ANALECTA PRAEHISTORICA LEIDENSIA 28

PUBLICATIONS OF THE INSTITUTE OF PREHISTORY
UNIVERSITY OF LEIDEN

INTERFACING THE PAST

COMPUTER APPLICATIONS AND QUANTITATIVE METHODS IN ARCHAEOLOGY CAA95 VOL. I

EDITED BY
HANS KAMERMANS AND KELLY FENNEMA

UNIVERSITY OF LEIDEN 1996

contents

VOLUME I

Archaeometry

Statistics and Classification

VOLUME II

Geographic Information Systems I

Kris Lockyear

Dmax based cluster analysis and the supply of coinage to Iron Age Dacia

1 Introduction

The analysis of Roman Republican coin hoards presents a number of statistical opportunities and problems. For example, the well-dated nature of the material provides an excellent test for seriation techniques. Conversely, the inherent time gradient will dominate a correspondence analysis (CA). Figures 1 and 2 present the sample and variable maps from a CA of 241 coin hoards, each of which has more than 30 well recorded denarii, dating from 147-2 BC (Lockyear 1996: section 8.2.3).[1] As can be seen, the 'horseshoe effect' dominates the results (Lockyear 1996: section 8.2.2). Although some interesting points can be made from these maps, the dominant gradient is time — other information is masked. Mixing hoards from different periods in one analysis does not 'aid interpretation', *contra* Creighton (1992: 32-35).[2]

One possible solution is to examine small subsets of the data, each with a restricted range of dates. The hoards presented in figures 1-2 were subdivided into 22 groups, each of which was analysed using CA (Lockyear 1996: section 8.3). This revealed many interesting aspects of variation in these hoards, often linked to the region from which the hoards were found, and some general observations are given below.

However, one particular question arose which suggested that some form of cross-period comparison would be useful. This paper will outline this question, and then will discuss the solution devised by the author in detail. Finally, the results and archaeological conclusions will be briefly presented. Full details can be found in Lockyear (1996); details of the data and the archaeological results and conclusions will be published elsewhere. Additional information including figures, tables and the data are available via the World Wide Web (http://caa.soton.ac.uk/caa/CAA95/LockyearA/) or from the author.

2 The problem

As Crawford notes:

> 'One of the most remarkable phenomena within the pattern of monetary circulation in antiquity is the presence of large numbers of Roman Republican denarii, for the most part struck between about 131 and 31 [BC], on the soil of present-day Romania, roughly ancient Dacia.'
>
> Crawford 1985: 226

What makes this phenomenon remarkable is that Dacia was not incorporated into the Roman Empire until the Trajanic Wars (AD 101-102, 105-106). The situation is further complicated by the evidence for the copying of denarii by the Geto-Dacians (Chiţescu 1971b, 1980, 1981; Glodariu *et al*. 1992; Lupu 1967) although the scale of the copying is disputed (cf. Chiţescu 1981; Crawford 1980). The date at which the denarii arrived in Romania has also been a topic of some debate. Mitrea (1958) has argued that there are three phases of the 'penetration' of denarii: the end of the second century BC, 90-80 BC and 49-30 BC. Many other scholars have basically agreed, although some have argued for 'more than a sporadic penetration of denarii into Romania by the year 100 BC (Chiţescu 1971a). Some Romanian scholars have disagreed. Preda (1971: 74) argues for a date after 80 BC; Babeş (1975) argues for a mid-1st century date based on the excavated finds from Cîrlomaneşti. Crawford (1977, 1985: 226-235) argues for a date from the mid or late 60s, and quite rightly notes that the periods claimed by Mitrea, and others, for the arrival of large numbers of denarii into Romania correspond to periods of high levels of official coin production. In her final work, Chiţescu maintained that these new alternatives were wrong and that the 'penetration' of denarii must have started by 100 BC (Chiţescu 1981). Poenaru Bordea and Cojocărescu (1984) argue that the majority of denarii arrived between *c*. 75 BC and *c*. 65 BC.

Before any interpretation of *why* these coins were there, and why they were copied, these basic questions need to be addressed. As part of a wider project, the author has been constructing a database of Roman Republican coin hoards. At the time of writing this database contained detailed information of 420 hoards, some 87,240 coins. Of these, 126 hoards were found in Romania. By analysing these hoards in the context of others from the rest of Europe, some important observations could be made.

– Although 13 of the 126 hoards from Romania date before 79 BC, the biggest hoard from Iclănzel has only 18 well identified denarii (ICL[3]; Chirilă/Grigorescu 1982). The small size of these hoards makes it likely that there is a large discrepancy between their closing dates and the true date of their deposition. Lockyear (1993:

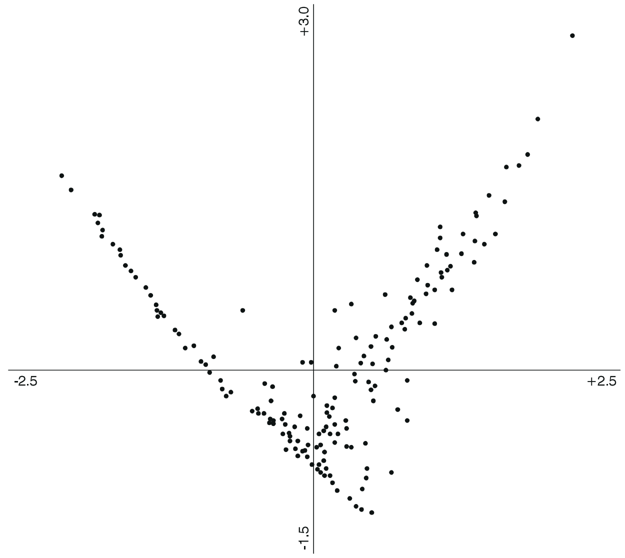

Figure 1. Sample map from CA of 241 Roman Republican coin hoards dating from 147-2 BC each with 30 or more well identified denarii. Data points are hoards. First (horizontal) and second axes of inertia.

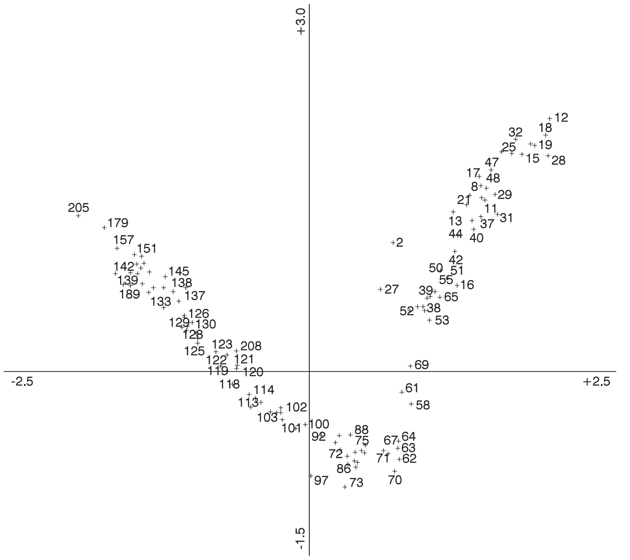

Figure 2. Species map from CA of 241 Roman Republican coin hoards dating from 147-2 BC each with 30 or more well identified denarii. Data points are years of issue. First (horizontal) and second axes of inertia.

