A spatial analysis of the robustness of the private kill abattoir network in the UK: a proof of concept study

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Abstract

Purpose - *To explore the impacts of long-term trends in the closure of abattoir businesses in the UK on the robustness of the network of abattoirs which provides private kill services.*

Design/methodology/approach - *This proof-of-concept study uses responses from a farmer and an abattoir survey in a spatial analysis to help visualise the private kill network. Monte Carlo simulation is used to estimate the impacts of possible further closures of private kill abattoirs on the robustness of the private kill network.*

Findings - *In August 2020, 18% of the area of the UK was more than 45 kms from a private kill abattoir, 21% was serviced by one, 14% by two, and 47% by three or more abattoirs. After randomly removing 9% and 18% of private kill abattoirs, to reflect the current trend in the closure of private kill abattoirs, the area of the UK more than 45 km from a private kill service, and the areas with one and two providers increased, while the area with three or more providers decreased for each scenario. This approach therefore can be used to quantify the network's resilience to further closures.*

Originality - *No other national or international study has attempted to quantify the robustness of the network of private kill abattoirs.*

Research limitations/implications – The *additional information that would be needed to allow this approach to help policymakers identify strategically valuable abattoir businesses is discussed.*

Key words Private kill, Farmer survey, Abattoirs, Spatial analysis, Monte Carlo, Network analysis

Paper type – Research paper

1 Introduction

It is because the UK government has policy objectives to reduce the unnecessary movement of livestock and support rural economies (Defra, 2021b) that the closure of abattoirs across the UK has become a matter of public concern (APGAW, 2020; Efra, 2021). Between 1979 and 2002 the number of abattoirs in the UK fell from 1,146 to 367 (FAWC, 2003), resulting in longer and more complex livestock journeys. More recent data show a disproportional rate of closure of smaller abattoirs, defined as abattoirs with a throughput below 5,000 livestock units (LSU)[1] (APGAW, 2020). Smaller abattoirs specialize in returning to the farmers the carcase (or butchered joints) of the same livestock the farmer had sent for slaughter (APGAW, 2020). This so-called private kill service requires abattoirs to establish robust traceability protocols throughout their processing line, from taking delivery of the livestock, through slaughtering, butchering and processing, and storage. This requirement not only imposes additional costs, but it also restricts annual throughput (Kennard and Young, 2018; APGAW, 2020; Efra, 2021; Franks and Peden, 2021).

The total farm gate value of cattle, pigs and sheep slaughtered in 2019 was £5,717m (Defra, 2021a). However, abattoirs are not required to report the number of livestock slaughtered for private kill. A tentative estimate of the size of this market, based on returns to our abattoir survey, puts the farmgate value of cattle, pigs and sheep slaughtered for private kill at some £65m (1.14% of total UK farmgate value). However, the estimate is subject to the assumptions used, and falls to £34m (or 0.6% of total UK farmgate value) when weighted by share of species slaughtered because private kill services slaughter a larger share of lower value sheep than of higher value cattle.[2] The range suggests these estimates must be treated with caution, however, although the private kill market appears to be a relatively small share of the total red meat species farmgate value, private kill services play an important role in adding value to livestock enterprises (Franks and Peden, 2022). Private kill abattoirs also proved to be strategic assets during Covid-19 by supplying local food chains at a time when consumers were locked-down and required to shop locally, thus contributing to the essential infrastructure needed to ensure a resilience food system (UK Parliament, 2020). However, the number of smaller abattoirs fell from 260 in 2001 to 170 in 2017 (APGAW, 2020: p 11): by January 2019 only 160 were still trading, and a further 13 closed in the 20 months to August 2020 (9% of the underlying population).

The closures threaten the farm business which depend on private kill service and the size of the locally-finished and -slaughtered red meat supply chain, and therefore have knock-on impacts for the rural economy (APGAW, 2020; Efra, 2021). These concerns, have resulted in abattoirs being recognized as a "national strategic asset" (Efra, 2021: p 4) by being included in the list of ancillary businesses eligible for support in the Agriculture Bill. However, no attempt has been made to estimate the impacts of further closures on the robustness of the private kill network, information which would help policy makers target support to better safeguard animal welfare, farm business survival and the rural economy.

This study addresses this deficiency. It uses farmer and abattoir survey data, spatial analysis software, and Monte Carlo simulations to provide visual representations and quantified estimates of the changes in the geographical area serviced by private kill abattoirs resulting from the further closure of abattoirs and compares these estimates with the baseline coverage in August 2020. Section 2 presents the methodologies used to identify the underlying population of private kill services in the UK in August 2020. Section 3 uses ArcGIS Pro to estimate the baseline geographical area of the UK covered at that date. Section 4 presents the results of Monte Carlo simulations. Section 5 discusses the additional information required to make this methodology more useful for policy purposes. Section 6 concludes.

2 Methods and materials

This analysis assumes that the robustness of the private kill network can be measured by changes to the area of the UK covered by multiple private kill abattoirs: more robust networks have larger areas of the UK covered by multiple private kill abattoirs and smaller (ideally no) areas without access to private kill abattoirs. In principle, therefore, the resilience of the private kill network can be quantified by removing abattoirs from the underlying population and calculating the resulting geographical coverage. The new coverage can then be compared against the baseline geographical coverage which is calculated for August 2020.

