Leach & Boocock 1995: 24 ff.). The measurements are then entered into a computer file by provenance and bone code. As an example of the procedure, measurements of bones from a shell midden site at Raumati Beach (Site R26/291) near Wellington were chosen. A typical selection of coded measurements from this site appears below:

Red Cod measurements from Raumati Beach
Bag 1 LQ1 5.15 RP2 10.84 RQ1 8.30
Bag 2 LD1 18.89 LD2 10.21 LD3 2.10 LP2 4.96 LP2 6.45 RA2 7.36

The fish bone assemblage from the Raumati Beach site is quite small, and only 69 bones of red cod were able to be measured; however, it still serves a useful purpose in outlining the procedures that need to be followed to obtain a size-frequency diagram of the original fish catch.

With the aid of a simple computer program, these 69 bone measurements were converted into estimates of total fish length using the coefficients listed in Table 3 and estimates of fish weight using the two-step model referred to above. The resulting histogram of fish length is illustrated in Figure 10, together with the dispersion statistics. The histogram displays shape characteristics that are only approximately normal. There is significant positive skewness and negative kurtosis (g1 and g2 depart from 0.0 and 3.0 respectively). There are clear signs in the graph of bimodality, representing two size classes of fish – juveniles and adults.

The mean weight of the fish represented by these



[red7.gle 6-11-00]

Fig. 9. Analysis of residuals when estimating total fish length from bone measurements (A), which is a one-step calculation, and the residuals when estimating weight using the two-step model (B) and one-step model (C). The 150 fish in the comparative collection produced 2982 measurements, which are used in this analysis. In A, the range of residuals is -18.39 to +25.08%, with a mean of +1.01%. In B, the range is -47.48 to +92.39%, with a mean of +4.56%. In C, the range is -37.35 to +90.72%, with a mean of +4.04%. The two-step model is preferred in cases of archaeological bones that are very small or very large.

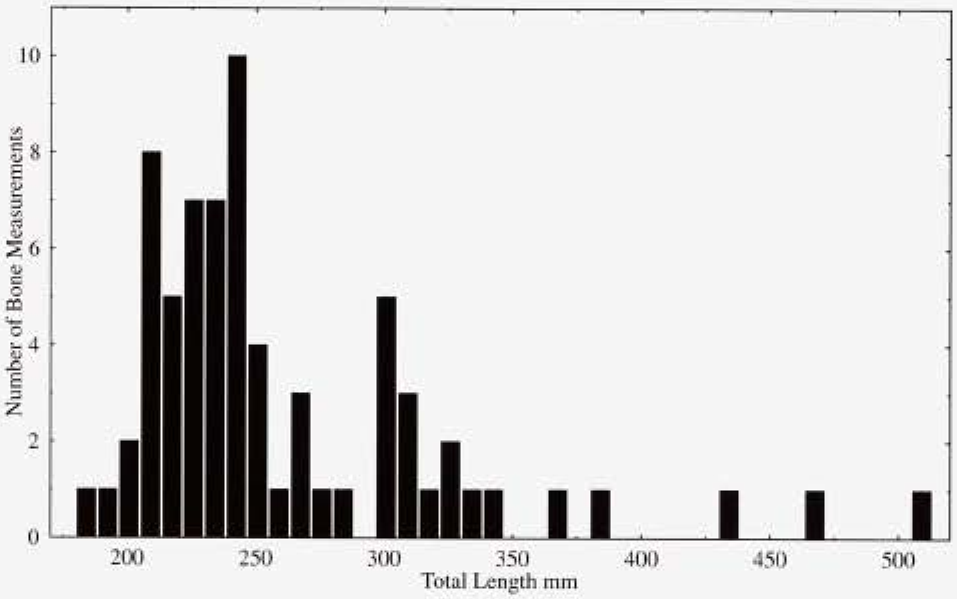


Fig. 10. Size-frequency histogram of red cod total lengths from the Raumati Beach site near Wellington. The total length range is 184 to 509 mm; with a mean of 262 ± 7.5 mm; SD = 62.4 ± 5.3 mm; g1/W1 = +1.9, 4.9; g2/W2 = +7.0, 7.8.

bones was estimated to be 232.8 ± 25.6 g (ie, ± 11%). From this, we can calculate the total weight of red cod, using the MNI value for the species. Of the total MNI of 86 fish at this site, 20 were red cod. Thus, the total weight of red cod can be calculated as:

Mean Body Weight	x	MNI	=	Total Body Weight	Usable Meat Weight
232.8 g	x	20	=	4656 ± 512 g	3259 g

Smith (1985: 487–8) recommends a figure of 70% for the amount of usable meat weight per total body weight for the common species of New Zealand fishes. At the Raumati Beach site, this is therefore estimated to be about 3.3 kg of red cod meat. The stated error of ± 512 g for the total body weight is based on the standard error of the mean weight of fish, which is ± 11%.

