CHAPTER 27

DO GREEN BELTS CHANGE THE SHAPE OF URBAN AREAS ? A PRELIMINARY ANALYSIS OF THE SETTLEMENT GEOGRAPHY OF SOUTH EAST ENGLAND

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Do Green Belts Change the Shape of Urban Areas? A Preliminary Analysis of the Settlement Geography of South East England

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LONGLEY P., BATTY M., SHEPHERD J. and SADLER G. (1992) Do Green Belts change the shape of urban areas? A preliminary analysis of the settlement geography of South East England, *Reg. Studies* **26**, 437–452. In this paper, we embark on a preliminary exploration of the settlement geography of South East England, with specific reference to the effect that the green belt has had upon the shape and size of towns comprising this region. In common with several other researchers who have examined the impact of such containment policies, we argue that the green belt is likely to have had a significant effect on the geometry of settlement, distorting the geometry from the urban forms which might have arisen in the absence of such policy. We tackle this problem by hypothesizing four different scaling relations which pertain to size and shape. These are based upon allometric relations which explain population size in terms of built-up area and the urban field within which urban development takes place, and upon geometric relations which explain how the irregularity of the envelope bounding urban settlements is related to the areas of the built-up development and the urban field. Using a unique and only recently available digital data base on the boundaries of settlement in South East England, we show that there are indeed significant differences between settlements which have been subject to green belt policy and those which have not been so affected. In essence, settlements which have been constrained by green belt policy are more irregular and fill less of the space available to them than settlements which are not so constrained. We also note that some caution is required in interpreting these results but that the analysis, which is in its preliminary stages, appears promising and has great potential for exploring the physical efficiency of settlement geometry and the extent to which this is changed through green belt policy.

Urban allometry   Urban morphology   Size and shape   Scaling relations   Urban development   Green belts

LONGLEY, P., BATTY M., SHEPHERD J. et SADLER G. (1992). Les ceintures vertes, changent-elles la forme des zones urbaines? Une première analyse de la géographie de l'habitat du Sud-Est de l'Angleterre, *Reg. Studies* **26**, 437–452. Cet article fait une première analyse de la géographie de l'habitat du Sud-Est de l'Angleterre en tenant compte de l'effet de la ceinture verte sur la forme et la taille des villes que comprend cette région. De pair avec d'autres chercheurs qui ont examiné l'impact de telles politiques d'endiguement, nous affirmons qu'il est probable que la ceinture verte a eu un impact considérable sur la géométrie de l'habitat en finissant par altérer les formes qui auraient pu évoluer en l'absence de telles politiques. Nous abordons ce problème à partir des hypothèses relatifs à quatre échelles différentes qui se rapportent à la taille et à la forme. Celles-là sont basées sur des rapports allométriques qui expliquent la taille de la population en termes de l'agglomération et de la zone urbaine au sein desquelles a lieu le développement urbain, et sur des rapports géométriques qui expliquent la

LONGLEY P., BATTY M., SHEPHERD J. und SADLER G. (1992) Verändern Grüngürtel die Form von Stadtgebieten? Eine vorläufige Analyse der Siedlungsgeographie Südostenglands, *Reg. Studies* **26**, 437–452. Dieser Aufsatz stellt eine vorläufige Untersuchung der Siedlungsgeographie von Südostengland dar, wobei die Aufmerksamkeit besonders auf die Wirkung des Gründgürtels auf Form und Grösse von Städten in diesem Gebiet gelenkt wird. Wie schon mehrere andere Forscher, die die Auswirkung solcher Beschränkungsbestrebungen untersucht haben, stellen die Autoren die Behauptung auf, dass der Grüngürtel wahrscheinlich die Geometrie der Besiedlung bedeutend beeinflusst und die Geometrie der Stadtformen, die ohne solch eine Politik entstanden wäre, verformt hat. Der Aufsatz geht dieses Problem mit Hilfe einer Hypothese von vier, nach Form und Grösse verschiedenen Grössenbeziehungen an. Diese beruhen auf allometrischen Beziehungen, welche Bevölkerungsgrösse von der Bebauungsfläche, und dem Stadtgebiet, in dem façon dont l'asymétrie de l'enveloppe qui englobe les habitats urbains se rapporte aux agglomérations et aux zones urbaines. A partir d'une base de données unique et numérique qui est maintenant disponible et qui concerne les limites des habitats dans le Sud-Est de l'Angleterre, nous montrons qu'il y a en effet des divergences considérables entre les habitats soumis à la politique de ceinture verte et les autres. Pour l'essentiel les habitats soumis à la politique sont plus asymétriques et occupent moins de l'espace qui leur est disponible par rapport aux habitats qui ne sont pas soumis à une telle contrainte. Nous constatons aussi qu'il faut interpréter les résultats avec prudence. Toujours est-il que la première analyse semble porteur et prometteur quant à l'examination de l'efficience physique de la géometrie des habitats et de l'importance des changements suite à la politique de ceinture verte.

Allométrie urbaine Morphologie urbaine
Taille et forme Rapport d'échelle
Développement urbain Ceinture verte

städtische Entwicklung stattfindet, her erklären, sowie auf geometrischen Relationen, welche zeigen, wie die Unregelmässigkeit der die städtischen Siedlungen begrenzenden Hülle sich zu Gebieten überbauter Erschliessungsgebiete und dem Stadtgebiet verhält. Unter Zuhilfenahme einer einmaligen und erst seit kurzem verfügbaren digitalen Datenunterlage betreff Siedlungsgrenzen in Südostengland wird aufgezeigt, dass es tatsächlich bedeutende Unterschiede zwischen Siedlungen gibt, die einer Grüngürtelpolitik unterworfen, und solchen, die davon nicht betroffen waren. Im Wesenlichen sind von Grüngürtelpolitik eingehemmte Sidelungen unregelmässiger, und füllen weniger des verfügbaren Raumes als nicht derartig eingezwängte Siedlungen. Es wird auch festgestellt, dass bei der Interpretation der Ergebnisse Vorsicht geboten ist, doch dass die Analyse, die sich noch in ihren Anfangsstadien befindet, vielversprechend zu sein scheint, und vielerlei Möglichkeiten der Untersuchung der physikalischen Leistungsfähigkeit der Siedlungsgeometrie und des Ausmasses bietet, indem sie dank Grüngürtelpolitik Veränderungen unterworfen ist.

Städtische Allometrie Städtische Morphologie
Form und Grösse Masstäbliche Relationen
Städtische Entwicklung Grüngürtel

INTRODUCTION

The idea of a 'green belt' of open land encircling a major city and embracing both small and medium sized settlements located in the hinterland of a 'core' city is one of the main philosophical and practical underpinnings of British town and country planning (RAVETZ, 1980). As such, both the idea and the practice of green belts as a planning policy instrument have been debated and implemented most extensively in relation to the Metropolitan Green Belt (MGB), an annular tract of land now extending for between 25–40 km in width around the Greater London conurbation. Not unnaturally, given both its scale and importance and the nature of the development pressures upon it, the MGB has, over the years, been the subject of considerable research attention on such matters as the distribution of land uses within it, its impact on land prices within urban areas, the function it performs in terms of human activities, and who gains and who loses from its continued existence (HALL *et al.*, 1973; MUNTON, 1983; ELSON, 1986; EVANS, 1989).

Although the origins of the MGB (and indeed of green belts generally) can be traced to the Garden City movement pioneered by Ebenezer Howard (1898) and the more conceptually based work of Raymond Unwin for the Greater London Regional Planning Committee (1927–36), the main post war impetus for the implementation of a complete *cordon sanitaire* around London came from Sir Patrick Abercrombie's 1944 Greater London Plan (ABERCROMBIE, 1945). This had the multiple aims of stopping the outward growth of London itself, preserving open land for agriculture and recreation and preventing the coalescence of towns contained within it. In 1946 the multiplicity of aims contained within Abercrombie's green belt proposals were accepted by central government, although the over-riding objective was, and continues to be, to contain the growth of urban areas (ELSON, 1986). The broader policy was to be effected through the development plan provisions of the Town and Country Planning Act 1947, and its proposals were implemented with a certain enthusiasm by the seven county planning authorities surrounding London (MANDELKER, 1962). The present extent of the MGB was basically established in the structure plans of the mid-1970s (SERPLAN, 1976) and although there were four main categories of green belt in operational terms (i.e. originally submitted and approved, approved extensions, extensions with interim approval and areas where green belt controls were operated with central government acceptance), to all intents and purposes broadly similar restraint measures became operative over the whole MGB area (ELSON, 1986).