373-375) discusses the problem of hoard size and dating in detail.

– Romanian hoards with closing dates in the 70s BC are very similar in structure[4] to Italian hoards of the same date. For example, cf. Zătreni (ZAT; Chiţescu 1981: No. 215) with San Mango sul Calore (MAN; Pozzi 1960-1961: 162-172).
– By the 50s BC Romanian hoards are archaic[5] in structure when compared to contemporary hoards from Italy. For example, cf. Dunăreni (DUN; Popilian 1970) with Mesagne (MES; Hersh/Walker 1984).
– In the 40s and 30s BC the pattern is more complicated with Romanian hoards being quite variable, but always more archaic than contemporary Italian hoards.

We can conclude that denarii did not arrive in this region in significant quantities, if at all, prior to 80 BC. The structure of hoards from the 70s suggests that significant supplies started at that time. The differences between Italian and Romanian hoards in the following decades suggest that the supply of coinage to Romania was not constant and did not reflect supply to Italy.

At this stage it seemed that further information concerning the supply of coinage to Romania could be gained by comparing hoards across date ranges. Various methods were considered. Comparisons were made by running CA on all hoards and then using the colour plotting facilities of WinBASP.[6] Although it was possible to see the sorts of comparisons needed in this fashion, it was difficult to produce some form of grouping in the continuum displayed. The methods used by Creighton (1992: section 2.5, 78-103) were rejected as they lack any sound statistical foundation. The problem appeared to be one which could be addressed by cluster analysis providing that the resulting clusters are viewed as subdivisions of a continuum of variation, not as clear, unequivocal groups.

3 Dmax based cluster analysis

Cluster analysis is a range of techniques with the basic aim of subdividing a set of objects or assemblages into subsets. There is no 'best' method of achieving this — see Orton (1980), Shennan (1988) and Baxter (1994) for the use of the technique in archaeology. In this particular case, the aim was to produce a moderately large number of subsets in order that we could examine the grouping of hoards and see if this provided us with any further insights, especially as regards the supply of coinage to Romania.

Some form of hierarchical agglomerative cluster analysis seemed appropriate. In this form of analysis, the analyst firstly has to choose a similarity or dissimilarity coefficient. Most standard texts list three common measures, Euclidian, squared Euclidian and city-block distance (e.g. Shennan 1988, 198-202). Many others exist for different data types. For example, SPSS allows for the use of χ^2 or Φ^2 as measures for count data (Norušis 1993: Chapter 5 especially 128, 133).

In this case, the variables used to describe the hoards are of an ordinal data type — the coins grouped by date of issue. For example, the Cosa hoard (COS; Buttrey 1980) has 2004 coins and closes in 74 BC. It has 9 coins of 211 BC, 3 of 209, 1 of 207, 4 of 206 and so on until… 32 of 74 BC. The author therefore wanted a measure which would:

a. not be over-influenced by rare issues especially if those rare issues were defining a hoard's closing date;
b. make full use of the ordinal nature of the data.

None of the software available to the author provided such a measure.

The author has had occasion to compare hoards using the Kolmogorov-Smirnov statistic, a significance test suitable for ordinal data (Shennan 1988: 55-61). This test involves calculating $Dmax_{obs}$, defined as the maximum difference between two cumulative proportion curves, and then comparing it to a critical figure for the significance level desired. Mass comparisons using this method (e.g. Lockyear 1989: section 2.2) were unsatisfactory for a number of reasons. For example, the large number of comparisons used in that study would lead to some results being significant by chance — the problem of multiplicity (Mosteller/Tukey 1977: 28f.). More importantly, we already know that the hoards are drawn from a global coinage pool with major regional variations and therefore should expect differences.

$Dmax_{obs}$ can, however, be viewed as a type of dissimilarity coefficient suitable for ordinal data, just as χ^2 can be used for nominal data. Dmax could, therefore, be used in cluster analysis, or some form of multidimensional scaling, as a dissimilarity coefficient. At the time of the analysis, the author did not know of the use of Dmax in this fashion.[7] No theoretical objections were raised by statisticians consulted[8] and it was decided to try the method and see if the results 'made sense' in the context of what was already known about these hoards.

Two hundred and seventeen hoards were selected from the database, closing between 147-29 BC, all with 30 or more securely identified denarii. The 23,436 dissimilarity coefficients were calculated using a dBASE program, and then converted into a triangular matrix. The only software available to the author which would allow the input of a user calculated dissimilarity matrix was MV-ARCH (Wright 1989). The matrix was therefore input to the HIERARCH module of that package for clustering. Output was produced on a plotter using the HIERPLOT module.

Seven types of clustering algorithm are available in MV-ARCH. Single-link cluster analysis (Shennan 1988: 213-214) tends to produce dendrograms with a strong chained effect (Baxter 1994: 158), especially when the technique is applied to data which does not have strong grouping. With this data set the chaining was such that the results were not usable. Ward's method (Shennan 1988: 217-220) produces strong clusters even from random data (Baxter 1994: 161-162) and again, the results from this data set were difficult to use.[9] Theoretically, Ward's method should only be used with squared Euclidian distance (Baxter 1994: 156). Wright (1989) strongly recommends the use of between-group average linkage despite the objections of Jardine *et al*. (1967). This method did indeed produce usable results (fig. 3) and it is these which will be discussed below. Calculation of some diagnostic statistics such as the cophenetic correlation coefficient (Shennan 1988: 230-232) would have been useful but these are not offered in the MV-ARCH package, and derivation from the dendrogram is not a viable proposition given the size of the matrix. Other validation techniques are not necessarily appropriate given that we are already aware that we are subdividing a continuum, although one method suggested by Aldenderfer (1982), comparison to other multivariate methods, had already been applied in the form of the CAs discussed above.

The final question of how many clusters to examine is not easy to answer in any problem. In this case, as noted above, we are slicing up a continuum, not identifying clear groups, and thus any decision is somewhat arbitrary, and the application of techniques such as Mojena's stopping rule (Aldenderfer 1982: 64-65) would be inappropriate. It was decided to cut the dendrogram at two levels, at 20%[10] and 30% dissimilarity.

