

The creation of 'Consistent Areas Through Time' (CATTs) in Scotland, 1981–2001

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Small area analysis of socio-demographic change over time is often impeded by the changing configuration of census zones for each decennial UK census. Approaches for matching zone configurations exist, but these typically require population estimation techniques, which inevitably involve some error. Because of the postcode-based geographical zoning system used in Scottish censuses, it is possible to create a local-area geography which is consistent for recent censuses. Here we present a methodology used to create three sets of consistent areas through time (CATTs) that can be used for analysing comparable small area data output from the 1981, 1991 and 2001 Censuses.

INTRODUCTION

The decennial collection of national census data is a costly and lengthy process. To justify the exercise it is essential that good use is made of the various outputs and the evidence suggests that it is good value for money.¹ However, while much use is made of the census, most studies use the data cross-sectionally and only relatively rarely are attempts made to analyse change through time by comparing the outputs from consecutive censuses. There are perhaps two main reasons for this. First, questions can change or disappear between censuses, making it impossible to investigate change through time. Second, and the focus of this article, boundaries change between censuses, making it difficult to compare data from two or more censuses for small geographical areas. Those studies that have investigated changes in population health and socio-demographics through time have therefore usually been restricted to large spatial units, such as Standard Regions or Parliamentary Constituencies.^{2,3} Such analyses are aided by the fact that the most detailed tabulations are usually provided for larger areas⁴ and because these areas are less susceptible to significant boundary changes between censuses than smaller areas such as Output Areas (OAs), Enumeration Districts (EDs), Wards or Pseudo Postcode Sectors. While the use of higher geographies may be useful for reporting changing demographic, socio-economic and health patterns through time, they can mask important local variations.

Of course, a number of methods exist that enable two or more geographies to be combined into a common geography.^{5,8} Most approaches use an areal interpolation process that involves the proportional redistribution of information from the source geographies to the target geography, based on a pre-defined weighting scheme. Necessarily, however, these techniques introduce error, which varies depending on the procedure that is used.⁸

Here we present an alternative approach, which uses 1981 EDs in Scotland as the base geography from which 'Consistent Areas Through Time' (CATTs) can be derived. It is possible to extract small area census data outputs from 1981, 1991 and 2001 for these areas without the need for areal interpolation methods. The method presented here is only possible because the General Register Office for Scotland (GROS) has endeavoured to maintain comparability between census areas since 1981. For the first time in Scotland, therefore, CATTs are available which allow for the reliable analysis of changing demographic, social and economic circumstances at the local level.

EXISTING APPROACHES FOR CREATING 'CONSISTENT' GEOGRAPHIES

Various approaches exist for creating consistent geographies through time. Norman *et al.*⁸ define four different approaches: freezing geographical history; updating historic data to contemporary zones; creating designer zones; and the aggregation of individual data to the geography that is best suited to the research question.

The simplest areal interpolation approach^{5,9} relies upon areal weighting, which assumes that the variable of interest (for example, population) is uniformly distributed within the source zone. If the proportion of the source zone that is in the target zone is known, it is simple to calculate the estimated value for the area of intersection, and then to sum the values to achieve a target zone estimate.

The problem with such areal interpolation is that variables are usually not distributed evenly over geographic space, and hence the error may be substantial. If part of the source area is known to be uninhabited (perhaps because it is under water, or predominantly industrial), dasymetric mapping techniques can be used to adjust the estimates. More generally, Flowerdew and Green⁵ have developed techniques for 'intelligent' areal interpolation, which can take into account any additional information relating to the source zones, which may provide further clues about the distribution of the variable of interest within the source zones.

Another approach is to 'remove' the boundaries and use the grid references of each areal unit to construct a smoothed population surface. Tobler's pycnophylactic interpolation¹⁰ is one method, but there are a number of other weighting methods such as inverse distance, kernel estimation and kriging. Bracken and Martin⁶ used surface modelling techniques to link 1981 and 1991 ED data for England and Wales. The 1991 ED data were left unchanged, but the 1981 ED data were remodelled to the 1991 geography. Although the boundaries for some EDs did not change between 1981 and 1991, the boundaries for many others did change. In these cases the 1981 ED grid references were allocated to a 1991 grid reference that was within 100 metres of the 1981 ED grid reference. If no match was possible, the 1981 data were reapportioned to the nearest 1991 EDs, and a distance function was used so that the population and variable totals were preserved. This approach provided a 'best fit' solution to matching the 1981 and 1991 geographies but, as with all these methods, it inevitably introduces error that will vary geographically.

An alternative strategy, which does not rely on areal interpolation, was introduced in the 1980s to allow results from the 1971 and 1981 Censuses to be analysed and compared in England and Wales. Approximately 48,300 Census Tracts were created in urban areas and each Census Tract comprised one or more EDs from 1971 and 1981 that nested within unchanged boundaries. These 48,300 Census Tracts allowed for comparisons between the 81,000 EDs from 1971 and 82,500 EDs from 1981 that fell in these urban areas, and they accounted for 76 per cent of the total population in 1981.¹¹ In rural areas, the Office of Population Censuses and Surveys (OPCS) used Civil Parishes as their

consistent geography. These areas covered 28,350 EDs from 1971 and 29,800 1981 EDs. However, although Morgan and Denham¹¹ envisaged that the Census Tracts and Parishes would be a convenient geography to which future Small Area Statistics (SAS) datasets could be linked, the OPCS did not publish lookup tables to link the 1991 Census data to the Census Tracts and the zones have rarely been used.

In this article, we present a method for creating consistent geographical areas in Scotland, which is similar in concept to the Census Tracts, but which allows for consistent comparisons of data from the three censuses conducted in 1981, 1991 and 2001.

