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A model for spatio-temporal injury surveillance: implications for the evolution of a trauma system

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Dr. Gene Moore
Editor
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(via electronic submission system)

Dear Dr Moore

A model for spatio-temporal injury surveillance: implications for the evolution of a trauma system

Please find attached a revision of our manuscript entitled “A model for spatio-temporal injury surveillance: implications for the evolution of a trauma system”, for consideration of publication in the Journal of Trauma.

We have addressed all of the reviewers’ comments, as detailed overleaf. We confirm that this is an original piece of work. An abstract was presented at the Academic Surgical Congress in Jacksonville, in 2018, but none of it has been submitted or published previously.

Please note that this manuscript contains one table, and six figures. We realize that this exceeds the number usually permitted. However, we believe the figures to be essential to the interpretation of the findings. One of the reviewers commented on the need for the figures to be reproduced in color to retain their clarity. We would be happy to meet the costs of color reproduction.

We have also have some of the technical details, as requested by reviewer 1. We thought it might still be helpful to include this in “boxes”, in the manuscript. However, if you would prefer for this to be supplemental material, this would be straightforward. We look forward to your editorial guidance in this matter.

Many thanks for your help.

Kind regards

Jan Jansen, MBBS, PhD
Associate Professor of Surgery
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REVIEWER 1	
The statement is made that they collect "high quality data". This in turn limits the transportability of this type of study especially to the United States.	We have addressed this issue in the discussion.
The selection of patients was made based on "final diagnostic codes" in a supplemental table which was not reviewed. Usually these are based on ICD9-CM 800 - 959.9. Again this may be an issue with transportability.	The final diagnostic code is also an MPDS code. We have clarified this in the methods, and also expanded on this issue in the discussion.
The modeling approach is described as is the spatio-temporal statistical model which although complete is even more incomprehensible to the average reader.	We have moved the technical aspects of the statistical approach into a "Box", to make the manuscript more readable and more accessible. If desired, this material could also be moved into a supplementary file. We would welcome your editorial guidance in this matter.
Likewise the "spatial data" refers to "ESRI shapefiles" presented as "choropleth maps", which I am sure the average reader can instantly relate to.	We have added an explanation of what a shapefile is, and deleted the reference to choropleth maps. We have also moved the description of the manipulation of the files into a further "Box", to make the manuscript more readable and more accessible. If desired, this material could also be moved into a supplementary file. We would welcome your editorial guidance in this matter.
The presentation of these maps bring a huge clarity to the study after the jargon dense methodology. They are however color coded. This should be retained for clarity.	Thank you. We intend to retain the colored maps, and are prepared to meet the cost of color reproduction.
There are a couple of curious statements e.g. indicating that "many of the penetrating injuries are assaults". The percentage of assault versus self-inflicted i.e. suicide/attempted suicide would be of interest.	We agree that this statement is misleading and not based on data presented, and have therefore removed it.
The differences between Glasgow and Edinburgh are "most likely reflection of changes in demographics of the two cities". This could probably be illuminated.	We agree that this statement is misleading and not based on data presented, and have therefore clarified it.
They make the statement that the incidence per area is "most relevant to the provision of services" rather than the incidence rate. Clearly the two are complimentary. This statement is probably over indexing the value of the spatio-temporal analyses.	We have amended this statement and clarified it.
the issue of lack of transportability of their findings, given the fact that their study relies on the fact that nearly all injuries are transported by	We have expanded on this issue in the discussion.

ambulance and that there is a single countrywide ambulance service with good data.	
They imply that the findings of such studies could help reconfigure the trauma system in Scotland, however this is somewhat locked based on the fact that there are only 4 major cities, Glasgow, Edinburgh, Dundee and Aberdeen and the distance time and transport limitations that are already in play.	Two of the four major trauma centers in Scotland have very low case volumes (less than 100 severely injured patients per year). Ongoing surveillance and re-evaluation of the system configuration is therefore important. We have added to the discussion to make this clearer.
REVIEWER 2	
…would be stronger if the discussion included the possible reasons for the change over time. For example, there are areas where the trauma incidents have decreased, is this because of reduced population? Some areas where there is a decrease in trauma incidents, the numbers with abnormal vital signs actually has increased - what may explain that?	We have added to the discussion to expand on this point. However, our analysis did not include an analysis with regards to population size.
A smaller issue is the dispatch/diagnostic codes. They do not seem to be mutually exclusive as some are related to mechanism (falls; road accidents etc) while in the same data point some are related to findings (laceration/hemorrhage). Is it not possible for road accident to result in laceration/hemorrhage? How did the authors classify these. This needs to be clarified in the text and also in Table I.	We agree. The MPDS coding system is crude, as it is intended for the despatch of vehicles, rather than as a diagnostic coding system. We have further emphasized this limitation. The codes were chosen by the paramedics, on the ambulances, rather than the authors of this study. We have expanded on this limitation.

ABSTRACT

Background

Geographical variations in case volume have important implications for trauma system configuration, and have been recognised for some time. However, temporal trends in these distributions have received relatively little attention. The aim of this study was to propose a model to facilitate the spatio-temporal surveillance of injuries, using Scotland as a case study.

Methods

Retrospective analysis of five years' (2009-2013) of trauma incident location data. We analysed the study population as a whole, as well as predefined subgroups, such as those with abnormal physiological signs. In order to leverage sufficient statistical power to detect temporal trends in rare events over short time periods and small spatial units, we used a geographically weighted regression model.

Results

There were 509,725 incidents. There were increases in case volume in Glasgow, the central Southern part of the country, the Northern parts of the Highlands, the North-East, and the Orkney and Shetland Islands. Statistically significant changes were mostly restricted to major cities. Decreases in the number of incidents were seen in the Hebrides, Western Scotland, Fife and Lothian, and the Borders. Statistically significant changes were seen mostly in Fife and Lothian, the West, some areas of the Borders, and in the Peterhead area. Subgroup analyses showed markedly different spatio-temporal patterns.

Conclusions

This project has demonstrated the feasibility of population-based spatio-temporal injury surveillance. Even over a relatively short period, the geographical distribution of where injuries occur may change, and different injuries present different spatio-temporal patterns. These findings have implications for health policy and service delivery.

Level of evidence

Level V

Study type

Epidemiological study

Keywords

Trauma; trauma systems; geographical information systems; geospatial analysis; geographically weighted regression

A model for spatio-temporal injury surveillance: implications for the evolution of a trauma system

Short Title: Spatio-temporal injury surveillance

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Conflicts of interest: The authors declare no conflicts of interest.

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Presentations: An abstract of this work was presented at the Academic Surgical Congress 2018.

BACKGROUND

Trauma is a global public health issue, resulting in more than 5 million fatalities per year, and contributing an estimated 11% of the world total of disability adjusted life years.(1, 2) Serious injury often necessitates specialist treatment, both pre- and in-hospital, and trauma systems – clinical networks comprising emergency medical services, as well as designated trauma centres – have been shown to save lives, and improve functional outcomes.(3, 4) The access to such specialist care is key,(5-7) and is determined by the degree of match between the geographical location of incidents occurrences, and that of assets such as ambulances, helicopters, and trauma centers. The spatial injury profile is thus an important consideration for a trauma system,(8) but descriptive epidemiology has traditionally focused on the characteristics of the person, and paid less attention to the place of injury occurrence.(9) Furthermore, there is increasing recognition that spatial injury profiles may change over time. (9-12)

The Centers for Disease Control and Prevention and the World Health Organization have developed the concept of "injury surveillance", which is defined as the ongoing and systematic collection, analysis, interpretation and dissemination of health information, with a view to informing the effectiveness of prevention and treatment. The evaluation of temporal trends is a recognised component of such analyses – trauma centers and public health departments routinely keep track of, for example, the number of patients with gunshot wounds. Similarly, geographical differences in case volume are well recognized: Gunshot wounds are more common (both in terms of absolute numbers, as well as per capita) in some areas than others. (2) However, temporal trends in these distributions – often referred to as spatio-temporal trends – have received relatively little attention, and recent reports have focused on relatively small areal units, and short time-scales.(9, 11-14) Every geographical region can be thought of having a "spatial injury profile", which describes the expected number of injuries occurring in each geographical location per unit of time. This concept can be applied to the injured population as a whole, as well as subgroups – such as those patients who suffered ballistic or penetrating injuries. Spatial injury profiles are important, because they determine, in conjunction with the configuration of the trauma system, its geospatial effectiveness.

We hypothesised that the spatial injury profile of a population as a whole may change over time, with implications for the trauma system serving it, and that different types of injuries may present different patterns of spatio-temporal change. The aim of this study was therefore to propose a model to facilitate the spatio-temporal surveillance of injuries. In particular we sought to enable the early detection of local increases or decreases in absolute numbers of cases that could inform the planning of trauma services infrastructure.

METHODS

This is a retrospective analysis of five years' of national data collected routinely by the Scottish Ambulance Service (SAS) for incidents attended between 1 January 2009 and 31 December 2013. Permission for this evaluation was provided by the SAS.

Setting

Scotland has a land area of 78,770 km^2, including 94 inhabited islands, and a mixed urban/rural population of 5.3 million. There are four major cities: Glasgow, Edinburgh, Aberdeen and Dundee. Key geographical areas are shown in figure 1. Large parts of the country, in particular the North and West, are remote. The population density of Scottish council areas ranges from 8/km^2 to 3,412/km^2.(15) The Scottish Ambulance Service (SAS) is, de facto, the sole provider of prehospital care, and collects high-quality prehospital data on all incidents attended. Furthermore, self-presentation with serious injury is rare. Prehospital data therefore lends itself to the population-based analysis of case volume and distribution, and has previously been used to study the country's static spatial injury profile.(16-19)

Design, data source, case definition, and subgroups

All trauma episodes attended by the SAS were electronically coded, by emergency medical service providers, using the MPDS system (Medical Priority Dispatch Systems, MPDS; Priority Dispatch Corporation, Salt Lake City, UT). The MPDS is a despatch system, rather than a diagnostic coding system. The SAS therefore record both an initial despatch code, based on caller interrogation, as well as a final diagnostic code, based on paramedic assessment, both using the MPDS system. A case was defined in terms of this final diagnostic code. We included incidents with trauma-related final diagnostic codes (see supplementary table 1), and extracted demographic, physiological, geographic, and dispatch data for analysis. We analysed the study population as a whole, as well as a number of subgroups, which had been agreed a priori, including patients with abnormal physiological signs (as defined by the Scottish Ambulance Service trauma triage protocol: systolic blood pressure <90mmHg, Glasgow Coma Scale <14, respiratory rate <10 or >29 breaths/min), and those with specific traumatic injuries, including "falls", "penetrating injuries", and "traffic/transportation-related injuries", which are categories used by the MPDS system. Patients with abnormal physiology were chosen because such abnormalities are often indicative of serious, or even life-threatening problems, and thus require more urgent care. Patients who had suffered falls were selected because this injury pattern represents the second largest cause of years lived with disability in the UK.(20) Penetrating trauma was chosen because these injuries are relatively rare in Scotland and occur in relatively confined areas. (21) Lastly, traffic-related incidents were analysed because of their presumed wide geographical distribution.