The context and the means for containing growth was set out in two circulars issued by the Ministry of Housing and Local Government (MHLG) in 1955 and 1957. They first established the *objectives* of green belt controls. These were: to check the further growth of a large built up area; to prevent neighbouring towns from merging into one another; and to preserve the special character of a town (MHLG, 1955). From this point on, therefore, the statutory support for operating development controls within green belts rested ultimately on concerns about urban *form* (and, working indirectly, through form on urban functions) and not on the preservation of urban land for agriculture or recreation (ELSON, 1986). The second circular (MHLG, 1957) introduced, among other things, the concept of 'white land' parcels between the town and the green belt which would not be developed in the contemporary plan period but which could be developed later without prejudice to the strategic and local objectives of a green belt. Thus whilst the objective of green belt planning was to be the control of urban form, there was also scope for some locally-declared policy which might, in the longer term, result in a changed settlement pattern (ELSON, 1986).

We might anticipate that this dual strategy of central direction about aims and local autonomy about means has had an impact upon the nature and form of settlements, yet this is a subject which has never yet been researched in anything but superficial descriptive terms. The only extensive studies of the impact of green belts upon urban form are those carried out by Elson and his colleagues and these show that, for a very small number of settlements, the provision of 'white land' on the periphery of settlements was indeed a significant local determinant of change in the pattern of urban land uses (ELSON, 1986). Clearly, however, there is a need for a more broadly based and systematic empirical analysis of the impact of physical planning controls such as green belts on the form of urban settlements.

In this paper we will make a first attempt to address this issue, using the Office of Population Censuses and Surveys (OPCS) urban areas database (OPCS, 1984) which has now become available in digital form for the first time. Using a series of indices of the size, shape and dimension of urban settlements which have recently been devised and refined in more theoretical terms (LONGLEY *et al.*, 1991), we will consider the degree to which the form and density of urban settlements has been influenced by green belt designation, and we will attempt to discern apparent variations in the spatial manifestations of what is first and foremost a national development policy. To this end, we will develop a straightforward analysis of the physical extent of urban areas in South East England and attempt to interpret shapes and forms with respect to the presence or absence of direct green belt policy on their development. We will also draw some general conclusions as to the prospects for devising more coherent settlement classification systems which incorporate quantitative measures of shape, dimension and density. Our analysis thus seeks to link new measures of urban shape and form to the practical consequences of policies which seek to mould and constrain urban development, using computer models and techniques and digital data available for such analysis for the first time. It is in this sense that our analysis is preliminary and thus represents only a starting point for a broader research agenda.

DEFINING AND MEASURING THE GEOMETRY OF URBAN DEVELOPMENT

In defining the impact of physical planning policies, particularly those involving restricting urban development using instruments such as green belts, it is essential to evaluate their effects by examining the extent to which the physical form of development departs from the 'norm'. In this quest, we need to define urban form not only in terms of the size of development but also in terms of its shape. This is important because policy instruments such as new towns and green belts have often been implemented in terms of idealized forms such as those characterizing the British new towns and garden cities. Rigorous study of the size and shape of urban settlements, however, is in its infancy. Despite the emphasis in land use planning upon controlling and influencing the size and shape of towns, most work has hitherto been cast in a somewhat idealistic mould reflecting a fascination with form and shape for its own sake rather than as a consequence of the processes and decisions which condition the spread of urban settlement.

Accordingly, in attempting to define and measure the physical influence of green belts, we must first introduce some relevant relationships based on size and shape which will serve to detect the sort of impacts we are searching for. In essence, we will define *size* in terms of *population* P and *shape* in terms of the length of the *envelope* E which bounds the development in question. Both these measures we will relate to the *area* of the settlement. In turn, we will introduce two definitions of area characterizing the development: first there is the *built-up area* A which is bounded by the envelope E and contains the population P; and, second, there is the *urban field* U which represents the circular space within which the settlement is developing, including space which has not yet been built-up but which can be thought of as the 'contact field' over which the growing settlement has influence (HAGERSTRAND, 1952).

The first set of relationships enables us to relate size to area. Typically, this involves us in allometric relations which have been quite widely explored in biology (GOULD, 1966; DUTTON, 1973) while the second set of relations based on shape and area typically involve geometry. Furthermore, allometry enables us to show that the relations we use are linked to density while geometry enables us to link our measures to measures of irregularity. In fact, this whole area involving the geometry and morphology of urban form is part of a new geometry of nature of major importance to both art and science (MANDELBROT, 1982). The implications of this new geometry for physical structure in a variety of disciplines are wide and diverse but their development here in anything other than a cursory fashion would be a digression. Interested readers are referred to a related paper by the authors (LONGLEY *et al.*, 1991) for a detailed discussion.

We will now define the relationships which we seek to use in measuring the impact of green belts later in this paper. In relating the size of the population to its built-up area, we define the following scaling relation:

$$P = bA^B \tag{1}$$

where: b = a constant of proportionality
B = a scaling parameter.

Equation (1) is the standard allometric relation. If the parameter B is greater than unity, this implies that population or mass grows at a faster rate than the area of the object in question—in other words, that there is a positive allometry. If B is less than unity, this is called negative allometry while if B is unity, then this is called isometry. However, in relations of this kind, it is more appropriate to represent area using a linear distance scale r which is assumed to be $\sqrt{A}$. Then equation (1) can be written as:

$$P = b[(A)^{1/2}]^d = br^d \tag{2}$$

where r can thus be considered a 'derived radius' of the settlement in question and d is a measure of dimension.

After we introduce each relation, we must explain its nature and the typical parameter values which such a relation might manifest in different contexts. In the case of equation (1) or equation (2), we would argue that populations grow at much the same rate as their built-up areas. We do not consider that the populations of towns grow faster than their areas, a relationship which would imply that the parameter B is greater than unity. This would also imply that settlements grow into their three-dimensional space and, although there are analysts who have suggested such positive allometry based on the notion that the archetypical style of twentieth century urban development is the skyscraper (NORDBECK, 1971), we would dispute this as a spurious argument based on giving the central core of cities too much emphasis in speculating on the way cities spread themselves out in the space available. Thus we would hypothesize that $B = 1$ or that $d = 2$. With this assumption, we also find that the density of a town taken as its population size divided by its area is also constant, that is that from equation (1) or equation (2), P/A = constant. This contention is more contestable but once again we would argue that the evidence that the density of towns increases with their size—positive allometry—is by no means clear and that in many studies so far, the definition of area is more problematic in being less restrictive than our own definition of built-up area (BUSSIERE and STOVALL, 1981; MILLS, 1970).

The second relation is based on linking size to the field—population P to the area of the field U—which, in turn, is defined as the minimal circle of space enclosing the city that is available for further growth at the particular instant of measurement. Then:

$$P = gU^G \tag{3}$$

where: g = a constant of proportionality
G = a scaling parameter

If we hypothesize that B above is equal to 1 and we assume that the field $U > A$, then it is necessary to hypothesize that $G < B$, in short that $G < 1$, that is the population grows less quickly than the area of its field. This is consistent with casual observation of the size and hinterlands of towns and cities. If we also associate a derived radius R with U as $R = \sqrt{U}$, then we can write equation (3) as:

$$P = g[(U)^{1/2}]^D = gR^D \tag{4}$$

From equation (4), D must be less than 2 (but greater than unity) while the density of the field given by P/U is decreasing as population and field size increase. We would argue that in the population density literature, there has been a major confusion for nearly half a century with respect to the assumption that population density increases with city size. We would argue that, at best, it is constant and that if the field rather than the built-up area is used as a measure, then gross density declines with city size (BATTY and KIM, 1991).

With respect to the influence of shape on size and area, we will relate the length of the envelope E defined as the bounding perimeter of the city, to both the built-up area A and the field U. The boundary E is likely to be somewhat more irregular than a circular perimeter but it is unlikely to be as convoluted as, for example, the structure of the road network which in most cities reflects the radial structure of the city about its core. We can relate E to built-up area A as:

$$E = hA^H \tag{5}$$

where: h = a constant of proportionality
H = a scaling parameter.