4 Discussion of the results

4.1 ARCHAEOLOGICAL RESULTS

The groups derived from the dendrogram given in figure 3 are presented in tables 1, 2, and 3. In the following discussion groups derived at a 20% dissimilarity are called 'groups', groups derived at a 30% dissimilarity are called 'supergroups'. A detailed list of the hoards used, and their group membership, is given in Lockyear (1996: table 10.1) and on the CAA WWW server.

An initial examination of the clusters revealed patterns which were in accord with the results of the CAs discussed above. For example, group *a* (table 1) contained three hoards, all of which closed in 32 BC, and all of which contained substantial numbers of legionary denarii (*Roman Republican Coinage* [RRC], Crawford 1974: No. 544).[11] A CA of all hoards dating to 32 BC showed that these three hoards were extremely similar (Lockyear 1996: section 8.3.19).

Group *b*, however, contained 40 hoards and had a range of closing dates from 82-32 BC. A more detailed

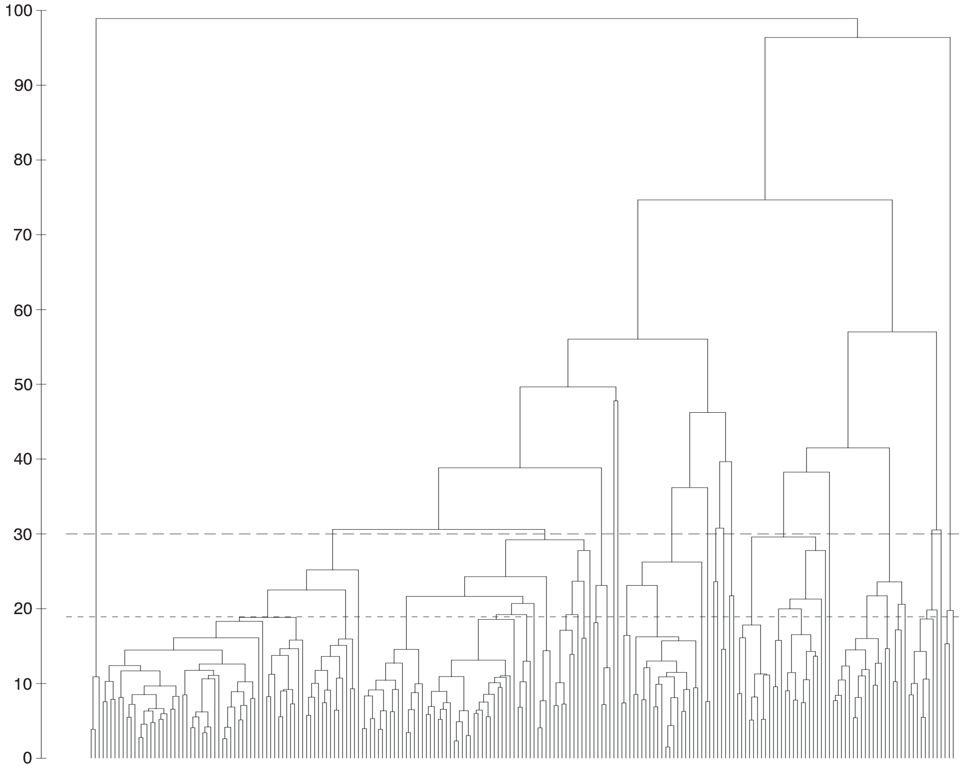

Figure 3. Dendrogram from average link cluster analysis of 217 Roman Republican coin hoards using Dmax as a dissimilarity coefficient. Short-dash line shows the cut to create the "groups" discussed in the text, long-dash line the "supergroups".

examination showed that of these hoards, ten came from Italy and Sicily. Of these ten, one closed in 82 BC, the remaining nine closed in the 70s BC. Twenty-one hoards in group *b* came from Romania, nine from other countries including Spain, Portugal, France, Greece, Elba and the former Yugoslavia. The non-Romanian hoards all closed in the 70s BC; the Romanian hoards close anywhere between the 70s and 32 BC with fifteen hoards from the 50s-40s BC.

In contrast, most hoards from the 40s occur in groups *f* or *g-i*. In the former group, 14 out of 16 hoards are from Italy, and 8 of those close in the 40s BC. Groups *g-i* contain 12 Romanian hoards, 9 of which close in the 40s BC.

Group *j* only contains four hoards all of which close in the 50s, three of which come from Italy, and again this is in accord with the results of the CAs (Lockyear 1996: sections 8.3.11-8.3.12). Hoards of the 50s are generally rare due to the low numbers of coins struck in that decade. Despite this, there are nine hoards from Romania closing in that decade but seven of these have been assigned to group *b*, and one each to groups *d* and *g*.

A detailed examination of the rest of the groups continued to reveal consistent patterns (Lockyear 1996: chap. 10) and therefore the groups made archaeological sense, especially when the hoards contained within them were examined by country of origin (table 2). Comparison of these results with the results of the 22 detailed CAs also showed a high level of agreement.

The broader pattern can be made clearer by examining the supergroups (table 3). Two supergroups are of interest, Β and Γ. Supergroup Β contains 64 hoards of which 16 come from Italy, and 31 from Romania; the Italian hoards close 82-71 BC whereas the Romanian hoards close 79-32 BC with a median of 56 BC. Group Γ contains 57 hoards of which 29 come from Italy and 17 come from Romania. The range of closing dates was surprisingly large for the Italian hoards: 80-29 BC, although the median was 46 BC. Consulting the agglomeration schedule it was found that groups *f-i* and *k-n* merged at a level of 29%. Splitting supergroup Γ into two along these lines resulted in supergroup Γ_1 containing 47 hoards, and supergroup Γ_2 containing 10 hoards. Supergroup Γ_1 contained 46 hoards of which 22 came from Italy with a range of 58-29 BC and a median of 46 BC. It also contained 14 Romanian hoards with a range of 54-29 BC and a median of 42. Supergroup Γ_2 has seven Italian hoards closing 80-72 BC and three Romanian hoards closing in 74, 62 and 49 BC. The only Romanian hoard not in supergroups Β or Γ was Işalniţa (ISA; Mitrea/Nicolaescu-Plopşor 1953) which occurs in supergroup Ν with Italian hoards of 101-82 BC, despite closing in 41 BC.

Table 1. Summary of cluster analysis results at a dissimilarity of 18.9%. Columns three and four give the next cluster to which the listed cluster joins and at what dissimilarity level. The final two columns give the range of 'end dates', and the median. Hoards CST and GRE omitted.