Modelling approach

Our analysis aimed at (1) characterizing the average geographical distribution of expected incident numbers within the country; (2) identifying any general, short-term temporal trend in incident numbers over five years and (3) identifying regional differences in temporal trends over five years. Serious injuries present typically low prevalence, especially in areas of low population density. This means that for a given highly resolved spatial unit, there will often be insufficient power to precisely estimate expected incidence or to detect temporal trends. Here, we propose to solve this general issue by adopting a "geographically weighted regression" (GWR) approach.(22) GWR smoothes model coefficients over space, under the assumption that variations in the numbers of cases are spatially correlated, i.e. that they are more similar among neighbouring units than among more distant units. In this way, GWR allows the sharing of information across neighbouring spatial units, which may very effectively increase the statistical power to detect regional temporal trends in rare events over relatively short time periods. Technical details of the statistical approach are shown in box 1.

Spatio-temporal statistical model

The Scottish Ambulance Service geocode incident locations by full UK postcode, of which there are around 188,000 in Scotland. We used aggregate counts per postcode district ("PCD" – the part of the postcode before the space, consisting of one or two letters, followed by one or two digits, numbering 444 in Scotland) for the statistical analysis, because full postcodes have too high a spatial resolution for the purpose of this study and would represent an unnecessarily high computational burden. Furthermore, while all administrative units of comparable size in use in the country, including Intermediate Zones,(23) have a higher density and spatial resolution (smaller size) in urban areas relative to countryside, postcode districts benefit from a relatively more homogeneous spatial resolution. For each PCD *i* we sought to estimate the average number of incidents (intercept α_i) as well as a linear temporal trend (coefficient β_i). Following the GWR approach, we constrained these two sets of coefficients to vary smoothly over space. The smoothing was implemented in discrete space by a Markov random field, conditioning estimates for each PCD on those from adjacent PCDs, as indicated by Eqs. (1-4).

$$Y_d \sim Poisson(\lambda_d) \quad (1)$$

$$\log(\lambda_d) = \alpha_i + \beta_i T_d \quad (2)$$

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$$\alpha_i|\alpha_j, i \neq j \sim \mathcal{N}\left(\frac{1}{n_i}\sum_{i\sim j}\alpha_j, \frac{1}{n_i\tau_\alpha}\right) \quad (3)$$

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$$\beta_i|\beta_j, i \neq j \sim \mathcal{N}\left(\frac{1}{n_i}\sum_{i\sim j}\beta_j, \frac{1}{n_i\tau_\beta}\right) \quad (4)$$

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~~where *d* is the datum index (incident count per spatial unit per year). The model assumes a Poisson distribution for the counts of incidents per PCD and per year (Eq. 1). Equation 2 assumes a linear trend in expected numbers of cases per PCD with intercept α_i and slope β_i for the centered year covariate T. n_i is the number of neighbours of spatial unit *i*, *i~j* reads "for all *j* sharing a border with *i*" and τ is the precision parameter. The model was implemented in R 3.2.1(24) as a Generalised Additive Model with the function 'gam:mgcv'.(25) The Gaussian Markov random fields represented in (3) and (4) were specified using the "bs= mrf" argument for the smooth component of the model.~~

Spatial data and presentation of results

We used freely available ~~ESRI~~ "shapefiles" (a widely used format for files containing geographical data) of Scottish postcode districts.(26) The results are presented as ~~choropleth~~ maps. Technical details of the manipulation of the shapefiles to create a neighborhood structure with adjacencies are given in box 2.

~~In order to compute Markov random field parameters, the Scottish postcode districts layer must be converted into a neighbourhood structure that relates postcode districts which are adjacent to each other. Because some PCDs on islands are not connected to any neighbours, trend estimates would tend to rely on too small sample sizes and hence become unstable and unreliable. We therefore modified the PCD layer by creating artificial connections between isolated PCDs and~~

adjacent island PCDs, located within a 20 km buffer area, assuming that islands within groups such as the Outer Hebrides should be similar to each other. We also created such connections between the islands of Arran and Gigha, and the Kintyre peninsula, again assuming that these areas shared common characteristics. This procedure was performed using QGIS (QGIS Version 12.2.1) and resulted in no PCD being left without “neighbour”. These modifications are visible as “bridges”, connecting the islands, on the maps.

RESULTS

Characteristics of study population

There were 509,725 incidents recorded over the duration of the study period. The baseline characteristics of the study population are shown in table 1. The number of patients per year varied from 96,797 in 2009 to 105,786 in 2012. The proportion of injured males was slightly higher (51.5%) than females (46.9%), with 1.6% of patients not having had their gender recorded. These proportions were consistent across the duration of the study. The median age was 55 years (interquartile range 30-79), but increased from 53 years in 2009 to 59 years in 2013. The distribution of final diagnostic code categories was similar, for the entire period, with the majority of incidents (54.4%) being due to falls, followed by assaults (11.9%), injuries involving haemorrhage/lacerations (11.8%), unspecified other traumatic injuries (10.5%), and traffic and transportation-related injures (7.2%). 6.8% of patients had at least one physiological abnormality (systolic blood pressure <90mmHg, respiratory rate <10 or >29 breaths per minute, or Glasgow Coma Scale <14).

All incidents

Figure 2a shows the mean number of incidents, per postcode district, per year. The distribution broadly reflects the distribution of the population as a whole. Case volume is high in the Central Belt area, lower in the North-East and South of the country, and very low in the Highlands and on the Islands. Figure 2b shows the spatio-temporal trends. There have been increases in the Glasgow area, the central Southern part of the country, the Northern parts of the Highlands, parts of the North-East, and the Orkney and Shetland Islands. Statistically significant changes were mostly restricted to major cities. Decreases in the number of incidents were see in the Hebrides, Western Scotland, Fife and Lothian, and the Borders. Statistically significant changes were seen mostly in Fife and Lothian, parts of the West of Scotland, some areas of the Borders, and in the Peterhead area.

Patients with abnormal physiology

Figures 3a and b show the distribution of trauma patients who were hypotensive, and/or had an abnormal level of consciousness, and/or respiratory rate. Figure 3a shows the mean number of incidents, per postcode district, per year. The distribution again broadly reflects the population distribution. The analysis of spatio-temporal trends (figure 3b), presents a very different picture, however: There has been an increase in volume in the Northern Highlands, on the Isles of Skye, and on the Orkney and Shetland Islands, although the change was only statistically significant for the Orkney Islands. Southern and Central Scotland, the central belt, Fife, and the West all saw decreases in the number of these patients, and many of these changes, particularly in the West and South-West, were statistically significant.

Falls

Patients who suffered falls present a more mixed picture. The baseline distribution is similar to previously (figure 4a). Figure 4b demonstrates the spatio-temporal trends. There were increases in parts of the Highlands, and on Orkney, as well as the North-East, around Glasgow, and in Southern Scotland. Statistically significant increases were mostly seen in and around Glasgow, in the Inverness area, and in the very South of the country. The central parts of Scotland, many areas of the West and Western Highlands, the Hebrides, Fife, and Lothian saw decreases in volume, many of which were also statistically significant.

Penetrating injuries

The volume of penetrating injuries was low, in most parts of Scotland, and there were many postcode districts with "zero counts". Only Glasgow and Dundee had PCDs with relatively high counts (figure 5a). However, the spatio-temporal analysis (figure 5b) showed that penetrating injuries had increased slightly in the Highlands and on the Outer Hebridean Islands, and parts of Western Scotland. However, these changes were not statistically significant, except for one district, around Pitlochry. The Central Belt, including Glasgow, the North-East, the South, and the Orkney and Shetland Islands, all witnessed decreases in the number of incidents involving penetrating injuries, with the changes in the Central Belt often being statistically significant.

Traffic and transportation injuries

The distribution of traffic and transportation injuries is shown in figure 6a. The number of incidents increased over the duration of the study period, in many parts of Scotland, including the Central Belt, the Highlands, the West, the South, the North-East, and the Orkney and Shetland Islands (figure 6b). Statistically significant changes were apparent particularly at the Western end of the Central Belt, as well as Edinburgh, Aberdeen, and on Orkney. The changes on the Islands of Mull, although marked, were not statistically significant. A few areas showed decreases, but these were also not statistically significant.

DISCUSSION

Spatio-temporal trends, and their importance in injury prevention and health policy, are gaining increasing recognition. However, recent publications have focused on smaller geographic areas, such as cities, and shorter time-scales.(9, 11-14) This large, population-based study of more than half a million trauma incidents in Scotland has shown evidence of spatially heterogeneous temporal trends in the injured population as a whole, over a 5-year period. These were however underpinned by idiosyncratic spatial patterns of change at the level of subgroups, such as those affected by different types or mechanisms of injury. The geographical distribution of trauma incidents broadly follows that of the population as a whole – people are usually, albeit with some exceptions, injured near to where they live or work.(17, 27) However, our results demonstrate regional trends, which are of importance to the future development of Scotland's trauma network, particularly if sustained. It is likely that these trends are the consequence of a combination of factors, such as demographic change, migration, changes to the road network, crime, etc. Our findings ~~furthermore~~ highlight the dynamic nature of spatial injury profiles, and the need to monitor trends.