As for equation (1), the derived radius of the built-up area A is taken as its square root r, and thus equation (5) can be written as:

$$E = h[(A)^{1/2}]^e = hr^e \tag{6}$$

We will hypothesize that e is less than 2 but greater than 1 but is likely to be less than D because the boundary will fill less space in the two-dimensional domain as the built-up area of the city itself.

Finally we can relate the bounding perimeter or envelope E to its field area U. Then:

$$E = kU^K, \qquad (7)$$

where k and K are proportionality and scaling parameters respectively. Equation (7) can be written in terms of the derived radius R as:

$$E = k[(U)^{1/2}]^q = kR^q. \qquad (8)$$

In equation (7), q would be less than 2 and greater than unity and is likely to be less than D and of the same order of magnitude as e in equation (6). The ratios which are calculated from E/A and E/U are not densities but measures of irregularity which pick up the shape and geometry of the settlements in question. To summarize then, the critical parameters are to be estimated for equations (1), (3), (5) and (7) from which the parameters d, D, e, and q in equations (2), (4), (6) and (8) can be calculated. The hypothesized range for these parameters is $1 < e,q < D < d = 2$.

Without launching into a detailed technical exposition, it is worth noting how these various parameters are estimated. Each of the above eight equations can be linearized by taking logarithmic transformations of their dependent and independent variables. The parameters of the resulting linear forms can then be estimated using ordinary least squares regression, and the usual set of statistical tests (e.g. R-squared statistics) can then be applied in judging the degree of the associated fits. Standard procedures also permit the calculation of confidence intervals about the parameter estimates. In our previous work, we also found this type of analysis to be useful in exploring the data, in identifying possible inconsistencies from the data set and detecting obviously suspect observations which should be excluded from subsequent analyses. We will employ this strategy in presenting the results which follow.

Before we begin to describe these computations, however, it is worth indicating the sorts of values which these parameters would take on for simple regular geometric figures so that some bounds on their value can be pointed to. If, for example, the built-up area of the city were exactly circular, and the population density within this area were constant with respect to increasing circle radius, then the field U would coincide with the built-up area A and the parameters $d = D = 2$. The city would thus be completely space-filling in the plane. In this case, $e = q = 1$ because the perimeter of the city would be the perimeter of the circle which would vary directly with the radius. At the other extreme, consider a city which is strung out along a straight line. This implies that the city has only linear area—the area of the line—and that the parameter $d = D = 1$. As the envelope is the same as the built-up area then the parameters $e = q = 1$ as well. For city shapes which lie between the circle and the line, the parameter D implies a fractional (or fractal) dimension between 1 and 2, and the values of e and q are likely to be less than D but greater than 1. A more detailed analysis of the implications of these ideas for the study of urban form and their relation to fractal geometry are given in a related paper by the authors (LONGLEY *et al.*, 1991).

We are now in a position to develop our analysis of the impacts of green belts on urban form with respect to these four measures relating size, shape and area to density and irregularity. In essence, what we will do is compute these measures for different classes of settlement, each of which is classified according to the policy instruments which have been applied in the control of their development. As we do not have parameter values of the four relationships for a given baseline, we will also be concerned with estimating the parameters of this baseline. In short, we need to develop the following estimates of values associated with the entire data set of settlements, the values associated with those settlements which are unlikely to have been affected by Green Belt Policy, and then those that have been so affected. It is thus the differences in parameter values between these various sets that we will be focusing upon. Before we present these, it is worth noting that the analysis could be inconclusive if our estimates of the values associated with the control baseline—the set of settlements not affected by policy instruments—are not significant or imply a poor performance of the model relationships. The same might be true of other sets of estimates and thus there is always the possibility that our assessment of impact will be dwarfed by poor performance or contradictory results from the various estimations.

THE DEFINITION OF URBAN AREAS AND THE MEASUREMENT OF URBAN FORM

Areal measures of 'development' are inherently ambiguous and thus quantitative measurements of size and density relations are inevitably prescribed by the quality of and functional basis to such measurements (see *inter alia*, NAROLL and VON BERTALANFFY, 1956; NEWLING, 1966; and WOLDENBERG, 1973). For purposes of this study, we are concerned with the physical extent of development which can for practical purposes be deemed 'irreversibly urban' in character, and we have used the OPCS urban areas database as our secondary digitized data source (OPCS, 1984). This source of vector mode digitized data defines urban areas as follows: land on which permanent structures are situated; transport corridors (roads, railways and canals) which have built-up sites that are less than fifty metres apart; transport features such as railway yards, motorway service areas, car parks as well as operational airfields and airports; mineral workings and quarries; and any area completely surrounded by built-up sites. The areas were identified using the 1981 1:10560 Ordnance Survey series in conjunction with 1981 Population Census Enumeration District (ED) base maps. These maps were used to ascertain which areas of urban land contained four or more EDs and these qualified as urban areas on this basis. Population figures from EDs which had 50% or more of their population within an urban area were included in the population total for that area. Our understanding of how urban land use fills space remains at a rudimentary level, and we have not, as yet, carried out any sensitivity analyses to determine the degree to which the results of our analyses are definition led: however, this data source is presently the most comprehensive, reliable and up-to-date digital representation of all significant urban settlements in England, and provides an important opportunity to begin to consider a range of analytical and measurement issues. Further general information and details of the treatment of small areas of population and discontinuous parcels of urban land can be found in OPCS, 1984, and SHEPHERD and CONGDON, 1990.

A sub-set of this database pertaining to all of the urban areas in the South East England planning region is shown in Fig. 1. Although the largest urban areas (notably London) are broken down into boroughs and districts in the original data set, these

