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A computer model of Roman landscape in South Limburg

1 Introduction

Edelman and Eeuwens (1959) proposed that the landscape of south Limburg (fig. 1) reveals the effects of a Roman centuriated land survey. This idea attracted some support (Lambert 1971: 48), but it is not generally accepted.[1] Despite this, we should keep an open mind. The hypothesis is difficult to dismiss on theoretical grounds, and it is supported by empirical results which show anomalies in the distribution of Roman sites, similar to those observed in other areas of centuriation.

The centuriation grid (fig. 2) can be located accurately by calculation (Peterson 1993: 43-47). The module is 711.61 m and the orientation is N 42.064° E. One point is located at the Limbricht St-Salviuskerk (186680, 336320) which, according to Edelman and Eeuwens (1959: 53), stands 'precies aan een hoekpunt' (precisely at a corner).

Their evidence for the centuriation is of five sorts: firstly a large number of existing boundaries have a consistent orientation; secondly major boundaries or roads are spaced at multiples of 2400 Roman feet (hence they could represent remnants of major divisions, or *limites*, of the grid); thirdly several medieval churches are positioned on these hypothetical *limites*; fourthly the orientation of some of these churches accords with the proposed grid, and fifthly Roman villas are positioned in a non-random way near the *limites*.

Some of their views can be supported by inspection. Maps show that existing roads, paths and boundaries coincide with the hypothetical *limites* of the centuriation, and on the ground it is clear that several of these features do not conform locally to natural topography.

Quantitative approaches may also be used, and are likely to provide a more secure basis for judgement. An earlier study was that of J.A. Brongers, B.M. Hilwig-Sjöstedt and E. Milikowski, who conducted a numerical analysis of the distribution of the orientation of boundaries. They concluded that the dominant orientations, which vary from place to place, are better related to the morphology of different parts of the landscape than to any overall general Roman influence on the parcelling in the whole region. However, they do not say that there is no centuriation, but that the information cannot be extracted solely from an analysis of modern parcel boundaries (Brongers, pers. comm.).

2 Quantitative study of site distribution

Since this earlier quantitative study was inconclusive, and since, in any case, undateable boundaries may not be seen as a good source of evidence, another approach is adopted here. This measures the claimed association between the grid and Roman sites of all types, including villas, using a database already independently assembled by Martijn van Leusen (1993: 105), using information from the Netherlands State Archaeological Service (ROB). In 1992 it held about 1300 records, of which 491 referred to Roman sites, including villas. This is a large data set which had not been collected together to suit Edelman and Eeuwens' hypothesis. It may therefore be used to test their claim. Given that many Roman (and later) sites are expected to be associated with the *limites*[2], we can examine the distribution of distances of sites from the grid lines, when compared to the distribution of distances which would be expected if the points are scattered uniform randomly with respect to the grid. It seems reasonable to assume that, for a large grid, this latter distribution would arise. The sites may be non-randomly related to natural features, but there is, in many places, very little relationship between these features and the grid (fig. 5).

The Kolmogorov-Smirnov single sample test may be used. The test statistic, D+, is the largest positive difference between the number of points observed at a given distance from the lines of the grid, and the number of points which would be expected on the basis of the null hypothesis (Lapin 1973: 422). In this case it is the maximum value of

$$\left| \frac{i}{n} - (1 - (1 - x_i)^2) \right|$$

where x_i is the distance of the i^{th} point in order of distance from the grid lines (Peterson 1993: 69).

Tables of critical values of D^+ show with what confidence we can reject the null hypothesis. One such table, giving values for sample sizes up to 100 was first presented by Miller (1956). For larger samples the critical value, D^+_α for a given probability, α, can be calculated