Implications for Scotland's trauma system

The gradual increase in the number of incidents, and the number of incidents involving patients with abnormal physiology, in remote mainland and island settings, should prompt a further evaluation of the provision of prehospital services in these areas. Patients with abnormal physiology, indicative of potentially serious or life-threatening injuries, require urgent treatment, and rapid onward transport to definitive care, at a major trauma centre. Additional work is required to determine whether such patients experience different outcomes in remote areas, and whether such treatment can be provided, given the increasing volume. Many remote areas of Scotland rely on single ambulances, staffed by paramedics, to cover large areas, and many Islands are only accessible by helicopter. The provision of physician-led prehospital care is patchy, and Scotland's helicopter emergency medical service currently relies on a small number of aircrafts. Its helicopters, furthermore, do not have night-flying capability, and only limited ability to operate in poor weather conditions, which impacts on the ability to reach patients injured in remote locations. Consideration should be given to expanding the network of aeromedical retrieval assets, to enhance on-scene and en-route care, in order to offset the increasing number of incidents occurring in remote and rural incidents, with poor direct access to definitive trauma care. The widespread increases in the number of traffic- and transportation related incidents also warrant further investigation with regards to preventability. This category currently covers a large number of diverse types of incidents, and further breakdown may be helpful.

The number of penetrating injuries~~, many of which are related to assaults,~~ is much smaller than that of the other categories. Nevertheless, the decrease seen in the central belt area is noteworthy, and should prompt further study of what has precipitated this positive change. There are also noteworthy differences not only between urban and rural areas of Scotland, but also between its two main cities, Glasgow and Edinburgh. Glasgow has seen an increase in the overall volume of trauma incidents, whereas the volume has decreased in Edinburgh. The number of patients with physiological abnormalities has decreased in both locations, but the number of patients who suffered falls has increased in Glasgow, and decreased in Edinburgh. These changes ~~are, most likely, a reflection of the changing demographics of the two cities,~~ highlight~~ing~~ the critical importance of a well-organised regional trauma system in the greater Glasgow area. At present, discussions regarding the configuration of this part of the network are ongoing. There are also concerns about the capacity of the Glasgow's major trauma centre. Our study indicates that these concerns are valid, as case volume in this area is increasing. In contrast, decreasing case volumes in the areas served by the remaining major trauma centres, in Edinburgh, Dundee, and Aberdeen, could further reduce already critically low case volumes,(16) threatening the viability of these centres.

This study intentionally investigated the volume of incidents per area, ~~which is most relevant to the provision of services,~~ rather than the incidence rate (number of incidents per population, per area). While the two measures are complimentary, case volume is more relevant to system configuration, whereas ~~However,~~ the latter measure, which should ideally also be gender- and age-adjusted, ~~would provide useful additional information, which~~ is particularly pertinent to the analysis of risk and injury prevention strategies. At present, there is little indication that changes in the incident distribution should prompt a re-evaluation of the configuration of Scotland's trauma centres, particularly in light of the decision to designate four major trauma centres, and thus prioritising accessibility over the ability to provide specialist care. However, given the low case volume of some of the recently designated major trauma centers, ongoing surveillance and frequent re-evaluation of system configuration is important.

Methodological considerations and limitations

The geographically weighted regression approach for injury surveillance makes only relatively weak assumptions over and beyond the standard assumptions of Poisson Generalized Linear Models (GLMs). The simplifying assumption of linear temporal trends for each locality appears reasonable given the short time span considered (5 years) and allows an intuitive interpretation of estimated rates of change. Where the time span is longer or prior knowledge suggests non-linear trends, the use of 3-dimensional smoothers over both space and time may be warranted. The existence of smooth spatial trends (i.e., spatial heterogeneity at scales broader than individual post code districts) is clearly supported by our data. The level and structure of the smoothing is constrained by the scale and shape of the administrative units used. In Scotland, the size of administrative units such as PCDs post code districts varies considerably between the least and most densely populated areas. As per standard practice in disease mapping in discrete space, the Markov Random Field implemented in our spatial model assumed that the correlation between neighbouring units was the same irrespective of the size of the spatial units involved. This assumption remains untested and may require further investigation for studies where the precision of estimates is key. A possible approach to circumvent the problem may involve models assuming latent spatial random fields in continuous space.

Our largely intuitive rule for regrouping neighbouring islands appeared to be well supported by the data, in the sense that greater variation was found between than within spatial clusters for all types of injuries (See Figs 2-6). There may be scope for further improving the model predictions for islands by fine-tuning the neighbourhood relationships between islands, but we expect such optimization to be case-specific and labour-intensive, with only modest returns.

While smoothing may mask local variation in case numbers at very fine spatial resolution, it first and foremost allows the efficient extraction of informative patterns from potentially sparse data, by pooling information across neighbouring districts. Thanks to effective methods for selecting optimal smoothing levels,(25) the spatial resolution of resulting estimates reflects the richness of the each data set. This is illustrated for example by the noticeably smoother estimates of spatial variation in temporal trends obtained for groups with few cases (such as abnormal physiology and penetrating injuries; see Figs 3 and 5), in contrast with the smaller-scale variation of estimates for common injuries such as falls (Fig 4). Geographically weighted regression showed good power for detecting short-term trends, hence it provides an effective, spatially-resolved early detection method that should remain useful for relatively rare diseases or injuries.

This study, together with some of our previous work, once again demonstrates the utility of using ambulance service data. The value of such data has also been noted by other investigators.(9) Hospital-based administrative datasets often do not record injury-specific details, such as incident location, which is a major impediment to geographical analysis. Ambulance service data, in contrast, does contain such information. However, we acknowledge that such data are not available in all settings, particularly when services are offered by a multitude of providers, as is often the case in the United States. This may limit the immediate generalizability of the findingsapproach in some countries.

The disadvantage of rRelying on such prehospital data sources does not take into account those patients who self-present, however this number is small in Scotland, and the vast majority have minor injuries. Lastly, However, the study does also have limitations. tThe MPDS coding is relatively crude, because it is intended to aid the despatch of EMS vehicles, rather than as a diagnostic coding system. Some of the codes are not mutually exclusive, and their application is determined by the SAS's operating procedures. .However, the methodology does not rely on any particular coding system, and could be performed with any other type system, such as ICD-9, or ICD-10. Linkage to a national administrative dataset (such as held by the Information Services Division of NHS Scotland) would allow a much more detailed analysis, but is administratively complex, as prehospital records often contain incomplete information on which to match.

CONCLUSIONS

This project has demonstrated the feasibility and power of population-based spatio-temporal injury surveillance. Even over relatively short time periods, the geographical distribution of where injuries occur may change, and different injuries present different spatio-temporal patterns. These findings have implications for the delivery and development of trauma and prehospital care in Scotland, and for injury prevention, at national and regional level. The method described is transferable, and can be applied to almost any population, as long as georeferenced incident location data are available. Further work should give consideration to how centralizsed health data repositories, such as those held by the Information Services Division of NHS Scotland, could be further linked to other sources, including prehospital and trauma registry data, in order to undertake more complex analyses.

ACKNOWLEDGEMENTS

We would like to thank the Scottish Ambulance Service for giving us access to the data for this study, and NHS Grampian Endowments for funding this research.

CONTRIBUTIONS

JOJ, JJM and TC conceived the idea for this study, and designed it. JOJ conducted the original processing of the data. TC designed and conducted the statistical analysis. JJM and PE assisted with the interpretation of the data. All four authors contributed to the writing of the manuscript.

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Box 1: Spatio-temporal statistical model

The Scottish Ambulance Service geocode incident locations by full UK postcode, of which there are around 188,000 in Scotland. We used aggregate counts per postcode district ("PCD" – the part of the postcode before the space, consisting of one or two letters, followed by one or two digits, numbering 444 in Scotland) for the statistical analysis, because full postcodes have too high a spatial resolution for the purpose of this study and would represent an unnecessarily high computational burden. Furthermore, while all administrative units of comparable size in use in the country, including Intermediate Zones,(23) have a higher density and spatial resolution (smaller size) in urban areas relative to countryside, postcode districts benefit from a relatively more homogeneous spatial resolution. For each PCD i we sought to estimate the average number of incidents (intercept α_i) as well as a linear temporal trend (coefficient β_i). Following the GWR approach, we constrained these two sets of coefficients to vary smoothly over space. The smoothing was implemented in discrete space by a Markov random field, conditioning estimates for each PCD on those from adjacent PCDs, as indicated by Eqs. (1-4).

$$Y_d \sim Poisson(\lambda_d) \quad (1)$$

$$\log(\lambda_d) = \alpha_i + \beta_i T_d \quad (2)$$

$$\alpha_i | \alpha_j, i \neq j \sim \mathcal{N}\left(\frac{1}{n_i}\sum_{i\sim j}\alpha_j, \frac{1}{n_i \tau_\alpha}\right) \quad (3)$$

$$\beta_i | \beta_j, i \neq j \sim \mathcal{N}\left(\frac{1}{n_i}\sum_{i\sim j}\beta_j, \frac{1}{n_i \tau_\beta}\right) \quad (4)$$

where d is the datum index (incident count per spatial unit per year). The model assumes a Poisson distribution for the counts of incidents per PCD and per year (Eq. 1). Equation 2 assumes a linear trend in expected numbers of cases per PCD with intercept α_i and slope β_i for the centered year covariate T. n_i is the number of neighbours of spatial unit i, $i\sim j$ reads "for all j sharing a border with i" and τ is the precision parameter. The model was implemented in R 3.2.1(24) as a Generalized Additive Model with the function 'gam:mgcv'.(25) The Gaussian Markov random fields represented in (3) and (4) were specified using the "bs=mrf" argument for the smooth component of the model.