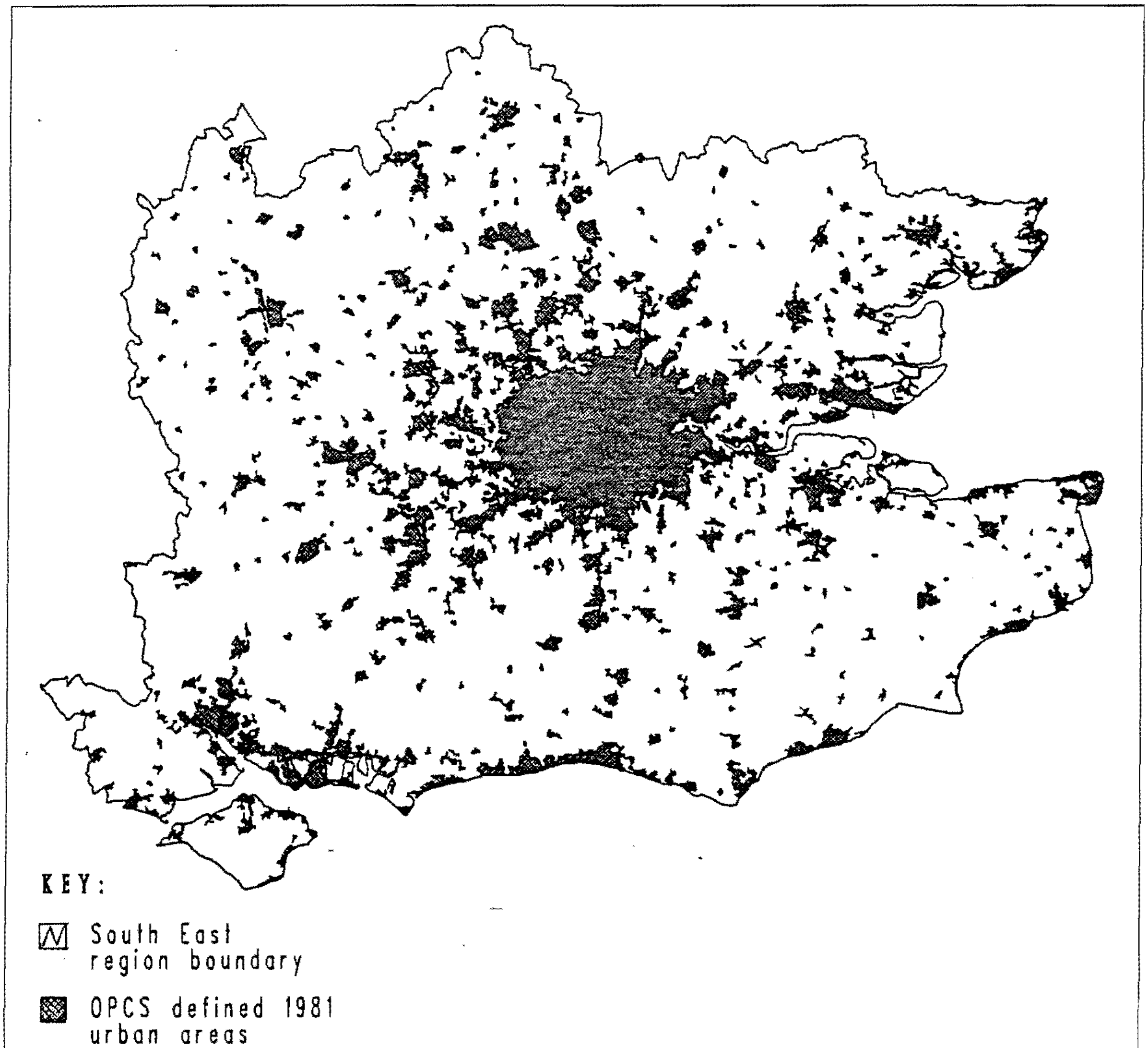

Fig. 1. The urban areas of South East England

administrative divisions have been removed for purposes of our analysis. What remains for these largest settlements is a number of large polygons which describe the bounding envelopes of continuous urban development. We recognized at the outset of our analysis that our posited relationships between settlement populations and the shapes of urban areas are unlikely to hold over the entire range of settlement sizes. Specifically, the geometry of these smallest settlements which comprise a mere handful of inhabited buildings are likely to be dominated by the intersection of transport links and thus will reflect the nature of the local and regional transport network rather than the intrinsic characteristics of growing settlements *per se*. The smallest settlements in the database were thus deemed irrelevant in terms of both population size and areal extent.

Fig. 2 illustrates this for the relationship between population and area in the whole digitized settlement system of the South East. There is a reasonably clear break in the dominant relationship amongst the very smallest settlements, and although we have estimated empirical relationships using the entire data set (Table 1), these results are neither statistically efficient nor theoretically coherent. In the bulk of our analysis, we have adopted the practice of excluding all settlements whose form was encoded using fifteen or fewer digitized points, since such settlements were deemed too small for our specific purposes. This amounts to a fairly minor amendment of the Department of the Environment definition of 'urban' land use and reduced our data set from the original 701 observations to 686 settlements.

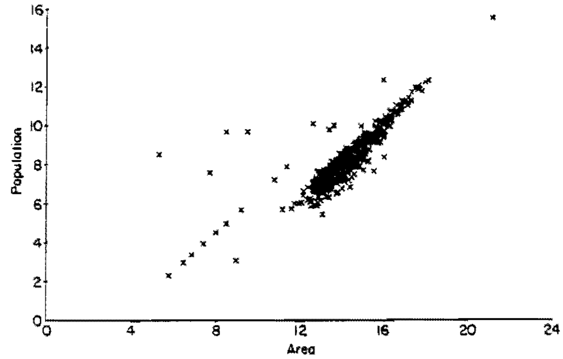

Fig. 2. Population–area (P-A) relationship for the entire South East England settlement system

A particular shortcoming of the data from the standpoint of our geometrical analysis is that there is no information pertaining to the 'derived radius' specified in our equations. From a theoretical standpoint, the radius should be given by the distance

Table 1. Parameter estimates, dimensional values and associated statistics for the green belt analyses

		Population–area	Population–'radius'	Envelope–area	Envelope–'radius'
All settlements (701)	(1)	0·808	1·569	0·619	1·258
	(2)	75·6	70·8	93·1	95·6
	(3)	1·616	1·569	1·238	1·258
	(4)	1·548–1·684	1·494–1·644	1·214–1·263	1·238–1·278
All usable settlements (686)	(1)	1·023	1·872	0·645	1·271
	(2)	89·0	79·0	91·1	93·9
	(3)	2·046	1·872	1·290	1·271
	(4)	1·992–2·100	1·800–1·944	1·275–1·305	1·247–1·296
Outside green belt (389)	(1)	1·047	1·868	0·635	1·236
	(2)	89·1	77·6	89·8	93·0
	(3)	2·093	1·868	1·271	1·236
	(4)	2·020–2·166	1·768–1·967	1·228–1·313	1·202–1·269
Partly in green belt (15)	(1)	1·083	1·890	0·719	1·317
	(2)	94·1	84·3	92·9	92·4
	(3)	2·167	1·890	1·439	1·317
	(4)	1·855–2·478	1·423–2·358	1·210–1·667	1·100–1·534
Within green belt (237)	(1)	0·994	1·875	0·663	1·323
	(2)	93·7	86·0	93·3	95·8
	(3)	1·988	1·875	1·326	1·323
	(4)	1·922–2·054	1·779–1·972	1·281–1·372	1·287–1·358

Notes: (1) Regression parameter value (*B*, *G*, *H* and *K*).
(2) *R*-squared goodness-of-fit (adjusted).
(3) Dimension (*d*, *D*, *e* and *q*).
(4) 95% confidence limits for dimension.
Data pertaining to settlements that lie within or astride the Oxford and the Southampton green belt boundaries have been omitted from the green belt analyses.

from the historical centre of each settlement to the furthest point on its developed boundary. Since the historical centre point is not digitized as part of the data set, we have approximated the settlement 'radius' as being equal to half the spanning distance joining the two widest-spaced digitized points on the settlement boundary. A further complication in the data set is that the population figures for the urban areas are not assigned to all of the individual parcels which together comprise a single named settlement. This means that exact population figures cannot be attributed to approximately sixty settlements. In practice, this was resolved by allocating populations to physically split named settlements in direct proportion to the area of the constituent parcels. This does not affect the weighting of such parcels in our regressions, although if such named settlements are outliers to the main scatter of points, this does result in the appearance of a parallel scatter of points about the main trend in the data, as is clearly seen in Fig. 2.

URBAN GROWTH IN AND AROUND LONDON'S GREEN BELT

In our empirical analyses we will examine the four sets of relations identified previously. These are: the population–urban area relation, *P–A*, based on equations (1) and (2) in accordance with established allometric analysis; the population–'radius' relation, *P–R*, based on equations (3) and (4) consistent with those (urban) forms which might be generated by constrained diffusion of urban growth (analogous to diffusion-limited aggregation—DLA—in physics: see BATTY, 1991); the envelope–area relation, *E–A*, based on equations (5) and (6) which enables us to identify whether there is any tangible evidence that boundaries are characteristic of growth processes; and the envelope 'radius' relation, *E–R*, based upon equations (7) and (8) which will identify whether the boundaries of the settlements are consistent with irregularly formed but systematic (fractal) growth. Figs. 3(a)–(d) illustrate each of the (logarithmically transformed) relations for the 686 settlements which were captured with sixteen or more coordinate pairs. The results of fitting regressions to the scatters shown in Fig. 3 are given in Table 1, and the 95% confidence intervals about the dimensional estimates are reproduced in diagrammatic form in Figs. 4(a)–(d). In interpreting these results, we will also draw comparisons with our previous empirical study of the settlement structure of Norfolk (LONGLEY *et al.* 1991). It was recognized at the outset of this study that no region of England even approximates the isotropic surface on which, for example, central place theory is developed. Norfolk was chosen for our first analysis because of the comparative homogeneity of its terrain and the absence of abnormal planning restrictions upon urban growth.

