

When is a time-trend not a time-trend? Scale and profile at Bronze Age Phylakopi (Melos)

Nick Winder

McDonald Institute for Archaeological Research, Downing Street, Cambridge CB2 3DZ, U.K.

Summary

This paper distinguishes two characteristics of a bone assemblage: its scale (or size) and profile (or composition). The investigation of bone assemblages often involves standardising the data to control for variation in scale so that the profile of assemblage subsets can be compared and contrasted.

A formal multiplicative or log-linear model of assemblage formation is proposed which implies that the standardisation methods commonly chosen by archaeozoologists (percentages, proportions and means) are inappropriate; they violate the independence of potentially distinct assemblage formation processes. When a standardisation method is needed (and it is not always needed) archaeozoologists should consider taking logarithms of bone frequencies and expressing each as a deviation from the assemblage mean.

Two analyses using this approach are presented as part of a re-assessment of the animal bone data from Bronze Age Phylakopi (Melos). They suggest that the time-trends Gamble observed may be artefacts of a partial excavation strategy and of taphonomic variation. A third analysis that does not require standardisation appears to confirm this view. Prospects for further analyses using such arguments are explored.

Introduction

The animal bones from Renfrew's excavations at Phylakopi were identified and described by C. S. Gamble who addressed three questions (Gamble 1982; 1985):

- (1) What is the general character and composition of the whole animal bone assemblage?
- (2) What variation in assemblage composition can be observed through time?
- (3) What can assemblage composition tell us about the spatial localisation of contemporary activities, particularly in the vicinity of the Sanctuary?

The questions were answered by setting out explicit assumptions and generalisations about the environment and the range of subsistence behaviours it could sustain, and building an interpretive paradigm for the bone data from these assumptions. Then the data were partitioned into classes on the basis of time phase or spatial location within the sedimentary matrix and examined for patterns

among these subsets. These patterns became the empirical evidence which was presented and interpreted.

Thus, Gamble argued from historical and environmental evidence that the maintenance of large numbers of cattle would have been impracticable given the periodic summer droughts and restricted pasturage available and that the consumption of meat at Phylakopi must have been a rare event, possibly restricted to public festivals and sacrifices (Gamble 1982, 161). He also noted the archaeological evidence for increased nucleation in the settlement pattern and concentrated his early attention on the search for the palaeoeconomic correlates of this nucleation.

Gamble found evidence of an increase in the relative abundance of cattle from the pre-city phase to phase III. In Phylakopi IV a slight reduction in cattle was observed. This pattern was interpreted as evidence that the nucleation of the site caused an increased demand for animal traction. The subsequent decrease in cattle is attributed to the establishment of donkeys as preferred beasts

of burden. The rarity of donkey bones (two bones only from phase IV) may reflect their disposal outside the settlement boundary (which is the common modern practice).

Gamble (1985) studied intra-stratum variation in the vicinity of the Mycenaean Sanctuary. He noted that the size of bone fragments between floor levels is generally smaller than that from post-abandonment fills and argued that large fragments would have been removed by routine sweeping. After abandonment, the assemblage changes somewhat and in some regions cattle predominate (at least by weight). It should be noted, however, that cow skeletons are appreciably heavier than those of sheep or pig. In this later work, Gamble distanced himself from the view that the Sanctuary would have formed the focus for public redistribution of meat which he now believed would have been environmentally unsustainable and for which he could find no evidence.

Archaeozoology as the interpretation of cross-classified data

The bones were split into meaningful subsets and patterning manifest between these was used to make generalisations about changes in animal exploitation through time and through contemporary space. This required the definition of a number of classificatory variables, or *factors*, that described the way the assemblage was to be split. Time phases, features, trenches and taxonomic groups are all instances of classificatory factors. The interpretation of the data hinged on the assumption that patterns manifest between designated time phases represented time-trends while patterns manifest within a given phase had a purely behavioural significance. In the remainder of this paper I will argue that this assumption, although intuitively attractive, may not actually be justified. In particular, I will present evidence that it is not supportable at Phylakopi.

Imagine a trench through an urban site in which two phases produce strikingly different assemblages. In the first there might be a mixed assemblage of sheep and pigs, for example, while in the second pigs predominate. 'Classical' archaeozoological method would encourage us to interpret this pattern as a time-dependent shift in human subsistence from a sheep-and-pig to a pig-based economy. Now imagine the same

pattern emerging from two trenches cut through contemporary levels. Suddenly there is 'obviously' a specialised pig processing area in one of the trenches. The only difference between the two interpretations is that in the former case we chose to ignore the possibility that temporal and spatial factors might be autocorrelated.

Classical archaeozoological analysis has been underpinned by an insupportable *unifactorial* assumption which holds that the way one partitions an archaeological assemblage somehow determines the meaning of patterns among the resulting subsets. Few archaeozoologists would dispute that this is unrealistic. Indeed, Gamble (1982, 166) expressed concern that the necessary assumptions of constancy in disposal patterns and uniformity of bone preservation may be unjustified.

Unfortunately it is widely believed that the only way to solve this problem would be to lay out a sampling frame and implement a random sampling strategy that ensured every possible combination of factors was sampled. Such a sampling strategy would impose unacceptable constraints on excavators who would surely object to being prevented from the further investigation of chance discoveries (like Mycenaean Sanctuaries, for example) by a table of random numbers.

Furthermore, even if an excavator was willing to contemplate such an approach, it would be hard to make it work on a real archaeological site. It is seldom possible to sample all time phases in an even-handed way because the distribution of standing features and the need to shore up baulks restrict access to the lower levels of a deeply stratified site. It is also very difficult to set up random sampling strategies for consecutive time phases when the only accessible regions of the lower phase are those at the bottom of trenches already cut through the upper phase. Since the mechanics of digging preclude the experimental solution to the problem, archaeozoologists, like many other 'specialists', feel they have to live with the unidimensional assumption regardless of the unease it causes.

In this paper I will try to show by a case study that a truly *multifactorial* analysis of bone data is feasible provided we pay attention to evidence of autocorrelations or 'interactions' between different classificatory factors. This allows a more rigorous investigation of manifest pattern without

imposing unacceptable demands on the excavator.