Ideally, the abattoirs removed from the network would be those most likely to close. However, this information is highly confidential and was not available from the abattoir survey (see below). Therefore, we use spatial analysis to visually represent the private kill abattoir network, and Monte Carlo simulations to randomly remove private kill abattoirs from the baseline August 2020 population. The study is therefore an exploration of the potential for spatial analysis tools to visualise and quantify the robustness of the private kill abattoir network and should be considered a proof of concept study.

2.1 Survey of abattoirs and farmers providing private kill services

Abattoirs are not required to record whether they offer private kill services. Therefore a telephone survey of abattoirs was undertaken of the 220 abattoirs licenced to slaughter red meat species in August 2020 to identify which offered this service using contact details then publicly available from the Agricultural and Horticultural Development Board (AHDB) supplemented by internet searched. This identified 147 abattoirs offering private kill services. Additional description of the survey methodologies can be found in Franks and Peden (2021).

The study also used information from an online survey of farmers who sent livestock to abattoirs. This was used to check the results from the telephone survey, and to recorded the number and the distance livestock travelled from the farm to abattoir for private kill slaughter.[3] Forty relevant organisations were approached via email for assistance in promoting the survey. Those which did not respond after four weeks were contacted again. A total of 21 organisations agreed to share the survey URL via their newsletters, social media streams and mailing lists. A total of 300 UK farmers completed the online survey during the period from 14th April to 26th May 2020, 185 of these for private kill retail enterprises. Respondents used 124 abattoirs in total, 82 of which offered private kill services.

2.2 Spatial analysis methodology

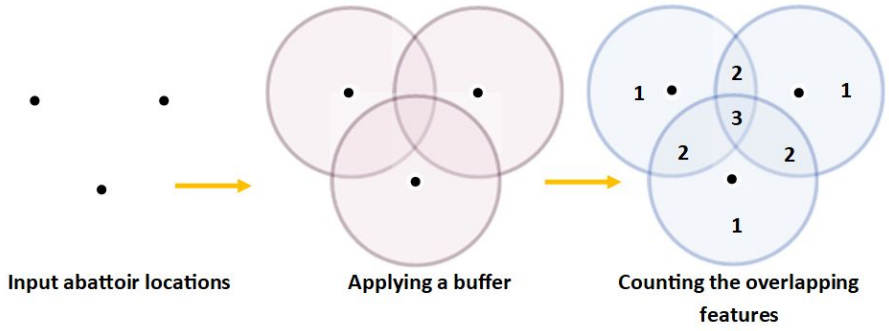
Maps and GIS can be used to visualise spatial relationships to help facilitate shared understanding of geographic phenomena and their interdependencies (MacEachren, 2000). Academics have been aware of the potential and flexibility of the tools available within ArcGIS

for these purposes for many years (Nelson, 2002) and spatial analysis has now been applied to a wide variety of different projects and disciplines. For example, climate vulnerability in agriculture (Casolani *et al.*, 2020), reducing damage of wildfires to agriculture (Cozzi *et al.*, 2019), assessing spatial greenhouse gas emission and spatial costs of abatement of carbon sequestration through reforestation (Ross, 2021), managing the trade off in ecosystem services across landscapes (Raudsepp-Hearne *et al.*, 2010) and enhancing the effectiveness of precision agriculture (Florax *et al.*, 2002).

This study uses spatial analysis in the same way and for the same purposes as Teagasc (2022), the Irish Agriculture and Food Development Authority, namely to help understand patterns in a geographic context by making visual representations of data available to a wider audience to promote discussion and debate. The approximate location of the abattoirs was obtained from the surveys. Appropriately formatted through excel as a .csv file, they were easily uploaded into the GIS program of choice (ArcGIS Pro) to produce baseline maps to estimate geographical coverage of the UK as of August 2020.

The stages of spatial analysis are demonstrated in Figure 1. Firstly, the buffer tool was applied to the abattoir dataset. A buffer is a zone drawn around any point, line, or polygon that encompasses all the area within a specified distance of the feature (Jensen and Jensen, 2013). The distance used to create the buffer zone was derived from the farmer survey and a review of the literature (see below). The output produced a series of circles denoting the spatial proximity of abattoirs to each other. For this research only the land area covered by the abattoir businesses is relevant, so the data were clipped and any areas of the buffers which overlayed the coastal outline of the UK were removed. In order to calculate the number of abattoirs servicing areas across the UK, buffers overlaying each other were counted to produce a dataset in which each area of the UK had a value of how many abattoirs serviced it.

Figure 1. Stages of spatial analysis used by GIS



This enabled the area of the UK to be classified as either further than the buffer distance from an abattoir or within the buffer distance of one, two, or three and more abattoirs. To calculate these areas overlapping features were removed to give a single dataset rather than

a series of buffers. This dataset was exported into Excel as a .csv file and used to create geographical area covered tables. This process was then repeated to produce geographical area coverage for the reduced population of abattoirs following the random removal of individual businesses identified by the Monte Carlo simulations.

3 Results: the baseline distribution of abattoirs (August 2021)

The choice of a straight-line 45 km as the radius for the buffer zones drawn around each of the 147 private kill abattoirs was based on results from the farmer survey and a review of the literature. Figure 2 shows that 45 kms is the distance 50% of livestock travelled from farm to abattoir for private kill slaughter (Franks and Peden, 2021) and Figure 3 shows that 60% of farmers farmed within this distance of the abattoir. As the buffer is created in as a straight line radius, and as Figure 2 estimates the distance travelled from farm to abattoir, the 45 km straight line buffer will encompass more than 60% of livestock and farmers. Secondly, it draws on findings of a literature review into consumer perceptions. Several studies reported consumers defining "local" food as food produced within 30 miles (48 kms) of the point of sale (Pearson *et al.*, 2011; Campaign to Protect Rural England, 2012; ICF Consulting Services, 2016).