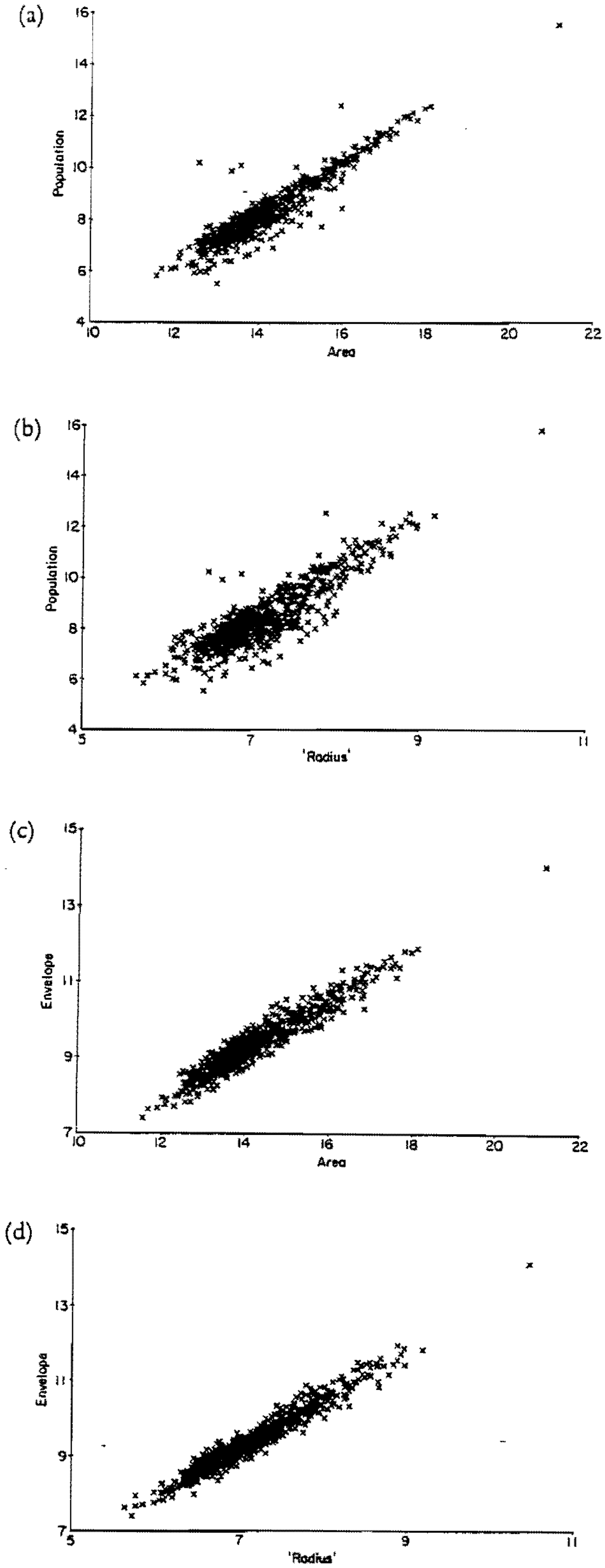

Fig. 3. Dimensional relations for the 686 significant settlements: (a) population–area (P-A); (b) population–'radius' (P-R); (c) envelope–area (E-A); and (d) envelope–'radius' (E-R).

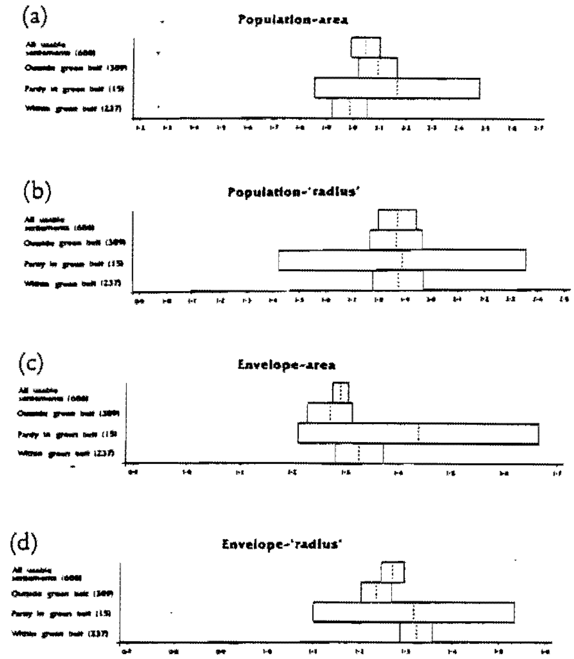

*Fig. 4. Confidence intervals about the dimensional estimates: (a) population–area (*P–A*); (b) population–'radius' (*P–R*); (c) envelope–area (*E–A*); and (d) envelope–'radius' (*E–R*)*

The results of our analyses of the South East England data generally conform with our *a priori* expectations. There are evident differences in the parameter and dimensional estimates between the analyses embracing all (701) settlements and those (686) settlements comprising sixteen or more coordinate pairs. In three of the four cases (*P–A*, *P–R* and *E–A*) these differences are statistically significant. The classic population–area relationship has dimension 2·046, which is quite close to the widely mooted value of 2. We made a similar finding in our Norfolk study, where a similar degree of over-all statistical fit (*R*-squared, corrected for degrees of freedom) was discerned. This general consistency between study areas is encouraging, particularly in view of the inclusion of London as an observation. London clearly constitutes a high potential leverage point in the analysis, although it is theoretically suspect to exclude the observation purely on grounds of size, since the impact of the green belt is likely to be most significant along and around the boundary of this area. In practice, however, this potential leverage transpires not to be against the trend in the rest of the data, and an exploratory analysis carried out with this dominant central settlement excluded, yielded results which were neither more consistent in substantive terms nor were significantly improved in terms of statistical fit.

The result of the population–'radius' regression yields a significantly higher dimension than was anticipated on *a priori* grounds, suggesting that settlements in the South East fill more of their urban fields than does the classic space-filling diffusion-limited aggregation model. This was not the case in any of our previous case studies (BATTY *et al.*, 1989; BATTY, 1991; LONGLEY *et al.*, 1991), in which the DLA structure provided a plausible theoretical baseline model, and may be taken to imply that pressures conspire to encourage the development of more intricate settlement forms within the urban fields of settlements in this region. The purely geometrical analyses yield values consistent with our expectations, and high levels of statistical fit characterize these relationships.

As a next step, the South East settlements were divided into three groups according to their position relative to the Greater London green belt: those (237) settlements which lay entirely within it; those (389) that lay entirely outside of it; and those (15) that lay astride the boundary. The South East region includes two other green belts, centred upon Oxford and Southampton. For purposes of our present analyses, it was considered that these green belts were different in spatial and temporal terms from the London green belt, and thus settlements that lay either within or astride the Oxford and Southampton green belt boundaries were omitted from our analysis at this stage. This classification is shown in Fig. 5. The results of separate regression analyses upon these sub-areas are shown in Table 1 and Fig. 4. There is no significant difference between the estimated dimensions for the population–area (*P–A*) relation, although the wider confidence intervals and the lower *R*-squared figure for the extra-green-belt settlements is indicative of greater variation in the effects of forces governing this relation. The lower estimated dimension for the population–area relation for the intra-green-belt settlements is indicative of a disproportionately small increase in area amongst larger green belt settlements, although the global level of statistical fit is insufficient to confirm an unequivocal difference.

Neither are clear distinctions apparent when considering the population–'radius' (*P–R*) relationship. Here, the estimated dimension and the extent of the confidence limits are remarkably similar for all of the settlement classes, although the modified *R*-squared statistic suggests greater heterogeneity amongst the extra-green-belt settlements. Regarding the envelope–area (*E–A*) relation, there is a very limited evidence to suggest that the larger settlements which straddle the green-belt boundary exhibit disproportionate increases in boundary length, and this might be indicative of contortions in urban form consequent upon differential planning restrictions. However, largely because of the small number of observations,