Box 2. Manipulation of shapefiles to create a neighborhood structure with adjacencies

In order to compute Markov random field parameters, the Scottish postcode districts layer must be converted into a neighborhood structure that relates postcode districts which are adjacent to each other. Because some PCDs on islands are not connected to any neighbors, trend estimates would tend to rely on too small sample sizes and hence become unstable and unreliable. We therefore modified the PCD layer by creating artificial connections between isolated PCDs and adjacent island PCDs, located within a 20 km buffer area, assuming that islands within groups such as the Outer Hebrides should be similar to each other. We also created such connections between the islands of Arran and Gigha, and the Kintyre peninsula, again assuming that these areas shared common characteristics. This procedure was performed using QGIS (QGIS Version 12.2.1) and resulted in no PCD being left without "neighbor". These modifications are visible as "bridges", connecting the islands, on the maps.

LEGENDS TO FIGURES

Figure 1. Map of Scotland

Figure 2. All patients. Map (a) shows the baseline estimate (number of incidents per area, per year). Map (b) shows the change over time. The colour of each postcode district represents the percentage change in case volume per year, over the 5-year period of the study. Blue areas indicate a negative change (decreased number of incidents), and red areas a positive change (increased number of incidents). Hatched postcode districts signify areas demonstrating a statistically significant change (based on the 95% confidence interval of temporal slope being different from 0).

Figure 3. Patients with abnormal physiology. Map (a) shows the baseline estimate (number of incidents per area, per year). Map (b) shows the change over time. The colour of each postcode district represents the percentage change in case volume per year, over the 5-year period of the study. Blue areas indicate a negative change (decreased number of incidents), and red areas a positive change (increased number of incidents). Hatched postcode districts signify areas demonstrating a statistically significant change (based on the 95% confidence interval of temporal slope being different from 0).

Figure 4. Incidents involving falls. Map (a) shows the baseline estimate (number of incidents per area, per year). Map (b) shows the change over time. The colour of each postcode district represents the percentage change in case volume per year, over the 5-year period of the study. Blue areas indicate a negative change (decreased number of incidents), and red areas a positive change (increased number of incidents). Hatched postcode districts signify areas demonstrating a

statistically significant change (based on the 95% confidence interval of temporal slope being different from 0).

Figure 5. Incidents involving penetrating injuries. Map (a) shows the baseline estimate (number of incidents per area, per year). Map (b) shows the change over time. The colour of each postcode district represents the percentage change in case volume per year, over the 5-year period of the study. Blue areas indicate a negative change (decreased number of incidents), and red areas a positive change (increased number of incidents). Hatched postcode districts signify areas demonstrating a statistically significant change (based on the 95% confidence interval of temporal slope being different from 0).

Figure 6. Incidents involving traffic and transportation injuries. Map (a) shows the baseline estimate (number of incidents per area, per year). Map (b) shows the change over time. The colour of each postcode district represents the percentage change in case volume per year, over the 5-year period of the study. Blue areas indicate a negative change (decreased number of incidents), and red areas a positive change (increased number of incidents). Hatched postcode districts signify areas demonstrating a statistically significant change (based on the 95% confidence interval of temporal slope being different from 0).

BACKGROUND

Trauma is a global public health issue, resulting in more than 5 million fatalities per year, and contributing an estimated 11% of the world total of disability adjusted life years.(1, 2) Serious injury often necessitates specialist treatment, both pre- and in-hospital, and trauma systems – clinical networks comprising emergency medical services, as well as designated trauma centres – have been shown to save lives, and improve functional outcomes.(3, 4) The access to such specialist care is key,(5-7) and is determined by the degree of match between the geographical location of incidents occurrences, and that of assets such as ambulances, helicopters, and trauma centers. The spatial injury profile is thus an important consideration for a trauma system,(8) but descriptive epidemiology has traditionally focused on the characteristics of the person, and paid less attention to the place of injury occurrence.(9) Furthermore, there is increasing recognition that spatial injury profiles may change over time. (9-12)

The Centers for Disease Control and Prevention and the World Health Organization have developed the concept of “injury surveillance”, which is defined as the ongoing and systematic collection, analysis, interpretation and dissemination of health information, with a view to informing the effectiveness of prevention and treatment. The evaluation of temporal trends is a recognised component of such analyses – trauma centers and public health departments routinely keep track of, for example, the number of patients with gunshot wounds. Similarly, geographical differences in case volume are well recognized: Gunshot wounds are more common (both in terms of absolute numbers, as well as per capita) in some areas than others. (2) However, temporal trends in these distributions – often referred to as spatio-temporal trends – have received relatively little attention, and recent reports have focused on relatively small areal units, and short time-scales.(9, 11-14) Every geographical region can be thought of having a “spatial injury profile”, which describes the expected number of injuries occurring in each geographical location per unit of time. This concept can be applied to the injured population as a whole, as well as subgroups – such as those patients who suffered ballistic or penetrating injuries. Spatial injury profiles are important, because they determine, in conjunction with the configuration of the trauma system, its geospatial effectiveness.

We hypothesised that the spatial injury profile of a population as a whole may change over time, with implications for the trauma system serving it, and that different types of injuries may present different patterns of spatio-temporal change. The aim of this study was therefore to propose a model to facilitate the spatio-temporal surveillance of injuries. In particular we sought to enable the early detection of local increases or decreases in absolute numbers of cases that could inform the planning of trauma services infrastructure.

METHODS

This is a retrospective analysis of five years' of national data collected routinely by the Scottish Ambulance Service (SAS) for incidents attended between 1 January 2009 and 31 December 2013. Permission for this evaluation was provided by the SAS.

Setting

Scotland has a land area of 78,770 km^2, including 94 inhabited islands, and a mixed urban/rural population of 5.3 million. There are four major cities: Glasgow, Edinburgh, Aberdeen and Dundee. Key geographical areas are shown in figure 1. Large parts of the country, in particular the North and West, are remote. The population density of Scottish council areas ranges from $8/km^2$ to $3,412/km^2$.(15) The Scottish Ambulance Service (SAS) is, de facto, the sole provider of prehospital care, and collects high-quality prehospital data on all incidents attended. Furthermore, self-presentation with serious injury is rare. Prehospital data therefore lends itself to the population-based analysis of case volume and distribution, and has previously been used to study the country's static spatial injury profile.(16-19)

Design, data source, case definition, and subgroups

All trauma episodes attended by the SAS were electronically coded, by emergency medical service providers, using the MPDS system (Medical Priority Dispatch Systems, MPDS; Priority Dispatch Corporation, Salt Lake City, UT). The MPDS is a despatch system, rather than a diagnostic coding system. The SAS therefore record both an initial despatch code, based on caller interrogation, as well as a final diagnostic code, based on paramedic assessment, both using the MPDS system. A case was defined in terms of this final diagnostic code. We included incidents with trauma-related final diagnostic codes (see supplementary table 1), and extracted demographic, physiological, geographic, and dispatch data for analysis. We analysed the study population as a whole, as well as a number of subgroups, which had been agreed a priori, including patients with abnormal physiological signs (as defined by the Scottish Ambulance Service trauma triage protocol: systolic blood pressure <90mmHg, Glasgow Coma Scale <14, respiratory rate <10 or >29 breaths/min), and those with specific traumatic injuries, including "falls", "penetrating injuries", and "traffic/transportation-related injuries", which are categories used by the MPDS system. Patients with abnormal physiology were chosen because such abnormalities are often indicative of serious, or even life-threatening problems, and thus require more urgent care. Patients who had suffered falls were selected because this injury pattern represents the second largest cause of years lived with disability in the UK.(20) Penetrating trauma was chosen because these injuries are relatively rare in Scotland and occur in relatively confined areas. (21) Lastly, traffic-related incidents were analysed because of their presumed wide geographical distribution.

Modelling approach

Our analysis aimed at (1) characterizing the average geographical distribution of expected incident numbers within the country; (2) identifying any general, short-term temporal trend in incident numbers over five years and (3) identifying regional differences in temporal trends over five years. Serious injuries present typically low prevalence, especially in areas of low population density. This means that for a given highly resolved spatial unit, there will often be insufficient power to precisely estimate expected incidence or to detect temporal trends. Here, we propose to solve this general issue by adopting a "geographically weighted regression" (GWR) approach.(22) GWR smoothes model coefficients over space, under the assumption that variations in the numbers of cases are spatially correlated, i.e. that they are more similar among neighbouring units than among more distant units. In this way, GWR allows the sharing of information across neighbouring spatial units, which may very effectively increase the statistical power to detect regional temporal trends in rare events over relatively short time periods. Technical details of the statistical approach are shown in box 1.

Spatial data and presentation of results

We used freely available "shapefiles" (a widely used format for files containing geographical data) of Scottish postcode districts.(26) The results are presented as maps. Technical details of the manipulation of the shapefiles to create a neighborhood structure with adjacencies are given in box 2.

RESULTS

Characteristics of study population

There were 509,725 incidents recorded over the duration of the study period. The baseline characteristics of the study population are shown in table 1. The number of patients per year varied from 96,797 in 2009 to 105,786 in 2012. The proportion of injured males was slightly higher (51.5%) than females (46.9%), with 1.6% of patients not having had their gender recorded. These proportions were consistent across the duration of the study. The median age was 55 years (interquartile range 30-79), but increased from 53 years in 2009 to 59 years in 2013. The distribution of final diagnostic code categories was similar, for the entire period, with the majority of incidents (54.4%) being due to falls, followed by assaults (11.9%), injuries involving haemorrhage/lacerations (11.8%), unspecified other traumatic injuries (10.5%), and traffic and transportation-related injures (7.2%). 6.8% of patients had at least one physiological abnormality (systolic blood pressure <90mmHg, respiratory rate <10 or >29 breaths per minute, or Glasgow Coma Scale <14).

All incidents

Figure 2a shows the mean number of incidents, per postcode district, per year. The distribution broadly reflects the distribution of the population as a whole. Case volume is high in the Central Belt area, lower in the North-East and South of the country, and very low in the Highlands and on the Islands. Figure 2b shows the spatio-temporal trends. There have been increases in the Glasgow area, the central Southern part of the country, the Northern parts of the Highlands, parts of the North-East, and the Orkney and Shetland Islands. Statistically significant changes were mostly restricted to major cities. Decreases in the number of incidents were see in the Hebrides, Western Scotland, Fife and Lothian, and the Borders. Statistically significant changes were seen mostly in Fife and Lothian, parts of the West of Scotland, some areas of the Borders, and in the Peterhead area.