Figure 4 shows the denser concentration of private kill provision along the spine of England - from East Yorkshire to Somerset, and the more limited provision in East Anglia, south-west Scotland and along the west coast of Wales. In August 2020, there was no provision across the Scottish Highlands, in Northumberland and parts of Hampshire, on Orkney, the Isle of Wight and on the Scilly Isles. Only two abattoirs offer private kill services in Northern Ireland.[4]

Figure 2. The cumulative distribution of the percentage of livestock and the distance travelled from farm to abattoir for private kill slaughter.

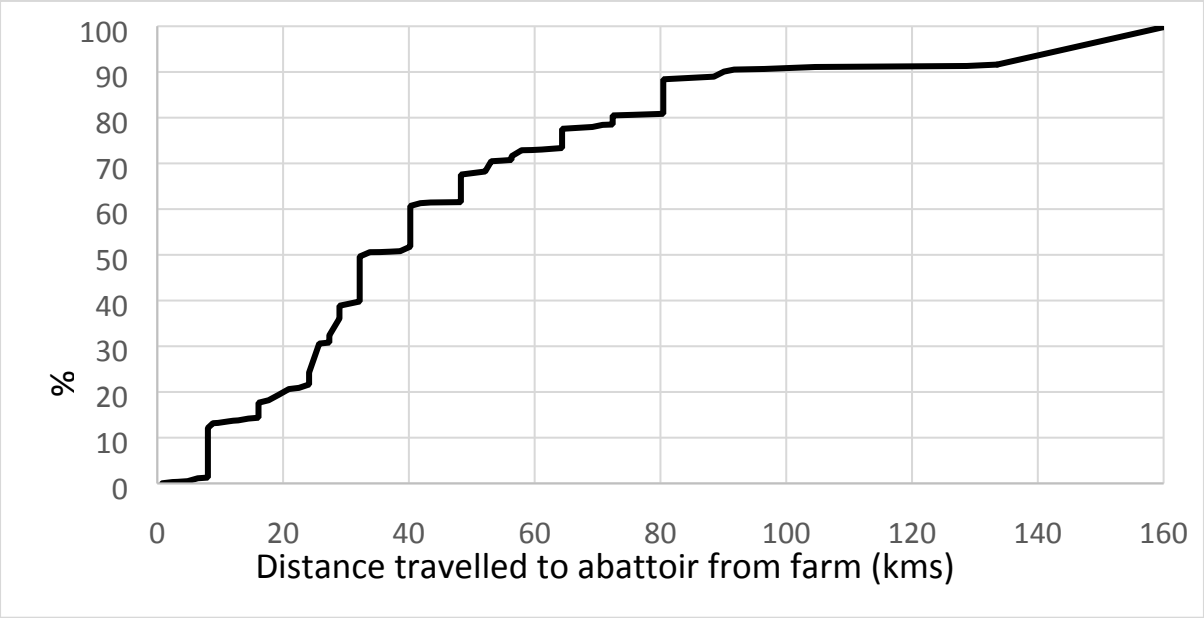


Figure 3. The cumulative distribution of the percentage of farmer and the distance travelled from the farm to abattoir for private kill slaughter.

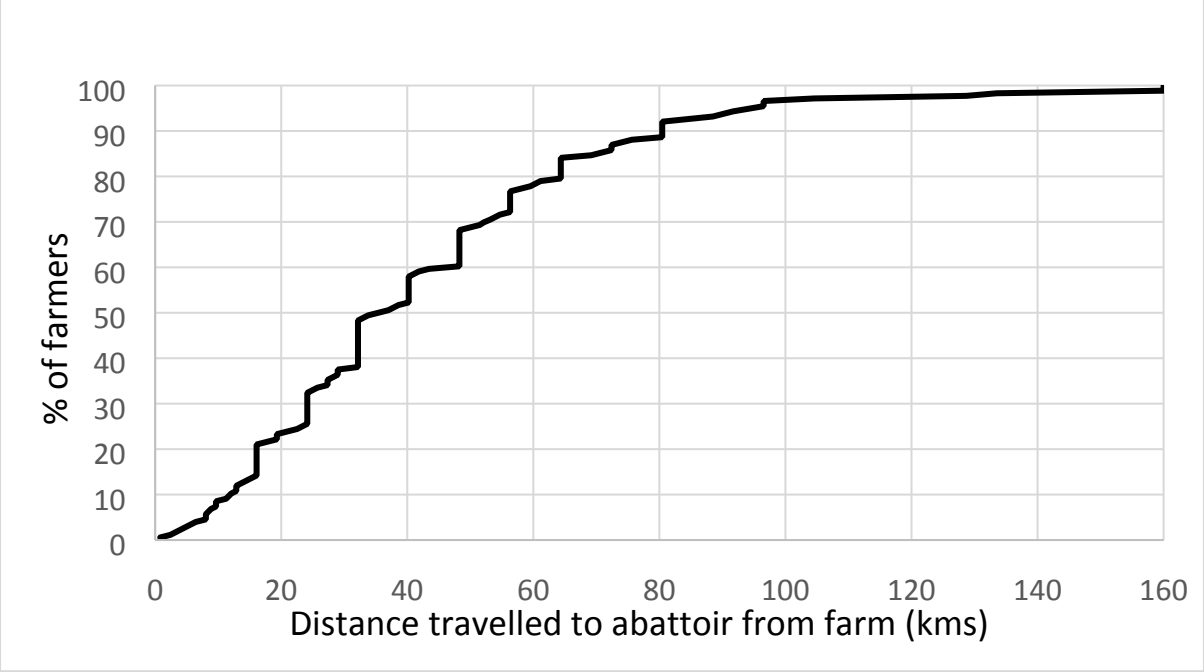


Figure 4. The location of the abattoirs offering private kill services in the UK in August 2020 with 45 km buffer zones.

