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Estimating Fish Size from Archaeological Bones within one Family: a Detailed Look at three Species of Labridae

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ABSTRACT: The allometric relationships between bone dimension and live fish size (fork length and ungutted weight) are examined in detail for three species of the Labridae family which are common in temperate New Zealand waters. These fish are not able to be identified more precisely than to family level using the five paired cranial bones normally used for identification. This suggests that we may be forced to use regression equations based on the three species combined together to estimate live fish size. It was found that some allometric relationships are very similar in all three species, but others are not. Regression equations were calculated for each species (N=122, 138, 126 respectively), and then for all species combined (N=386). These equations are then used to estimate the fork length and weight of a collection of Labridae fishes from an archaeological site at Waihora in the Chatham Islands (N=3,095). Although the four catch size-frequency diagrams are superficially similar, the estimated mean fork length and mean fish weight are significantly different from one model to another. Total meat weight varies by 10% depending on which model is employed. Although in the meantime we may have to accept this level of imprecision, we also suggest a method by which the combined fish catch can be separated into its three components so that the approximate contribution of each species to the total can be estimated.

KEY WORDS: ARCHAEOZOOLOGY, NEW ZEALAND, FISH, LABRIDAE, ALLOMETRY

RESUMEN: Se examinan en detalle las relaciones alométricas entre dimensiones del hueso y tamaño del individuo (longitud en la horquilla y peso eviscerado) en tres especies de la familia Labridae frecuentes en las aguas templadas de Nueva Zelanda. Estos peces no es posible identificarlos por debajo del nivel familia utilizando los cinco huesos pares craneales que normalmente se utilizan en su identificación. Todo ello sugiere que podríamos vernos forzados a utilizar ecuaciones de regresión basadas en datos combinados de las tres especies para realizar las estimaciones de tamaño del pez en vivo. Se comprueba que algunas relaciones alométricas son muy semejantes en las tres especies pero esto no es así en todos los casos. Se calcularon ecuaciones de regresión para cada una de estas tres especies (tamaños muestrales de 122, 138 y 126 casos) y posteriormente para una muestra combinada de las tres especies (N=386). Estas ecuaciones son posteriormente utilizadas para inferir la longitud en la horquilla y el peso en una muestra de lábridos procedentes de un yacimiento arqueológico en Waihora en las islas Chatham (N=3095). Aunque los cuatro diagramas de frecuencias de tallas capturadas son superficialmente parecidos, las longitudes medias en la horquilla y los pesos medios de los peces son significativamente diferentes entre los distintos modelos. El peso cárnico total varía hasta en un 10% en función de qué modelo es utilizado. Si bien de momento no quede otro remedio que aceptar estos márgenes de imprecisión en el trabajo se sugiere un método con el cual la captura combinada de peces puede ser desglosada en sus tres componentes de tal suerte que las contribuciones aproximadas de cada especie al total puedan ser mejor estimadas.

PALABRAS CLAVE: ARQUEOZOOLOGÍA, NUEVA ZELANDA, PECES, LABRIDAE, ALOMETRÍA

INTRODUCTION TO THE PROBLEM

The establishment of methodologies for estimating live fish size (fork length and ungutted weight) from archaeological bone dimensions with an acceptable level of accuracy is an important step in studying past fishing behaviour and the effects of human predation on fish populations. It enables us to compare the size frequency distribution of catches of particular species through time. It is also an essential step in estimating the meat weight contributed by particular fish to the diet of particular human communities.

We are fortunate that most of the fish commonly captured by pre-European Maori in the temperate waters of New Zealand have no close inshore relatives and we can therefore be confident that we are dealing with the bones of a single species. In the case of labrids, however, there are three common inshore species with very similar bones but somewhat different size ranges and habitats. If we cannot reliably distinguish the bones of the three species, what are the implications of using regression relationships based on the pooled bones to estimate fish size? In this paper we explore in detail the allometric relationships between bone dimension and fish size of the three species and discuss the implications of using pooled bones.

THE LABRIDAE FAMILY IN NEW ZEALAND

Sixteen species of labrids are found in the temperate New Zealand waters (Ayling & Cox, 1982: 251). They range in size from the small crimson cleaners (*Suezichthys* sp.) which are about 15 cm long and weight about 30 g to the large banded wrasse (*Pseudolabrus fucicola*) which can be up to 60 cm long and weigh about 3 kg. Only three species occur commonly; the others are either very rare or only occur in the most northern sub-tropical waters in outlying areas, such as the Poor Knight Islands.

In archaeological sites, bones of labrid fishes are especially common in central and southern New Zealand and in the Chatham Islands to the east of the mainland. We are fairly sure that most if not all of these bones belong to the three common species, mainly on the grounds of their modern distribution. These common species are the spotty (*Notolabrus celidotus*), the scarlet wrasse (*Pseudolabrus miles*) and the banded wrasse (*Pseudolabrus fucicola*). The size range of these three species is rather different; this is illustrated in Figure 1. From this it will be observed that the banded wrasse is by far the largest, but the lower end of its size-frequency distribution overlaps with the upper end of that of the scarlet wrasse. There is a smaller overlap between the scarlet wrasse and the smallest of the three species, the spotty. We have carried out several archaeological studies of the bones of these fish with mixed fortunes as far as separating the three species using either qualitative anatomical features or osteometric measurements is concerned (Leach & Anderson, 1979; Leach *et al.*, 1997, 1999).