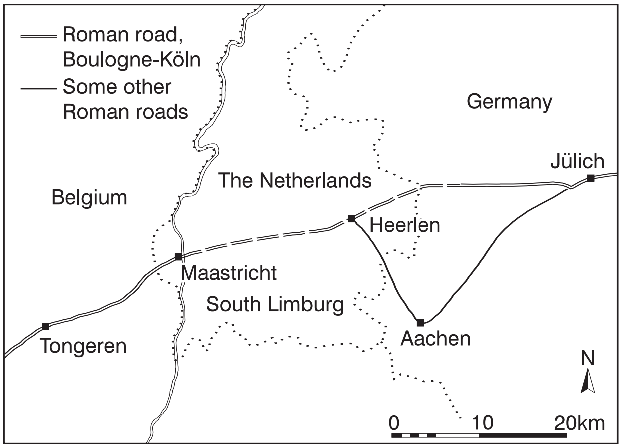
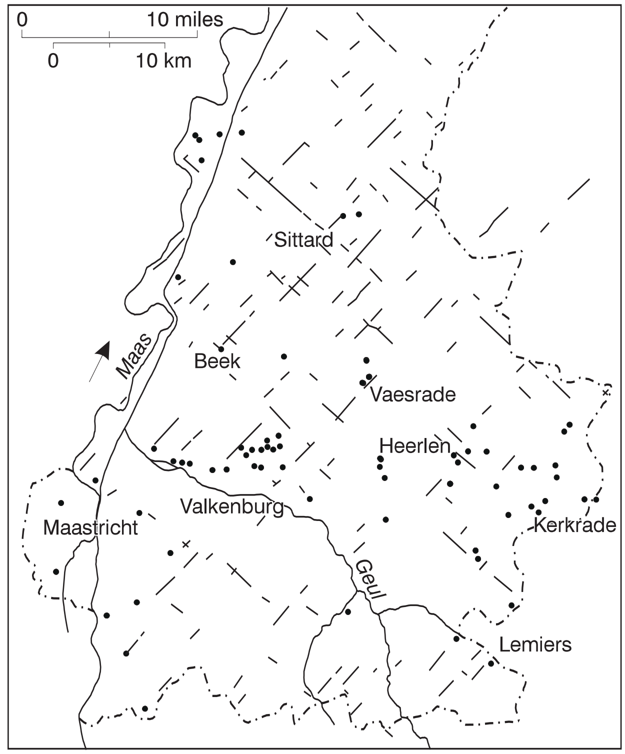


Figure 1. Situation of South Limburg.



× Remnants of decumani and cardines
• Remains of Roman buildings, mainly villas

Figure 2. South Limburg Roman grid (after Edelman and Eeuwens (1959)).

using a version of the asymptotic formula given by Miller, which was originally due to Smirnov:

$$D^{+}_{\alpha} = \frac{\sqrt{\dfrac{-\log_{e}\alpha}{2}}}{\sqrt{n}}$$

We can calculate values of the numerator of this expression for commonly used significance levels (table 1).

Each numerator value divided by the square root of the sample size gives the critical value of D^+. So, for example, if we have 400 observations (square root = 20) the critical value for the .005 significant level is .082. If the D value for the observations achieves this then we can say that the observed distribution would have occurred with less than 0.5% probability on the basis of the null hypothesis.[3]

3 Treatment of the data and initial results

The 491 Roman records were most kindly supplied by Martijn van Leusen, who was not aware of the parameters which had been calculated for the hypothetical grid (and who has no responsibility for my conclusions). They were transmitted as a text e-mail message and read directly into a Microsoft works database (fig. 3).

Prior to performing the tests no attempt was made to modify the data in any way. It was clear that some coordinates referred to the same site, which might for example have both signs of habitation (bewoning) and graves (graf). It was supposed that an objective way of treating the data would be to ignore these cases, on the assumption they were not likely to bias the result of the tests in any particular direction. Several sets of data were tested (table 2) These calculations were performed originally by purpose-written programs on a DEC VAX minicomputer, and again more recently by a Microsoft Excel spreadsheet. Very similar results were obtained in both cases.

In this table, the column headed ‘Near %’ gives the percentage of the sites in each category which lie in the half of the area nearest to the *limites*. For this category the value of distance is less than 0.29289.

‘Significance Level’ indicates which critical value of D is exceeded for the particular number of records. There is clearly some approximate inverse correspondence between this and the measure of bias.

The first line of the table shows that if we take all the data, making no attempt to alter or analyse it in any way, we can say that (as a formal result) there is less than a 0.25% chance that the 491 values are drawn from a set of points distributed at random with respect to the hypothetical survey grid. In other words, it appears that the odds are more than 400:1 against the hypothesis of random distribution.[4] The relatively high significance of this D value must be attributed to the large size of the population, since the degree of bias towards the grid lines is low.