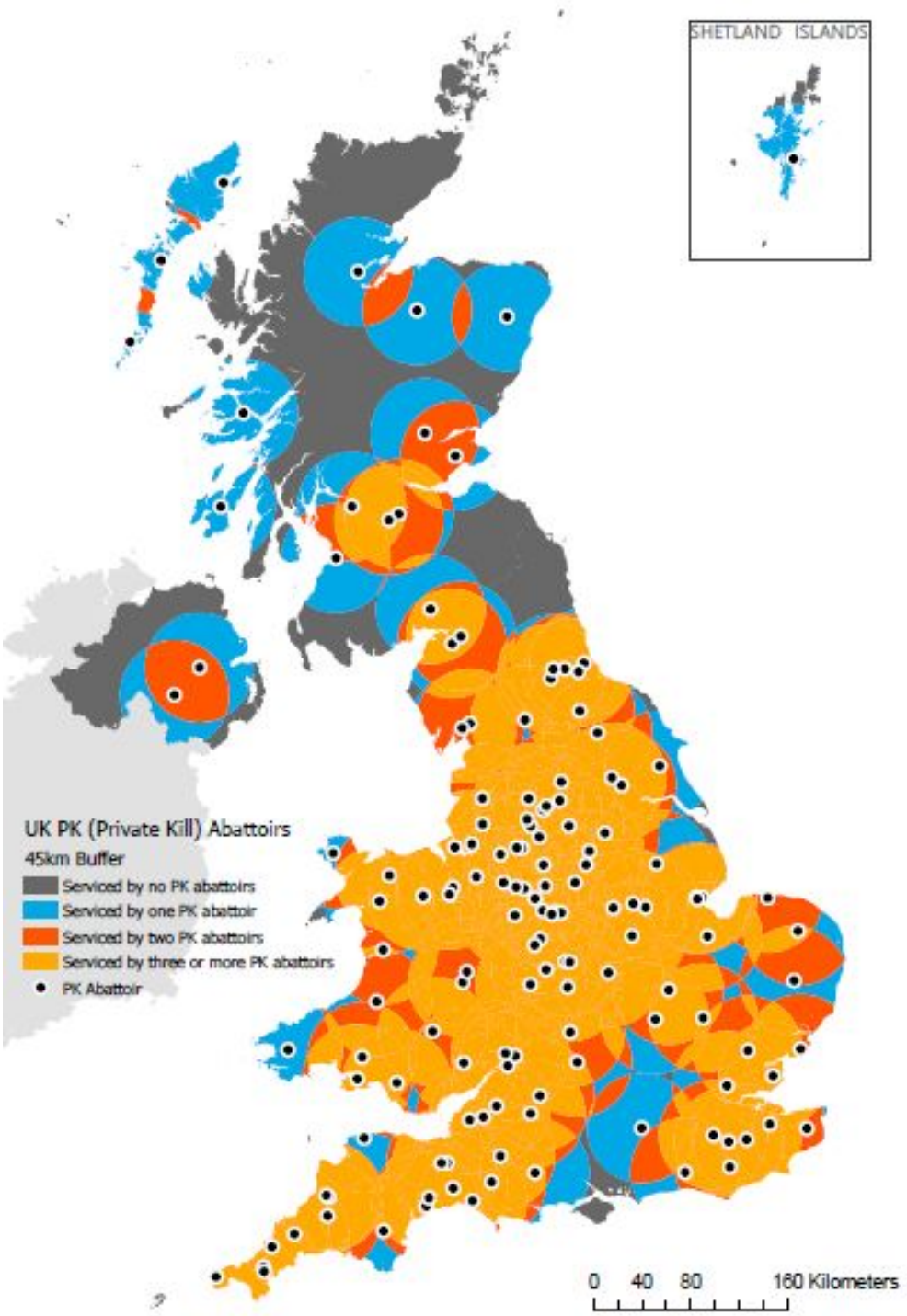


Table I presents the geographic coverage of private kill services across the UK based on 45 km buffer zones. It shows that in August 2020, 18.2% of the UK was further than 45 kms from an abattoir offering private kill services, and 20.9% of the UK had only one abattoir providing this service within this distance of the farm.

Table I. The area (km^2) and percentage of the UK without private kill abattoir provision, covered by one, two and three or more abattoirs (based on 45 km buffers).