SIMILARITY AND DISPARITY IN BONE ALLOMETRICS

In our first major osteometric study of the labridae fishes in New Zealand (Leach *et al.*, 1997), our comparative collection consisted of 122 modern specimens of scarlet wrasse, 18 of spotty, and no banded wrasse. In order to examine the problem of differentiation in more detail the first requirement was to collect and process a much larger sample of all three species in question. We therefore collected a total of 386 specimens, boiled them down and prepared the five cranial bones for measurement. The new sample consisted of 122 scarlet wrasse, 138 spotty, and 126 banded wrasse. We took 30 measurements on the bones. Together with the live fork length and weight, this provides a database of 12,352 measurements. We believe this is now sufficient to explore the osteometric issues thoroughly.

Figure 2A shows the fork length plotted against the ungutted weight of the three species. Open circles are the spotty at the small end of the size range, triangles are the scarlet wrasse in the middle size range, and squares represent the banded wrasse at the large end of the size range. It is virtually impossible to distinguish the different symbols, because they overlap so much.

It is obvious that the allometric relationship between body length and body weight is very similar for the three species. This is further reinforced when one bone dimension is plotted against another. In Figure 2B the width of the pharyngeal grinding mill is plotted against the pharyngeal tooth

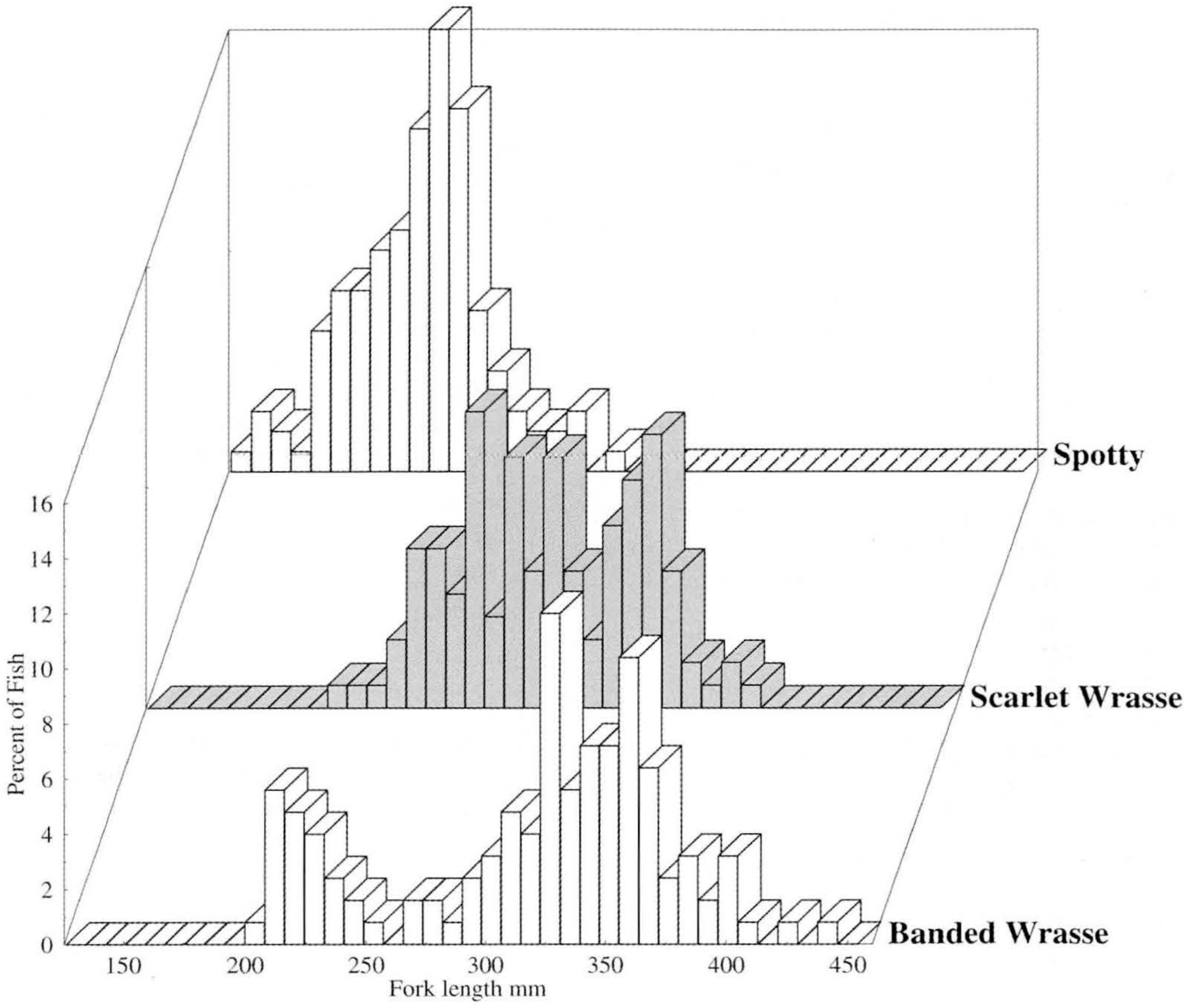

FIGURE 1

Size-frequency diagrams of three common species of Labridae in New Zealand: spotty (*Notolabrus celidotus* N=138), scarlet wrasse (*Pseudolabrus miles* N=122), and banded wrasse (*Pseudolabrus fucicola* N=126).

row. Each species follows a very similar allometric relationship with increasing size. It may be noted that there are two outliers in this graph. When these bones were checked it was found that there were errors in the original measurements. They have been left in this illustration to show how closely the allometric relationship is followed by these three species, enabling error outliers to be easily recognised.