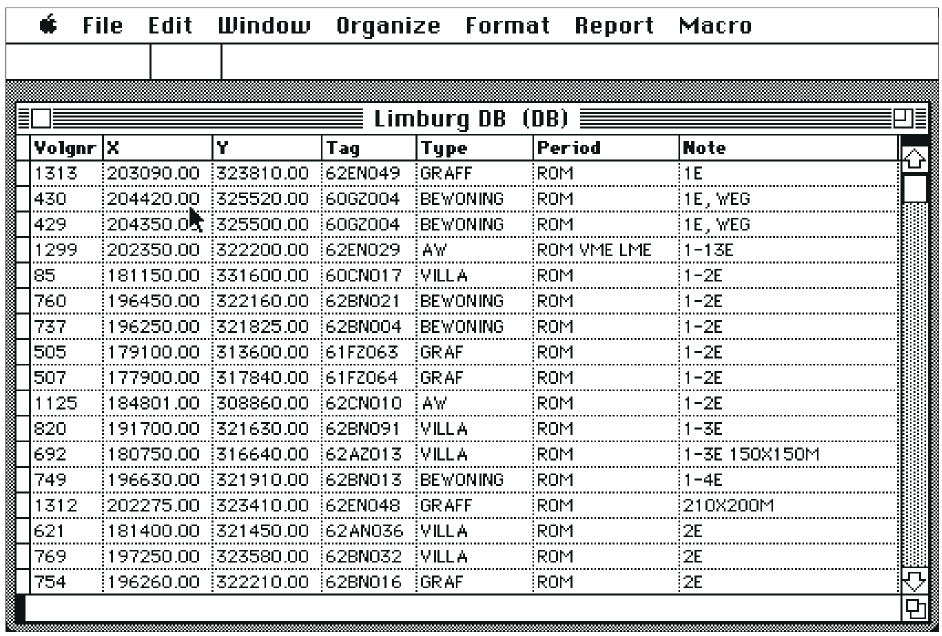
The D values for properly defined subset populations were also considered, since, according to David Clarke

Table 1. Numerator values for calculating significance levels of D^+.

Probability of rejection (α)	.1	.05	.025	.01	.005	.0025	.001	.0005
Numerator Value ($D^+_\alpha \times \sqrt{n}$)	1.07	1.22	1.36	1.52	1.63	1.73	1.86	1.95

Table 2. Some Kolmogorov-Smirnov test results for Limburg data.

	Type	No.	D	Near %	Signifance level
1	All types of record	491	.0825	56.4	0.0025
2	All types (definite and not IA)	419	.0846	56.8	0.0025
3	Definite dwellings (not IA)	85	.1793	62.4	0.005
4	All dwellings	107	.1223	57.0	0.05
5	All villas	153	.1198	56.9	0.025
6	Definite villas	135	.1045	54.8	0.1
7	Temples	2	.8007	100	0.05



Volgnr	X	Y	Tag	Type	Period	Note
1313	203090.00	323810.00	62EN049	GRAFF	ROM	1E
430	204420.00	325520.00	60GZ004	BEWONING	ROM	1E, WEG
429	204350.00	325500.00	60GZ004	BEWONING	ROM	1E, WEG
1299	202350.00	322200.00	62EN029	AW	ROM VME LME	1-13E
85	181150.00	331600.00	60CN017	VILLA	ROM	1-2E
760	196450.00	322160.00	62BN021	BEWONING	ROM	1-2E
737	196250.00	321825.00	62BN004	BEWONING	ROM	1-2E
505	179100.00	313600.00	61FZ063	GRAF	ROM	1-2E
507	177900.00	317840.00	61FZ064	GRAF	ROM	1-2E
1125	184801.00	308860.00	62CN010	AW	ROM	1-2E
820	191700.00	321630.00	62BN091	VILLA	ROM	1-3E
692	180750.00	316640.00	62AZ013	VILLA	ROM	1-3E 150X150M
749	196630.00	321910.00	62BN013	BEWONING	ROM	1-4E
1312	202275.00	323410.00	62EN048	GRAFF	ROM	210X200M
621	181400.00	321450.00	62AN036	VILLA	ROM	2E
769	197250.00	323580.00	62BN032	VILLA	ROM	2E
754	196260.00	322210.00	62BN016	GRAF	ROM	2E

Figure 3. Initial part of database of Roman archaeological records for South Limburg.

(1978: 150), 'One important corollary of the aggregate or composite nature of archaeological entities is that such populations exhibit their own specific 'behavioural' characteristics which are more complex than the simple sum of the characteristics of the components and more predictable than that of the individual components. One of the main tasks therefore, is to detect and trace these persistent regularity patterns in archaeological data and to use these predictable regularities as tests for real data. If the real data displays the regularity predicted then it should fulfil some already established conditions. If the real data departs from the predicted pattern then some conditions are not fulfilled and the nature of the discrepancy may suggest the divergent conditions responsible for the anomaly.'