Number of private kill abattoirs	Area covered (km^2)	% of UK covered by the number of abattoirs in column 1
0	44,510	18.2%
1	50,989	20.9%
2	33,809	13.8%
3 or more	114,917	47.1%
Total	**244,226**	**100%**

4 Results: robustness of the network of private kill services using Monte Carlo simulations.

The next step is to use Monte Carlo simulations to randomly remove abattoirs from the underlying population, and then to use ArcGIS Pro software to visualize and calculate the geographical coverage of private kill services provided by the remaining abattoirs. These results are compared again the baseline coverage in August 2020 shown in Table I.

The number of abattoirs removed from the underlying August 2020 population was derived from the rate of closure of private kill abattoirs in the 20 months to August 2020, when thirteen abattoirs (9% of the underlying population) ceased trading. Therefore, the first simulation randomly selected and removed (i.e. assumed closed for trading) 9% of the 147 abattoirs offering private kill services, simulating the possible network in 20 months assuming a constant rate of attrition. Given our limited resources, it was decided seven simulation runs would provide sufficient data to prove the value of the concept. Each of the seven runs created a unique data set containing 134 abattoirs. Table II presents the results averaged across all seven simulations: 20.6% of the UK was further than 45 km from an abattoir, 21.2% was covered by one, 15.4% by two, and 42.8% by three or more abattoirs. Table II also shows the areas covered by the simulation runs that resulted in the smallest area (i.e. the most optimistic outcome) (18.6%) and the largest area (i.e. the least optimistic outcome) (23.1%) further than 45 km from an abattoir. The maps for the simulation runs with the smallest and largest areas more than 45 kms from a private kill abattoir are shown in Figures 5 and 6 respectively.

To simulate the possible network of private kill provision after 40 months, a second set of seven simulations was run randomly removing 18% of the 147 abattoirs in the August 2020 population. This created seven further datasets, each with 121 abattoirs. Table II shows the average across the seven simulations: 24.2% of the UK was further than 45 km from a private kill abattoir, 21% was covered by one, 15.5% by two, and 39.3% by three or more abattoirs. The maps for the simulation runs resulting in the smallest (most optimistic) and largest (least optimistic) areas further than 45 kms from a private kill abattoir are shown in Figures 7 and 8 respectively.

Table III compares the coverage shown in Table II with the baseline coverage for August 2020 shown in Table I. The area further than 45 km from a private kill abattoir increased in both simulations, by 2.3% (from 18.2% to 20.6%) and by 6% (from 18.2% to 24.2%). Farmers in areas no longer within 45 km of an abattoir will have longer livestock journeys, adding to their transport costs and making it more economical to use commercial transports rather than farm transport to move livestock, which is likely to result in more complex journeys from farm to abattoir.

There is also a small expansion in the geographical areas covered by one single abattoir, by 0.3% and 0.1% for the 9% and 18% runs respectively, and by two abattoirs, by 1.5% and 1.6% respectively, thus expanding the areas covered by fewer than three abattoirs. However, these increases are slight because any increase in area resulting from the removal of an abattoir in areas previously covered by only one or two abattoirs is at least partially offset by the increase in these area due to the removal of abattoirs in areas previously covered by three or more abattoirs, which reduced in size by 4.2% and 7.8% in the 9% and 18% runs respectively. Whilst the areas with three or more abattoirs remain substantial (42.8% and 39.3% respectively), taken together these results clearly show this methodology can be used to estimate redundancy in private kill provision across the private kill network.

The results derived from the study confirm that the combination of survey and estimation methods used can assess the robustness of the network of private kill abattoirs to the closure of private kill abattoirs. However, Table II shows that the resulting geographical coverage varies widely depending on which abattoirs are assumed to close, which indicates that additional Monte Carlo runs are needed to deliver more robust distribution and area estimates. A more significant improvement for the development of the policies and instruments needed to support the private kill network, would be to use abattoir-specific and private kill retail farmer-specific information to identify abattoirs that are most likely to close rather than using Monte Carlo simulations for this purpose.

APPROXIMATE LOCATION OF *Table II.*

Table II. The average areas averaged across all seven Monte Carlo simulations, and the simulations that show the smallest and largest areas further than 45 kms from a private kill service.

% of abattoirs randomly removed (number)	Number of abattoirs within 45km	Km coverage			% coverage		
		Average across all seven data sets	Smallest area without coverage	Largest area without coverage	Average across all seven datasets	Smallest area without coverage	Largest area without coverage
9% (13)	0	50,239	45,402	56,309	20.6%	18.6%	23.1%
	1	51,808	48,235	57,591	21.2%	19.8%	23.6%
	2	37,571	34,869	40,377	15.4%	14.3%	16.5%
	3 or more	104,609	101,312	109,550	42.8%	41.5%	44.9%
	Total	**244,226**			**100%**		
18% (26)	0	59,151	49,797	78,991	24.2%	20.4%	32.3%
	1	51,337	37,686	61,499	21.0%	15.4%	25.2%
	2	37,832	28,934	44,790	15.5%	11.8%	18.3%
	3 or more	95,9076	90,034	99,314	39.3%	36.9%	40.7%
	Total	**244,226**			**100%**		

APPROXIMATE LOCATION OF *Table III.*

Table III. Change in the geographical area covered by abattoirs following the closure of 9% and 18% of population of private kill abattoirs trading in August 2020.