Again, when the maximum length of the premaxilla is plotted against its height (Figure 2C) it is clear that all three species follow the same type of allometric relationship for this bone also. However, it might be noted that there is increasing variability amongst the larger specimens.

When the articular length is plotted against height (Figure 2D) we begin to see signs of allometric difference. Almost all of the banded wrasse, represented by the squares, plot out above the scarlet wrasse, represented by the triangles, and the spotty lies in between these two. In this case, the regression lines for these three species are quite different.

In the case of the maxilla (Figure 2E), the opposite pattern is observed. Here the banded wrasse plot out below the regression line for the scarlet wrasse. The triangles are on the top and the circles and squares below. This shows that although the bones may be hard to distinguish from one species to another, their relative dimensions are slightly different, and therefore their relationship to body size and weight is different too.

The final example is of the dentary (Figure 2F). Here we can see that all of the banded wrasse plot

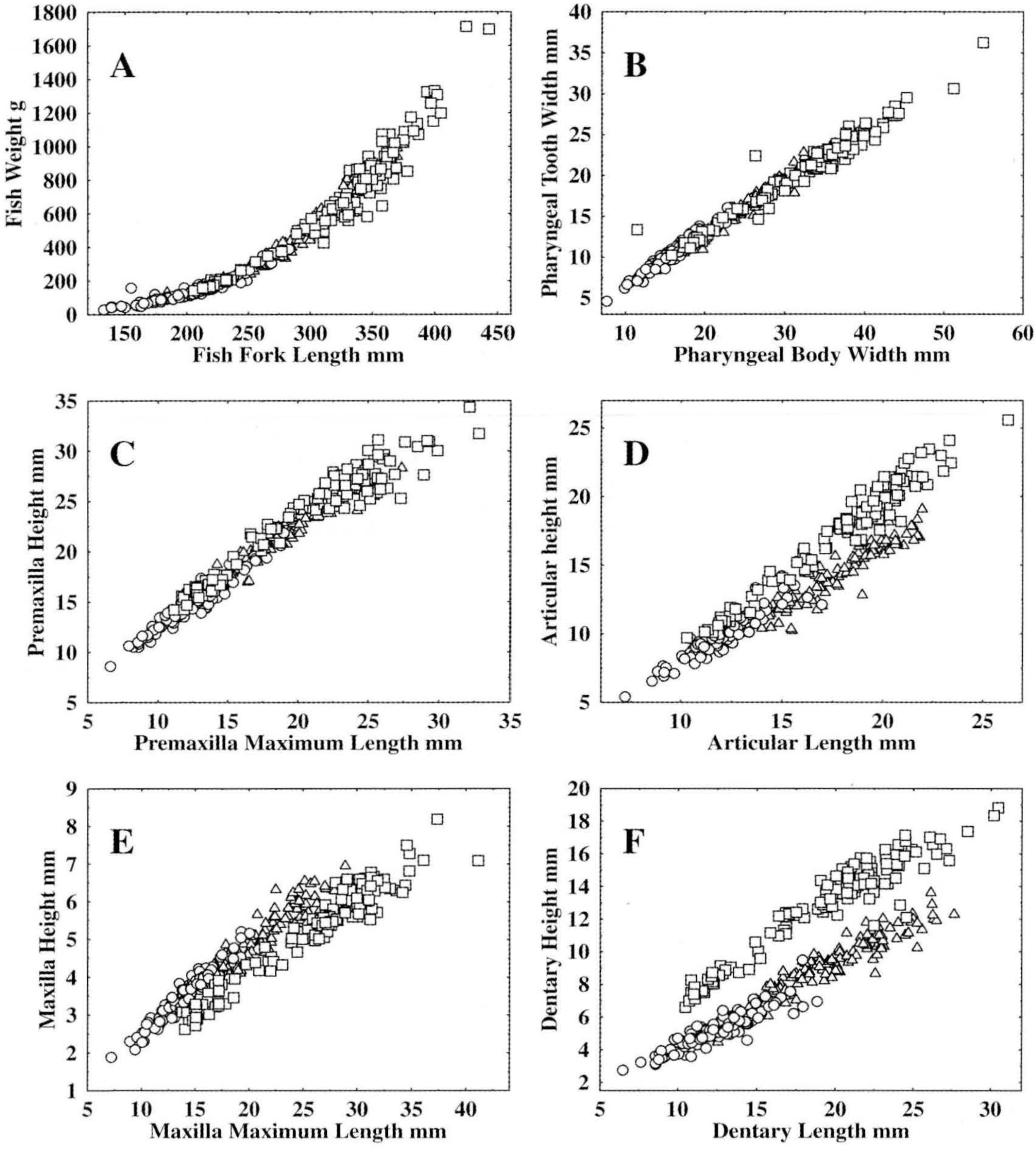

FIGURE 2

Scatter plots of various bone dimensions showing the extent of overlap between the three species. The open circles are the spotty at the small end of the size range, the triangles are the scarlet wrasse in the middle size range, and the squares represent the banded wrasse at the large end of the size range.

out well above the other two species. This is cause for some alarm, because if we attempt to reconstruct the live fork length or weight from these measurements without taking into account what species the bone belonged to, we may introduce unacceptable errors.