				'end dates'	
cluster	number of members	next cluster	level	range	median
a	3	b-ρ	95.229	32-32	32
b	40	c	18.992	82-32	71
c	10	b	18.992	81-63	76
d	13	b-c	22.474	82-32	74
e	1	b-d	25.041	-	74
f	16	g-i	21.676	48-29	42
g	22	h	19.338	55-39	46
h	4	g	19.338	47-29	44
i	1	g-h	20.736	-	29
j	4	f-i	24.180	58-55	57
k	6	l	19.338	74-49	73
l	1	k	19.338	-	74
m	2	k-l	23.590	80-79	79h
n	1	k-m	27.501	-	79
o	2	p	23.063	87-81	84
p	3	o	23.063	87-82	86
q	1	r	46.556	-	46
r	1	q	46.556	-	74
s	3	t	23.055	40-29	29
t	17	s	23.055	46-29	41
u	1	s-t	26.034	-	46
v	2	s-u	35.522	49-48	48h
w	1	x	23.550	-	41
x	1	w	23.550	-	41
y	2	w-x	30.365	32-29	30h
z	1	α	21.736	-	43
α	1	z	21.736	-	45
β	9	γ-ζ	29.218	118-86	109
γ	3	δ	20.073	104-85	101
δ	9	γ	20.073	112-83	102
ε	1	γ-δ	21.310	-	104
ζ	1	γ-ε	27.495	-	115
η	1	β-ζ	37.474	-	113
θ	13	ι	21.723	100-82	92
ι	2	θ	21.723	46-41	43h
κ	3	λ	20.640	101-92	100
λ	1	κ	20.640	-	92
μ	7	ν	19.929	125-112	121
ν	1	μ	19.929	-	130
ξ	1	μ-ν	30.108	-	136
π	2	ρ	19.885	147-141	144
ρ	1	π	19.885	-	146

From both the groups and the supergroups we can make a number of broad generalisations.

1. Within the groups/supergroups, Italian hoards are of broadly similar dates. Each decade has at least one group associated with it. This reflects the dynamic nature of the Italian coinage pool with new coins entering the system, coins being lost from the system, and a reasonable speed of circulation to distribute coinage around the system.

Table 2. Cluster analysis – date ranges and median ‘end date’ for groups by region. Ordered by median ‘end date’ for Italian (including Sicilian and Sardinian) hoards. Hoards CST and GRE omitted.

	Italy			Romania			Iberian peninsula			total		
group	total	range	median	total	range	median	total	range	median	total	range	median
ρ	1	-	146	-	-	-	-	-	-	1	-	146
π	2	147-141	144	-	-	-	-	-	-	2	147-141	144
ξ	1	-	136	-	-	-	-	-	-	1	-	136
ν	1	-	130	-	-	-	-	-	-	1	-	130
μ	5	125-112	121	-	-	-	-	-	-	7	125-112	121
β	6	118-86	115	-	-	-	3	109-101	104	9	118-86	109
δ	3	102-83	100	-	-	-	6	112-101	106h	9	112-83	102
κ	3	101-92	100	-	-	-	-	-	-	3	101-92	100
γ	2	101-85	93	-	-	-	1	-	104	3	104-85	101
λ	1	-	92	-	-	-	-	-	-	1	-	92
θ	11	100-82	92	-	-	-	2	100-100	100	13	100-82	92
p	2	87-82	85h	-	-	-	-	-	-	3	87-82	86
o	2	87-81	84	-	-	-	-	-	-	2	87-81	84
d	1	-	82	9	79-32	74	2	74-74	74	13	82-32	74
m	2	80-79	80h	-	-	-	-	-	-	2	80-79	80h
c	5	81-74	79	1	-	63	2	74-74	74	10	81-63	76
n	1	-	79	-	-	-	-	-	-	1	-	79
b	10	82-71	74	21	77-32	54	4	78-71	74	40	82-32	71
l	1	-	74	-	-	-	-	-	-	1	-	74
k	3	74-72	74	3	74-49	62	-	-	-	6	74-49	73
r	1	-	74	-	-	-	-	-	-	1	-	74
j	3	58-55	56	-	-	-	-	-	-	4	58-55	57
g	7	55-42	51	11	54-39	42	2	51-46	49h	22	55-39	46
v	1	-	48	-	-	-	-	-	-	2	49-48	49h
α	1	-	45	-	-	-	-	-	-	1	-	45
z	1	-	43	-	-	-	-	-	-	1	-	43
t	8	46-38	42h	-	-	-	2	46-44	45	17	46-29	41
f	12	48-29	42	2	42-29	36h	1	-	42	16	48-29	42
s	1	-	40	-	-	-	1	-	29	3	40-29	29
a	1	-	32	-	-	-	-	-	-	3	32-32	32
y	2	32-29	31h	-	-	-	-	-	-	2	32-29	31h
e	-	-	-	-	-	-	1	-	74	1	-	74
h	-	-	-	1	-	47	1	-	46	4	47-29	44
i	-	-	-	-	-	-	-	-	-	1	-	29
q	-	-	-	-	-	-	-	-	-	1	-	46
u	-	-	-	-	-	-	1	-	46	1	-	46
w	-	-	-	-	-	-	-	-	-	1	-	41
x	-	-	-	-	-	-	-	-	-	1	-	41
ε	-	-	-	-	-	-	1	-	104	1	-	104
ζ	-	-	-	-	-	-	1	-	115	1	-	115
η	-	-	-	-	-	-	1	-	113	1	-	113
ι	-	-	-	1	-	41	-	-	-	2	46-41	44h

2. Romanian hoards can be divided into two broad classifications:
   – Class One hoards are mainly similar to Italian hoards of the 70s BC (supergroups Β, Γ_2, Ν);
   – Class Two hoards (supergroup Γ_1) are generally similar to Italian hoards of the 50s-30s BC, although of the Italian hoards that close in this time period, those which occur in supergroup Γ_1 are more archaic than Italian hoards of the same date which occur in supergroups Η, Θ and Ω.
3. At a more detailed level, Class Two Romanian hoards tend to occur in groups together, e.g. group *g*, whereas

Table 3. Cluster analysis supergroups - date ranges and median ‘end date’ for supergroups by region. Hoards CST and GRE omitted. †Only one hoard, from Sardinia (BER), closes in 82 BC; without this hoard the group range is 101-88.