Conclusions

The New Zealand red cod was one of the more important species for pre-European Māori fishermen, particularly in the southern half of New Zealand. It has been identified in 77 of 126 archaeological sites for which there is information in the data base at the Archaeozoology Laboratory of the Museum of New Zealand Te Papa Tongarewa.

This study has shown that it is possible to estimate total length of red cod from archaeological bones with a standard error of less than 23 mm, and fish weight with a standard error of less than 194 g. A modern sample of 150 red cod was used. The fish were weighed, measured, and 20 measurements taken on cranial bones. Four regression models were examined (linear, logarithmic, exponential, and power curve). In the case of fish length, both power curve and linear models gave very good fits, with standard errors of the estimate of ± 15 mm. The residuals were slightly better for the power curve fit. In the case of fish weight, the power curve gave the best fit, with a standard error of the estimate of ± 115 g, closely followed by the cubic model. It was concluded that the power curve provided the best option for both length and weight.

Weight may be estimated in either one or two steps. The one-step model calculates weight from bone dimension. The two-step model works from bone dimension to length and then from length to weight. In this study of red cod, similar results were obtained using both methods. We suggest, however, that the two-step model is preferable when the archaeological fish are either very large or very small.

The method established was applied to a small archaeological collection from a site at Raumati Beach, north of Wellington. This revealed bimodality, suggesting the presence of two age grades among the fish caught. They ranged in length from 153 to 509 mm, with a mean of 301 mm. The mean weight was 232.8 g. The small size of some of the fish suggests that they may have been caught in nets.

Acknowledgements

We would like to express our sincere thanks to Sealords Dunedin, for generously providing us with the sample of red cod used in this study, and to Jim Samson at the University of Otago, who assisted with their collection. We would like to acknowledge Larry Paul, National Institute of Water and Atmospheric Research Ltd (NIWA), for useful discussions while this project has been underway. We would like to thank the Foundation for Research, Science and Technology for financial support for this research (Contract MNZ801).

References

Annala, J.H., Sullivan, K.J., & O'Brien, C.J. 2000. *Report from the fishery assessment plenary, May 2000: stock assessment and yield estimates.* Ministry of Fisheries.

Ayling, T. & Cox, G.J. 1982. *Collins guide to the sea fishes of New Zealand.* Collins, Auckland.

Beentjes, M.P. 1992. *Assessment of red cod based on recent trawl survey and catch sampling data.* New Zealand Fisheries Assessment Research Document 92/16. 41 pp.

Bulmer, R.N.H. 1967. Why is the Cassowary not a bird? A problem of zoological taxonomy among the Karam of the New Guinea Highlands. *Man* 2: 5–25.

Bulmer, R.N.H. 1970. Which came first, the chicken or the egg-head? *In:* Pouillon, J. & Maranda, P. *eds.* Èchanges et Communications, Mélanges offerts à Claude Lévi-Strauss à l'Occasion de son 60ème Anniversaire. Pp. 1069–91. Mouton, The Hague.

Buranarugsa, M. & Leach, B.F. 1986. The three-dimensional analysis of the Polynesian skull. *Man and Culture in Oceania* 2: 81–100.

Buranarugsa, M. & Leach, B.F. 1993. Coordinate geometry of Moriori crania and comparisons with Māori. *Man and Culture in Oceania* 9: 1–43.

Carter, C.L. & Malcolm, J. 1926. Food values of New Zealand fish. Part 5: The fats of the red cod in relation to its food. *Transactions of the New Zealand Institute* 56: 647–650.

Chaplin, R.E. 1971. *The study of animal bones from archaeological sites.* Seminar Press, London.

Conklin, H.C. 1962. Lexicographic treatment of folk-taxonomies. *International Journal of American Linguistics* 28 (2), Part IV: 119–141.

Doogue, R.B. & Moreland, J.M. 1966. *New Zealand sea anglers' guide.* A.H. and A.W. Reed, Wellington.

Fisher, D. & Bradford, E. 1999. National marine recreational fishing survey 1996: catch and effort results by fishing zone. *NIWA Technical Report* 67.

Graham, D.H. 1956. *A treasury of New Zealand fishes.* A.H. and A.W. Reed, Wellington.

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: 147–159.

Leach, B.F. & Boocock, A. 1993. *Prehistoric fish catches in New Zealand.* British Archaeological Reports, International Series 584. 303 pp.