AN ARCHAEOLOGICAL EXAMPLE — DIFFERENT MODELS

It is useful to try and trace the possible effects that such pooling might have on archaeological studies. A suitable test case for this purpose is the fish remains from an archaeological site known as Waihora in the Chatham Islands. This is an extensive collection and contains a sizeable number of labrids (see Table 1).

We were able to measure 69% of the labrid bones (3,095 of the 4,509 present). This provides a suitable database with which to trace the possible effects of assuming that one set of regression equations is acceptable for this family of fish, regardless of species.

There are four possible regression models which could be followed in cases such as we have here.

Model 1: We could base the model only on the species of labrid known as spotty in the modern comparative collection. Thus, we would derive equations for each bone appropriate to spotty and then assume that *all* the specimens in the archaeological site *were* spotty.

Model 2: We could base the model only on scarlet wrasse, etc.

Model 3: We could base the model only on banded parrotfish, etc.

Model 4: We could base the model on all three species combined, etc.

When we do this, we obtain four different catch-frequency diagrams, which are illustrated in Figure 3. At first glance, these size-frequency dia-

Family	**Common Name**	**MNI**	**NISP**
Mugiloididae	blue cod	2547	10301
Odacidae	greenbone	1701	5582
Labridae	spotty, etc.	1509	4509
Gempylidae	barracouta, etc.	273	477
Latrididae	blue moki, etc.	183	295
Cheilodactylidae	tarakihi, etc.	180	360
Nototheniidae	Maori chief	179	293
Moridae	red cod, etc.	81	108
Congridae	conger eel	72	88
Anguillidae	freshwater eels	48	54
Balistidae	leatherjacket	33	33
Percichthyidae	groper	22	39
Ophidiidae	ling	20	21
Chondrichthyes	sharks, etc.	19	26
Carangidae	trevally, etc.	18	38
Scorpaenidae	scarpee, etc.	14	17
Triglidae	red gurnard	4	4
Pleuronectiformes	flounder, Sole etc.	2	2
Aplodactylidae	marblefish	1	1
Merlucciidae	hoki	1	1
Total	-	**6,907**	**22,249**

TABLE 1

Fish MNI from the Waihora sites in the Chatham Islands.

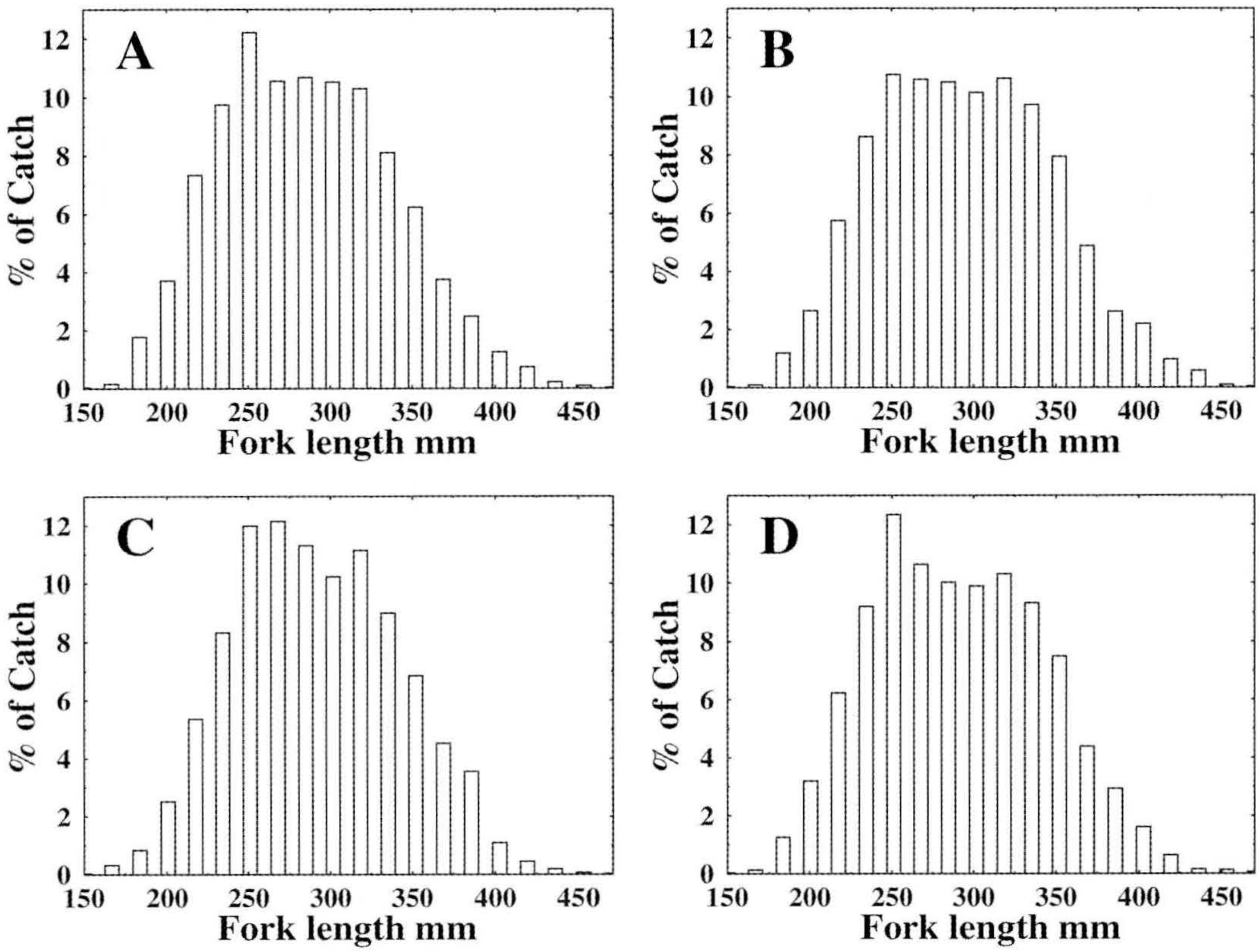

FIGURE 3

Size-frequency diagrams for the labrid fish catch at the site of Waihora in the Chatham Islands (N=3,095), using four different regression models for estimating fork length. A = based on spotty, B = based on scarlet wrasse, C = based on banded wrasse, and D = based on all three species combined.