Patients with abnormal physiology

Figures 3a and b show the distribution of trauma patients who were hypotensive, and/or had an abnormal level of consciousness, and/or respiratory rate. Figure 3a shows the mean number of incidents, per postcode district, per year. The distribution again broadly reflects the population distribution. The analysis of spatio-temporal trends (figure 3b), presents a very different picture, however: There has been an increase in volume in the Northern Highlands, on the Isles of Skye, and on the Orkney and Shetland Islands, although the change was only statistically significant for the Orkney Islands. Southern and Central Scotland, the central belt, Fife, and the West all saw decreases in the number of these patients, and many of these changes, particularly in the West and South-West, were statistically significant.

Falls

Patients who suffered falls present a more mixed picture. The baseline distribution is similar to previously (figure 4a). Figure 4b demonstrates the spatio-temporal trends. There were increases in parts of the Highlands, and on Orkney, as well as the North-East, around Glasgow, and in Southern Scotland. Statistically significant increases were mostly seen in and around Glasgow, in the Inverness area, and in the very South of the country. The central parts of Scotland, many areas of the West and Western Highlands, the Hebrides, Fife, and Lothian saw decreases in volume, many of which were also statistically significant.

Penetrating injuries

The volume of penetrating injuries was low, in most parts of Scotland, and there were many postcode districts with "zero counts". Only Glasgow and Dundee had PCDs with relatively high counts (figure 5a). However, the spatio-temporal analysis (figure 5b) showed that penetrating injuries had increased slightly in the Highlands and on the Outer Hebridean Islands, and parts of Western Scotland. However, these changes were not statistically significant, except for one district, around Pitlochry. The Central Belt, including Glasgow, the North-East, the South, and the Orkney and Shetland Islands, all witnessed decreases in the number of incidents involving penetrating injuries, with the changes in the Central Belt often being statistically significant.

Traffic and transportation injuries

The distribution of traffic and transportation injuries is shown in figure 6a. The number of incidents increased over the duration of the study period, in many parts of Scotland, including the Central Belt, the Highlands, the West, the South, the North-East, and the Orkney and Shetland Islands (figure 6b). Statistically significant changes were apparent particularly at the Western end of the Central Belt, as well as Edinburgh, Aberdeen, and on Orkney. The changes on the Islands of Mull, although marked, were not statistically significant. A few areas showed decreases, but these were also not statistically significant.

DISCUSSION

Spatio-temporal trends, and their importance in injury prevention and health policy, are gaining increasing recognition. However, recent publications have focused on smaller geographic areas, such as cities, and shorter time-scales.(9, 11-14) This large, population-based study of more than half a million trauma incidents in Scotland has shown evidence of spatially heterogeneous temporal trends in the injured population as a whole, over a 5-year period. These were however underpinned by idiosyncratic spatial patterns of change at the level of subgroups, such as those affected by different types or mechanisms of injury. The geographical distribution of trauma incidents broadly follows that of the population as a whole – people are usually, albeit with some exceptions, injured near to where they live or work.(17, 27) However, our results demonstrate regional trends, which are of importance to the future development of Scotland's trauma network, particularly if sustained. It is likely that these trends are the consequence of a combination of factors, such as demographic change, migration, changes to the road network, crime, etc. Our findings highlight the dynamic nature of spatial injury profiles, and the need to monitor trends.

Implications for Scotland's trauma system

The gradual increase in the number of incidents, and the number of incidents involving patients with abnormal physiology, in remote mainland and island settings, should prompt a further evaluation of the provision of prehospital services in these areas. Patients with abnormal physiology, indicative of potentially serious or life-threatening injuries, require urgent treatment, and rapid onward transport to definitive care, at a major trauma centre. Additional work is required to determine whether such patients experience different outcomes in remote areas, and whether such treatment can be provided, given the increasing volume. Many remote areas of Scotland rely on single ambulances, staffed by paramedics, to cover large areas, and many Islands are only accessible by helicopter. The provision of physician-led prehospital care is patchy, and Scotland's helicopter emergency medical service currently relies on a small number of aircrafts. Its helicopters, furthermore, do not have night-flying capability, and only limited ability to operate in poor weather conditions, which impacts on the ability to reach patients injured in remote locations. Consideration should be given to expanding the network of aeromedical retrieval assets, to enhance on-scene and en-route care, in order to offset the increasing number of incidents occurring in remote and rural incidents, with poor direct access to definitive trauma care. The widespread increases in the number of traffic- and transportation related incidents also warrant further investigation with regards to preventability. This category currently covers a large number of diverse types of incidents, and further breakdown may be helpful.

The number of penetrating injuries is much smaller than that of the other categories. Nevertheless, the decrease seen in the central belt area is noteworthy, and should prompt further study of what has precipitated this positive change. There are also noteworthy differences not only between urban and rural areas of Scotland, but also between its two main cities, Glasgow and Edinburgh. Glasgow has seen an increase in the overall volume of trauma incidents, whereas the volume has decreased in Edinburgh. The number of patients with physiological abnormalities has decreased in both locations, but the number of patients who suffered falls has increased in Glasgow, and decreased in Edinburgh. These changes highlight the critical importance of a well-organised regional trauma system in the greater Glasgow area. At present, discussions regarding the configuration of this part of the network are ongoing. There are also concerns about the capacity of the Glasgow's major trauma centre. Our study indicates that these concerns are valid, as case volume in this area is increasing. In contrast, decreasing case volumes in the areas served by the remaining major trauma centres, in Edinburgh, Dundee, and Aberdeen, could further reduce already critically low case volumes,(16) threatening the viability of these centres.

This study intentionally investigated the volume of incidents per area, rather than the incidence rate (number of incidents per population, per area). While the two measures are complimentary, case volume is more relevant to system configuration, whereas the latter measure, which should ideally also be gender- and age-adjusted, is particularly pertinent to the analysis of risk and injury prevention strategies. At present, there is little indication that changes in the incident distribution should prompt a re-evaluation of the configuration of Scotland's trauma centres, particularly in light of the decision to designate four major trauma centres, and thus prioritising accessibility over the ability to provide specialist care. However, given the low case volume of some of the recently designated major trauma centers, ongoing surveillance and frequent re-evaluation of system configuration is important.

Methodological considerations and limitations

The geographically weighted regression approach for injury surveillance makes only relatively weak assumptions over and beyond the standard assumptions of Poisson Generalized Linear Models (GLMs). The simplifying assumption of linear temporal trends for each locality appears reasonable given the short time span considered (5 years) and allows an intuitive interpretation of estimated rates of change. Where the time span is longer or prior knowledge suggests non-linear trends, the use of 3-dimensional smoothers over both space and time may be warranted. The existence of smooth spatial trends (i.e., spatial heterogeneity at scales broader than individual post code districts) is clearly supported by our data. The level and structure of the smoothing is constrained by the scale and shape of the administrative units used. In Scotland, the size of administrative units such as post code districts varies considerably between the least and most densely populated areas. As per standard practice in disease mapping in discrete space, the Markov Random Field implemented in our spatial model assumed that the correlation between neighbouring units was the same irrespective of the size of the spatial units involved. This assumption remains untested and may require further investigation for studies where the precision of estimates is key. A possible approach to circumvent the problem may involve models assuming latent spatial random fields in continuous space.

Our largely intuitive rule for regrouping neighbouring islands appeared to be well supported by the data, in the sense that greater variation was found between than within spatial clusters for all types of injuries (See Figs 2-6). There may be scope for further improving the model predictions for islands by fine-tuning the neighbourhood relationships between islands, but we expect such optimization to be case-specific and labour-intensive, with only modest returns.

While smoothing may mask local variation in case numbers at very fine spatial resolution, it first and foremost allows the efficient extraction of informative patterns from potentially sparse data, by pooling information across neighbouring districts. Thanks to effective methods for selecting optimal smoothing levels,(25) the spatial resolution of resulting estimates reflects the richness of the each data set. This is illustrated for example by the noticeably smoother estimates of spatial variation in temporal trends obtained for groups with few cases (such as abnormal physiology and penetrating injuries; see Figs 3 and 5), in contrast with the smaller-scale variation of estimates for common injuries such as falls (Fig 4). Geographically weighted regression showed good power for detecting short-term trends, hence it provides an effective, spatially-resolved early detection method that should remain useful for relatively rare diseases or injuries.

This study, together with some of our previous work, once again demonstrates the utility of using ambulance service data. The value of such data has also been noted by other investigators.(9) Hospital-based administrative datasets often do not record injury-specific details, such as incident location, which is a major impediment to geographical analysis. Ambulance service data, in contrast, does contain such information. However, we acknowledge that such data are not available in all settings, particularly when services are offered by a multitude of providers, as is often the case in the United States. This may limit the immediate generalizability of the approach in some countries.

The disadvantage of relying on prehospital data sources does not take into account those patients who self-present, however this number is small in Scotland, and the vast majority have minor injuries. Lastly, the MPDS coding is relatively crude, because it is intended to aid the despatch of EMS vehicles, rather than as a diagnostic coding system. Some of the codes are not mutually exclusive, and their application is determined by the SAS's operating procedures. However, the methodology does not rely on any particular coding system, and could be performed with any other type system, such as ICD-9, or ICD-10. Linkage to a national administrative dataset (such as held by the Information Services Division of NHS Scotland) would allow a much more detailed analysis, but is administratively complex, as prehospital records often contain incomplete information on which to match.

CONCLUSIONS

This project has demonstrated the feasibility and power of population-based spatio-temporal injury surveillance. Even over relatively short time periods, the geographical distribution of where injuries occur may change, and different injuries present different spatio-temporal patterns. These findings have implications for the delivery and development of trauma and prehospital care in Scotland, and for injury prevention, at national and regional level. The method described is transferable, and can be applied to almost any population, as long as georeferenced incident location data are available. Further work should give consideration to how centralized health data repositories, such as those held by the Information Services Division of NHS Scotland, could be further linked to other sources, including prehospital and trauma registry data, in order to undertake more complex analyses.

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CONTRIBUTIONS

JOJ, JJM and TC conceived the idea for this study, and designed it. JOJ conducted the original processing of the data. TC designed and conducted the statistical analysis. JJM and PE assisted with the interpretation of the data. All four authors contributed to the writing of the manuscript.