		Italy			Romania			Iberian peninsula			total		
supergroup	group	total	range	median	total	range	median	total	range	median	total	range	median
Α	*a*	1	-	32	-	-	-	-	-	-	3	32-32	32
Β	*b-e*	16	82-71	74h	31	79-32	56	9	78-71	74	64	82-32	74
Γ	*f-n*	29	80-29	49	17	74-29	46	4	51-42	46	57	80-29	46
Γ_1	*f-i*	22	58-29	46	14	54-29	42	4	51-42	46	47	58-29	46
Γ_2	*k-n*	7	80-72		3	74-49	62	-	-	-	10	80-49	74
Δ	*o-p*	4	87-81	84h	-	-	-	-	-	-	5	87-81	86
Ε	*q*	-	-	-	-	-	-	-	-	-	1	-	46
Ζ	*r*	1	-	74	-	-	-	-	-	-	1	-	74
Η	*s-u*	9	46-38	41	-	-	-	4	46-29	45	21	46-29	41
Θ	*v*	1	-	48	-	-	-	-	-	-	2	49-48	48h
Ι	*w-x*	-	-	-	-	-	-	-	-	-	2	41-41	41
Κ	*y*	2	32-29	30h	-	-	-	-	-	-	2	32-29	30h
Ω	*z*-α	2	45-43	44	-	-	-	-	-	-	2	45-43	44
Λ	β-ζ	11	118-83	101	-	-	-	12	115-101	104h	23	118-83	104
Μ	η	-	-	-	-	-	-	1	-	113	1	-	113
Ν	θ-λ	15	101-82†	92	1	-	41	2	100-100	100	19	101-41	92
Ξ	μ-ν	6	130-112	123	-	-	-	-	-	-	8	130-112	123
Π	ξ	1	-	136	-	-	-	-	-	-	1	-	136
Υ	π-ρ	3	147-141	146	-	-	-	-	-	-	3	147-141	146

Italian hoards in the same supergroups mainly occur in separate groups, e.g. group *f*. This suggests variation at a detailed level.

My interpretation of this pattern is as follows. The main influx of coinage to Romania from Italy is in the late 70s and early 60s BC. Thereafter, the supply of coinage is at a much lower level and Romanian hoards become archaic in structure. The similarity between Romanian hoards in these periods is due to the similarity of the coinage pool from whence the coins were withdrawn. Hoards closing in the 70s BC have a high probability of actually being concealed in the 60s and 50s BC as there were few coins struck in those decades, and even fewer imported to Romania. During the 40s BC a second influx of coinage enters the area. This second influx is not simply a result of the increased levels of coin production at this time. This influx results in some hoards looking similar at a general level to contemporary hoards in Italy, but at a detailed level having some differences leading to an archaic structure. Other contemporary hoards, however, continue to have a structure similar to hoards from Italy from the 70s. This suggests that the circulation of coinage in Romania was slow and erratic.

This pattern also gives us a context for the copying of coins in Romania. If the original influx of denarii into Romania resulted in those coins obtaining a specific and important role in some aspect of Dacian society, the lack of supply from the late 60s to the mid-40s may have stimulated the production of the copies. Indeed, this author has yet to detect copies in the early coin hoards examined whereas copies have been detected in later hoards such as Poroschia (PRS; Chiţescu 1980) which closes in 39 BC (Lockyear 1996; Lockyear *et al*. forthcoming).

What is more difficult is to suggest a context for these periods of import. Romanian scholars generally suggest that trade was the major reason (e.g. Mitrea 1945). Crawford (1977, 1985) suggests that the slave trade, in conjunction with Spartacus’ revolt and the suppression of piracy, was the primary cause although this suggestion has met with some hostility from Romanian scholars (Chiţescu 1981; Poenaru Bordea/Cojocărescu 1984). The latter influx is only partly due to the large numbers of coins minted at that date — an observation given more weight by the fact that the huge legionary issue is, comparatively, not very common in Romanian hoards. The Akornion inscription, from Dionysopolis on the Black Sea Coast (Dittenberger 1917: No. 762; Sherk 1984: No. 78), records a meeting between Akornion acting as emissary for Burebista (the ‘first and greatest of the Kings in Thrace’, lines 22-23 of the inscription), and Pompey, at some point during the Civil Wars. Although Burebista is an ill-known figure, and unfortunately communist propaganda used him extensively, clouding further what is actually known, he does seem to

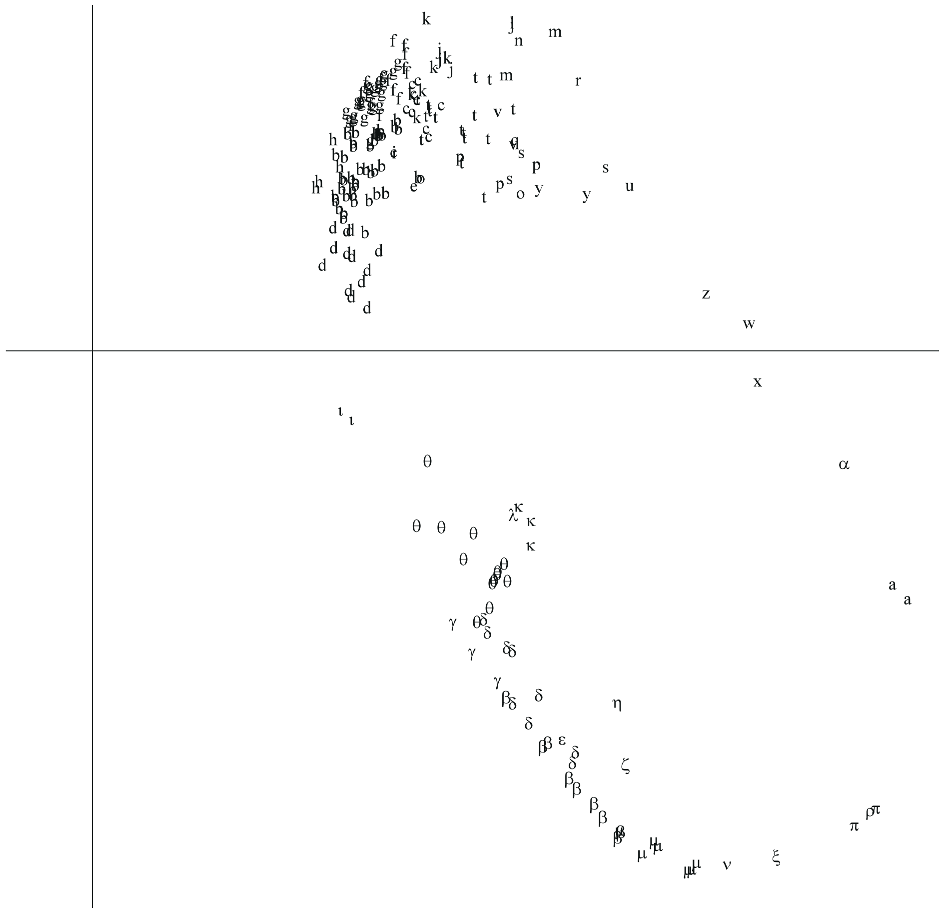

Figure 4. Map from Principal Co-ordinates Analysis of the same 217 hoards analysed using cluster analysis. This analysis has also used Dmax as a dissimilarity coefficient. Data points are hoards; the point symbol is the group membership from the cluster analysis (table 1); first (horizontal) and second axes.

have been in a powerful position in Dacia for a short period.[12] The Akornion inscription shows that he had some influence in the Black Sea region, whereas Strabo (*Geography* 7.3.11, 7.5.2) records a campaign beyond the river 'Parisus' (Παρίσου, probably the Tisza in modern Hungary). It *may be* that Pompey paid Burebista to keep out of the civil wars. Much of this is, and will have to remain, at least for the moment, unsatisfactory speculation, and still leaves many archaeological questions unanswered. For a more detailed discussion see Lockyear (1996; forthcoming).