	% of UK covered			
	Number of abattoirs within 45km			
	0	**1**	**2**	**3 or more**
Baseline (147)	18.2	20.9	13.8	47.1
Removal of 9% of abattoirs (134)	20.6	21.2	15.4	42.8
Removal of 18% of abattoirs (121)	24.2	21.0	15.5	39.3
	Change in % area covered compared to baseline areas			
Closure of 13 abattoirs (134)	2.3	0.3	1.5	-4.2
Closure of 26 abattoirs (121)	6.0	0.1	1.6	-7.8

Figure 5. Map showing the smallest area of the UK without any private kill provision (assuming 9% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

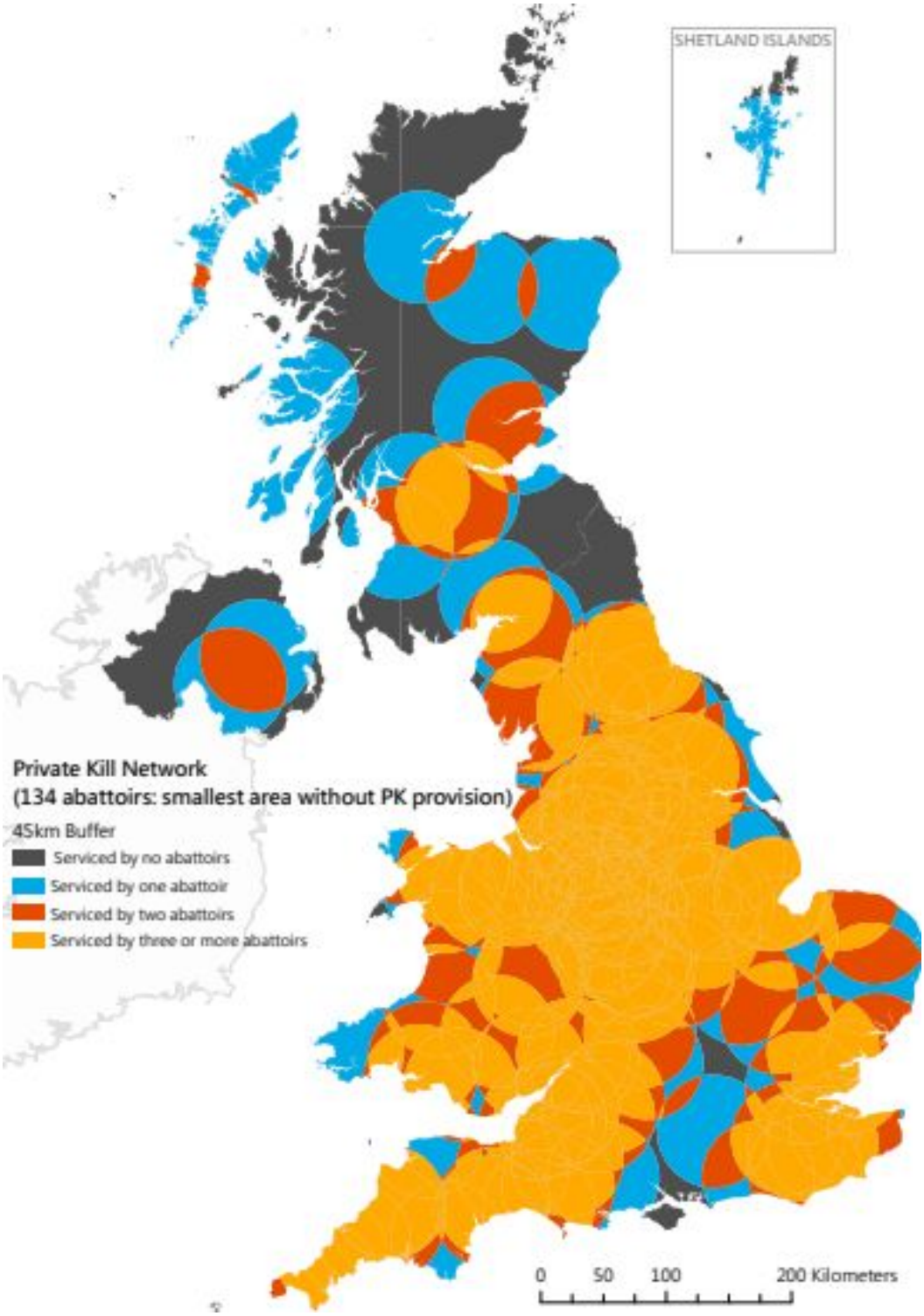


Figure 6. Map showing the largest area of the UK without any private kill provision (assuming 9% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