Clarke seems to be suggesting that we can split up the data and observe the discrepancies to see if they suggest divergent conditions. Only one variable is being measured in this case (the distance of sites from *limites*), but we can consider predefined subset populations (those have already been defined by attribute values in the database). This does nothing to invalidate the result obtained from the population as a whole, and may provide us with additional useful information.

One subset of the data is obtained if we exclude sites with previous Iron Age use, together with sites not certainly identified or not certainly Roman. For this set (table 2, line 2) the bias towards the grid lines increases slightly, but otherwise we gain little new information.

Another way of selecting subsets is by the type of site. Settlement sites are called ‘bewoning’ (dwelling) or ‘villa’. Definite Roman dwelling sites with no Iron Age occupation on the same site (see line 3) have a very definite bias towards the *limites*. Their distribution is approximately 20 times more unlikely than that of dwelling sites in general (see line 4). This seems to confirm our expectation that, in general, sites with signs of Iron Age habitation will not be significantly associated with the grid, and that their inclusion in the set of Roman dwelling sites will reduce its apparent degree of association.

For villas (table 2, lines 5 and 6) we see the opposite. The more certainly they are villas, the less anomalous is their distribution. This apparently paradoxical result may not be totally due to a reduction in the sample size. It has been suggested (Peterson 1993: 75) that some genuine villas, as opposed to Roman dwellings of lower status, would be deliberately placed away from *limites*.

These results are shown in graphical form (fig. 4). The continuous lines show the levels of significance for D^+.

Finally, table 2 also gives a D value for the two temples in the area. The significance of this is high because, to the accuracy of 10 m with which grid location is determined, the temples both lie on *limites*. This was predicted, following the example of other centuriations and written evidence on the practice of the Roman land surveyors.

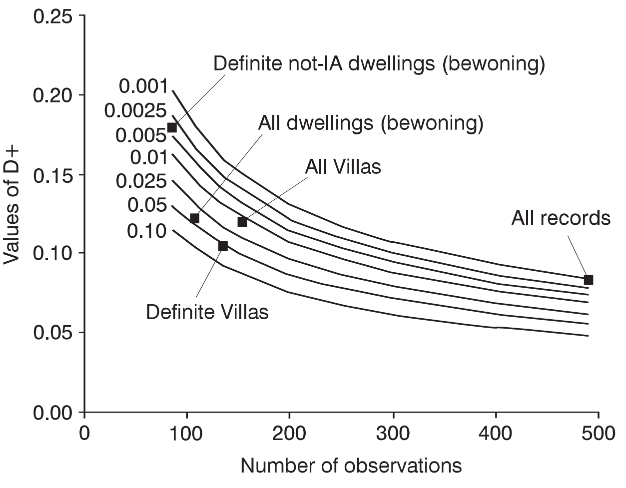


Figure 4. D values for all records for different types of settlement.

4 Studies of a sample area

Willems (1987) considers in greater detail the area of Heerlen (Coriouallum), near the centre of South Limburg, in which there are 118 database records, including data on 52 settlement sites. There are relatively few possible traces of *limites* in existing landscape features, but the D value for records of all types, which is significant at the 5% level, gives us no reason to think that the area is different from South Limburg as a whole. This independently selected sample thus seems suitable for tests of two alternative hypotheses on the origin of the landscape.

Willems’ view (1987: 50), in reference to his map of Roman site distribution in the area (fig. 5), is that ‘Waar het landschap door beken wordt doorsneden is ook heel fraai te zien dat op elk plateau daartussen steeds een villa ligt. Er was dan ook geen sprake van een kunstmatige landindeling — (*centuriatie*) maar men paste zich aan het landschap aan.’ (Where the landscape is cut through by streams it is very satisfying to see that on each intervening plateau there is the site of one villa. There is thus no question of an artificial land allotment (*centuriation*). Rather, the sites are related to the [natural] landscape.)