grams all look rather similar. Careful inspection of the dispersion statistics is warranted. There is very slight positive skewness in all four histograms, with values ranging from +0.18 to +0.27, but these are highly significant ($p<.001$). There are somewhat greater signs of negative kurtosis, with values ranging from 2.5 to 2.6 (expected 3.0), and once again these are all highly significant ($p<.001$). Thus, we can conclude that as far as the shape characteristics of these four alternative catch-frequency diagrams are concerned, it matters very little which model is employed. This is important, because the shape of the catch-frequency diagram provides evidence for a number of useful aspects of fishing behaviour, such as the use of different gill net mesh sizes, the catch of different age grades, and changes through time following particular catch strategies, such as the targeting of large specimens. We can be confident that from this point of view it does not matter what model is used.

However, the shape of the size-frequency curve is not the only thing which matters, we also need to consider the possible effects which the choice of model might have on the mean and standard deviation of the fork length and live weight. These statistics are given in Table 2, and plotted out in Figure 4.

In Figure 4A the X-axis is the mean fork length, and the Y-axis is the standard deviation. Each of the four models is plotted. The error bars represent the standard errors in each case. It is clear from this that there is wide discrepancy. The models based upon the spotty and the scarlet wrasse, for example, are more than four standard errors apart. It will be seen in Table 2 that the range of results across the four models is ± 1.4, 5.2% of the mean

	Fork Length mm		Weight g	
Model	**Mean**	**SD**	**Mean**	**SD**
Spotty	286.1 ± 0.94	52.5 ± 0.67	496.8 ± 5.5	303.2 ± 3.9
Scarlet	294.9 ± 0.96	53.5 ± 0.68	546.8 ± 5.8	325.8 ± 4.1
Banded	292.1 ± 0.91	50.6 ± 0.64	524.4 ± 5.3	297.1 ± 3.8
Combined	290.5 ± 0.94	52.5 ± 0.67	520.3 ± 5.6	308.8 ± 3.9
Mean	**290.9 ± 1.4,5.2%**		**522.1 ± 4.8%**	

Total weight labrid fish in site kg	
Model	**Weight**
Spotty	1538
Scarlet	1693
Banded	1623
Combined	1611
Mean	**1616 ± 4.8%**

TABLE 2
Basic statistics for fork length and weight, for the four models.

value of the four models. This is an unacceptable spread of results. Similarly, in Figure 4B when mean fish weight is plotted out using the four different models, we again find an unacceptable range of ± 4.8% of the mean value of the four models.

Consequently, it would be difficult to use statistics relating to mean fish size to suggest changes

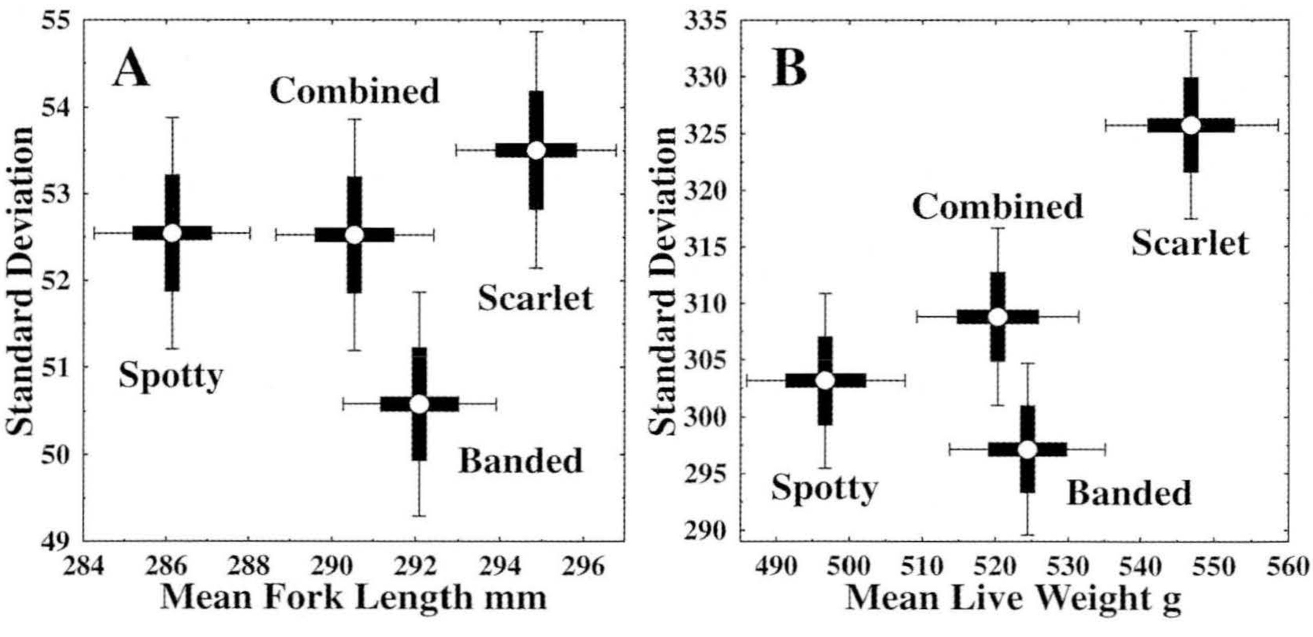

FIGURE 4
Estimated mean fork length and mean ungutted fish weight plotted against standard deviation for labrid fish from Waihora, using the four different models described in the text.