Scale and profile in assemblage formation

Animal bones are seldom recovered from a site in the relative frequencies observed in the whole skeleton. In the course of moving from the ancient biosphere to the modern lithosphere some elements must have been removed or lost. Since archaeozoologists routinely encounter assemblages in which certain elements are consistently under-represented, we must conclude that bone destruction or loss is selective. It is a short step from accepting that different elements of the skeleton of a given animal will have differential survival probabilities to postulating that the elements of different animals may also be differentially preserved, though finding evidence to support this hypothesis is difficult.

The study of processes which convert a population of animals in the ancient biosphere into a population recovered from the modern lithosphere is called *taphonomy*. Variation in the taphonomic careers of different assemblages condition both the size (or *scale*) and composition (or *profile*) of the bone assemblage. Different types of process are believed to produce different signatures which can, in theory, be read in the profiles of assemblage subsets. Taphonomists classify formation processes by their cause and take care to distinguish the effects of scavenging from weathering or fluvial sorting, for example (see papers in Behrensmeyer and Hill 1980).

It is rare for an archaeological assemblage to be conditioned by only one formation process. Typically its taphonomic career begins with a *biotic* phase of degradation during which animals, plants and microorganisms draw out selected resources. As time passes and the entropy of the carcasses increases, biotic exploitation is attenuated and gives way to a *climatic* or weathering phase and ultimately to more gradual *edaphic* decay as soil percolates and the weight of accumulated sediments destroy the bones. On an archaeological site this process culminates in another short burst of biotic activity as the bones are excavated and some are lost or destroyed.

Individual bones, viewed in isolation, tell us little of archaeological interest except that

anatomical part x of species y was recovered from context z . However, populations of bones may bear the traces of readable taphonomic signatures which are of considerable interest though these may have been overwritten and obscured. In general, the most interesting formation processes are those from the biotic phase. We want to know about the selection and slaughter of animals, the relative abundance of species consumed, the spatial organisation of carcass exploitation, dismemberment strategy, and waste disposal, both through time and through contemporary space. Disentangling 'interesting' from 'uninteresting' taphonomic processes may be virtually impossible because both suites of processes may have similar effects on the assemblage. Archaeozoologists must deal with the assemblage, with the effects of a suite of processes rather than with their individual causes. Consequently, 'bone reports' can seldom be written with the certainty or clarity of interpretation achievable in taphonomy.

The usual way to interpret a bone assemblage is to split it into interpretable subsets and prepare the data to allow these subsets to be compared and contrasted. Observed patterning among subsets is sometimes interpretable in the light of known taphonomic regularities. In general, the taphonomic signatures we wish to decipher are coded into the profile of the assemblage; the scale is of secondary interest. It would clearly be of value to develop ways of processing assemblage data so as to remove or standardise the effects of scale without disrupting any taphonomic signatures coded into the profile. This is not difficult in practice but requires us to think clearly about the analytical implications of mundane data transformations.

Consider an artificial assemblage of two elements both of which are subjected to two statistically independent formation processes. ('Independence' means that the vectors are uncorrelated one with the other.) Formation processes represented by independent vectors will have analytically distinguishable effects.

If each formation process destroys a fraction of the population of bones we can write where $A(1)$ and $A(2)$ are the sizes of the

$$A(1) = PP(1) * B(1,1) * B(1,2)$$

$$A(2) = PP(2) * B(2,1) * B(2,2)$$

(1)

assemblage of elements 1 and 2, PP(1) and PP(2) are the sizes of the antecedent or potential populations of element 1 and B(1,1) and B(1,2) are the proportions of elements 1 and 2 destroyed by process 1. This multiplicative model of assemblage formation amounts to a definition of a formation process as some factor that removes a proportion of the bones it encounters.

Now suppose we have two assemblage subsets to compare which differ from each other both in scale and in profile. We start with the simple situation in which the profile of both potential populations is identical. Our task is to find a way of controlling for the differences in scale between the two populations that does not violate the statistical independence of the formation processes. A glance at equations (1) shows that expressing bone frequencies as percentages or proportions or subtracting mean element frequencies will not do, because this has the effect of dividing each formation process by the sums of products of all other processes:

$$\frac{A(1)}{A(1)+A(2)} = \frac{PP(1)*B(1,1)*B(1,2)}{PP(1)*B(1,1)*B(1,2)+PP(2)*B(2,1)*B(2,2)} \quad (2).$$

The solution is straightforward. Equations (1) describe a log-linear model of assemblage formation because taking logarithms of the element frequencies gives a set of linear equations (it may be necessary to add a small constant to all bone frequencies or to mask out elements which occur with a frequency of zero before taking logs):

$$\begin{aligned} \text{LOG}(A(1)) &= \text{LOG}(PP(1)) + \text{LOG}(B(1,1)) + \text{LOG}(B(1,2)) \\ \text{LOG}(A(2)) &= \text{LOG}(PP(2)) + \text{LOG}(B(2,1)) + \text{LOG}(B(2,2)) \end{aligned} \quad (3)$$

Once we have a model of assemblage formation expressible in terms of a suite of linear equations, the system becomes much more tractable because we can appeal to the large body of statistical theory relating to the

generalised linear model. In particular, we can remove the effects of differences in scale between assemblages with similar potential populations without violating the independence of the formation processes by expressing each logarithmically transformed frequency as a deviation from the assemblage mean. Assemblage composition data standardised in this way will have a mean of 0.0 and a non-zero variance.

The argument is completely general and can be extended to assemblages of more than two elements and more than two independent formation processes without modification. Assuming *n* formation processes acting on a potential population, these variances will satisfy:

$$V(A) = V(PP) + V(B1) + V(B2) + \dots \quad (4)$$

where V(A) signifies the variance of the assemblage, V(PP) that of the potential population and so on. Two assemblages drawn from potential populations with similar taphonomic careers will have similar values for V(A) in equation (4) (subject to sampling errors) because their respective potential populations will have identical variances and they will have been subject to similar formation processes.

Differences between logarithmically transformed assemblage variances can, therefore, be interpreted in terms of differences in the formation processes to which the respective PPs were exposed. There will be a general agreement between the number and severity of the formation processes in effect and the variance of the standardised assemblage.