CONSTRUCTING CONSISTENT AREAS THROUGH TIME (CATTs) IN SCOTLAND

The General Register Office for Scotland (GROS) is responsible for the preparation, collection and outputs of Scotland's Census. For each census, the GROS constructs Enumeration Districts (EDs) to manage the workloads of the enumerators who collect census returns. Unlike in England and Wales, the 1981 Scottish EDs were constructed from aggregations of one or more whole unit postcodes. There were 17,767 Scottish EDs in 1981, which were also used for census outputs. In 1991, the GROS defined 38,254 OAs, based on aggregations of postcodes, which were used to distribute census outputs. These generally nested neatly within 1981 EDs. In 2001 the GROS developed 42,604 OAs from postcodes for the small area output of census results with the aim that they would nest within the boundaries of other administrative units as much as possible. However, a consultation exercise was conducted which informed the decisions about which geographies the 2001 OAs should nest within; Box 1 provides the preferred ranking. Each 2001 OA was assigned a 'master' postcode, which was used by the GROS to allocate the OAs to all of the 'higher' geographies. With the exception of Council Areas (into which 2001 OAs fit exactly), all higher geographies are best-fit approximations.¹² Because less weighting was given to the structure of the 1991 OAs, the relationship between 1991 and 2001 is far from perfect. Consequently, it is not simple to analyse change through time at the local level using data from these two censuses. This is addressed here.

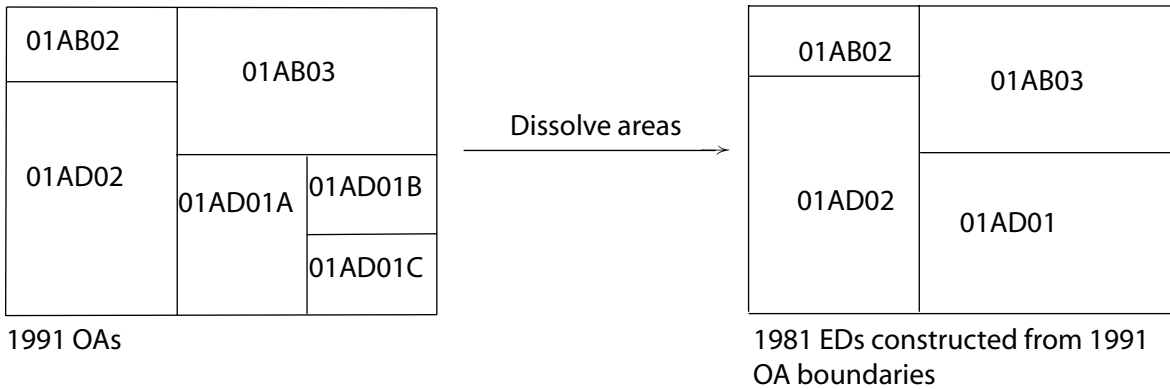
In 1981 the 17,767 Scottish EDs were not digitised, but were represented geographically by population-weighted grid centroids. In 1991 there were 38,098 OAs with digitised boundaries (the other 156 OAs were large communal establishments and were geographically represented as points rather than polygons). In most cases, the 1991 OAs were simply neat subdivisions of 1981 EDs and the naming convention made it relatively easy to identify these cases; 1991 OAs tended to have the same name, except with an alphabetical suffix added. For example, the 1991 OAs 5601AB03A, 5601AB03B and 5601AB03C were subdivisions of the 1981 ED 5601AB03. By aggregating the three 1991 OAs together, small area census data outputs for 1991 and 1981 can be accurately compared for the same geographical areas (Figure 1a). The majority of 1981 EDs were split into two (6,015) or three (6,109) 1991 OAs, but the 1981 ED 6018AA01 was divided into 22 1991 OAs because of significant population growth in the area (Portlethen, Aberdeenshire). Thus, for 16,096 of the 1981 EDs, directly equivalent combinations of 1991 OAs could be produced. However, this left 1,670 1981 EDs which could not be reconstructed from 1991 OAs in the same manner.

Despite the fact that there were significantly more 1991 OAs than 1981 EDs, the confidentiality requirements introduced for the 1991 Census meant that a relatively small number of 1981 EDs were too small to be retained as distinct 1991 OAs and these had to be increased in size. No 1991 OA could contain less than 50 people, or 16 households (in 1981 the comparable rule was that no ED could contain less than 25 people or eight households¹³). In cases where the 1981 ED did not meet both of these rules in 1991, the zone was increased in size by allocating one