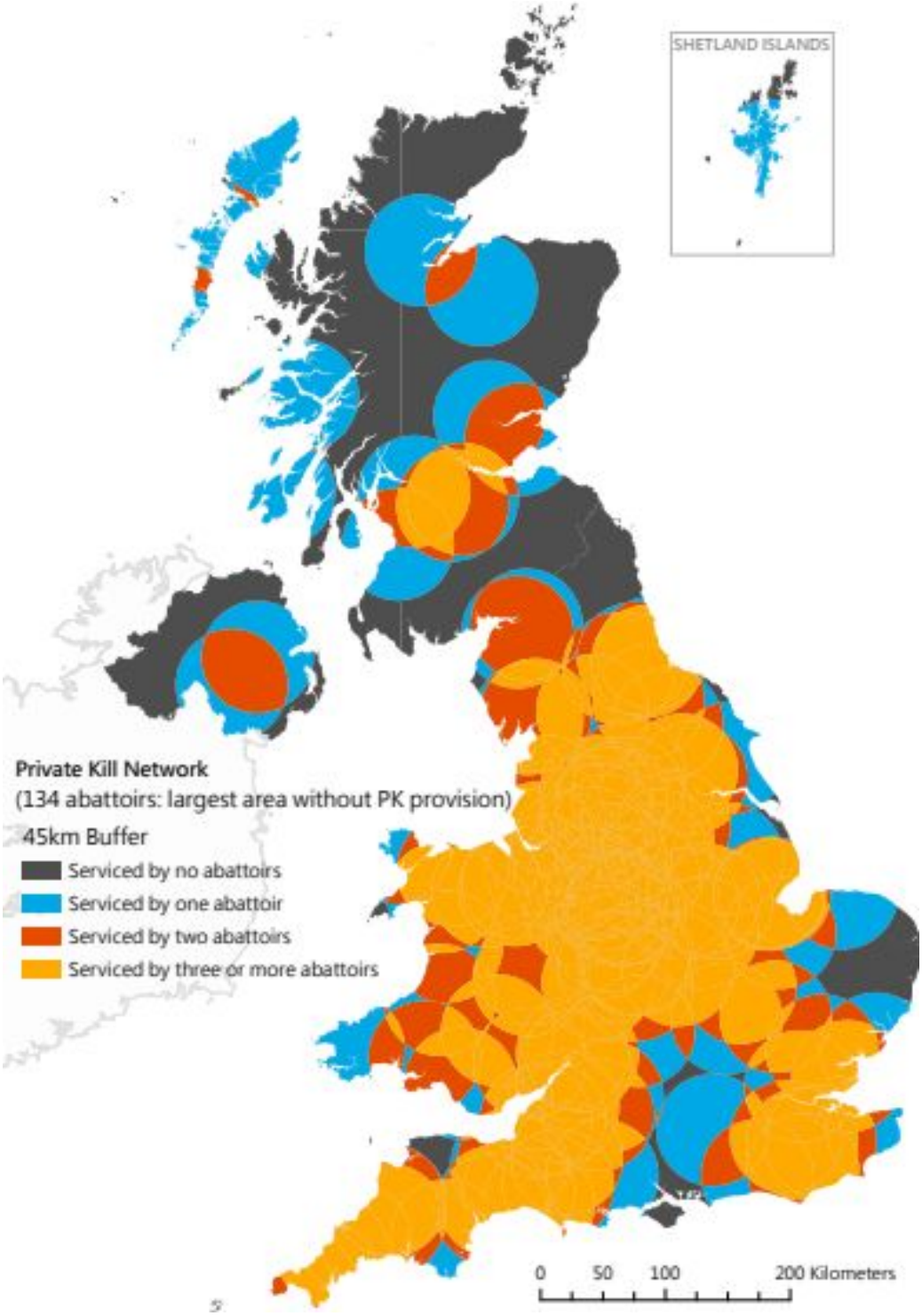


Figure 7. Map showing the smallest area of the UK without any private kill provision (assuming 18% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