When (as is usually the case) we have more than one assemblage vector to consider, these can be standardised using the method just described so as to bring all subsets onto a common scale with a mean of 0.0 and a variance and profile determined by its individual taphonomic history. In vector notation, we can write:

$$PROF = PP' + B1' + B2' + \dots + Bn' \quad (5)$$

where PROF is a standardised assemblage (or *profile*) vector, PP' is a standardised potential population (shared by all assemblage subsets) and B1' to Bn' are standardised formation process vectors that condition assemblage profile. Profile data can be processed further or used to form the input matrix for any multivariate statistical method based on the generalised linear model. These include such methods as regression analysis, correspondence analysis, principal components analysis, and discriminant analysis.

More than one taxon

Throughout the argument it has been assumed that two PPs may differ in scale but will not differ in profile. There are circumstances under which this assumption is obviously valid. If, for example, an assemblage is defined as representing only one taxon, the potential population will consist of a set of whole skeletons.

Obviously the requirement that an assemblage must consist of at most one species is too limiting for routine analytical use and we must consider the possibility of handling assemblages of two or more taxa. Suppose we have such a population. We can now define an hypothetical population vector C, each element of which contains an arbitrary constant. We can now write:

$$PP = C + B \quad (6)$$

where PP is unstandardised and B is a 'formation process' that transforms an arbitrary vector with zero variance (C) into a 'real' potential population, PP. Since the vector C has zero variance, it disappears on standardisation and we obtain a revised version of (5):

$$PROF = B' + B1' + \dots + Bn' \quad (7)$$

where all vectors are standardised with a mean of 0.0. This analytical device allows us to extend the method to assemblages consisting of more than one taxon by expressing such purposive human actions as animal husbandry and the selection of animals for slaughter as virtual formation processes whose cumulative effects can be read by

comparing the profile of standardised assemblage data with that of an hypothetical or 'average' potential population with zero variance. (Readers unfamiliar with computer jargon may find the word 'virtual' confusing. By a 'virtual formation process' I mean something which, while not recognised as a formation process in the strict sense, nonetheless has the same impact on a potential population as a formation process.)

Once data have been standardised, it remains a matter of convenience whether we analyse them in their logarithmic form or exponentiate the standardised frequencies and handle them as log-linear variables. Re-exponentiating gives us an assemblage vector in which each element frequency has been divided by the geometric mean of all element frequencies.

Analysing the Phylakopi data

This case study is based on a database which has already been published. The site's phasing, organisation, architectural features and small finds have also been described in the same volumes (Renfrew *et al.* 1982; 1985). Accordingly, the present paper will be restricted to describing the small number of variables needed to understand and interpret the results presented here. I have tried to keep the terminology used to describe phases, trenches and structures consistent with that already published wherever possible.

The analyses I wish to present relate to three aspects of the assemblage: utility as a food resource, the 'survivability' or toughness of skeletal elements under attrition, and variation in taxonomic composition between assemblage subsets.

Factors used to classify the assemblage

Contextual variables

Gamble's archive described the specimens identified from all contexts in the course of excavation. These were recovered from a number of trenches spread over a wide area of the site. For the purposes of the present study it was convenient to group these trenches into a series of 'complexes' each of the constituent trenches of which is separated from its nearest neighbour within the complex by a narrow baulk. Similarly, seven chronological units were recognised, of which the first two

Factor 1. Trench Complex

Code	Description
1	The Sanctuary Complex: NLa-e, OLc, OLd, PLa and PK
2	North East of megaron: trenches II B & II C
3	South West of megaron: trenches II D and II E
4	South of megaron: trench II A
5	Trench II S

Factor 2. Phase

Code	Description	Excavator's code	Phase
0	Pre City phases	A1-A2	
1	First City	B	I
2	Second City	C	II
3	Third City	D	III
4	Late Helladic	E	IV
5	Late Helladic	F	IV

Factor 3. Type

Code	Description
1	Walls, foundations and footings
2	Floors
3	Pits
4	Sediments overlaying floor surfaces (mostly occupational debris and rubbish)
5	Make-up and fill
6	External contexts
7	Other

Table 2. Factors used to subdivide the assemblage from Phylakopi.

pre-city phases (A1 and A2) have been amalgamated here and Phase IV which was subdivided into sub-phases E and F was treated as two units. Each unit recognised in the present study was assigned a numeric code. Finally, in addition to complex and phase, the assemblage has been subdivided into a large number of 'levels' or features, each of which was assigned to one of a fixed number of 'types'. This gives us three different ways of splitting the assemblage summarised in Table 2.

Handling the bone data level by level resulted in very small assemblage subsets many of

Pig	Cow	Ovicaprid
Mandible	Mandible	Mandible
Maxilla	Maxilla	Maxilla
—	—	Atlas/Axis
Scapula	Scapula	Scapula
Humerus	Humerus	Humerus
Ulna	Ulna	Ulna
Radius	Radius	Radius
Pelvis	Pelvis	Pelvis
Femur	Femur	Femur
Tibia	Tibia	Tibia
Metapod	Metacarpal	Metacarpal
—	Metatarsal	Metatarsal
Astragalus	Astragalus	Astragalus
Calcaneum	Calcaneum	Calcaneum
Phalange 1	Phalange 1	Phalange 1
Phalange 2	Phalange 2	Phalange 2
—	Horn	Horn

Table 3. Anatomical part codes for principal taxa.

which yielded so few bones that any patterns would be swamped by sampling errors. Accordingly, every unique combination of the values of factors *Phase*, *Complex* and *Type* was treated as a minimal assemblage subset in its own right. The large number of levels from the whole site were thus resolved into 40 analytical units, each of which was uniquely defined by the contextual variables.

Archaeozoological variables

The records of bones of the major taxa (ovicaprid, cow and pig) were recorded using a modification of the coding scheme originally developed by the British Academy Major Research Project on the Early History of Agriculture in the 1960s. There have always been problems with this coding scheme (Winder 1986; 1991). In practice, not all of the variables were needed and a simplified subset of the data was prepared for the present study which only used four variables: Context, Species, Anatomical Part and Hand (left or right). The list of anatomical part codes was reduced to a set which were relatively abundant and could be considered as discrete and universally distinguishable even when broken (see Table 3).