4.2 Statistical Results

Although it is dangerous to suggest the validity of a statistical method solely on the basis of the archaeological credibility of its results, this cluster analysis using $Dmax_{obs}$ as a dissimilarity coefficient has produced results which make sense in archaeological terms. Comparison to the 22 CAs showed consistency between the two types of analysis.

A check on the results was undertaken by using the same matrix of dissimilarities and performing a principal co-ordinates analysis, also known as classic metric multi-dimensional scaling. This was performed using the Dirpcord module of the Mv-Arch package (Wright 1989). Figures 4 and 5 are the first and second, and the second and third axes from this analysis; the data points are the groups from the cluster analysis. As is expected, the results do not entirely match those of the cluster analysis but there is large degree of similarity which lends confidence to the results as a whole.

The measure also appears to be robust. Included in the analyses were three hoards which were thought to contain extraneous coins or to have other data problems. The Castelnovo hoard (CST; Crawford personal records) appeared odd in the CA of hoards from 46 BC (Lockyear 1996: section 8.3.14) and contained only three coins dated after 71 BC, which is highly unusual for Italian hoards of

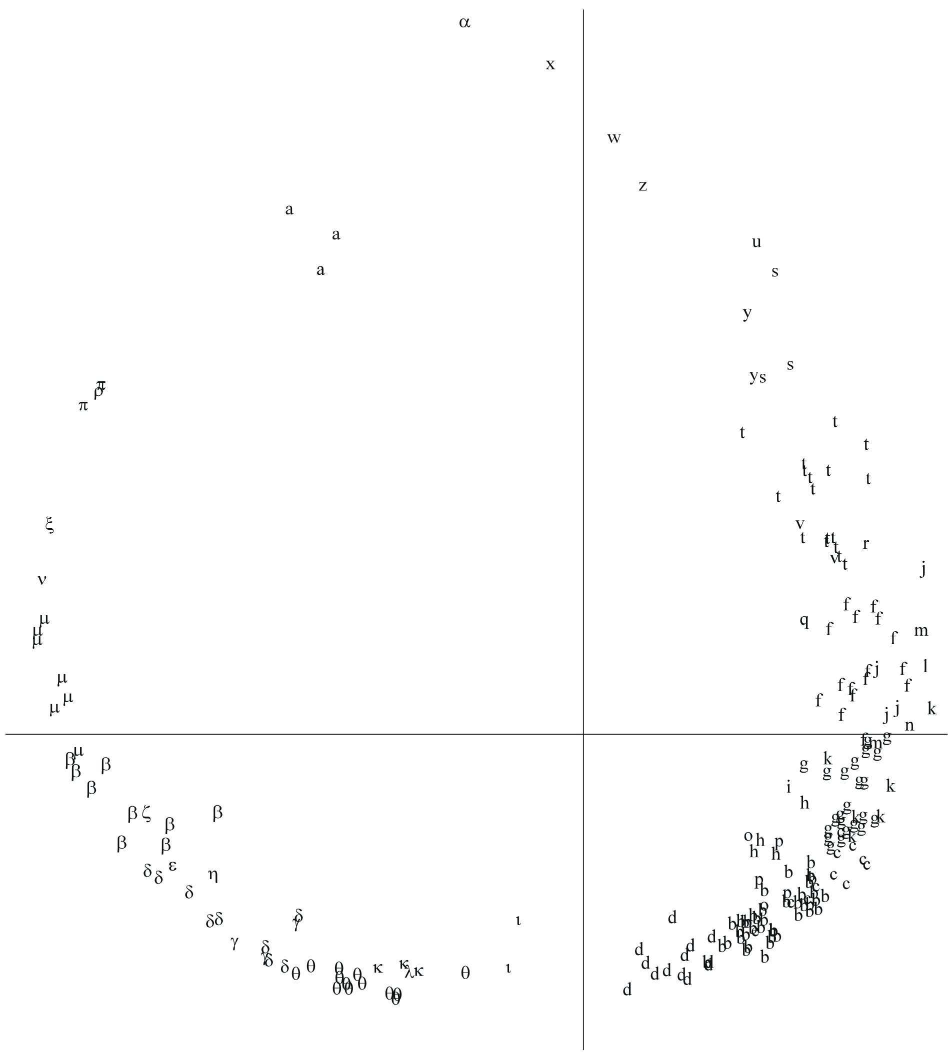

Figure 5. As for figure 4 – second (horizontal) and third axes.

46 BC. This hoard was placed in group *b* with other Italian hoards of the 70s BC, and would be dated to 71 BC if the three aforementioned coins are omitted. The Torre de Juan Abad hoard (JUA; Vidal Bardán 1982) contains two coins of 82-79 BC which were thought by Vidal Bardán to be extraneous; without them the hoard dates to 105 BC. With or without these two coins, this hoard is placed in group *δ* which consists of other hoards of that date. Finally, the San Gregorio di Sassola hoard (GRE; Cesano 1903) appeared to close in 44 BC but was placed in group *g* with 7 other Italian hoards, and 15 hoards from elsewhere. Six of the Italian hoards date from 55-49 BC, one from 42 BC. A re-examination of the database showed that a couple of coin types had been wrongly entered by myself and the correct closing date for San Gregorio is in fact 58 BC. Conversely, there is no obvious explanation for the Piedmonte d'Alife hoard (PIE; Crawford 1969: No. 406, data from Crawford's personal records) having such an archaic profile that it is grouped with hoards from 58-49 BC.

Leese has used Dmax as a similarity coefficient in two papers (Leese 1983; Middleton *et al*. 1985). In the former paper she compares the size distributions of inclusions in pottery thin sections using Dmax as a dissimilarity coefficient; the results reflecting sherd groups originally defined by other criteria. In the latter paper she compares different methods of counting grains from ceramic thin sections using Dmax, called Kolmogorov-Smirnov distances (K_{ij}), input to non-metric multidimensional scaling. Again, significant grouping is displayed on the resultant plot (Middleton *et al*. 1985: fig. 6).