Willems’ hypothesis is, therefore, that natural topography, and nothing else, has determined settlement locations. If this is really so, then it seems to be influencing settlement distribution in a way normally associated with centuriation, as the Kolmogorov-Smirnov statistic indicates. Assuming for a moment that the villas really are located on the plateaux between streams, could the spacing and orientation of these plateaux be in some way peculiar? Perhaps they are regularly spaced at about 710 m, and by some strange chance the grid (which was determined by distant and independent features) happens to coincide with their crests. This seems unlikely. We already have evidence of a number of differently oriented, naturally induced, parcel boundaries in different parts of South Limburg, which implies that the natural topography does not have significant uniform orientation or regularity. In fact, on this map there is little evidence of the grid coinciding with natural topography. Only in the northwest corner is this so; but there we see *limites* coinciding with the valleys of streams, not with plateaux.

Could these difficulties be caused by the assumption that Willems’ claim is true? Does a close look at the map confirm that the villas really are on the plateaux? The answer is ‘only in some cases’, for we can see villa sites (A-E) which appear to be on the boundary between ‘beekdal’

1 stream valley (beekdal)
2-4 loess
5 peat
6 quarry
7 grave (field)
8 road
9 villa
10 non-villa settlement
11 industry

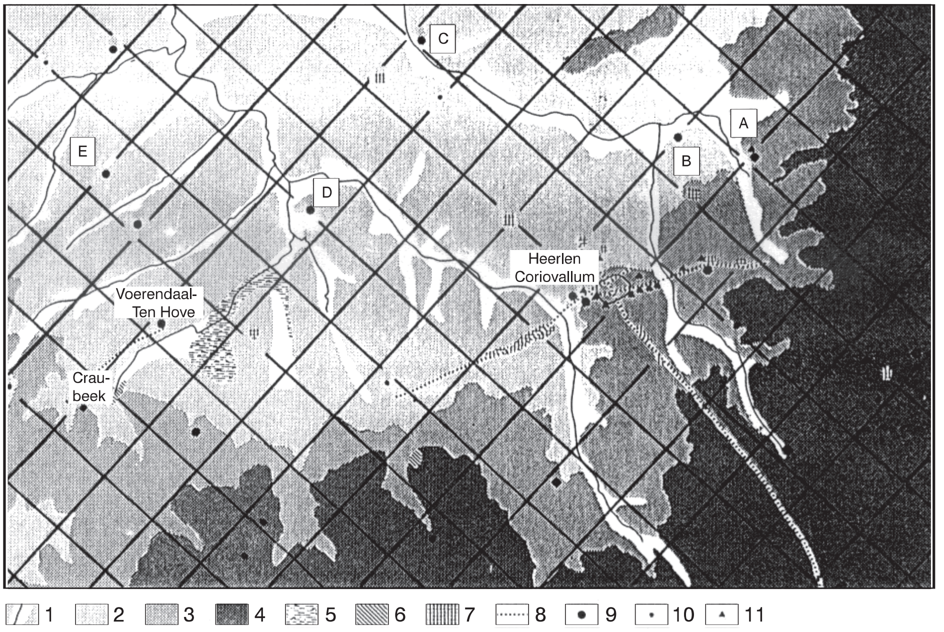


Figure 5. Roman sites in the area of Heerlen (after Willems 1987), with theoretical *limites* superimposed).

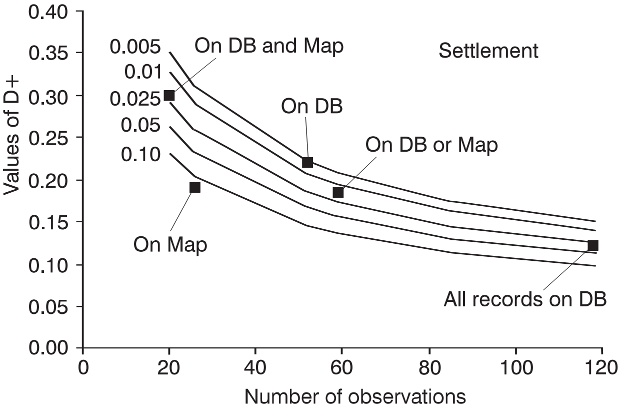


Figure 6. Comparison of D values for settlement in the Heerlen area on Database (DB) and on Willems' (1987) map.

(stream valley) and loess. The villa at point E is a case in point, despite the fact that it also lies on the plateau between two other streams. Thus Willems' statement about villa siting in relation to the natural landscape results from a particular interpretation of the data. He did not draw the centuriation on his map. He was thus not in a position to see the coincidences of settlements and *limites* to the west and north of Heerlen, and in particular those counter-examples to his theory of environmental influence which might be better explained by the presence of the centuriation.