Each element was divided into three states with regard to age at death, these were 0 (no data), 1 (immature) and 2 (mature). These categories were primarily intended to indicate

	Caprid	Pig	Cow
Phase code			
0	742	562	195
1	713	610	237
2	718	574	645
3	703	626	591
4	822	586	460
5	796	435	618
1-2	443	32	100
3-4	591	202	352
Trench			
1	779	587	615
2	721	748	550
3	609	192	204
4	678	458	667
5	638	190	314
Context type			
1	724	538	705
2	324	91	38
3	685	477	513
4	706	579	622
5	653	567	608
6	726	577	346
7	665	419	411
Whole assemblage			
	686	593	561

Table 4 Phylakopi: bone utility by phase, trench and context type.

whether bones had survived sufficiently well for age data to be had. Information on age at death was of secondary interest in the present study.

Thus only a small subset of Gamble's field data was selected for re-examination. Other variables employed by the coding scheme were examined before the decision to rationalise the archive was taken. Some variables were ignored because the coding scheme could not furnish the fine-grained information required but the only occasion this rationalisation reduced the usefulness of results was when considering general utility indices (see below).

Analysis 1: measuring general utility

Ethnographers and taphonomists have studied the disposition of meat and fat resources on the animal carcass and have tried to relate these to butchery practice. In general, it has

Phase code	Complex	Type	Sum of squares
0	2	1	62.026
0	2	6	64.834
0	3	5	9.942
1	2	1	33.848
1	2	2	6.972
1	2	4	58.945
1	2	5	11.768
1-2	3	4	31.097
2	1	1	51.930
2	1	2	4.415
2	1	4	4.415
2	1	7	63.045
2	2	3	53.853
2	2	4	19.941
2	2	5	10.226
2	3	5	34.570
2	4	5	33.251
2	5	3	37.012
2	5	4	15.474
2	5	5	17.905
3	1	4	58.322
3	1	6	30.689
3	2	4	6.971
3	4	3	10.785
3	4	4	36.888
3	5	5	30.862
3-4	4	5	49.457
4	1	1	58.633
4	1	2	26.682
4	1	4	41.366
4	1	5	13.513
4	1	6	31.728
4	2	1	2.310
4	2	3	3.888
4	4	5	61.036
5	1	3	9.340
5	1	4	41.954
5	1	5	48.565
5	1	6	75.779

Table 5. Phylakopi: sum of squared deviations of standardised bone frequencies by context.

been noted that the large bodies of muscle are situated on the proximal and posterior elements of the skeleton, whilst the best sources of marrow tend to be the anterior and distal elements. Much of this work has been carried out by Binford and reviewed by him in two books (Binford 1978 and 1981). In the first of these he developed a series of general utility indices by means of which he was able to characterise and interpret butchering strategies and the debris they produce.

Phase code	Mean sum of squares
0	45.601
1	27.833
2	27.321
3	29.086
4	29.782
5	43.815
1-2	31.097
3-4	49.457
Complex	
1	37.334
2	27.923
3	25.203
4	28.283
5	22.077
Type	
1	36.313
2	12.690
3	22.876
4	31.501
5	29.170
6	50.757
7	63.045

Table 6. Phylakopi: mean sum of squares (attrition index) by phase, complex and type.

The most general of these is the modified general utility index (MGUI). Although this index has been criticised (by Lyman 1985, for example) it has been used by Speth (1983) to very good effect. MGUI was employed as a general measure of utility for different skeletal elements at Phylakopi. The MGUI assigns a value between 1 and 100 to all elements of the ungulate skeleton on the basis of an assessment of general utility. In the original formulation, different MGUI values were assigned to the proximal and distal ends of long bones.

It was difficult to decide which part of the element was being described in all data records from Phylakopi because of inherent limitations in the coding scheme. However, a study of those cases where discrimination was possible showed that at Phylakopi, as on many other sites, one end of most long bones was consistently commoner than the other. For example, the distal humerus was consistently commoner than the proximal humerus, distal tibia was commoner than the proximal tibia and so on. It was also found that the less common end of these bones was seldom

recovered in isolation; one either got the whole humerus or the distal end, never the proximal end alone. MGUI indices for the commoner end were used in the present study. For example, Binford gives an MGUI of 43.47 for the proximal humerus and 36.52 for the distal humerus, so the value of 36.52 was used for all humeri. If this study was to be repeated from scratch, a more flexible and unambiguous coding scheme would be used.

General utility at Phylakopi

We can now use the analytical device for bringing all assemblage subsets onto a common scale in conjunction Binford's General Utility measures to look at the Phylakopi data directly. The assemblage from each phase, each complex and each context type was standardised, species by species, in the manner described above. Standardised frequencies were exponentiated to bring them back onto a log-linear scale and a general utility statistic calculated for each subset as follows:

$$UTIL(j) = \sum_i A(i,j) * MGUI(i) \tag{8}$$

where $A(i,j)$ is the standardised frequency of element i of assemblage subset j , $MGUI(i)$ is that element's MGUI and $UTIL(j)$ is a measure of the relative utility of assemblage subset j . The results are presented in Table 4.

In general, the more common the species, the less variation in UTIL was manifested between assemblage subsets. The strongest and most coherent variation in UTIL was between context types. It seems from these figures that floors tend to produce assemblages of low utility whilst subsets derived from walls, footings, external contexts and between floors (types 1, 4 and 6) produce high utility assemblages, supporting the view that these were the loci in which domestic refuse was commonly dumped.

Two interesting observations have been made using Binford's utility measure. The bulk of the material recovered seems to have been produced by large scale refuse disposal and to be taphonomically and behaviourally uniform (as suggested by Gamble 1982). However, there are assemblage subsets which deviate from this general pattern and these tend to be the smaller subsets between floors, in the vicinity of walls and in 'external contexts'.