Leach, B.F. & Boocock, A. 1995. The estimation of live fish catches from archaeological bone fragments of the New Zealand snapper *Pagrus auratus. Tuhinga, Records of the Museum of New Zealand* 3: 1–28.

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

Leach, B.F. & Davidson, J.M. 2000. Pre-European catches of snapper (*Pagrus auratus*) in northern New Zealand. *Journal of Archaeological Science* 27: 509–522.

Leach, B.F., Davidson, J.M., & Fraser, K. 2000. Pre-European catches of blue cod (*Parapercis colias*) in the Chatham Islands and Cook Strait, New Zealand. *New Zealand Journal of Archaeology* 21 (1999): 119–138.

Leach, B.F., Davidson, J.M., & Horwood, L.M. 1997a. The estimation of live fish size from archaeological cranial bones of the New Zealand blue cod *Parapercis colias*. *International Journal of Osteoarchaeology* 7: 484–496.

Leach, B.F., Davidson, J.M., Horwood, L.M., & Anderson, A.J. 1996a. The estimation of live fish size from archaeological cranial bones of the New Zealand barracouta *Thyrsites atun*. *Tuhinga, Records of the Museum of New Zealand* 6: 1–25.

Leach, B.F., Davidson, J.M., Horwood, L.M., & Mallon, S. 1996b. The estimation of live fish size from archaeological cranial bones of the New Zealand kahawai *Arripis trutta*. *Tuhinga, Records of the Museum of New Zealand* 7: 1–20.

Leach, B.F., Davidson, J.M., Samson, J., & Burnside, G. 1997b. The estimation of live fish size from archaeological cranial bones of New Zealand Labridae. *Archaeofauna* 6: 41–58.

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'ostéologie animale pour l'archéologie Serie A: Poissons. Centre de Recherches Archéologiques du CNRS.

Paul, L. 1986. *New Zealand fishes: An identification guide*. Reed Methuen, Auckland.

Rosello-Izquierdo, E. 1986. *Contribución al atlas ostéologico de los Teleosteos Ibericos I. dentario y articular*. Ediciónes de la Universidad Autonoma de Madrid.

Schefler, W.C. 1969. *Statistics for the biological sciences*. Addison-Wesley, London.

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

Snedecor, G.W. & Cochran, W.G. 1967. *Statistical methods*. Iowa State University Press.

Sternberg, M. 1992. *Ostéologie du loup. Dicentrachus labrax* (Linnaeus, 1758) *Labrax lupus* (Cuvier, 1828). Fiches d'ostéologie animale pour l'archéologie Serie A: Poissons. Centre de Recherches Archéologiques du CNRS.

Tregear, E. 1891. *The Maori-Polynesian comparative dictionary*. Lyon and Blair, Wellington.

Wheeler, A. & Jones, A.K.G. 1989. *Fishes*. Cambridge Manuals in Archaeology. Cambridge University Press.

Williams, H.W. 1975. *A dictionary of the Maori language*. Government Printer, Wellington.

Manuscript submitted July 2000, accepted October 2000.

Appendix 1

Red Cod in New Zealand Archaeological Sites

The relative abundance of red cod in New Zealand archaeological sites 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 126 sites throughout New Zealand, with a total MNI of 40,433 fish. Of these sites, 35 contain red cod with a frequency greater than 10% of the total fish recovered in the excavation. These are listed below. In addition, 18 sites have an MNI of >300 fish but have lower than 10% red cod, and these are also included to indicate places where low abundance is not merely a chance statistic.