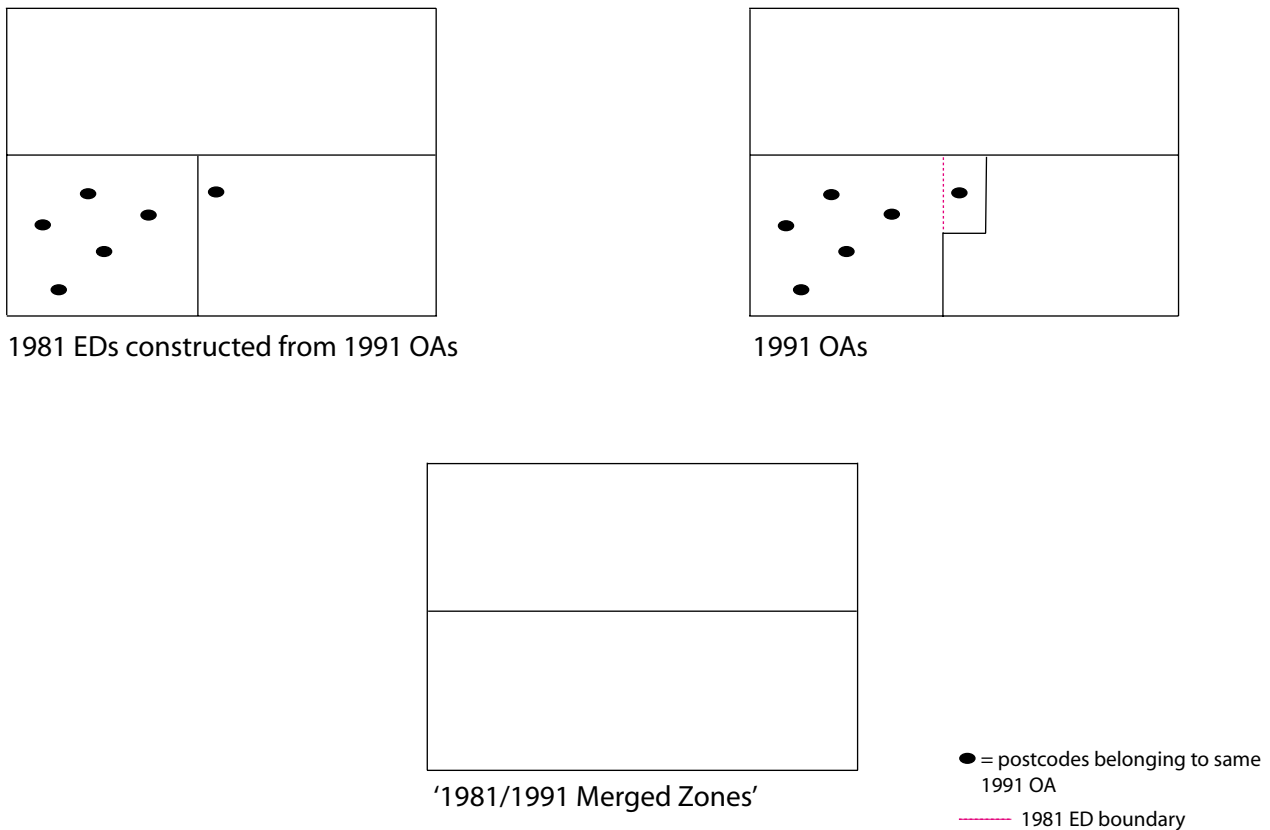
Figure 1

Creating the '1981/1991 merged zones'

a)



b)



or more postcodes from a neighbouring 1981 ED. In these cases, the boundaries of 1991 OAs did not fit neatly within the boundaries of the 1981 EDs, as a 1991 OA could overlap with two or more 1981 EDs.

Fortunately, a lookup table was created by GROS, which identified each of these cases, linking all postcodes which were allocated to a different 1991 OA than might have been expected, and providing a reason for this decision. Most of these anomalies occurred because there were too few persons or too few households for the 1981 ED to become a distinct 1991 OA. Other reasons included postcodes that were in special (suppressed) 1981 EDs that became ordinary (unsuppressed) 1991 OAs; the deletion of postcodes between censuses; administrative boundary changes of

larger zones such as wards; and zone re-labelling between the 1981 and 1991 Censuses.

For the creation of CATTs, these problems needed to be resolved. Where 1991 OAs included postcodes that fell in more than one 1981 ED the two 1981 EDs were merged (Figure 1b). There were some instances where three or more EDs needed to be aggregated. This resulted in a total of 15,921 '1981/1991 merged zones' which encompassed all of Scotland.

Manual checking of the '1981/1991 merged zones' highlighted a small number of occasions where two non-neighbouring 1981 EDs were combined into a single '1981/1991 merged zones'. In these instances

we merged all of the 1981 EDs that fell between non-adjacent '1981/1991 merged zones'. In addition we found a small number of errors in the GROS lookup table that created non-adjacent zones that were very distant from each other. These generally arose from typographic errors, and were rectified using the postcode information in the Central Postcode Directory (CPD). These manual modifications decreased the number of '1981/1991 merged zones' from 15,921 to 15,739 unique zones for which reliable comparisons can be made between 1981 and 1991 Census data.

The final step was to account for the 2001 Census geography. The GROS attempted to maintain consistency between the 1991 and 2001 Census geography, but the consultation exercise suggested that maintenance of settlement or locality boundaries was more important than retaining consistency with 1991 OAs (Box 1).^{12,14} In addition, the dramatic increase of approximately 30,000 postcodes in the 1990s, and increased confidentiality thresholds, meant that inconsistencies were inevitable at the OA level. Some 2001 OAs were created by sub-dividing 1991 OAs, but because the naming convention used to label OAs changed between 1991 and 2001 it was more difficult to identify these occurrences without using Geographical Information Systems (GIS).