PHASE	COM.	TYPE	OVICAPRID			COW			PIG		
			SCALE	AGED	ZERO	SCALE	AGED	ZERO	SCALE	AGED	ZERO
0	3	5	8	4	10	0	0	16	2	0	12
0	2	6	108	36	2	8	4	11	8	6	9
0	2	1	93	28	3	2	1	14	8	6	8
1	2	1	35	17	4	2	1	14	8	5	10
1	2	2	14	6	13	0	0	16	0	0	14
1	2	4	81	47	3	2	2	15	18	11	5
1	2	5	10	4	9	1	0	15	1	1	13
2	1	1	70	24	4	33	15	4	15	9	8
2	5	1	8	5	12	0	0	16	0	0	14
2	1	2	1	0	16	2	0	14	1	0	13
2	2	3	134	56	1	32	7	5	24	12	3
2	5	3	40	21	4	7	5	12	2	1	12
2	2	5	9	3	12	0	0	16	0	0	14
2	3	5	33	23	8	4	2	12	6	1	10
2	4	5	39	6	3	7	6	11	10	6	8
2	5	5	12	3	9	4	1	13	4	2	11
2	2	4	20	12	5	1	1	15	2	2	12
2	5	4	14	9	7	1	0	15	2	1	12
2	1	4	3	2	14	0	0	16	1	1	13
2	1	7	178	79	1	27	5	5	21	7	3
3	4	3	8	3	12	0	0	16	2	0	12
3	1	6	15	5	9	16	1	10	10	3	8
3	1	4	169	91	2	67	23	1	30	14	4
3	2	4	6	4	13	0	0	16	0	0	14
3	4	4	54	21	1	14	5	7	13	6	6
3	5	5	33	11	6	2	0	14	1	0	13
4	1	1	107	47	1	10	3	8	28	10	5
4	2	1	2	0	15	0	0	16	0	0	14
4	1	6	33	14	5	0	0	16	8	2	7
4	1	4	63	23	2	22	7	6	15	8	5
4	1	5	4	1	15	2	1	14	7	1	11
4	4	5	92	36	2	10	5	11	16	7	7
4	1	2	23	13	8	0	0	16	6	4	11
4	2	3	2	0	15	0	0	16	1	1	13
5	1	4	56	21	2	5	0	12	6	2	9
5	1	3	4	1	15	0	0	16	4	3	12
5	1	6	142	45	2	7	3	11	41	14	3
5	1	5	72	24	2	26	8	6	16	9	7
3-4	4	5	83	35	1	14	4	7	12	6	8
1-2	3	4	36	7	2	1	1	15	1	0	13

Table 7. Phylakopi: species abundance data (COM. = Complex).

Analysis 2: measuring survivability

Although the factors that destroy animal bones may have many substantively different causes, it is the common observation of many archaeozoologists that they often have broadly similar effects on assemblage profile: bones which tend to survive, tend to survive. This is because two mechanical factors are determining a bone's resilience to destruction, its density and its

surface area to volume ratio. Spongy bones which fuse late (like proximal humerus for example) and flat, thin laminoid bones (like blade of scapula) are not well equipped to survive the effects of dogs, weather, trampling, etc.

We have already seen that the variance of the columns of A are related to the variances of the independent formation processes in a very simple way:

$$V(A) = V(B) + V(B1) + \dots \quad (9)$$

The greater the variance of A, the greater will have been the sum of the variances of the formation processes. Since formation processes (as defined here) destroy bones, the variances of these columns can be used as crude indices of the severity of bone attrition experienced during the taphonomic career of that assemblage. The variance is simply the mean of the squared standardised frequencies and the standard deviation is the square root of the variance, so these quantities can also be used as crude attrition indices too.

The assemblage was subdivided into 40 uniquely defined composite sets using the factors phase, complex and type. All bone frequencies were standardised together across species. The total sum of squares of the standardised frequencies of all elements of the skeleton was then calculated. They are presented in Table 5. These values can be averaged by phase, complex and type to give a crude attrition index (Table 6).

Phases 0 and 5 which Gamble (1982) indicated as having relatively few cattle also show evidence of high rates of attrition. It is possible the change in cattle abundance may be an artefact of differential preservation. Types 2 (floors) and 3 (pits), in which assemblages tend to be small, have relatively low attrition indices possibly indicating that these contexts are favourable for bone preservation. At Phylakopi, as on many Aegean Bronze Age sites, floors and pits are often associated. As floor surfaces become damaged they are often covered with a layer of fill, sometimes containing artefacts and bones, and the whole sealed to form a new floor surface. It is not surprising, therefore, that floors and pits produce low attrition indices.

We now have evidence to support a new interpretation of the Melos data. It is possible that Gamble's time-trend is an artefact of differential preservation. It is clearly necessary to undertake a direct examination of species representation which does not employ the standardisation procedure to see whether the pattern is sufficiently robust to emerge from an independent approach.

Analysis 3: taxonomic variability

The same 40 uniquely defined composite units from the preceding study were re-employed.

Eigenvalues		
Eigenvalue	% of trace	Cumulative %
7.0579	78.42	78.42
1.0700	11.89	90.31

Variable loadings on the first two components

Variable	Component 1	Component 2
S/G Total bones	0.3541	-0.2025
S/G Bones aged	0.3506	-0.0969
S/G Elements absent	-0.3072	0.3133
COW Total bones	0.3255	0.4648
COW Bones aged	0.3072	0.5174
COW Elements absent	-0.3334	-0.4277
PIG Total bones	0.3390	-0.2446
PIG Bones aged	0.3368	-0.2076
PIG Elements absent	-0.3427	0.2862

Table 8. Results of Principal Components Analysis on data in Table 7.

Each unit contained between 2 and 266 identified elements. For each of the three major species (ovicaprid, cow and pig) 3 variables were defined, these were:

- (1) Number of bones in assemblage subset.
- (2) Number of bones successfully aged in subset.
- (3) Number of skeletal elements absent altogether from the subset (i.e. the number of zero frequencies recorded).

The number of bones is probably the simplest (arguably 'crudest') indicators of scale available.

The number of bones successfully aged (i.e. the number for which fusion data was available) is, in addition to being an index of scale, also an index of 'goodness of preservation' as it only documents those bones which survive sufficiently well to permit supplementary data to be gathered. The third variable, the number of elements absent, was transformed onto a logarithmic scale, and is also considered as a 'dual purpose' variable, an index of assemblage scale and goodness of preservation. If preservation is good, LOG(number of zero frequencies) will be low and *vice versa*.