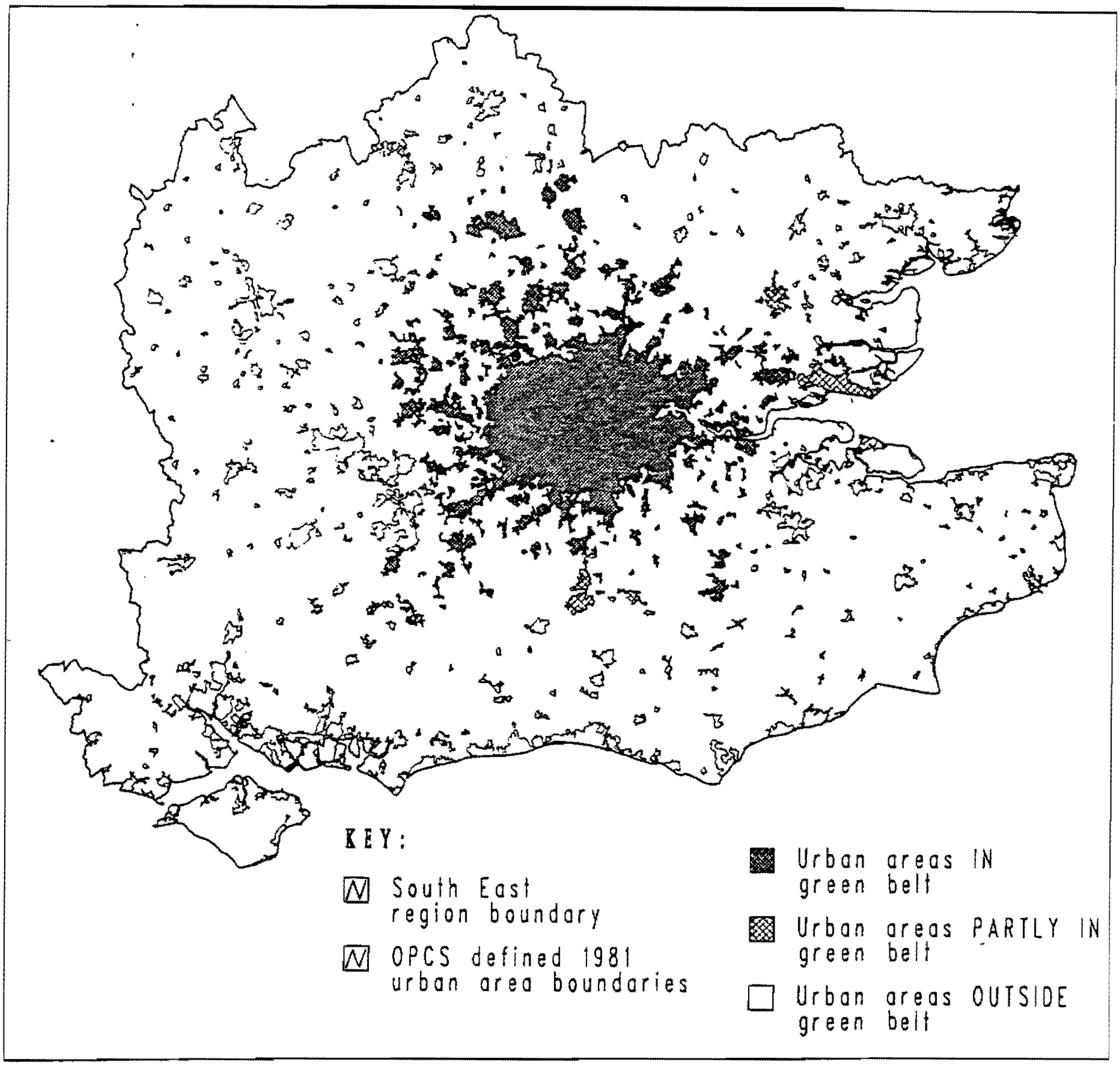

Fig. 5. Green belt status of settlements in the South East

no statistically significant differences are apparent. Significant differences do, however, exist between the envelope–'radius' (*E–R*) relations for extra- versus intra-green-belt settlements. The intra-green-belt dimensional estimate is higher, suggesting that these settlements are more circular and compact than those outside.

These, then, are our preliminary attempts to utilize detailed vectorized boundary data in order to gauge the general spatial impact of an important component of spatial policy. Of course, this discussion presumes that settlement shapes in South East England would be free to evolve in an unconstrained manner in the absence of Green Belt planning policy. The spirit of our approach is to assume that the multitude of other factors which conspire to mould urban form (terrain, fluvial features, land ownership patterns, etc.) do not obscure the central impact of this strict planning control. One of the most obvious and important confounding influences is that of the coast, which clearly has constrained the shape, form and density of many settlements in our study region. Consequently, a separate set of analyses were carried out in which the coastal settlements illustrated in Fig. 6 were excluded. The results are presented in Table 2, and show that there exist some minor differences in dimensional estimates and confidence intervals and that the previously significant differences between the 'partly in' and 'outside' dimensional estimates for the envelope–area relation disappears. The results nevertheless show the same broad relationships as identified in Table 1, and the maintenance of the

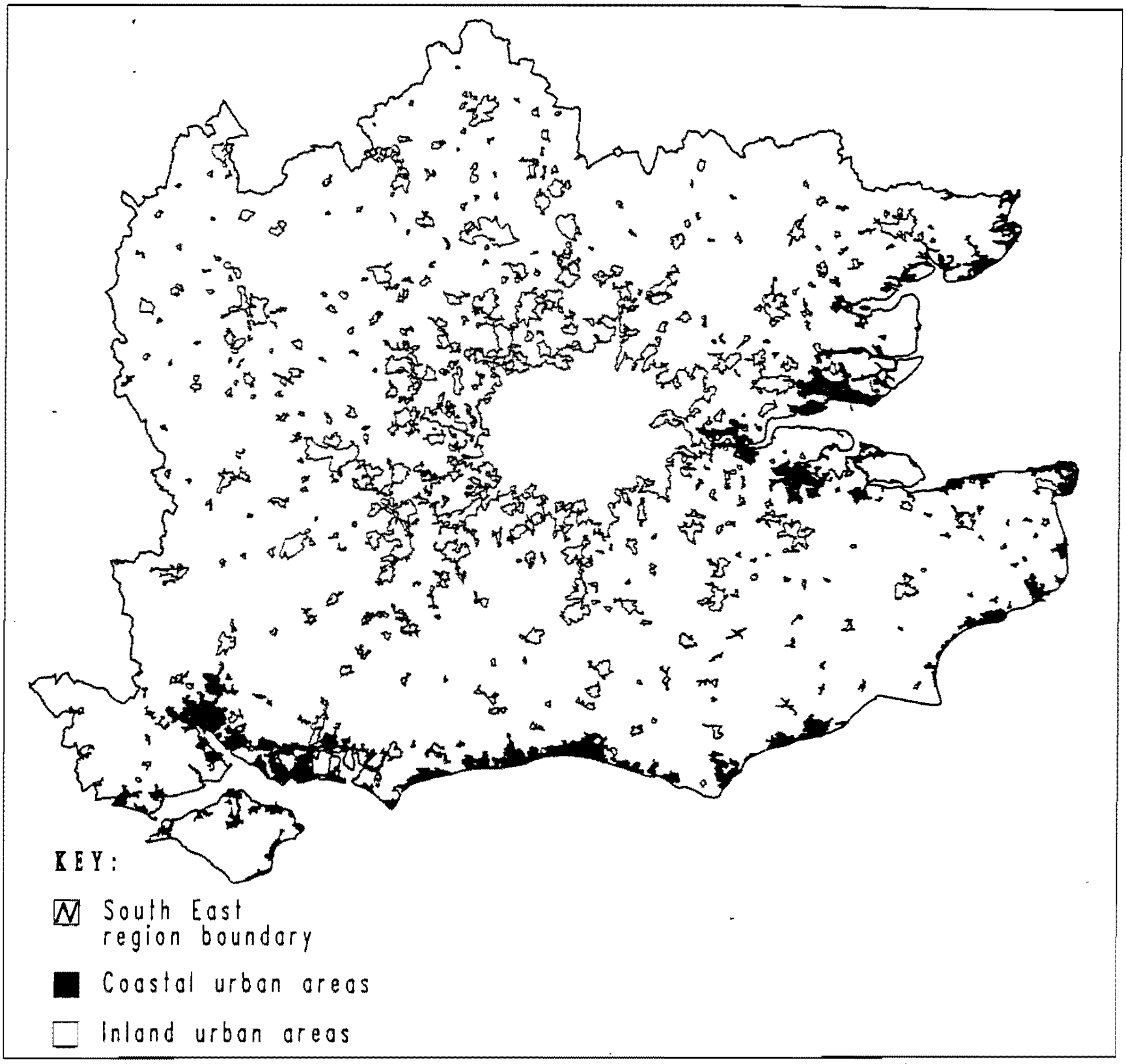

Fig. 6. Coastal settlements excluded from the analysis

population–'radius' differences suggests that the distorting impact of the sea is less than that generated by green belt planning policy.