through time between one layer and another in archaeological sites. As archaeologists, we would be seeking changes which might reflect the ongoing effects of human predation on inshore stocks, or changes in population structures due to other external environmental effects, such as changes in recruitment rate with different surface sea water temperature regimes. However, any observed changes might in fact turn out to be due to changes in relative abundance of the undifferentiated species and not to these other factors at all.

The disparity in mean fish weight also has implications for dietary reconstructions based upon archaeological data on fish catches. The statistics for the four models are provided in Table 2, but the problem is more obvious when illustrated in Figure 5.

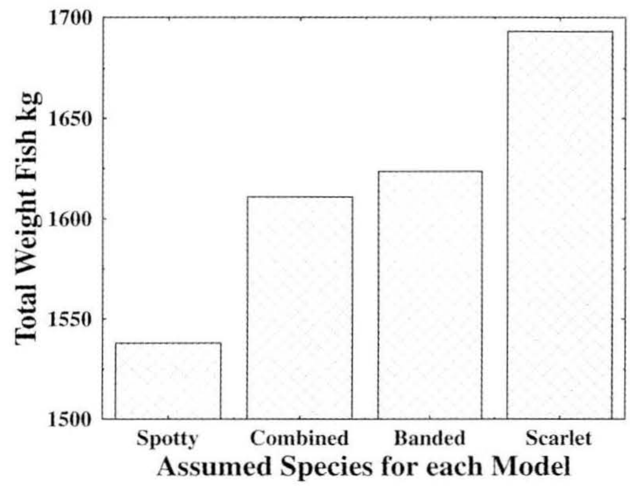

FIGURE 5

Estimated total meat weight from labrid fish at the Waihora archaeological site, using the four different models. There is a 10% range of 155 kg.

Figure 5 shows the estimated total weight of live labrid fish from these 3,095 measured bones, using the four different models. The range from one model to another is 155 kg, representing a range of 10% of the value for spotty. One has to bear in mind the purpose of doing such calculations in the first place. This is not mere tinkering with interesting facts and figures. The purpose here is to understand the nature of human economic systems in the past — and in particular, the contribution of food from different sources to the diet of prehistoric people. We aim to keep systematic errors at all stages to less than 1% wherever possible. That is a useful yardstick to follow in most areas of scientific investigation. This 10% range is therefore extremely important.

We must accept, therefore, that this is a most disappointing outcome, and that pooling species together in this way does have down-the-line implications for archaeological reconstructions about past human behaviour, environmental changes, and subsistence economics. It may be of small consequence if one is only interested in bones and mathematics, but for prehistorians, this pooling approach is not very satisfactory.

ALTERNATIVE METHODS OF SPECIES DIFFERENTIATION

This paper is primarily concerned with the theoretical issue of whether there are or are not implications for prehistoric studies of pooling closely similar species together when attempting to estimate fish size from archaeological bones. The answer must be a positive Yes. But we need to consider too, what can be done to alleviate the problem — after all, the suggestion of pooling species is not made lightly. It is made precisely because of the difficulty of identifying all relevant anatomy to species, or even to genus in some fish families.

Fortunately, there may be a small glimmer of hope, at least as far as the New Zealand labrids are concerned. It was mentioned at the outset that it is not possible to distinguish these three species on the basis of all the parts of the anatomy which we normally identify. However, careful attention to detail does permit the three species to be distinguished on the basis of *some* bones.

For example, the general shape of the dentary of the banded wrasse is somewhat different to the other two species, so these may be separated out. Also, the dentary symphysis of the scarlet wrasse has clear crenellations along its length, rather like some species of Scaridae. So these bones may be separated from the spotty. In the case of the premaxilla, the banded wrasse has a distinctly curved posterior end, but the other two species cannot be so distinguished. Thus it can be seen that some parts of the anatomy can be used to estimate the relative abundance of the three species in a collection, even though not all identifiable bones may be distinguished.

There is another method by which we can estimate the relative abundance of the three species. 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 (Macdonald & Pitcher, 1979; Schnute & Fournier, 1980; Everitt & Hand, 1981; Titterington *et al.*, 1985; Macdonald, 1987; McLachlan & Basford, 1988). Peter Macdonald at McMaster University 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.

In Figure 1 we illustrated the size-frequency diagram of all the specimens in our comparative collection. From this collection, we can calculate dispersion statistics (such as the mean and standard deviation) for each species, which can then be used in a decomposing algorithm developed by Mcdonald. The results are presented in Figure 6.

Figure 6A shows the Waihora labrid size frequency diagram, based upon the fourth regression model (that is, all species combined). In Figure 6B we show the three species separated out using the modern dispersion characteristics and Macdonald's algorithm.