It was possible that some '1981/1991 merged zones' and 2001 OAs comprised more than one polygon. This might have occurred when a particular zone spanned a water body, or when two or more islands were aggregated into one zone to maintain confidentiality thresholds. Thus, the '1981/1991 merged zones' and 2001 OA polygon files contained more polygons than the total number of zones in each file. We therefore overlaid the 42,747 polygons representing the 42,604 2001 OAs onto the 16,260 polygons representing the 15,739 '1981/1991 merged zones', within a GIS, to create a new polygon file, which contained 112,415

Box one

THE HIERARCHY OF ZONES THAT THE 2001 OAs IN SCOTLAND WERE DESIGNED TO NEST WITHIN

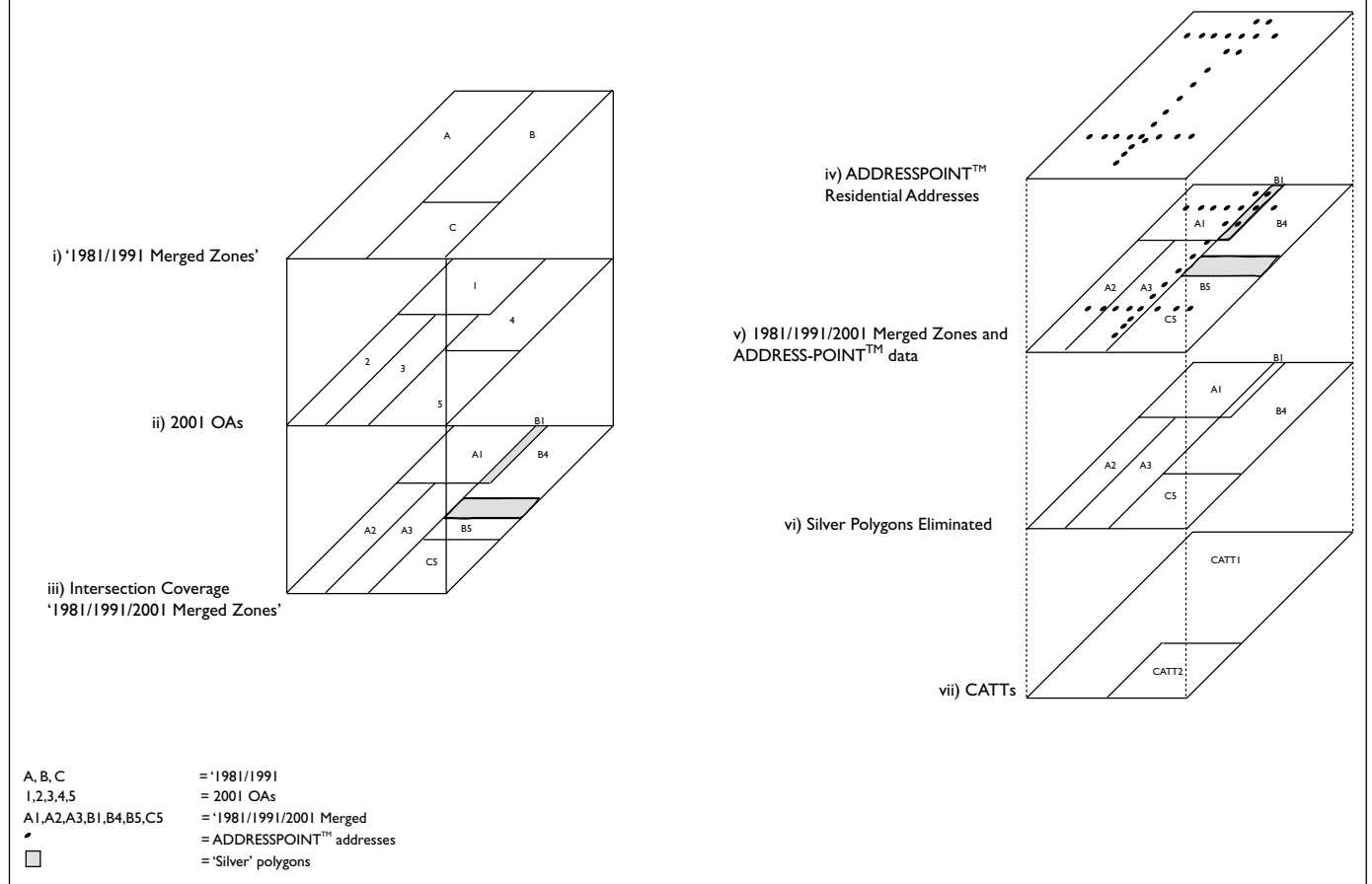
| (Ranking | Aggregation |
|---------------------|-----------------------------|
| 1 (most important) | 2001 Council Area |
| 2 | 2001 Locality ¹⁵ |
| 3 | 1991 OA |
| 4 | 2001 Postcode Sector |
| 5 (least important) | 2001 Electoral Ward |

Source: ¹²

polygons (see Figure 2i-iii). This large number of polygons demonstrates that there were some substantial differences between the '1981/1991 merged zones' and the 2001 OA boundaries. The key issue was to distinguish deliberately redrawn boundaries, where households were moved between areas, from the sliver polygons that were created by merging the two polygon files.¹⁶ Thus, were areas B1 and B5 in Figure 2iii slivers, or intentional boundary changes designed to reallocate people between different areas, perhaps because of confidentiality requirements.

In order to identify and remove the sliver polygons that did not include any households the GROS performed a point-in-polygon overlay of each residential address in Scotland derived from ADDRESS-POINT™

Figure 2 Combining the '1981/1991 merged zones' with 2001 OAs



which is a point coverage containing 2,378,170 addresses. The number of residential addresses that fell within a single polygon ranged from 0 to 1,739. There were 57,639 polygons that contained at least one residential address and the mean number of addresses in a polygon was 41.

In Figure 2v area B1 was identified as a genuine boundary change designed to reallocate people between areas (this may have occurred because the households in B1 were in the same postcode as households in 2001 OA 1, rather than 2001 OA 4). On the other hand, area B5 did not include any addresses, and hence could be ignored as a 'sliver' in our intersection of the '1981/1991 merged zones' and the 2001 OAs. Thus, in Figure 2vii polygon B5 was eliminated since it contained no addresses. Note that the elimination of polygons, such as B5 in Figure 2vii, was controlled so that the 2001 OA boundaries were retained.