However, it is not just a question of interpretation. Judgements also vary according to the evidence which is presented, as we can see if we compare the settlement sites (villas and dwellings) on the database with those Willems shows on his map. Willems' map of sites can be matched to a reduced copy of the Topographische Dienst 1:25,000 topographic map, which includes the Dutch survey grid. When duplicates had been eliminated from the data base, it was possible to identify those database sites most closely corresponding to Willems' map features. Hence we can identify the discrepancies in the data, including settlements on the database which he does not show, and settlements shown by him which are not on the database (see table 3).

D values can also be calculated (fig. 6). It is curious to see how the database records (the author's data source) give the highest D value (P< 0.01), and the map points (Willems' source) the lowest. In fact, the distribution of the latter with respect to the centuriation could not be regarded as significantly different from random. Nevertheless, there are 20 records, those in both sets, about which there is agreement. An independent arbitrator who selected these would find that they have a significantly high D value. The idea that they are randomly distributed with respect to the grid can be rejected at odds of 40:1.

So, if we select from Willems' sites only those which are independently confirmed, we find that they do not speak against the idea that the centuriation exists.

Table 3. Comparison of Willems map and Database data.

		Coordinates			Type		
Volgnr	Tag	X	Y	dist.	(DB)	(Map)	Notes
767	62BN030	19010	32090	61	BEWONING	N G V	N G V = non villa settlement
846	62BN111	19048	32435	64	BEWONING	N G V	
840	62BN108	19085	32069	47	BEWONING	N G V	
746	62BN011	19108	32315	7	VILLA	VILLA	Nearest of four Volgnr
824	62BN094	19120	32450	54	VILLA	VILLA	Nearest of two Volgnr
864	62BN127	19140	32310	248	VILLA	-	
843	62BN109	19145	32262	89	VILLA	VILLA	
818	62BN091	19166	32163	18	VILLA	VILLA	Voerendaal, nearest of two Volgnr
810	62BN081	19206	32044	311	VILLA	VILLA	
860	62BN123	19207	32165	164	?BEWONING	-	
771	62BN035	19215	32130	108	VILLA	-	?Error, in area of “veen” (bog)
819	62BN091	19215	32165	110	VILLA	-	
770	62BN034	19240	32070	64	BEWONING	-	
		19260	31910			N G V	
869	62BN131	19278	31965	41	BEWONING	N G V	
868	62BN130	19335	32278	109	VILLA	VILLA	
836	62BN104	19412	32095	22	?VILLA	N G V	
835	62BN103	19452	32460	110	VILLA	VILLA	
870	62BN132	19458	31926	216	?BEWONING	N G V	
855	62BN119	19470	32400	24	?BEWONING	N G V	
907	62BN163	19501	32017	4	?BEWONING	-	
831	62BN099	19593	31990	78	VILLA	VILLA	
772	62BN037	19595	32030	10	VILLA	-	
733	62BN001	19597	31995	74	BEWONING	-	
		19610	32190			VILLA	?A generic point
737	62BN004	19625	32183	76	BEWONING	VILLA	
778	62BN043	19628	32178	93	BEWONING	-	
777	62BN042	19630	32160	75	BEWONING	-	
779	62BN044	19640	32180	2	BEWONING	-	
764	62BN025	19640	32240	175	BEWONING	-	
780	62BN045	19642	32190	90	BEWONING	-	
792	62BN056	19645	32186	80	BEWONING	-	
760	62BN021	19645	32216	303	BEWONING	-	
739	62BN006	19650	32185	94	BEWONING	-	
743	62BN010	19652	32180	46	BEWONING	-	
789	62BN052	19657	32197	122	BEWONING	-	
784	62BN048	19660	32180	14	BEWONING	-	
776	62BN041	19660	32185	20	VILLA	-	
793	62BN057	19660	32190	53	BEWONING	-	
816	62BN088	19660	32205	154	BEWONING	-	
761	62BN022	19660	32207	167	BEWONING	-	
749	62BN013	19663	32191	38	BEWONING	-	
753	62BN015	19670	32180	88	BEWONING	-	
785	62BN049	19670	32195	12	BEWONING	-	
775	62BN040	19690	32215	2	BEWONING	-	
847	62BN112	19698	32208	108	BEWONING	-	
769	62BN032	19725	32358	15	VILLA	VILLA	
		19760	32210			VILLA	
806	62BN073	19780	32215	41	BEWONING	-	
		18790	32150			N G V	?Badly plotted Volgnr 806
		19810	32330			VILLA	
833	62BN101	19839	32026	192	VILLA	-	
808	62BN076	19845	32020	188	VILLA	VILLA	
925	62BZ015	19900	31865	117	BEWONING	VILLA	
748	62BN012	19906	31955	114	BEWONING	-	
		19940	32080			N G V	
814	62BN085	19980	32133	142	VILLA		
834	62BN102	19990	32126	21	VILLA	VILLA	