Site No	**Site Name**	**% of MNI**	**Site MNI**
B43/7	Breaksea Sound 2, Chatham Point 3, BSS/2	100.00	1
K30/2	Fox River, Te Onumata, Potikohua River	86.27	102
W21/1	Tiromoana N135/1	83.33	6
N27/118	Appleby	61.72	128
I44/17	Mapoutahi S164/13	53.57	140
N36/72	Panau, Canterbury Peninsula	52.94	68
N26/16	Bark Bay	50.00	50
I44/21	Purakanui Inlet, Otago	46.38	2745
N25/50	Taupo Point	45.45	11
G36/1	Bruce Bay	44.44	54
S28/48	Makotukutuku M1 Camp Site, Palliser Bay	40.00	5
N26/18	Awaroa N26/18	37.50	32
E47/13	Tiwai Point, Bluff Harbour	35.92	103
I44/5	Otokia Mouth, Brighton Beach, Otago	33.33	3
I44/1	Omimi, Otago	33.33	27
N26/214	N26/214	32.57	261
C46/19	Port Craig Midden, Foveaux Strait, PC/4	32.14	28
D46/38	Wakapatu, Western Southland	31.91	94
J43/4	Pleasant River (Anthropology) S155/8	27.78	54
P26/208	Titirangi Sandhills, Marlborough Sounds	23.40	47
I43/1	Huriawa Peninsula. Areas A,B,Salvage	23.40	453
C46/16	Port Craig Cave, Foveaux Strait, PC/1	20.18	114
O27/56	Haulashore Island	20.00	25
J43/4	Pleasant River (Smith)	19.31	145
O32/10	Hudson's Site, Goose Bay, Kaikoura	18.52	27
J43/4	Tumai, Pleasant River Mouth South	16.98	106
J42/22	Waianakarua Mouth, North Otago	16.67	6
E48/34	Parangiaio, Ruapuke Island, PP/1	16.67	12
J43/2	Shag River Mouth	15.89	2134
I44/23	Long Beach, Dunedin	14.26	5770
B45/14	Southport 4, Cave Site, Fiordland, SP/4	13.95	86
I43/22	Ross Rocks, Otago	13.89	144
S28/49	Washpool Site, Palliser Bay	12.97	771

B45/15	Southport 5, Cave Site, Fiordland, SP/5	11.67	120
G47/50	Papatowai S184/5	10.34	29
C240/680	CHB, Chatham Islands	0.10	4978
C240/283	Waihora, Chatham Islands	1.43	4197
N3/59	Houhora	0.04	2425
R26/141	Mana Island North Settlement R26/141	0.41	1206
B44/41	Breaksea Sound 1, Discovery Cove, BSS/1	5.55	1153
C240/681	CHA, Chatham Islands	0.00	884
O6/317	Kokohuia, Hokianga	0.59	844
S28/104	Black Rocks BR4 Crescent Midden Palliser	4.40	705
M2/162	Twilight Beach, Northland	0.00	635
R26/141	Mana Island South Midden R26/141A	0.17	596
O27/1	Rotokura, Tasman Bay	6.84	585
R10/25	Sunde Site Oyster lens	0.17	584
T10/399	Cross Creek Site	0.00	481
B45/11	Southport 1, Fiordland, SP/1	3.61	443
H47/1	Pounawea, Otago	8.18	428
R10/25	Sunde Site soft shore midden	0.00	401
C46/31	Sandhill Point 3, Foveaux Strait, SHP/3	0.00	364
O6/290	Waipoua	0.00	329

Appendix 2

Definition of Measurements made on Cranial Bones of Red Cod

The landmarks are illustrated in Figure 1 for the left bones, and the measurements and landmarks are described below.

Abbreviation and Landmarks		**Dimension**	**Description**
LD1	A-B	Dentary Maximum Length	The maximum length of the dentary body. Rotate the callipers between points A and B. NB: Point A is most ventral part of the dentary symphysis, and corresponds to the most anterior part of the dentary. There is a small protuberance on the medial side of the bone in the vicinity of the symphysis; this is ignored in positioning the callipers at Point A.
LD2	A-C	Dentary Fragment Length	The length between points A and C taken on the medial side of the bone. Point C is the most anterior point in the angle of the medial notch.
LD3	A-D	Dentary Symphysis Height	This measurement is taken with the jaws of the callipers firmly on the top and bottom of the symphysis, but not on the surface of the teeth.
LA1	E-F	Articular Maximum Length	The length from the most posterior point of the articular notch (E) to the most anterior point of the body (F), rotating the callipers at E to find the maximum.
LA2	G-H	Articular Maximum Height	Point G is the most superior point of the dorsal articular process. Point H is a point along the inferior margin of the bone where the maximum distance is found by rotating the callipers.
LQ1	I-J	Quadrate Length	Point J is the point of intersection of the dorsal and posterior margins of the bone. Point I is the most anterior point on the lateral condyle.
LP1	K-L	Premaxilla Fragment Length	Point L is the most anterior point of the body of the bone. Point K is the most anterior point in the angle of the notch between the two parts of the body.
LP2	M-N	Premaxilla Maximum Height	Point N is the most superior point on the posterior of the two vertical processes. Point M is the place along the ventral margin of the premaxilla body which is at the maximum distance from Point N, when rotating the callipers at right angles to the line of the body.
LM1	O-P	Maxilla Maximum Length	Point O is the most anterior point of the body of the maxilla, and P is the most posterior point. Rotate the callipers.
LM2	Q-R	Maxilla Width	The maximum width of the anterior end of the maxilla while rotating the callipers, excluding the bulbous articulating notch.