By this method, we estimate that spotty make up about 10% of the fish catch, scarlet wrasse about 65%, and banded wrasse about 23%. Separating the three species in this way may be important in studying the changing composition of fish catches in a particular place through time. Here in the Chatham Islands, for instance, we think that there was a progressive shift in the exploitation of the three labrid species through time and that this is reflected in the assemblages from three adjacent sites of different ages (Leach *et al.*, 1999).

What then can be done about the second problem identified above, that of estimating the mean weight of fish represented by the archaeological collection? This requires a different approach, whereby accurate identification to species is necessary. As pointed out above, some bones may be identified to species, but not uniformly across all parts of the anatomy. This effectively means that reliable identification of bones will result in a greatly reduced database to work with. It is also important to avoid any possibility of systematic bias. Our detailed review of anatomical differences suggested that only the dentary might be usable to distinguish these three species. Once separated into species, this bone could then be used to estimate individual fork lengths and weights, and then mean values calculated. Once this is done, the total meat weight can be estimated by adding up the products of mean weight and the appropriate MNI value for that species (0.1 x 1509 for spotty, 0.65 x 1509 for scarlet wrasse, and 0.23 x 1509 for banded wrasse).

In other words, we need a reliable method for sorting *some* of the larger sample into species, and using this as the basis of our estimating technique.

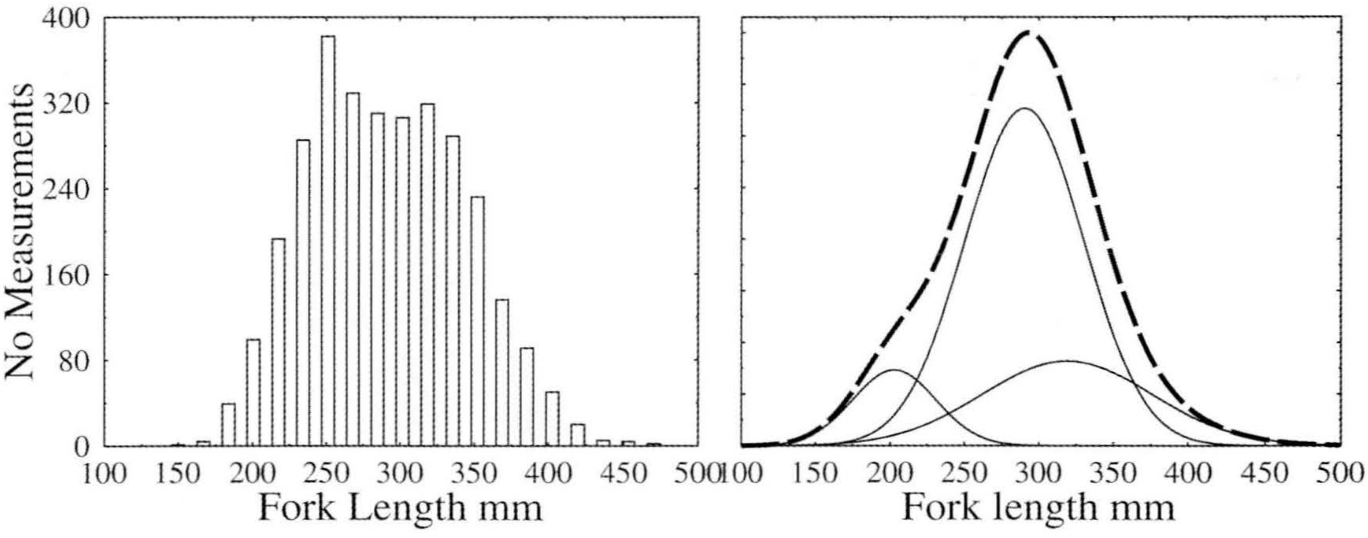

FIGURE 6

The Waihora archaeological labrid collections decomposed into its constituent three species, using the Macdonald algorithm (see text).

We could of course use the species proportions established from this smaller data set rather than the Macdonald algorithm on the larger database. Which option to choose will depend upon how large a sample one is dealing with in each case, and which is considered the more reliable in a real situation.

We should mention that multivariate statistical techniques can also be helpful in cases like this. To illustrate this, we used the data presented in Figure 2F; that is, the two measurements of the dentary on the three species of labrids considered here. We used Kovach's Multivariate Statistics Package (MVSP, version 2.1K) for this purpose.

The eigenvalues for the two components were 36.9 and 2.2, accounting for 94% and 5.6% of the variance respectively. The eigenvectors are as follows:

$$X = 0.806 * \text{Dentary Length} + 0.592 * \text{Dentary Height}$$
$$Y = -0.592 * \text{Dentary Length} + 0.806 * \text{Dentary Height}$$

The individual bones were plotted out using these eigenvectors. The results are given in Figure 7.

It can be readily seen that there is an excellent separation of all three species in the plot, with banded wrasse most distant from the other two. There is some overlap between spotty and scarlet wrasse, but it is not great.