5 The trustworthiness of the Kolmogorov-Smirnov test results

The statistics of Roman site distribution in general, and especially the distribution of settlement in the area of Heerlen, seem to provide evidence against the well-established belief that the centuriation of Limburg does not exist. We must therefore examine them carefully for possible flaws. For this purpose a number of simulations were run, generating a further 812 Kolmogorov-Smirnov D values.

First, duplicate grid references were eliminated, giving 456 (rather than 491) data items. For this set the probability of observing the D value at random was 1:280, rather than 1:802. This reduction in significance suggests that an 'objective' approach to the data, as used originally, may give a misleading result. Clearly, the significance of a particular D value will be increased by maintaining the same cumulative distribution of observations, while increasing their number. For this reason the settlement data for the Heerlen area were processed to remove duplicates. Another surprise was that a shift of origin of the grid — from that originally used to another point calculated using the grid parameters — produced a noticeable change in the probability of the D value. For the 491 original data items it changed from 1:802 to 1:594. For 456 unique sites it changed from 1:280 to 1:222. These changes are probably caused by the precision of calculating grid intersection coordinates, which is only to 10 m.

Following a suggestion by Irwin Scollar, it was tested whether the same grid, with the same origin points, might fit the data just as well at other angles. All possible angles (42.064° ±45°, at intervals of 1°) were tried, using both data sets for the original origin and the reduced set for the shifted origin. This produced 267 D values for other angles. Of these, seven were less probable than 1:89 — that is about twice as many as expected — and two were less probable than the values observed at 42.064°. A further simulation was run with 456 randomly generated grid references in a 4 km by 4 km square. Again there were 3 trial runs, each covering 90°. The results showed 40 D values with a probability of less than 1:5 — roughly the expected value. However, there were five D values which were less probable than 1:90. This is again more than expected, but further work would be needed to see if the difference is significant.

The conclusion for the tests on the whole data set is that the significance may be exaggerated by a factor of two, but the reason for this is currently unknown. The practical implication is that the p values for the significance levels given above (table 2) should be doubled. Despite this, inferences drawn from the figures are unchanged.

Similar simulations were conducted on the Heerlen data. For 3 runs of 90° each, there were 52 D values with a probability of less than 1:5 and 31 with a probability of less than 1:10 — very near the expected values. However, excluding the values for 42.064°, there were five values with a probability less than 1:89. Hence, looked at from random angles, these site coordinates have the characteristics of random data, but the lowest probabilities obtained in 'real' trials may be not totally reliable. Nevertheless, the test results (fig. 6) are still useful, even if the significance level p values are doubled.

6 Proposals for further work

To test Edelman and Eeuwens' hypothesis further, even more data would be useful. This might be obtained from areas of the centuriation lying outside the modern day borders of the Netherlands, which would have to be located on other national maps. Dutch maps use the national rectangular coordinate system (as does the ROB database), but they also include in the margin the lines of the UTM zone 31 kilometre grid. From this the parameters of the centuriation may be recalculated. Hence coordinates for the grid intersections may be calculated and plotted for Belgium, which uses UTM grids.

Similarly the centuriation grid may be extended to Germany, using slightly different methods. The geographic coordinates of two intersection points of the centuriation could perhaps be calculated from their UTM zone 31 coordinates, and then used to calculate the equivalent Gauss-Krüger (GK) coordinates for German maps, by means of Scollar's (1989) computer programmes. Alternatively, it is easier in practice to plot intersection points, already plotted on overlapping Dutch and Belgian maps, at the same positions on the German maps. Coordinates can then be read directly, and the angle of the centuriation calculated in terms of north in the local GK grid.