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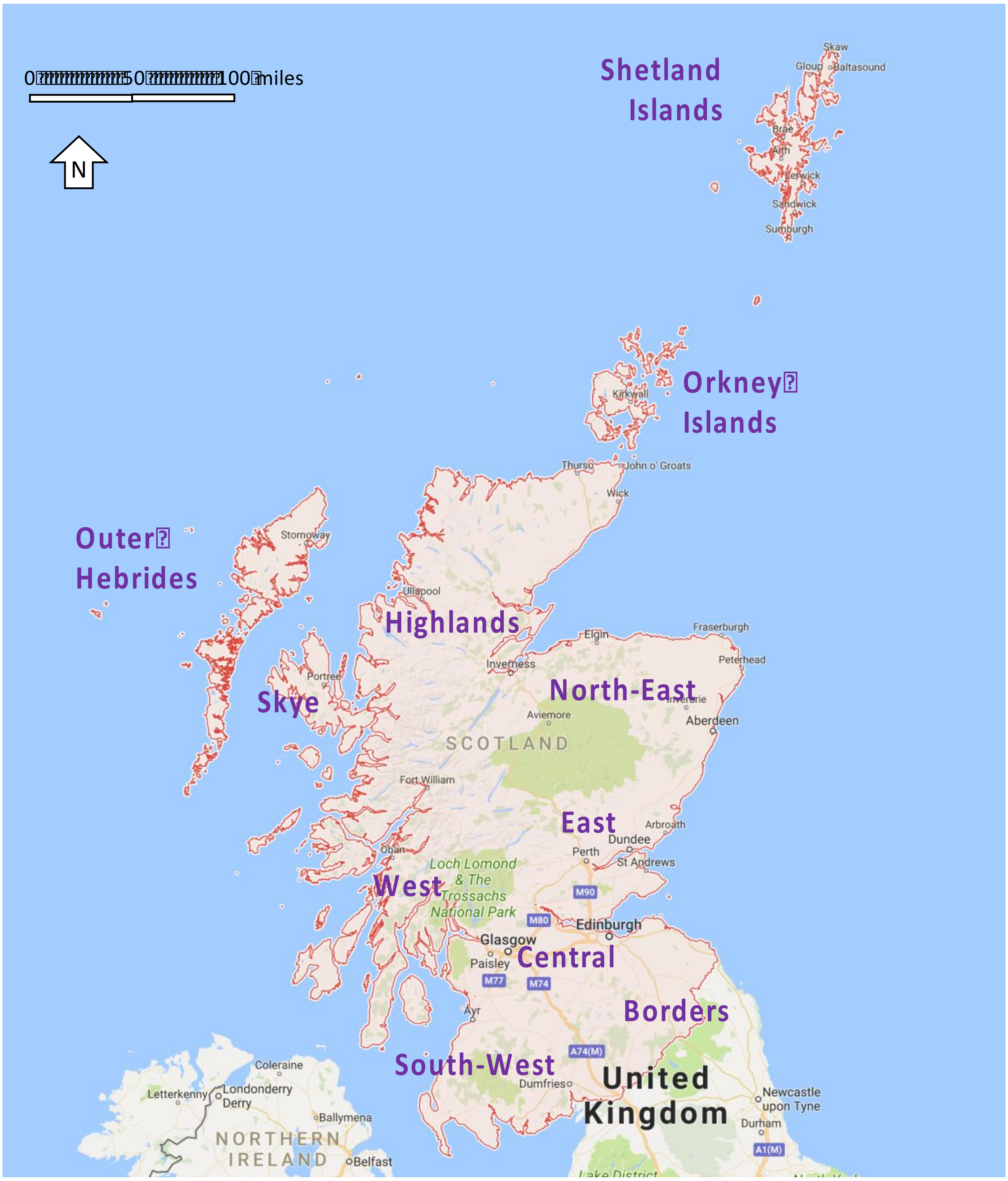
TABLES

Table 1: Baseline characteristics of study population as a whole, and by year

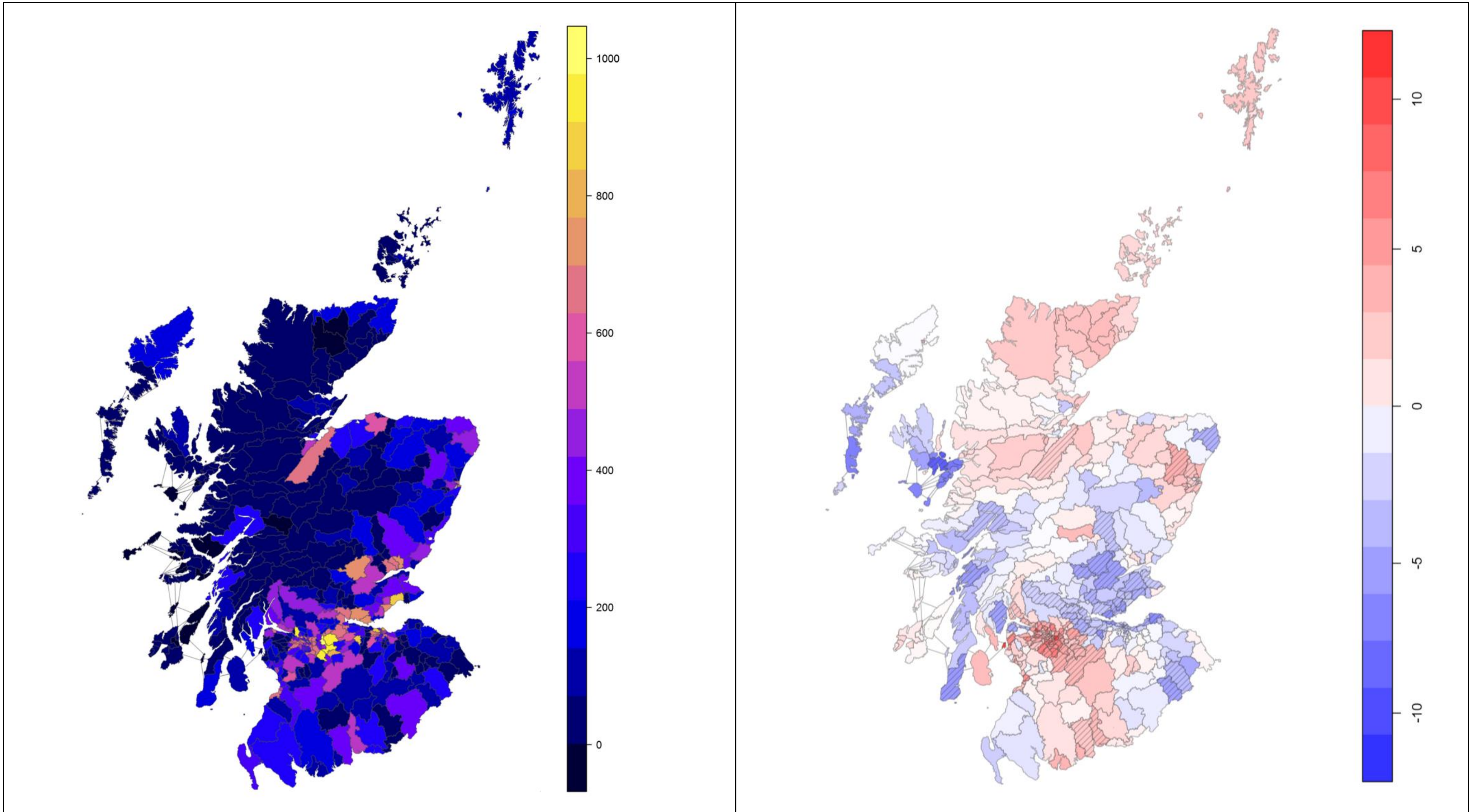
	All	2009	2010	2011	2012	2013
n	509,725	96,797	103,199	104,162	105,786	99,781
Gender						
Male	262,745 (51.5%)	50,262 (51.9%)	53,511 (51.9%)	53,941 (51.8%)	53,935 (51.0%)	51,096 (51.2%)
Female	238,909 (46.9%)	44,133 (45.6%)	47,761 (46.3%)	48,765 (46.8%)	50,671 (47.9%)	47,579 (47.7%)
Not recorded	8,071 (1.6%)	2,402 (2.5%)	1,927 (1.9%)	1,456 (1.4%)	1,180 (1.1%)	1,106 (1.1%)
Age (years)						
Median(IQR)	55 (30-79)	53 (28-78)	54 (28-78)	54 (29-79)	57 (31-80)	59 (32-80)
Medical Priority Dispatch System (MPDS) final diagnostic code						
Animal bites/attacks	1104 (0.2%)	194 (0.2%)	210 (0.2%)	215 (0.2%)	218 (0.2%)	267 (0.3%)
Assaults	60,536 (11.9%)	12,569 (13.0%)	12,897 (12.5%)	13,217 (12.7%)	11,462 (10.8%)	10,391 (10.4%)
Cardiac Arrest/Death	685 (0.1%)	114 (0.1%)	112 (0.1%)	87 (0.1%)	147 (0.1%)	225 (0.2%)
Falls	277,058 (54.4%)	52,000 (53.7%)	56,256 (54.5%)	56,473 (54.2%)	58,268 (55.1%)	54,061 (54.2%)
Hemorrhage/Laceration	60,051 (11.8%)	11,500 (11.9%)	12,053 (11.7%)	11,588 (11.1%)	12,518 (11.8%)	12,392 (12.4%)
Deliberate Self Harm	16,540 (3.2%)	3,095 (3.2%)	3,658 (3.5%)	4,047 (3.9%)	3,737 (3.5%)	2,003 (2.0%)
Penetrating Injuries	3,498 (0.7%)	796 (0.8%)	692 (0.7%)	760 (0.7%)	661 (0.6%)	589 (0.6%)
Traffic/Transportation	36,537 (7.2%)	6,995 (7.2%)	6,792 (6.6%)	6,790 (6.5%)	7,568 (7.2%)	8,392 (8.4%)
Other	53,716 (10.5%)	9,534 (9.8%)	10,529 (10.2%)	10,985 (10.5%)	11,207 (10.6%)	11,461 (11.5%)
Number of abnormal physiological parameters (low blood pressure or Glasgow Coma Scale, abnormal respiratory rate)						
0	474,834 (93.2%)	89,455 (92.4%)	95,548 (92.6%)	97,049 (93.2%)	99,299 (93.9%)	93,483 (93.7%)
1	33,593 (6.6%)	7,056 (7.3%)	7,435 (7.2%)	6,865 (6.6%)	6,212 (5.9%)	6,025 (6.0%)
2	1,229 (0.2%)	273 (0.3%)	210 (0.2%)	229 (0.2%)	254 (0.2%)	263 (0.3%)
3	69 (0.0%)	13 (0.0%)	6 (0.0%)	19 (0.0%)	21 (0.0%)	10 (0.0%)