Phase	Complex	Type	Score
4	2	1	-2.6265
1	2	2	-2.5323
3	2	4	-2.4852
4	2	3	-2.4859
2	2	5	-2.4533
2	1	2	-2.4343
2	5	1	-2.4280
2	1	4	-2.3964
3	4	3	-2.2744
0	3	5	-2.1890
5	1	3	-2.1087
1	2	5	-2.1038
4	1	5	-1.8936
2	5	4	-1.8153
3	5	5	-1.6995
2	5	5	-1.5700
2	2	4	-1.4678
1-2	3	4	-1.3796
4	1	2	-1.3557
2	3	5	-0.8718
4	1	6	-0.8558
2	5	3	-0.6274
1	2	1	-0.5588
3	1	6	-0.5360
2	4	5	0.3065
0	2	1	0.3807
5	1	4	0.5319
0	2	6	1.1605
4	4	5	1.7081
1	2	4	1.7171
3	4	4	1.7209
3-4	4	5	1.8411
4	1	4	2.3750
5	1	5	2.4818
2	1	1	2.9926
4	1	1	3.1891
5	1	6	4.0654
2	1	7	4.9666
2	2	3	5.0191
3	1	4	8.6749

Table 9. Principal Components scores for Component 1 ('Scale').

Thus, evidence of variation in scale of the assemblage subsets would come in the form of strong, joint co-variation of all three variables of all three species, whilst evidence for variation in profile (expressed as changes in species abundance) would be in the form of low or negative co-variation between the indices of two or more of the three major species. For any one species, variables 1 and 2 will be positively correlated with each other and negatively correlated with 3.

Phase	Complex	Type	Score
5	1	6	-2.7668
1	2	4	-1.8671
4	1	1	-1.6703
0	2	1	-1.1060
5	1	4	-1.1048
2	1	7	-0.9232
4	1	6	-0.8036
4	4	5	-0.6878
2	2	3	-0.5481
1	2	1	-0.5316
0	2	6	-0.5292
4	1	2	-0.3602
3-4	4	5	-0.2683
1-2	4	4	-0.2333
3	4	4	-0.1767
2	2	4	-0.0514
2	5	4	0.0338
2	4	5	0.0965
3	5	5	0.1054
5	1	3	0.1368
0	3	5	0.1632
2	3	5	0.2260
3	4	3	0.2290
1	2	5	0.2329
2	5	5	0.3303
2	1	4	0.3344
2	5	1	0.3675
4	2	3	0.3707
2	2	5	0.3723
4	1	4	0.3762
4	1	5	0.3876
3	2	4	0.4072
1	2	2	0.4245
4	2	1	0.4899
3	1	6	0.5319
2	1	2	0.6175
2	5	3	0.6345
5	1	5	0.7252
2	1	1	2.4303
3	1	4	3.6050

Table 10. Principal Components scores for Component 2 ('Profile').

The raw data for all 40 uniquely defined subsets, before logarithmic transformation of the third variable, are shown in Table 7. Principal Components Analysis was used to clarify the inter-relationships between these variables. This analysis extracted two eigenvectors with eigenvalues explaining more than 10% of the variation described in the correlation matrix. The remaining seven eigenvalues each explained less than 4% of the variation characterised in the correlation matrix (see Table 8).

Classified by phase

Phase code	Mean 'scale'	Size of class
0	-0.2189	3
1	-0.8694	4
2	-0.2138	13
3	0.5668	6
4	-0.2398	8
5	1.2426	4
1-2	-1.3796	1
3-4	1.84111	1

Classified by complex

Complex	Mean 'scale'	Size of class
1 (Sanctuary)	1.1798	15
2 (NE Megaron)	-0.7008	12
3 (SW Megaron)	-1.4831	3
4 (S Megaron)	0.6604	5
5 (II S)	-1.6280	5

Classified by type

Type	Mean 'scale'	Size of class
1 (walls, etc.)	0.1582	6
2 (floors)	-2.1074	3
3 (pits)	-0.4091	5
4 (debris/refuse)	0.5475	10
5 (make-up/fill)	-0.5866	11
6 (external)	0.9585	4
7 (other)	4.9666	1

Table 11. Mean scores on Component 1 ('scale').

The first component, which accounts for 78% of the variation in the correlation matrix, satisfies the criteria suggested as indicating variation in scale. All the direct indicators of assemblage scale ('total bones', 'bones aged' and '-LOG(Elements absent)') are positively correlated with it.

The principal component scores may usefully be tabulated in ascending rank order, so that any obvious association between the three contextual variables and the scale and profile components may be seen (Tables 9 and 10). A visual comparison of the raw data (Table 7) with the scores of each subset is sufficient to

Classified by phase

Phase code	Mean 'scale'	Size of class
0	-0.4907	3
1	-1.7413	4
2	3.9204	13
3	4.7018	6
4	-1.8975	8
5	-3.0096	4
1-2	-0.2333	1
3-4	-0.2683	1

Classified by complex

Complex	Mean 'scale'	Size of class
1 (Sanctuary)	0.1011	15
2 (NE Megaron)	-0.1947	12
3 (SW Megaron)	0.0520	3
4 (S Megaron)	-0.1615	5
5 (II S)	0.2943	5

Classified by type

Type	Mean 'scale'	Size of class
1 (walls, etc.)	-0.0034	6
2 (floors)	0.2273	3
3 (pits)	0.1646	5
4 (debris/refuse)	0.1323	10
5 (make-up/fill)	0.1683	11
6 (external)	-0.8199	4
7 (other)	-0.9232	1

Table 12. Mean scores on Component 2 ('profile').

indicate a general agreement between a subset's score on Principal Component 1 and the relative quantity of bone recovered from that context.

To test this, each of the 40 subsets was given two ranks, one of which was the ranking of that subset on the first component and the other was its rank order of assemblage size (the total number of identified bones). Spearman's rank correlation coefficient was then calculated between these two ranked variables over all 40 subsets. Spearman's coefficient, like Pearson's R to which it is related, takes on a value of 1.0 for a perfect

positive correlation, -1.0 for a perfect negative correlation and 0.0 for no correlation. The value obtained was 0.959: strong evidence that Principal Component 1 represents assemblage scale.

Principal Component 2 satisfies the criteria suggested for recognising profile. This is a component on which the small artiodactyls (ovicaprid and PIG) have low negative loadings and the COW indices have moderate positive loadings. Thus assemblages with high positive scores on this component would be those in which cow were relatively abundant and ovicaprid and pig relatively scarce.

Thus a very simple pattern has emerged from this PCA in which the whole assemblage, on subdivision into contextually defined subunits, manifests only two major sources of variation. Since 78% of the variation in assemblage data was explained by the scale component, we must conclude that the bulk of the variation between assemblage subsets is attributable to scale and a much smaller proportion of the variation represents profile of assemblage. Variation in profile typically takes the form of shifts in the relative abundance of small and large artiodactyls. There is virtually no evidence for variation in the relative abundance of pigs and ovicaprids.