In a final series of analyses, we have begun to investigate whether our empirical settlement relations vary between county planning authorities. It is conceivable that, over half a century, different county planning authorities have evolved consistently different interpretations of green belt policy. Our four relations were thus estimated for each of the thirteen county divisions within the South East Region (see Fig. 7), although the small number of usable observations for a few of these counties leads to quite wide confidence intervals. In the case of Greater London, the four relations were estimated for each of thirty-six administrative divisions of the area, and so these results are not strictly comparable with those of the other counties. The results of this county based analysis are reproduced in Table 3 and Fig. 8. There are no evident significant differences amongst the population–area and population–'radius' results, suggesting that population pressures across different counties have not had the effect of distorting regional population density norms.

However, there is evidence that the settlement geometry differs between individual counties. First, the envelope–area (*E–A*) relation suggests that bounding envelopes are significantly shorter for a given settlement area in Oxfordshire and Hertfordshire than in any of Kent, Surrey, Greater London and (for the case of Oxfordshire only) Berkshire. The envelope–area (*E–A*) relations for these two counties ble Parameter estimates, dimensional values and associated statistics for the green belt analyses, exd.lding coastal settlements

Table 2. Parameter estimates, dimensional values and associated statistics for the green belt analyses, excluding coastal settlements

		Population–area	Population–'radius'	Envelope–area	Envelope–'radius'
All usable settlements (592)	(1)	0·998	1·836	0·645	1·289
	(2)	88·0	77·6	90·3	93·9
	(3)	1·996	1·836	1·290	1·289
	(4)	1·937–2·056	1·756–1·915	1·256–1·324	1·263–1·315
Outside green belt (324)	(1)	0·996	1·744	0·628	1·250
	(2)	84·4	69·8	86·1	92·3
	(3)	1·992	1·744	1·256	1·250
	(4)	1·898–2·085	1·619–1·868	1·201–1·310	1·211–1·289
Partly in green belt (8)	(1)	1·005	2·270	0·650	1·486
	(2)	96·5	93·9	92·6	92·6
	(3)	2·010	2·270	1·300	1·486
	(4)	1·689–2·330	1·789–2·751	0·944–1·607	1·136–1·836
Within green belt (222)	(1)	0·997	1·903	0·661	1·323
	(2)	94·2	87·2	94·0	95·8
	(3)	1·995	1·903	1·321	1·323
	(4)	1·929–2·060	1·807–2·000	1·277–1·365	1·287–1·360

Notes: (1) Regression parameter value (B, G, H and K).
(2) R-squared goodness-of-fit (adjusted).
(3) Dimension (d, D, e and q).
(4) 95% confidence limits for dimension.
Data pertaining to settlements within or astride the Oxford and Southampton green belt boundaries have been left out of the green belt analyses.

are also significantly smaller than the estimates derived from the complete set of (686) settlements (Table 1). This can be seen as indicative that growth has been contained within more compact areas in these two counties. The envelope–radius (E–R) relation for Oxfordshire also exhibits a significantly lower dimensional estimate than for the set of all settlements or for the individual counties of Berkshire, Essex, Hertfordshire, Kent, Surrey and Greater London suggesting that growth in Oxfordshire has been contained within more compact areas than has been the case in these other counties. A significant difference in the envelope–area (E–A) relation also exists between Buckinghamshire and Surrey.

CONCLUDING COMMENTS

So far we have identified statistical differences between the various sub-groupings of settlements based on the implementation of green belt policies, geometrical constraints such as those posed by the coastline, and administrative differences in the operation of planning policies but we have not commented on the substantive differences which our analysis has revealed. In *a priori* terms, we might expect that where green belt policy is rigidly enforced, this would constrain the form of settlement and development and, in turn, would make the boundaries of such settlement more irregular in contrast to development not so constrained. However, such constraints also imply that the amount of space in the field about such settlements would be reduced by green belt policy. This implies that the value of D associated with the population–field relation would be less than that for the unconstrained growth, while the value of q for the constrained case would be greater than for the unconstrained case. In fact these hypothesized values are borne out in Table 1, although the variance in the parameters of the green belt affected settlements is much greater than the unconstrained set of settlements. In the case of the population–area relation, the parameter of the constrained case is just less than two while for the unconstrained it is a little greater than two. The same degree of difference is borne out in the envelope–area parameter values. In the case of the county-based analysis, there is very wide variation between the purely geometrical dimensions, whereas population-based relations are more stable across counties. This suggests the paramount importance of form in the implementation of planning policy. What is clear is that it is geometrical relations which exhibit the greatest diversity, and that such relations should be incorporated into classficiations of settlements *vis-à-vis* planning policy. More detailed interpretations are possible but these must await further research and analysis and more meaningful classifications of settlements with respect to both morphology and planning policy.

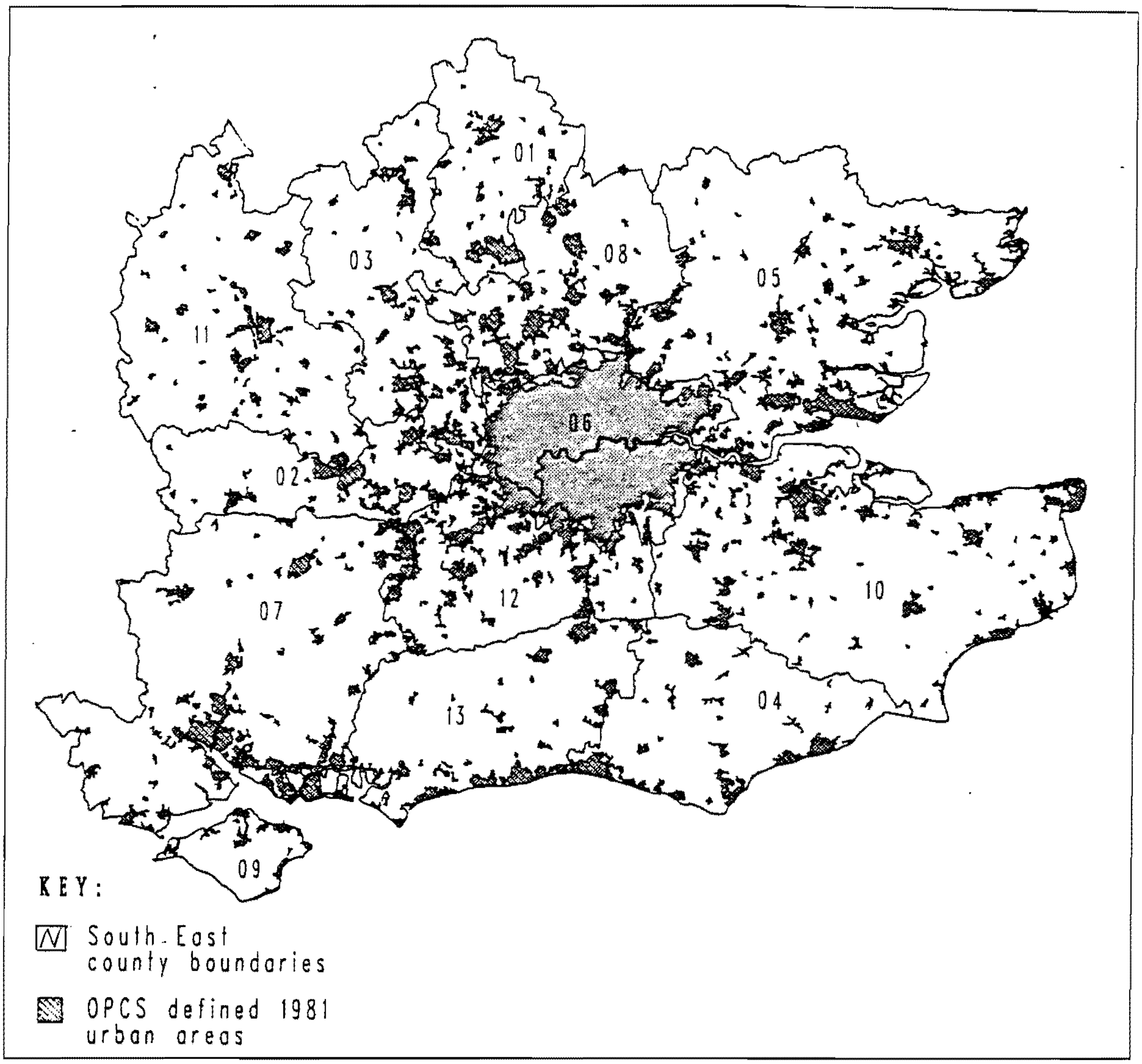

Fig. 7. County divisions in South East England

Key: 01, Bedfordshire; 02, Berkshire; 03, Buckinghamshire; 04, East Sussex; 05, Essex; 06, Greater London; 07, Hampshire; 08, Hertfordshire; 09, Isle of Wight; 10, Kent; 11, Oxfordshire; 12, Surrey; 13, West Sussex.