To make use of such a separation, one would measure the two dimensions on a dentary, calculate the X and Y coordinates from the two eigenvector equations given above, and then plot the bone on the graph to see which species it belonged to. In cases where the bone plotted in the uncertain area between spotty and scarlet wrasse, it would have to

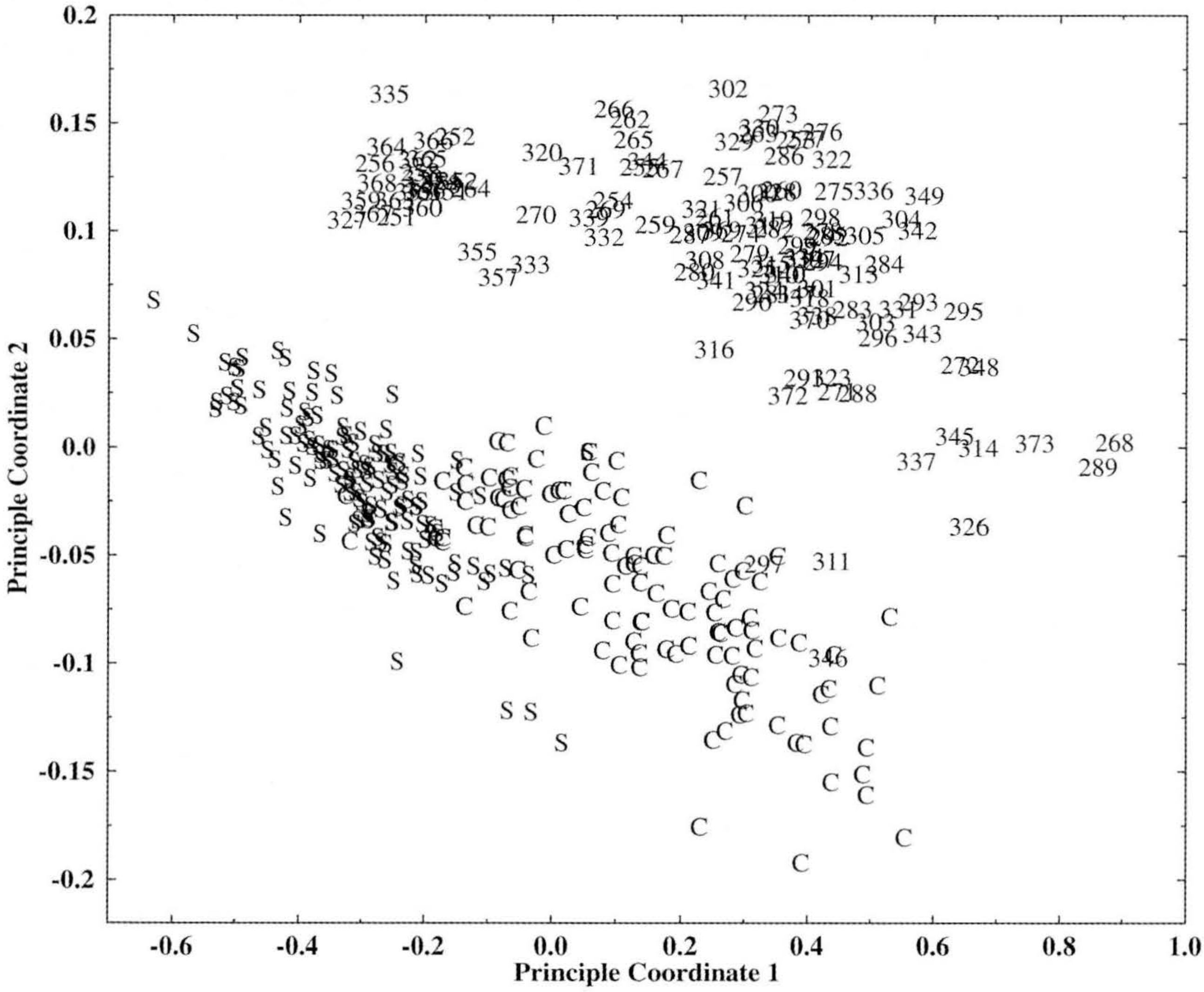

FIGURE 7

Principal coordinates analysis of dentary measurements of labridae, showing clear separation between the three different species. S – Spotty, C = Scarlet wrasse, and B = Banded wrasse.

be set aside as of uncertain species. In this somewhat laborious manner one should be able to separate at least the dentaries into the three species. This is obviously not an ideal solution, and cannot be carried out on many of the cranial bones of labridae recovered from archaeological sites. However, it would at least enable an unbiased estimate to be made of mean fork length and weight of each species in a site, even though it would be based on a much smaller sample size than the full complement of bones.

CONCLUSION

The purpose of this intensive study of three species of labrids from New Zealand archaeological sites was to explore the possible implications of not identifying to species level when carrying out osteometric analysis. It has been shown that the shape of size frequency diagrams may not be adversely affected by using a pooled statistic. That is, skewness and kurtosis statistics appear to be reasonably stable, regardless of which regression model is used. However, it was found that mean size and standard deviation are affected by choice of model, and this has profound effects further down the line. For example, it would make it difficult to interpret any observed changes through time. Such changes might be due to different proportions of the three species being harvested, rather than to the effects of human predation on inshore fish stocks, or effects of environmental change such as fluctuations in recruitment rate. The potential range of error of not separating species is about 10% of the observed mean values. This represents a substantial problem in attempts to reconstruct aspects of subsistence economics using meat weights to estimate the contribution of protein and fat from different food resources.

The problems identified in this study should not be taken as a counsel for despair. On the contrary, we see them as contributing greater clarity when we interpret osteological collections from archaeological sites. It is all too easy now, with such ready access to computer facilities, to throw osteometric data into regression procedures and believe at face value the printed out standard errors. It is only by paying careful attention to all the potential sources of error that our interpretations of the past will be refined and become more enduring.

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