The effects of context on species representation

The Principal Components Analysis just described treated the whole assemblage as an amorphous set of analytical units. Of course, this is not the case and the factors that allow us to partition the assemblage can be used to interpret the principal component scores. We begin by calculating a mean score on each of the two components for each unique value of phase, of context type and of trench complex. These mean scores are interpreted by remembering that a subset with a negative mean score on the first (scale) component may be said to be of small scale and vice versa, whilst a subset with a negative mean score on the second component must have comparatively few cattle bones and vice versa. The results of these calculations are presented in Tables 11 and 12.

Although there is no clear pattern in assemblage scale between phases, there is a tendency for the earlier phases (0-2) to produce subsets on a generally smaller scale

than the later. This is probably because a larger area of the later phases was stripped than of the earlier. Consequently, each context type was better represented in the former. Among the complexes there are certain obvious 'outliers'. The sanctuary complex is a notable instance because a large area was stripped around the sanctuary, producing larger assemblages. The South West Megaron complex consists of small soundings made into areas between free standing structures cleared by previous excavation. Probably as a consequence of this only small quantities of bones were recovered from each of the contextual units defined therein.

When we look at variation in scale between context types, we see that floors, pits, make-up and fill, which are quickly formed and sealed deposits produce smaller assemblages than those deposits formed by gradual accumulation.

Quite a dramatic variation in profile is manifested between the various phases of the site (Table 12). As observed by Gamble (1982), there appears to be an increase in the relative abundance of cows to a maximum in phase 3 after which the proportion of cow bones falls back to a little above its level in phase 0. The fact that this pattern shadows that established in Table 6, where attrition indices show relatively poor survival prospects in phases 0 and 5, is suggestive.

Variation between complexes is not as striking as that observed between phases. Furthermore, these results do not correlate as clearly with the corresponding data from Table 6, possibly because assemblages from complexes 4 and 5 are very much smaller than the rest. Complex 2 (IIB & IIC) contains virtually no material later than phase 2.

When we look at context types we see that exposed external contexts in which deposition rates are low seem on average to produce fewer cattle remains than those which are quickly filled and sealed. Context types 1, 6 and 7 also produced high attrition indices in Table 6, indicating poor preservation. Note that, whereas cow bones are generally well represented in make-up and fill (mean profile 0.1683), they are not well represented in trench complex 4 (IIA). The bulk of the bone from this trench was, nonetheless, derived from two large fill deposits. These were unusual in that both were extremely well drained; one of these was described in the level notes provided by the excavator as 'mixed gritty

Phase	Poor	Medium	Good	Total
0	124	103	10	237
1	0	146	26	172
2	226	170	371	767
3	41	313	46	400
4	41	247	163	451
5	190	67	122	379
1-2	0	38	0	38
3-4	0	0	109	109
Total	622	1084	847	2553

Table 13. Number of bones recovered from each of the three preservation classes, subdivided by phase.

fill', and the other as an 'intensely rubbly fill apparently from the levelling of the Second City walls. More stone than earth!'. It seems likely that at least one, and possibly both, of these 'fills' should in fact have been categorised differently, perhaps included in the 'other' category (7).

Cattle abundance: preservation or palaeoeconomy?

Analyses 2 and 3 have shown that attrition indices and cattle abundance appear to be negatively correlated between time phases and between context types. Although Gamble attributed the shifts in cattle representation to changes in the demand for animal traction, this correlation implies that differential preservation is a more likely explanation. Of course, it is possible that the correlation is spurious; a mere coincidence. This possibility could be tested in a number of ways and one of the most obvious is to see whether the bulk of the bones actually recovered came from those contexts in which attrition indices were high. If this is not the case, the negative correlation between profile and attrition index is almost certainly spurious. We can classify the seven contextual types into three subsets (Table 15) on the basis of the attrition indices in Table 6.

Table 7 can be used to obtain the bone yields from each of these preservation classes by phase (Table 13). Expressing these figures as percentages and re-tabulating gives Table 14. We can weight these three categories to reflect goodness of preservation by assigning poor preservation contexts a weight of 1.0, medium

Phase	Poor	Medium	Good	PRES
0	52.39	43.46	4.22	1.5
1	00.00	84.88	15.12	2.1
2	29.46	22.16	48.37	2.2
3	10.25	78.25	11.50	2.0
4	9.09	54.77	36.14	2.3
5	50.13	17.68	32.19	1.8
1-2	00.00	100.00	00.00	2.0
3-4	00.00	00.00	100.00	3.0

Table 14. Percentage of bones from three preservation classes and derived estimate of 'goodness of preservation' (PRES) by phase.

preservation contexts a weight of 2.0, and good preservation contexts a weight of 3.0. An index of goodness of preservation (PRES) can now be calculated using a weighted average. Thus in phase 0, 52% of the bones are from poor contexts, 43% from medium and 4 % from good contexts and a weighted mean is obtained using:

$$PRES = (1.0*0.52)+(2.0*0.43)+(3.0*0.04) = 1.5 \tag{10}$$

Table 14 shows that the PRES statistic varies as follows. Mean PRES rises to 2.1 in phase 1, to 2.2 in phase 2, falls back to 2.0 in phase 3, rises to 2.3 in phase 4 and falls back to 1.8 in phase 5. Clearly, the material from phase 0 and phase 5 not only contain fewer cow bones than the intermediate phases but a larger proportion of the bones were recovered from contexts uncongenial to bone survival. The pattern is clear; we tend to get more cattle bone in those phases and contexts where preservation is relatively good.

We cannot be absolutely certain that differential preservation is the *cause* of changes in cattle bone representation because it is possible that cattle bones were simply cleared away from open areas or were consumed and dumped separately from the smaller artiodactyls. The hypothesis that differential preservation was the cause of variability in cattle bone distribution could be tested further using attrition indices of the sort proposed by Maltby (1985) or direct estimators of survival

rates based on release-recapture methods (Fieller and Turner 1982; Winder 1993). These methods would require re-examination of the bone and the preparation of new data.