Leese (1983: 52) suggests that the area between the two curves, rather than Dmax, could be used. This is the procedure used by Creighton (1992). Using the area between the curves would be space dilating, analogous to using squared Euclidian distances instead of Euclidian distance. In Leese's paper she has control over the number of grains in each sample and is able to ensure an adequate sample size. In the analysis of hoards, the number of coins in a hoard is beyond the analyst's control although a lower size bound has to be set. Small hoards will have a jagged cumulative proportion line and thus will create a large area between the lines; larger hoards will have smoother lines and the distortion will be less. Although this problem of sample size will affect both the area measure and Dmax, the former method will exaggerate the problem. Creighton sets his lower bound at five coins which creates severe problems with his analysis. My results, using a lower bound of 30 well identified denarii and Dmax, are not affected by variations in hoard size.

Dmax has also been used in other situations. Geman *et al.* (1990) use the measure in texture based image segmentation. They compare the distribution of gray scales between blocks of pixels using this measure.

5 Conclusions

Dmax has been successfully used as a dissimilarity coefficient suitable for ordinal data in cluster analysis or multidimensional scaling although a theoretical appraisal of its properties (cf. Sibson 1972) is still needed.

The cluster analysis performed has significantly added to our understanding of the supply of Roman Republican denarii to ancient Dacia, roughly modern Romania, although the archaeological and historical explanation of the pattern revealed will continue to be the subject of some debate. However, the solution of the basic aspects of the 'Romanian problem' means that the debate now has firmer foundations and can focus on the more interesting aspects of Dacian society, and its use of these coins.

Acknowledgements

I would like to thank Michael Crawford for allowing access to his personal records, and to Andrew Burnett, Roger Bland and the staff of the Department of Coins and Medals for arranging easy access to those records and their library. Thanks are also due to Clive Orton for his help with the original research, Bob Laxton for his comments at the conference, and Richard Wright for his help and comments. I would also like to thank Morven Leese for bringing my attention to her papers, and Thomas Hofman for bringing my attention to the paper by Geman *et al*. (1990). I would also like to thank the Department of Archaeology, University of Southampton, especially Timothy Sly, for allowing me access to their hardware and software. Finally, I would like to thank all my friends and colleagues in Romania, especially Adrian Popescu, Gh. Poenaru Bordea and Virgil Mihăilescu-Bîrliba and their families, for making my research in Romania both possible and pleasant. Any errors remain, as always, the responsibility of the author.

notes

1 The analysis was undertaken using CANOCO (Ter Braak 1987-1992) and the plots produced using CANODRAW (Smilauer 1992). The analysis was performed using symmetric scaling and no transformation of the original variables was performed. The first axis has an eigenvalue of 0.460 explaining 18.5% of the variation in the data set; the second axis has an eigenvalue of 0.305 explaining 12.3% of the data set. Given the size of this data set, these figures are quite acceptable.

2 In his analysis, Creighton is performing Principal Components Analysis, not cluster analysis as stated. Also, for unstated reasons, he uses percentages rather than the original counts and thus needlessly introduces the problem of compositional data (Aitchison 1986).

3 Hoards mentioned in the text are followed by a three-letter code in SMALL CAPITALS; these codes are the unique identifiers from the author's *Coin Hoards from the Roman Republic* (CHRR) database and allow cross-reference to that database, the material deposited on the WWW, and previous publications (e.g. Lockyear 1993). The CHRR database will be made publically available (Crawford and Lockyear forthcoming).

4 The 'structure' of a coin hoard in this paper refers to the pattern of representation of coins in a hoard, grouped by their date of manufacture. Creighton uses the term 'age profile' (Creighton 1992). The term derives from the statistical literature where the aim of some multivariate techniques is described as looking for 'latent structure' (Wright 1989).

5 The terms 'archaic' and 'modern' were coined by Creighton (1992). In this paper, a hoard with an archaic structure has relatively more old coinage than other contemporary hoards; a modern hoard has relatively more new coins than other contemporary hoards; an average hoard is a hoard which has a structure between the two extremes.

6 The Windows version of the *Bonn Archaeological Statistics Package*.

7 Subsequent to the analysis and the presentation of this paper, Morven Leese kindly drew my attention to her papers (Leese 1983; Middleton/Freestone/Leese 1985) which used Dmax as a dissimilarity coefficient. Note however, that Leese uses the term *Kolmogorov-Smirnov distance* to denote Dmax as used here, and *Dmax* to denote the maximum diameter of inclusions in pottery fabrics.

8 Consultation included a posting to the statistics mailing list ALLSTAT.

9 The dendrograms from both these analyses are available on the CAA web server.

10 The initial examination of the results was performed using the dendrogram only. When the detailed results were compiled the agglomeration schedule was consulted, and it was found that the 'cut' had been made at 18.9%. As the level of the cut was arbitrary, it was decided to continue with these groups.

11 This coinage, produced to pay the troops prior to the battle of Actium, is dated by Crawford to 32-31 BC. In all cases where a cointype has a range of dates, the earliest date is used. Hence, these three hoards close in 32 BC, but are almost certainly not concealed until 31 BC or very soon after.

12 Little is written in English about Burebista. Crişan (1978) gives an account, in English, of what is known, although much of the book is speculative.

references

Aitchison, J.A. 1986 *The Statistical Analysis of Compositional Data*. London: Chapman and Hall.

Aldenderfer, M.S. 1982 Methods of cluster validation in archaeology, *World Archaeology* 14 (1), 61-72.

Babeş, M. 1975 Problèmes de la chronologie de la culture Geto-Dace à la lumière des fouilles de Cîrlomăneşti, *Dacia* New Series 19, 125-139.

Baxter, M.J. 1994 *Exploratory Multivariate Analysis in Archaeology*. Edinburgh: Edinburgh University Press.

Braak, C.J.F. ter 1987-1992 *CANOCO; a FORTRAN program for Canonical Community Ordination*. Ithaca, New York: Microcomputer Power.

Buttrey, T.V. 1980 The Cosa hoard, *Memoirs of the American Academy at Rome* 34, 79-153.

Cesano, L. 1903 S. Gregorio di Sassola – Ripostiglio di monete familiari rivenuto nel territorio comunale, *Notizie degli Scavi*, 604-620.

Chirilă, E. / M.Fl. Grigorescu 1982 Tezaurul monetar de la Iclănzel, *Acta Musei Porolissiensis* 6, 141-144.