Eliminating all polygons within the '1981/1991/2001 merged zones' file that did not contain any addresses resulted in a boundary file with 58,030 polygons. This file included all 42,747 of the 2001 OAs termed '1981/1991/2001 merged zones', but there were 47 '1981/1991 merged zones' missing. These were in the urban areas of Dundee, Edinburgh, Glasgow and Renfrewshire and resulted from estate demolition since 1991. These areas had been merged with neighbouring zones in 2001.

The majority (31,286) of the 2001 OAs fell within a single '1981/1991 merged zone', but some large 2001 OAs overlapped up to 10 '1981/1991 merged zones'. To ensure consistency through time, whenever a 2001 OA overlapped more than one '1981/1991 merged zone', the affected zones were aggregated. For example, in Figure 2vi one 2001 OA ('1') overlaps '1981/1991 merged zones' 'A' and 'B'. Thus, these '1981/1991 merged zones' were aggregated to create one of the CATTs shown in Figure 2vii. Aggregating all the necessary polygons reduced the number of zones considerably to 5,741. These zones are unique CATTs (referred to as 'CATT0') for which census data from 1981, 1991 and 2001 can be reliably compared.

Unfortunately, while these CATTs are genuinely consistent, their size and shape varies considerably. A number of large, unusually shaped zones were created (Figure 3a), a problem which also occurred in the development of Census Tracts.¹¹

Bearing in mind that previous attempts to integrate different geographies had usually relied on postcodes to decide whether boundary changes were significant,^{7,8,17} our approach was extremely conservative. We had used the strict criteria that any polygon with at least one address point should be treated as an intentional sliver and this usually resulted in the merger of neighbouring zones. We therefore created two further sets of CATTs that were slightly less conservative. First, the construction of CATT1s relaxed the rule so that a sliver polygon that contained less than two addresses was eliminated. This resulted in 8,588 CATT1s, (Figure 3b). Second, CATT2 relaxed the rule slightly more, so that slivers with two or less addresses were eliminated, resulting in 10,058 CATTs (Figure 3c). Thus, three sets of CATTs have been created (CATT0, CATT1 and CATT2). Given that 2001 OAs contained a minimum of 20 households, removing polygons containing one or two points was not considered too significant. Indeed, only 102 of the 42,604 OAs in 2001 contained as few as 20 households.

CASE STUDY: THE POPULATION AND SIZE OF CATTs IN FIFE

As the number of CATTs increases, so too does the similarity between the CATTs and the 2001 OAs. There were 2,924 2001 census OAs in Fife, with populations ranging from 50 to 562, with a mean of 119. There were 247 CATT0s in Fife, with 2001 populations ranging from 58 to 143,868, with a mean population of 1,614. There was one CATT0 zone

Table 1 Population summary statistics for the three sets of CATTs and, for comparison, 2001 OAs and Census Area Statistics (CAS) Sectors

| | 2001 OA | 2001 Sector | CATT0 | CATT1 | CATT2 |
|--------------|---------------|--------------|--------------|--------------|---------------|
| Min | 50 | 51 | 50 | 50 | 50 |
| Max | 2,357 | 20,512 | 143,868 | 36,283 | 18,510 |
| Mean | 119 | 5,011 | 882 | 589 | 503 |
| Std. Dev. | 45 | 3,441 | 3,907 | 1,274 | 831 |
| Total | 42,604 | 1,010 | 5,741 | 8,588 | 10,058 |

that included a considerable proportion of Fife and this is a good example of the daisy-chain effect that can occur in the creation of CATTs, because the strategy of aggregating two or more '1981/1991 merged zones' to accommodate 2001 OAs was a recursive process (Figure 4a). Therefore, while the CATT0 configuration is the most reliable, because any sliver with a single address was treated as a 'genuine' boundary change, the zones are not particularly practical in some parts of Scotland.

Relaxing the rule so that slivers were ignored if they included zero or one residential address increased the number of CATTs to 485 in Fife (Figure 4b). The large CATT0 polygon was split into 107 individual zones. The maximum 2001 population dropped considerably to 36,283, and the mean population reduced to 778. The number of zones increased again to 616 with the CATT2 generation (Figure 4c). These had a maximum 2001 population of only 18,510 and a mean of 605. Furthermore, the large CATT0 zone that covered most of Fife was split into 167 smaller CATTs in the CATT2 generation. Many of the small settlements that were initially absorbed into rural zones in the CATT0 version have been retained and are more clearly defined in Figure 4c.

Table 1 provides a list of summary statistics for the total populations from the 2001 census populations for OAs and the CATTs. One of the 'costs' of creating a consistent geography through time was that there was no control over the maximum population within a particular CATT. The minimum population threshold for OAs in 2001 was 50 and only one or two CATTs (depending on the generation) had a population of exactly 50. Between 15 (CATT2) and 54 (CATT0) CATTs have a population greater than 10,000, which is comparable in size to a typical 2001 Census Area Statistic Postcode Sector (Table 1).