Figure 1



Map data © Google 2017

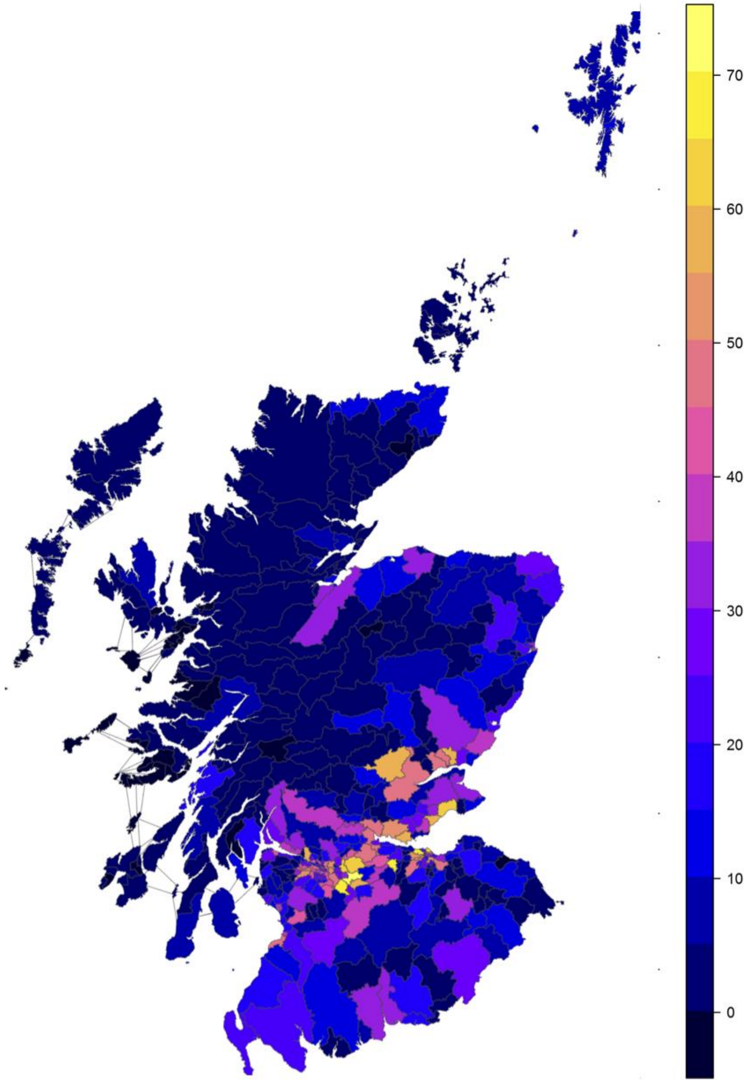
Figure 2



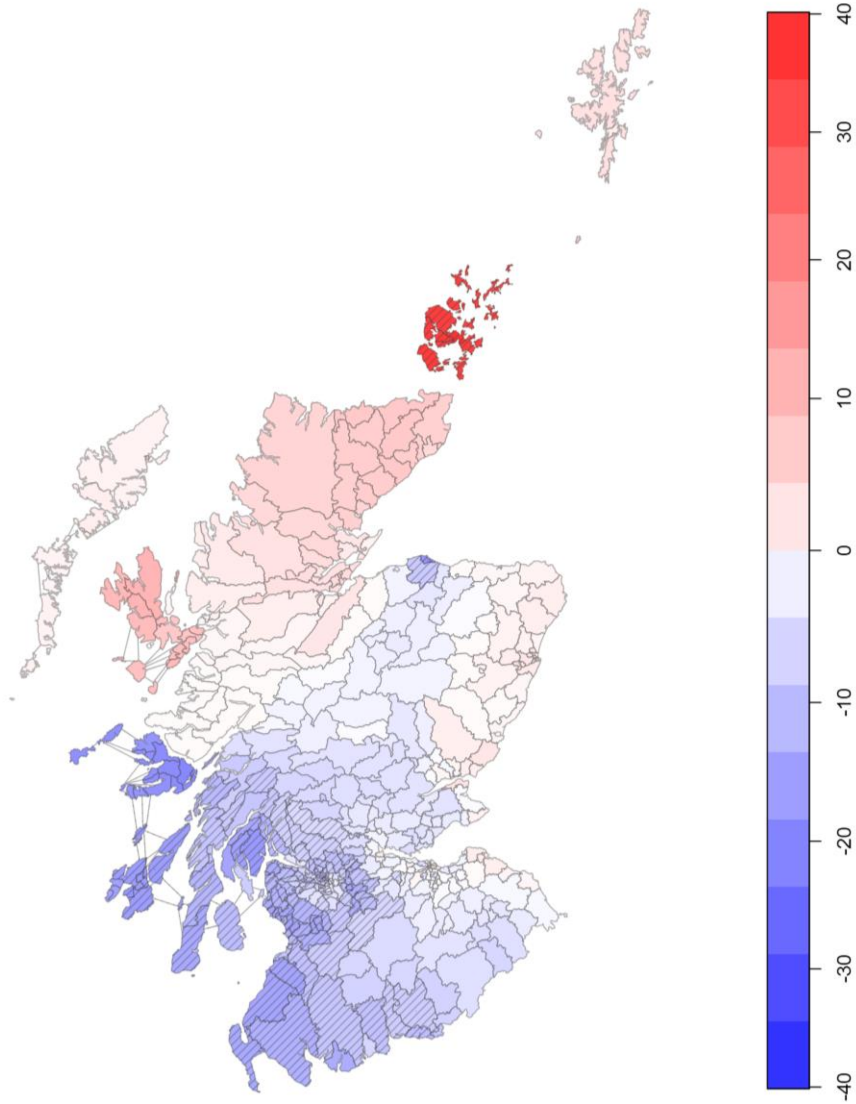
(a) Baseline estimate (number of incidents per area)

(b) Percentage change over time

Figure 3

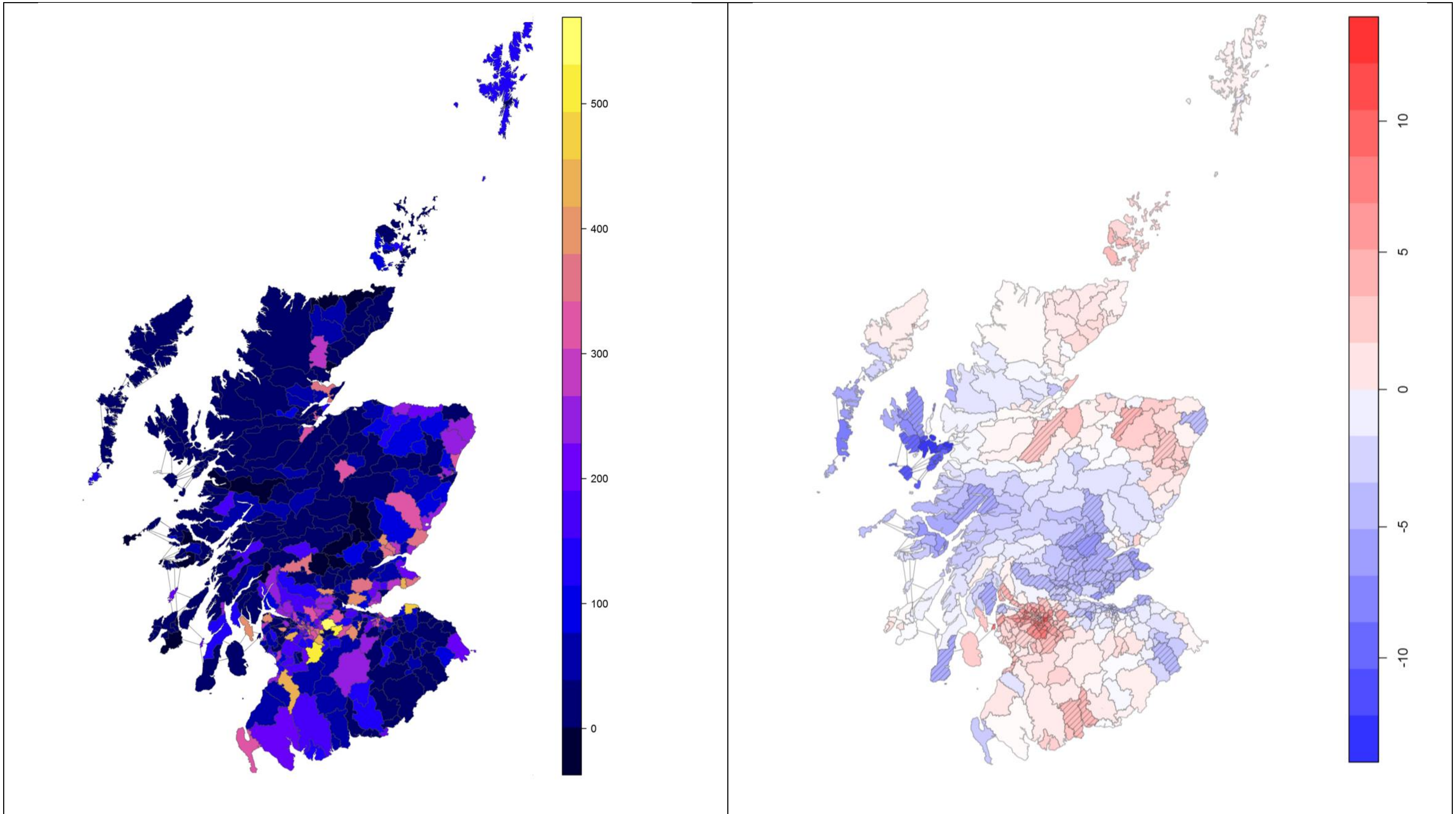


(a) Baseline estimate (number of incidents per area)