In this paper, we have been content to simply develop descriptive measures of settlement form based on standard methods of scaling and dimensionality which underpin the study of morphology, through allometry and fractal geometry. We have not implied, in any sense, that settlement forms, which are characterized by particular dimensions indicating their density and space-filling properties, provide any indicator of their optimality or efficiency. In fact, one of the most controversial issues in the study of urban form has been over questions of whether very different forms such as linear versus concentric, high versus low density, radial versus grid, are more optimal than one another. For example, from the point of view of transport accessibility, indices can be derived which show that these various forms all embody some ideal attributes of such accessibility. Questions of optimal urban form from the point of view of energy use also provide contradictory conclusions depending upon what measures are constructed. Moreover, in this context, it could be argued that green belt policy has both increased the journey to work at a cost but increased access to the countryside as a benefit. In future studies we intend to address these issues but our immediate priority is to refine our existing analysis further and to produce more definitive results by restructuring our data set and by exploring its quality through different types of spatial classification in the manner used here.

Table 3. Parameter estimates, dimensional values and associated statistics for the county-based analyses

		Population–area	Population–'radius'	Envelope–area	Envelope–'radius'
Bedfordshire (33 settlements)	(1)	0·854	1·564	0·622	1·208
	(2)	64·3	57·7	93·7	95·2
	(3)	1·709	1·564	1·244	1·208
	(4)	1·253–2·164	1·086–2·042	1·127–1·360	1·110–1·306
Berkshire (41)	(1)	1·027	1·908	0·663	1·272
	(2)	95·0	90·3	94·7	96·0
	(3)	2·055	1·908	1·327	1·272
	(4)	1·902–2·207	1·705–2·111	1·226–1·428	1·189–1·356
Buckinghamshire (51)	(1)	0·995	1·733	0·644	1·205
	(2)	96·1	87·4	90·6	95·2
	(3)	1·989	1·733	1·289	1·205
	(4)	1·876–2·103	1·547–1·920	1·171–1·407	1·128–1·282
East Sussex (29)	(1)	1·150	1·971	0·595	1·187
	(2)	94·8	72·8	84·8	89·5
	(3)	2·300	1·971	1·190	1·187
	(4)	2·091–2·509	1·508–2·434	0·995–1·384	1·030–1·344
Essex (87)	(1)	1·046	1·891	0·648	1·277
	(2)	91·2	78·5	91·7	93·9
	(3)	2·092	1·891	1·296	1·277
	(4)	1·952–2·232	1·678–2·104	1·211–1·380	1·207–1·347
Greater London (42)	(1)	1·011	1·993	0·683	1·376
	(2)	98·4	94·7	96·4	96·9
	(3)	2·022	1·993	1·367	1·376
	(4)	1·940–2·103	1·696–2·290	1·284–1·450	1·221–1·531
Hampshire (96)	(1)	1·072	1·986	0·629	1·269
	(2)	84·1	73·5	89·7	93·1
	(3)	2·144	1·986	1·258	1·269
	(4)	1·953–2·334	1·743–2·229	1·171–1·345	1·129–1·410
Hertfordshire (40)	(1)	1·040	2·192	0·577	1·311
	(2)	97·5	87·0	90·6	94·4
	(3)	2·079	2·192	1·153	1·311
	(4)	1·972–2·186	1·918–2·466	1·033–1·274	1·208–1·415
Isle of Wight (13)	(1)	1·097	1·643	0·637	1·053
	(2)	90·7	66·5	86·8	79·4
	(3)	2·194	1·643	1·273	1·053
	(4)	1·755–2·634	0·924–2·363	0·963–1·584	0·719–1·387
Kent (93)	(1)	0·995	1·759	0·694	1·343
	(2)	85·4	72·5	90·5	92·4
	(3)	1·990	1·759	1·388	1·343
	(4)	1·820–2·161	1·535–1·984	1·295–1·481	1·263–1·423
Oxfordshire (56)	(1)	0·931	1·748	0·530	1·089
	(2)	78·1	69·1	84·8	90·3
	(3)	1·861	1·748	1·060	1·089
	(4)	1·595–2·127	1·433–2·062	0·939–1·182	0 ·993–1·186
Surrey (40)	(1)	0·965	1·756	0·705	1·389
	(2)	93·7	81·7	93·1	95·5
	(3)	1·929	1·756	1·410	1·389
	(4)	1·768–2·090	1·487–2·024	1·286–1·534	1·291–1·486
West Sussex (46)	(1)	1·124	1·914	0·644	1·202
	(2)	90·5	77·7	90·2	93·5
	(3)	2·248	1·914	1·287	1·202
	(4)	2·030–2·467	1·606–2·222	1·160–1·415	1·107–1·297

Notes: (1) Regression parameter value (B, G, H and K). (2) R-squared goodness-of-fit. (3) Dimension (d, D, e and q).
(4) 95% confidence limits for dimension.

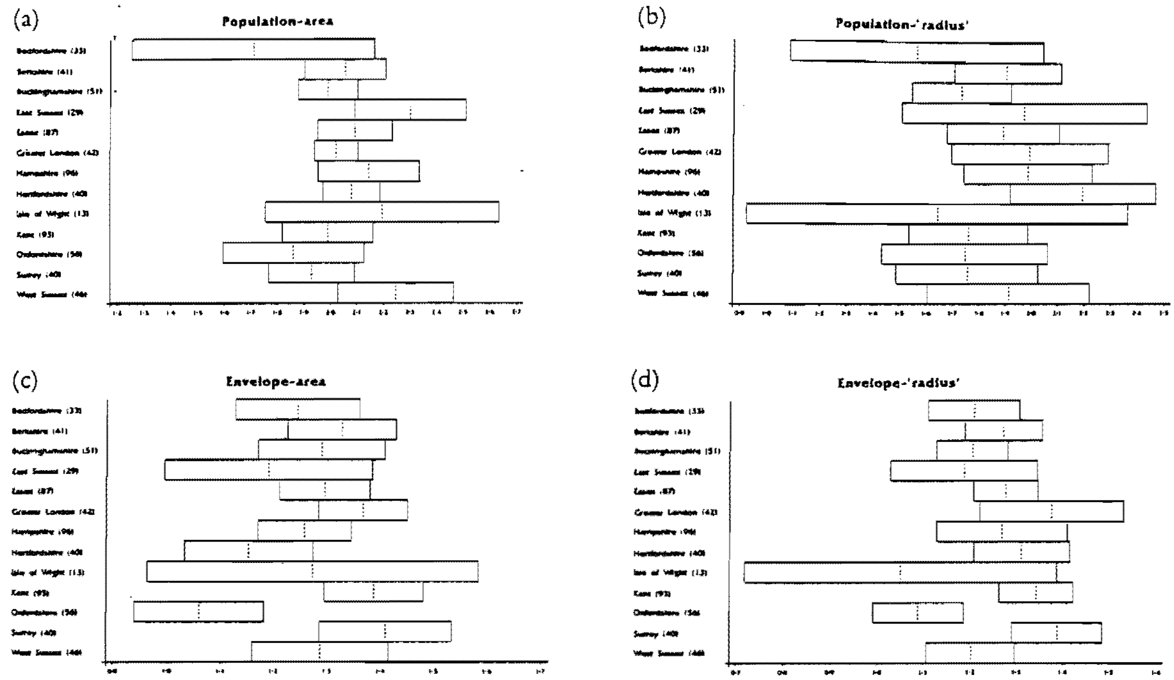

Fig. 8. Confidence intervals about the county-based analyses: (a) population–area (P–A); (b) population–'radius' (P–R); (c) envelope–area (E–A); and (d) envelope–'radius' (E–R)

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