Archaeozoological conclusions and prospects

Throughout the late 1960s and 70s we were encouraged (in my view wrongly) to think of bone assemblages as 'samples' which had been 'biased' by the formation processes acting on them. An extensive theoretical literature on faunal quantification followed from this which focused our attention on analytical problems without proposing an effective set of solutions. This in turn put many practitioners into a serious bind. If we accept the 'sample bias' paradigm, the rigorous analysis and interpretation of bone assemblages is an almost impossibly complex problem.

Among many practitioners, this view fostered a belief that the best we could do was to get large faunal samples and use counts and percentages (all measures of relative *scale*) to draw palaeoeconomic and behavioural conclusions. Large 'samples' do not eradicate so-called 'bias'. Indeed, the results presented above show that, at Phylakopi, larger samples seem to be more biased (i.e. have more evidence for differential preservation) than smaller ones.

The desire for a large sample has caused many archaeozoologists to 'lump' assemblages together as much as possible so as to get a viable sample. The resulting *unifactorial* analyses may well lead to a naive interpretation of observed patterning. It is relatively common, for example, to infer time-trends in assemblages from which all intra-phase variability has been expunged. The dangers of the unifactorial approach are widely acknowledged in the textbook literature on statistics (see, for example, Fienberg 1977) but seem to have been ignored in the archaeozoological and, indeed, the wider archaeological literature.

As we have seen at Phylakopi, the auto-correlation of intra-phase (or 'lateral') variation with inter-phase (or chronological) variation may well result in a spurious time-trend that can only be detected when the effects of both factors are considered *simultaneously*. Phylakopi is not an isolated case; a more recent study has characterised spurious time-

Preservation class	Type	Description
Poor	7	Other
	6	External
	1	Walls
Medium	4	Occupation debris/refuse
	5	Make-up and fill
Good	3	Pits
	2	Floors

Table 15. Preservation classes derived from attrition classes in Table 6.

trends in the data for bones from the Palaeolithic rock-shelter at Klithi (Winder, in prep.).

A rigorous, multifactorial approach to the interpretation of bone data is possible using relatively simple data transformations (like taking logs and subtracting means) before applying mainstream statistical methods. In this paper, I have restricted myself to the generation of weighted means and variances and these alone were sufficient to provide valuable new insights that could be tested with a PCA on a summary dataset and a rank correlation coefficient. The possibilities for future work of this sort are unbounded.

Suppose, for example, we had grounds to believe that an assemblage of bones was modified by dog-gnawing. We could take an assemblage produced by experimental studies of dog-gnawing and standardise it in the manner described above. This would give us a profile vector for a potential population that had only experienced dog-gnawing. By regressing the dog-gnawing vector on an archaeological profile vector, we could obtain a least-squares estimate of the proportion of variation in the assemblage that could be attributed to dog-gnawing. The residuals about this regression line would describe that portion of assemblage variability that was independent of the effects of dog gnawing (including some of the effects of human behaviour). Patterning among the residuals could be interpreted directly by inspection or by further regression steps.

Finally, we should note that the key to mounting a truly multifactorial analysis of animal bone data is the recognition that assemblage formation processes alter both the

scale and the profile of the potential population in a consistent and mathematically tractable way. We have been accustomed by twenty or more years of conventional wisdom to consider differences between the profiles of assemblages and potential populations as part of a 'problem' which we 'solve' by lumping assemblages and undertaking unifactorial analysis of variation in crude measures of assemblage scale (MNI, NISP, weight, etc.). In fact, the only evidence we have about the severity and nature of assemblage formation processes is written into the profile of the assemblage. Our best prospect of understanding these signals is to invert the traditional approach; to find intelligent ways of correcting for gross differences in scale before mounting a truly multifactorial investigation of assemblage profile.

Acknowledgments

I am most grateful to Clive Gamble for allowing me to use his data as an analytical test-bed for the methods described in this paper. I also acknowledge a grant from the Science and Engineering Research Council (RF/8186) that allowed me to locate this work in a wider statistical context.

References

- Behrensmeyer, A. and Hill, E. (eds.) (1980). *Fossils in the making*. Chicago: University Press.
- Binford, L. (1978). *Nunamiut ethnoarchaeology*. New York: Academic Press.
- Binford, L. (1981). *Bones: ancient men and modern myths*. New York: Academic Press.
- Fieller, N. R. J. and Turner, A. (1982). Number estimation in vertebrate samples. *Journal of Archaeological Science*. 9, 49-62.
- Fienberg, S. (1977). *The analysis of cross-classified categorical data*. Cambridge, Mass.: MIT Press.
- Gamble, C. (1982). Animal husbandry, population and urbanisation, pp. 161-8 in Renfrew, C. and Wagstaff, M. (eds.), *An island polity: the archaeology and exploitation of Melos*. Cambridge: University Press.
- Gamble, C. (1985). Formation processes and the animal bones from the sanctuary, pp. 479-88 in Renfrew, C., Mountjoy, P., French, E., Younger, J., Cherry, J., Daykin, A., Moody, J.,

Morgan, L., Bradford, N., MacFarlane, C., Torrence, R., Gamble, C. and Whitelaw, T., *The archaeology of cult; the sanctuary at Phylakopi*. London: Thames and Hudson.

Lyman, R. (1985). Bone frequencies: differential transport, in situ destruction and the MGUI. *Journal of Archaeological Science* 12, 221-36.

Maltby, M. (1985). Patterns in faunal assemblage variability, pp. 33-74 in Barker, G. and Gamble, C. (eds.), *Beyond domestication*. London: Academic Press.

Speth, J. (1983). *Bison kills and bone counts*. Chicago: University Press.

Winder, N. (1986). *Faunal analysis; studies in the analysis and interpretation of animal bones from large, multi-phase archaeological excavations*. Ph.D Thesis, University of Southampton.

Winder, N. (1991). Interpreting a site: the case for a reassessment of the Knossos Neolithic. *Archaeological Review from Cambridge* 10(1), 37-52.

Winder, N. (1993). Using modern bone assemblages to estimate ancient populations. *Circaea* 10(2) 63-8.

Winder, N. (in press). The confounding of excavation method with spatio-temporal indicators. In G. Bailey (ed.), *Excavations at Klithi 1983-1988: Palaeolithic archaeology and landscapes in Epirus, Northwest Greece*. Cambridge: McDonald Institute for Archaeological Research.

Revised disk copy received: February 1995 (the Editors apologise for the delay in publication).