Preliminary results show that near Aachen (fig. 1) some existing topographic features and the former main road from Aachen to Jülich have the same orientation as the hypothetical grid. This is also true of three of the four villas (Gaitzsch 1987) which were excavated in the Hambacher Forst, east of Jülich, between that place and Köln. Wolfgang Gaitzsch in another article (1986: 427) concludes that 'Die regelmäßigen Eingrenzung der Wohn- und Wirtschaftsbereiche ist der Ausdruck einer planmäßigen Limitation des Nutzlandes der CCAA' (the regular boundary layout of living and working space is the expression of a planned *limitatio* [i.e. Roman land survey] of the productive land of CCAA [Köln]). Further data on site location in this area could be used to test the compatibility of Edelman and Eeuwens' with Gaitzsch's hypothesis.

7 Conclusions on the objections to the centuriation hypothesis

There are two principal theoretical objections to the centuriation hypothesis. The first is that a large centuriation such as that of South Limburg could not exist and that it could not extend so far. This view is mistaken. A larger and much less visible system existed in an equally marginal situation in the empire, in southern Tunisia (Trousset 1978). Not only was it very large, but it ignored tribal boundaries, which were established in the area of the existing survey. So, we may, with Monique Clavel-Lévêque (1993:19), be sceptical that a centuriation could cross a Roman provincial boundary which in this case is thought to lie at about Aachen (King 1990: 212), but such a thing is possible. As Tate (1992) has suggested in the case of Roman surveys in Syria, ‘Juxtaposés ou superposés, ces réseaux ne dépendent pas des *limites* entre provinces, cités ou finages de villages. Ils occupent des aires si vastes qu'ils ne peuvent avoir été construits que par ordre d'une autorité supérieure, ...’. So, according to him also, surveys ignored provincial boundaries. There is thus no theoretical objection to the extension of the South Limburg centuriation across the border, even if we knew precisely where it was.

The second objection is the one Willems raises. In short, if natural features explain settlement location, then an alternative explanation is false. This is mistaken in practice, because close examination of the map of sites — in conjunction with the database — does not confirm that they are really located according to some simple environmental constraint. It is also mistaken in principle. Even if a convincing demonstration had been made that settlement in the area of Heerlen is strongly influenced by natural topography, the centuriation could not be ruled out. Surely, we must allow the world to be a complex reality in which many factors act at the same time to influence human actions, a world in which human beings, by use of their intellect within a cultural framework, manage to satisfy different types of constraint simultaneously.

Much of ‘hard’ science seems to be founded on a mistrust of complexity, on a feeling that simple answers are most likely to be true and on the acceptance of William of Occam's principle that explanations need not be expanded beyond what is necessary. This is not appropriate to the study of landscapes which have been worked and reworked by man. They need a more open approach, such as that advocated by Lawson and Staehali (1990), which fits the author's experience of Roman systems of land management (Peterson 1993: 255). If investigation methods were framed in this spirit, we would be more suspicious of attempts to give such simple answers and we would more easily avoid the self-destructive over-application of Occam's razor.

notes

1 It is surprising that sceptics include Oswald Dilke (1971: 140), who discussed other equally controversial systems in favourable terms.

2 This association is hardly in doubt. It may be for symbolic reasons, as in the case of Roman temples marking the survey lines. It may also be economic, since *limites* existing as means of communication, i.e. roads or canals, provide low cost access. There are very clear examples, such as sites in the northern *Ager Cosanus* dated to the 2nd century BC, which have been found ‘only on the major axes of the centuriation’ (Attolini *et al*. 1990: 145). Again, according to Caillemer and Chevallier (1954: 458), ‘Des routes, des voies ferrées, des pistes d'aérodrome, des *limites* de commune s'orientent de même pour éviter de couper les cultures dont les contours correspondent toujours à la répartition antique du sol; il arrive souvent que des grandes fermes modernes soient situées à l'emplacement de ruines romaines, dans l'angle de centuries.’ It should, however, be noted that these are extreme cases in which all or most sites are on or near *limites*. Other cases are less clear. They may require statistical techniques in order to measure the association.

3 If we were interested in both positive and negative values of D, we would calculate the critical values, D_α using the very similar asymptotic formula (Rohlf/Sokal 1969: 249):

$$D_\alpha = \frac{\sqrt{\dfrac{-\log_e 1/2\alpha}{2}}}{\sqrt{n}}$$

However, in this case it seemd most appropiate to follow Lapin in considering only positive values, since this is the deviation from randomness which has meaning in the context of our theory. Lapin's published critical D values for a sample of 100 (taken from Miller), are then close to values calculated using Smirnov's formula.

4 According to the calculations described above, the chance of such a high D being seen at random is about one in 800.

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