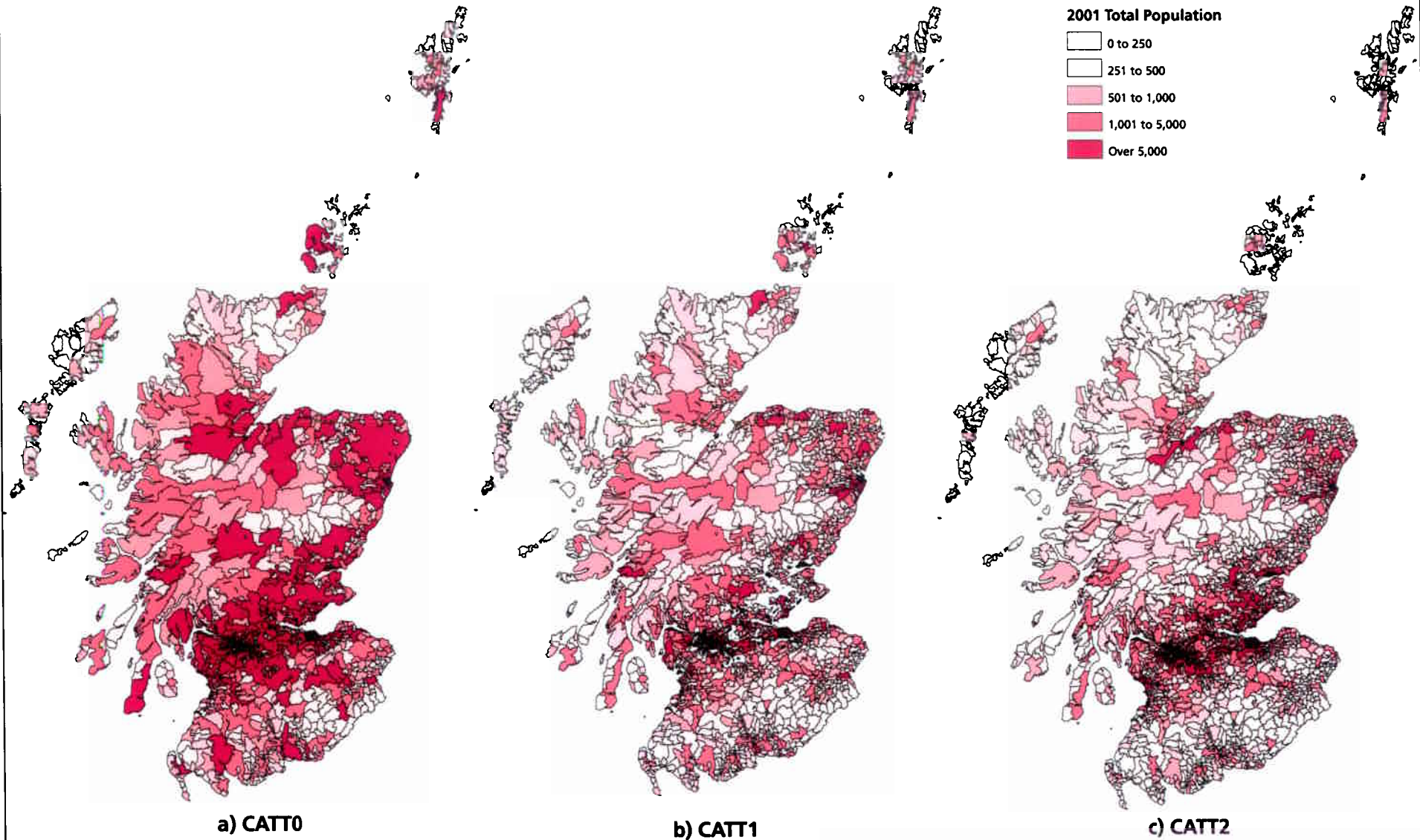
Note also that one outcome of the construction of the CATTs (in each generation) was the creation of 'mainland islands', which are small CATT zones surrounded by larger CATT zones. These mainland islands are scattered throughout Scotland, but tend to be located in rural or suburban areas. The islands represent towns/villages whose boundaries did not change through time.

The creation of consistent areas through time means that *changes* in census variables can also be examined. In 1981, there were 326,627 residents in Fife. The population of each CATT2 in Fife ranged from 52 to 12,569, with a mean of 540. While the total Scottish population declined between 1981 and 2001, the total population of Fife increased by eight per cent to 353,181. In 2001, the population in the CATT2s ranged from 58 to 18,510, with a mean of 584.

Between 1981 and 2001, the CATT2-level population change in Fife ranged from a decrease of 64 per cent to an increase of 1,067.50 per cent, with a mean growth of 4.9 per cent. As Figure 5 demonstrates, the areas of population growth were typically the geographically larger, more rural CATT2s, while the population in the more urban or suburban areas tended to decline over time.