Chiţescu, M. 1971a Cîteva tezaure monetare romane republicane din Moldova, *Carpica* 4, 159-166.

1971b Copii şi imitaţii de denari romani republicani în Dacia, *Memoria Antiquitatis* 3, 209-258.

1980 Tezaurul de la Poroschia (jud. Teleorman) şi unele probleme privind monedele geto-dacice de tip roman republican, *Studii şi Cercetări de Numismatică* 7, 53-70.

1981 *Numismatic Aspects of the History of the Dacian State*. BAR International Series 112. Oxford: British Archaeological Reports.

Crawford, M.H. 1969 *Roman Republican Coin Hoards*. London, Royal Numismatic Society Special Publication No. 4.

1974 *Roman Republican Coinage*. Cambridge: Cambridge University Press.

1977 Republican denarii in Romania: the supression of piracy and the slave trade, *Journal of Roman Studies* 67, 117-124.

1980 Imitation of Roman Republican Denarii in Dacia, *Studii şi Cercetări de Numismatică* 7, 51-52.

1985 *Coinage and Money under the Roman Republic*. London: Methuen and Co. Ltd.

Crawford, M.H. / K. Lockyear forthcoming *Coin Hoards of the Roman Republic*. Forthcoming combined paper and electronic publication.

Creighton, J.D. 1992 *The Circulation of Money in Roman Britain from the First to the Third Century AD*. Unpublished PhD thesis, Durham University.

Crişan, I.H. 1978 *Burebista and his time*. Bucureşti: Editura Academiei Republicii Socialiste România.

Dittenberger, W. 1917 *Sylloge Inscriptionum Graecarum,* volume 2. Leipzig. Photomechanical reprint 1960, Hildesheim: Georg Orms.

Geman, D., S. Geman, C. Graffigne, P. Dong 1990 Boundary dectection by constrained optimization, *Institute of Electrical and Electronic Engineers: Transactions on Pattern Analysis and Machine Intelligence* 12 (7), 609-628.

Glodariu, I., E. Iaroslavschi, A. Rusu 1992 Die Münzstätte von Sarmizegetusa Regia, *Ephemeris Napocensis* 2, 57-68.

Hersh, C., A. Walker 1984 The Mesagne Hoard, *American Numismatic Society Monographs and Notes* 29, 103-134, pls. 16-19.

Jardine, C.J., N. Jardine, R. Sibson 1967 The structure and construction of taxonomic hierarchies, *Mathematical Biosciences* 1 (2), 173-179.

Leese, M.N. 1983 The statistical treatment of grain size data from pottery, In: A. Aspinall/S.E. Warren (eds), *Proceedings of the 22nd Symposium on Archaeometry, Bradford,* 47-55. Bradford.

Lockyear, K. 1989 *A Statistical Investigation of Roman Republican Coin Hoards.* Unpublished M.Sc. dissertation submitted to the Department of Archaeology, University of Southampton.

1993 Coin hoard formation revisited.... In: J. Andresen/T. Madsen/I. Scollar (eds), *Computing the Past. Computer Applications and Quantitative Methods in Archaeology CAA92,* 367-376. Aarhus: Aarhus University Press.

1996 *Multivariate Money. A statistical analysis of Roman Republican coin hoards with special reference to material from Romania.* PhD thesis submitted to University College London.

forthcoming State, symbol or swindle? The problem of Roman Republican *denarii* in Romania.

Lockyear, K., M.J. Ponting, Gh. Poenaru Bordea forthcoming Metallurgical analysis of Roman Republican *denarii* from Romania. To be submitted to *Dacia.*

Lupu, N. 1967 Aspekte des Münzumlaufs im vorrömischen Dakien, *Jahrbuch für Numismatik und Geldgeschichte* 17, 101-121.

Middleton, A.P., I.C. Freestone, M.N. Leese 1985 Textural analysis of ceramic thin sections: evaluation of grain sampling procedures, *Archaeometry* 27 (1), 64-74.

Mitrea, B. 1945 Penetrazione commerciale e circolazione monetaria nella Dacia prima della conquista, *Ephemeris Dacoromana* 10, 1-154.

1958 Legături comerciale ale Geto-Dacilor din Muntenia cu Republica Romană, reflectate în descoperiri monetare, *Studii şi Cercetări de Numismatică* 2, 123-238.

Mitrea, B., C.S. Nicolaescu-Plopşor 1953 Monete din timpul republicii romane descoperite la Işalniţa (Dolj), *Materiale Arheologice* 1, 543-587.

Mosteller, F., J.W. Tukey 1977 *Data Analysis and Regression.* Reading, Massachusetts: Addison-Wesley.

Norušis, M.J. 1993 *SPSS for Windows, Professional Statistics Release 6*. Chicago: SPSS.

Orton, C.R. 1980 *Mathematics in Archaeology*. London: Collins.

Poenaru Bordea, Gh. M. Cojocărescu 1984 Contribuţii la circulaţia monetară din centrul Transilvaniei în secolul I î.e.n.: tezaurul monetar descoperit la Icland (com. Ernei, jud. Mureş), *Studii şi Cercetări de Numismatică* 8, 53-75.

Popilian, G. 1970 Tezaurul de monede romane republicane descoperit la Dunăreni (jud. Dolj), *Historica* 1, 53-66.

Pozzi, E. 1960-1 Ripostigli Repubblicani Romani nel Museo Archeologico Nazionale di Napoli, *Annali dell'Instituto Italiano di Numismatica* 7-8, 153-245.

Preda, C. 1971 Monedele getice de tip Vîrteju-Bucureşti, *Studii şi Cercetări de Numismatică* 5, 51-79.

Shennan, S.J. 1988 *Quantifying Archaeology*. Edinburgh: Edinburgh University Press.

Sherk, R.K. 1984 *Rome and the Greek East to the death of Augustus*. Translated documents of Greece and Rome volume 4. Cambridge: Cambridge University Press.

Sibson, R. 1972 Order invariant methods for data analysis, *Journal of the Royal Statistical Society Series B* 34, 311-338. With discussion, 338-349.

Smilauer, P. 1992 *CANODRAW. A companion program to CANOCO for publication-quality graphical output*. Ithaca, New York: Microcomputer Power.

Vidal Bardán, J.M. 1982 Tesorillo de denarios romano-republicanos de Torre Juan Abad (Ciudad Real) en el Museo Arqueológico Nacional, *Acta Numismàtica* 12, 79-95.

Wright, R. 1989 *Doing Multivariate Archaeology and Prehistory*. Sidney: Department of Anthropology, University of Sydney.

Kris Lockyear
88 Kent Road
St. Denys
Southampton SO17 2LH
United Kingdom
e-mail: K.Lockyear@soton.ac.uk