(b) Percentage change over time

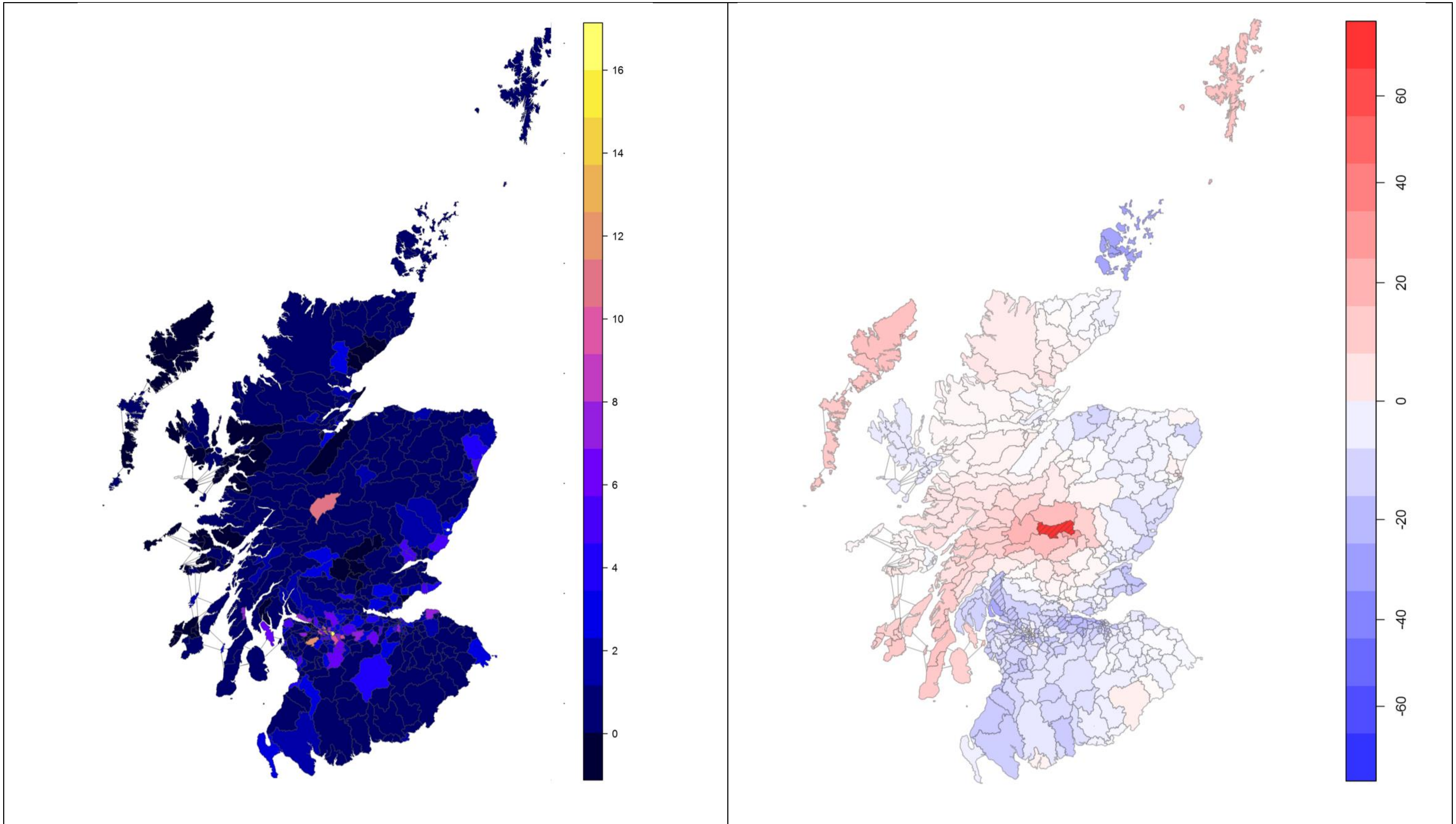
Figure 4



(a) Baseline estimate (number of incidents per area)

(b) Percentage change over time

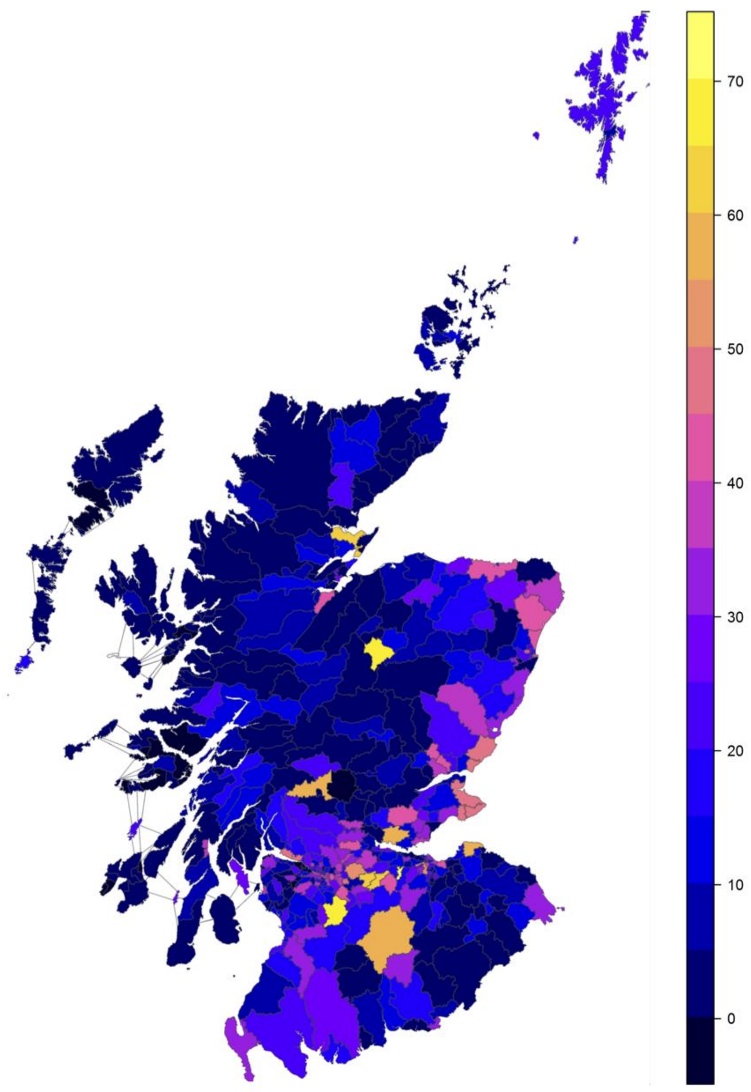
Figure 5



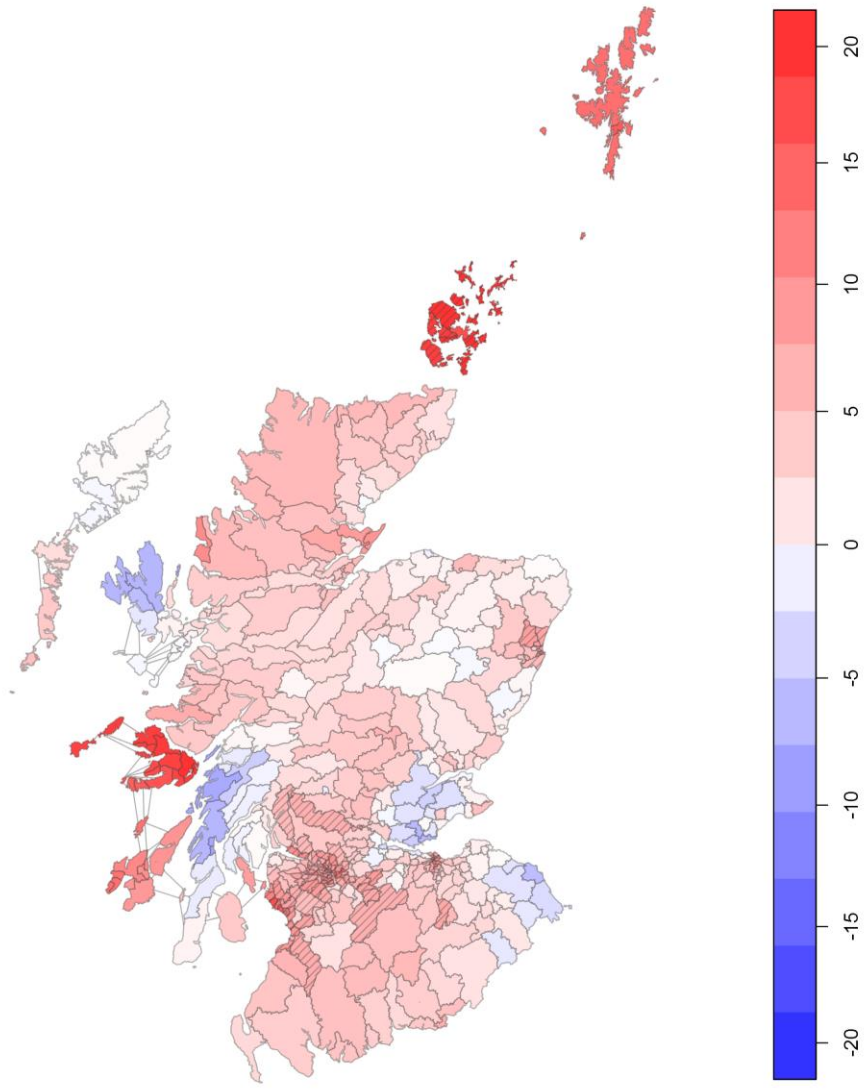
(a) Baseline estimate (number of incidents per area)

(b) Percentage change over time

Figure 6



(a) Baseline estimate (number of incidents per area)



(b) Percentage change over time