Figure 3

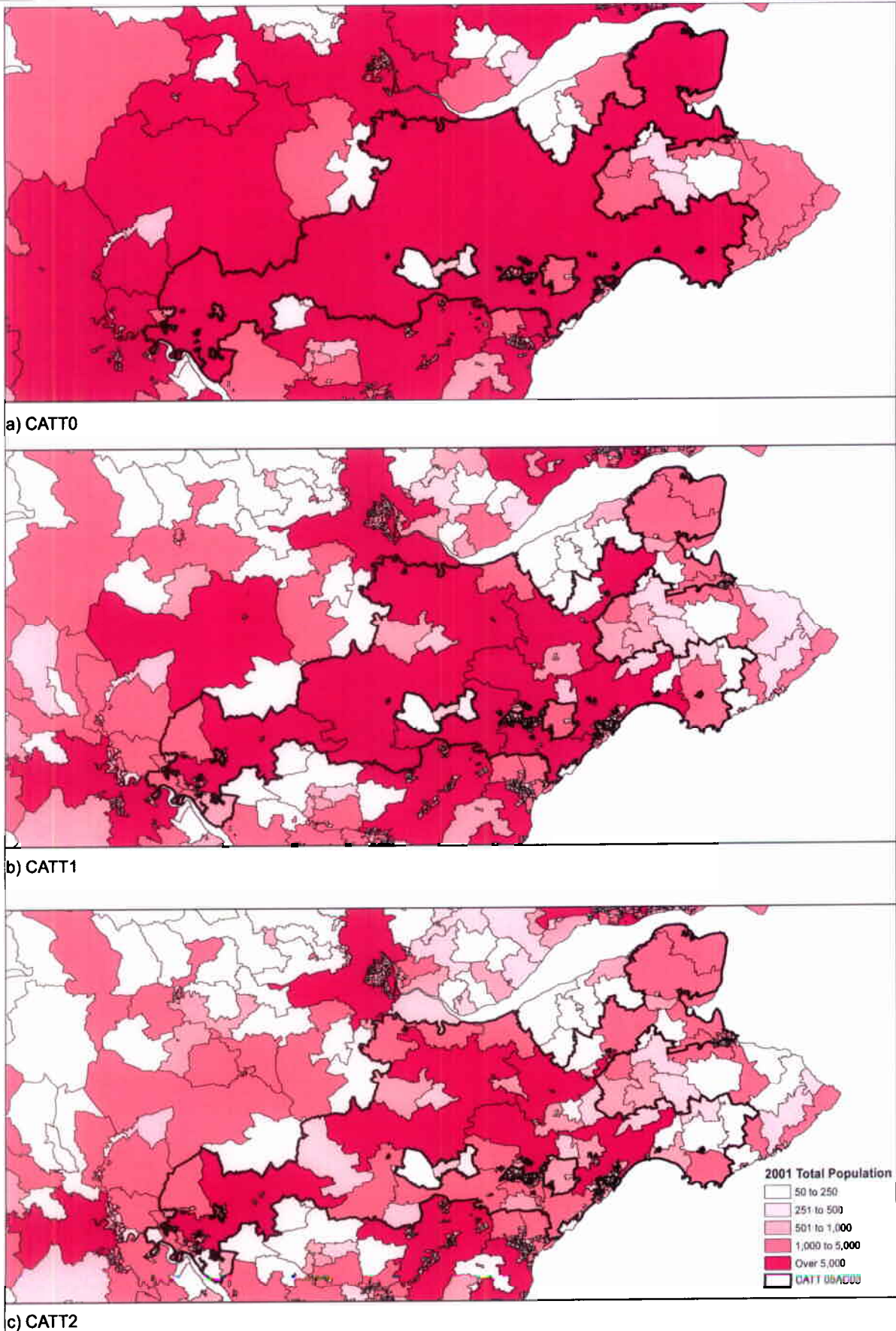
The 2001 total populations for the three different generations of CATTs in Scotland



ONS would usually recommend that count data are displayed in proportional symbol maps. In this case the author has chosen choropleth maps to illustrate the specific points that are being made in this article.

Figure 4

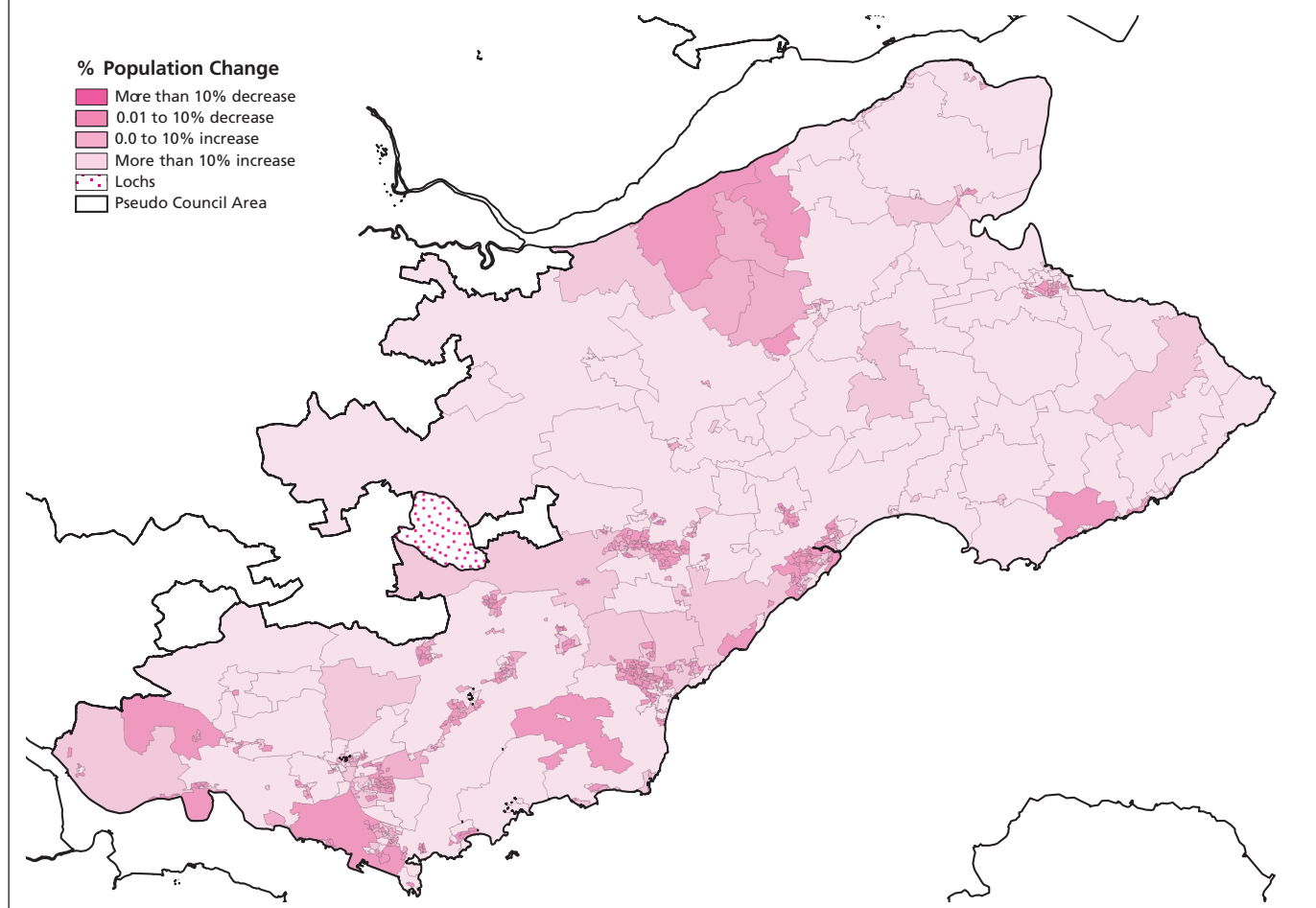
The 2001 total populations for the three different generations of CATTs in the Fife Pseudo Council Area



ONS would usually recommend that count data are displayed in proportional symbol maps. In this case the author has chosen choropleth maps to illustrate the specific points that are being made in this article.

Figure 5

Percentage population change (1981–2001) for CATT2s in the Fife Pseudo Council Area



LINKING 1981, 1991 AND 2001 DATA TO CATTs

Nine geographical conversion tables (GCTs) have been constructed to link 1981 EDs and OAs from 1991 and 2001 to each set of CATTs. Each GCT consists of three fields: the source zone (for example, 1981 ED), the target zone (for example, CATT2), and the population for the target zone and the particular census year (for example, 1981 total population). Unlike traditional GCTs, there is no need for a weight as each of our CATTs is constructed from one or more complete 1981 EDs, 1991 OAs and 2001 OAs, and therefore no further data manipulation is required.

Population weighted grid references derived from 2001 OA centroids have been created for each generation of the CATTs, which can be used to create approximations of higher geographies, such as Postcode Sectors, Wards, and Parliamentary Constituencies, using point-in-polygon queries. Note that when aggregating from CATTs to Postcode Sectors and Wards, it is possible that there will be fewer zones than in the official data sets, because some CATTs may overlap more than one of the target zones.

CONCLUSION AND FUTURE RESEARCH

A number of approaches exist for creating consistent geographies through time. However, these approaches usually involve estimation and hence some error results. Here, we present a method for creating 'Consistent Areas Through Time' (CATTs) where the basic rule was that each CATT should be created from one or more complete 1981 ED, 1991 OA or 2001 OA. This approach is more accurate than interpolation

techniques because the populations derived for each area are based on data from complete census zones (barring, at most in CATT2, two residential addresses).

Three sets of CATTs have been produced. The first, CATT0, consists of 5,741 zones and is the most conservative as it involved the strictest criteria for aggregating zones together. The configuration of zones is compromised to some extent due to the merging processes used to create them, and many of the CATT0 zones are very large. The least conservative set of zones, CATT2, contains 10,058 zones, and is recommended by the authors for use in most analyses. We envisage the CATTs being appropriate for a wide range of data analyses that are pertinent to the health and well being of the Scottish population.

Undoubtedly, the configuration of the OAs (or their equivalent) for the 2011 Census will differ from those from the 2001 Census in order to reflect the population distribution. However, the CATT2s could be modified to accommodate the 2011 Census OAs, by adopting the same approach that was used for integrating the 2001 Census geography with the '1981/1991 merged zones'. Thus, the 2011 OA zones could be overlain upon the CATT2 zones while ADDRESS-POINT™ data would be used to distinguish between deliberate boundary changes and sliver polygons. In this case, the CATT2s would be used as the target geography, and whenever the 2011 OA zone overlapped more than one CATT2 zone, the affected CATT2s would be merged.

It is not possible to adopt the methodology presented in this article to create a consistent small area geography between 1981 and 2001

Key findings

- Because Scottish census zones have been constructed from postcodes since 1981, it is possible to create a local area geography that is consistent over this period
- Existing methods for creating consistent geographies usually depend on the proportional allocation of data from source zones to target zones, which inevitably incurs error
- We present an alternative method for creating three sets of 'Consistent Areas Through Time' (CATTs), which uses a 'merging' strategy. If a source zone overlaps more than one target zone, then the affected zones were merged
- Three sets of CATTs have been produced, which are based on more or less strict rules about when zones should be merged
- The CATTs provide a local-area Scottish geography which allows 1981, 1991 and 2001 census data to be compared reliably through time

for England and Wales, as the EDs in England and Wales were not constructed using postcodes as the base geography. However, the recently developed Super OAs in England, Wales and Northern Ireland will allow the methodology presented here to be used for comparing small areas from the 2001 and 2011 Censuses.

The lookup tables required to aggregate the 1981 EDs and OAs from 1991 and 2001 to the CATT2 level have been made available from UKBORDERS: <http://www.edina.ac.uk/ukborders> and MIMAS: <http://www.census.ac.uk/cdu>.

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15. There were 587 localities in 2001, which ranged in population from 443 to 629,501, and had an average population of 7,742. In 2001, localities were based on the boundaries of the 1991 localities, and were subdivisions of Settlements, which were groups of neighbouring urban postcodes, with a minimum population of 500 residents.
16. In 2001 boundaries may have been 'improved' from 1991 so that they fell more neatly along the middle of a road, for example. However, when comparing the two coverages this would have created a sliver, which did not involve the redistribution of any households between the two zones.
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