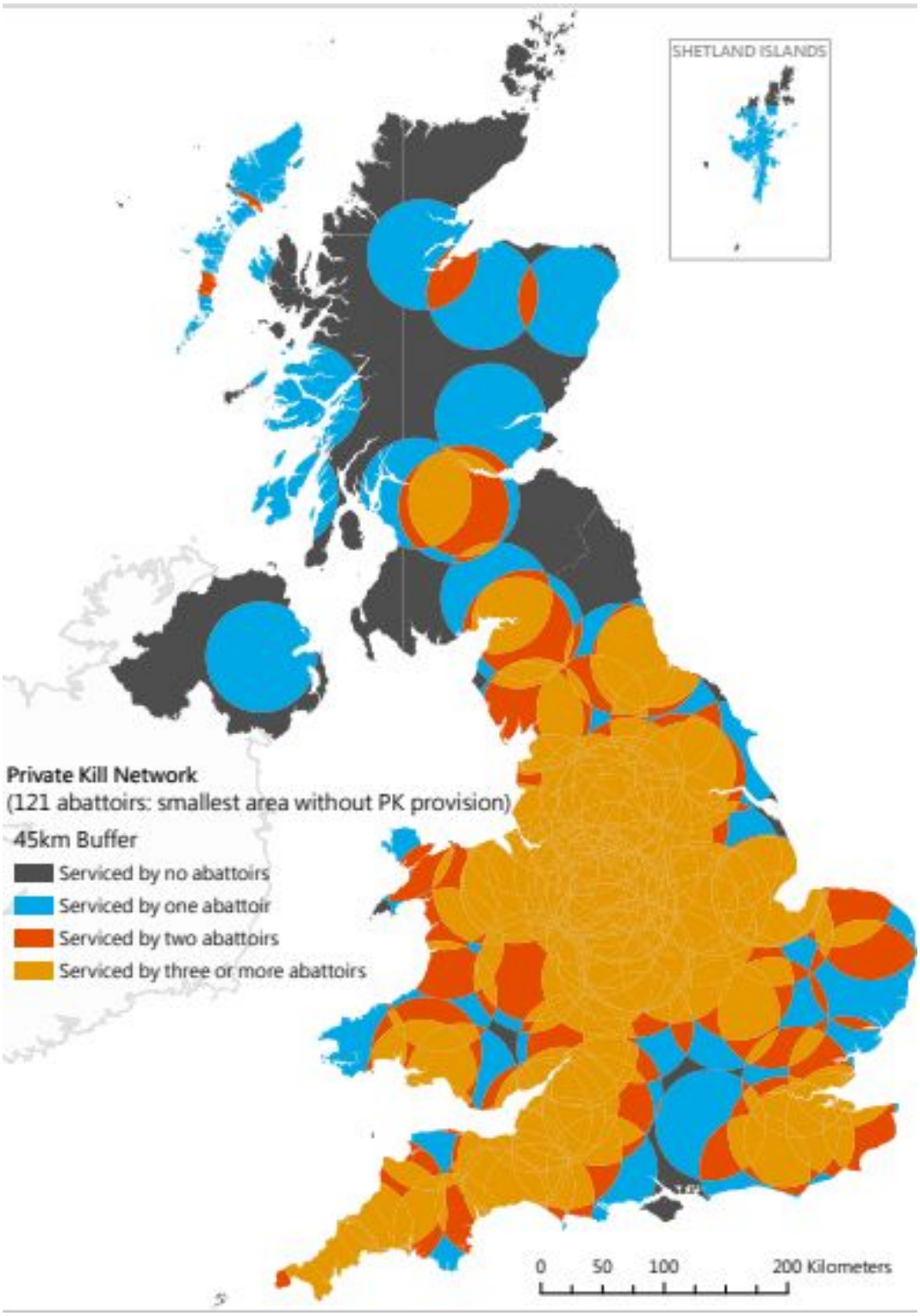
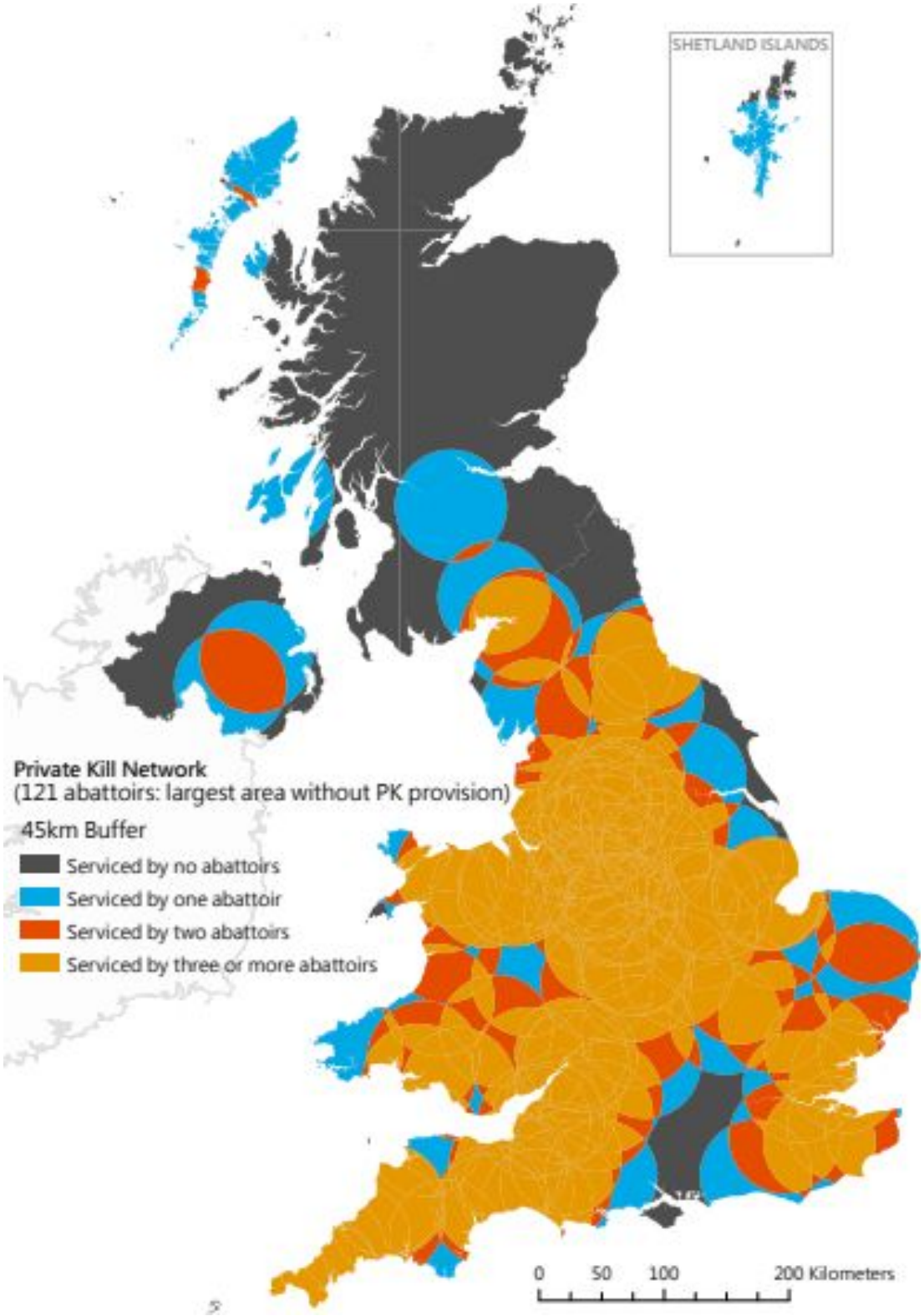


Figure 8. Map showing the largest area of the UK without any private kill provision (assuming 18% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)



5 Discussion and implications

The estimated change in geographical coverage shown in Table II highlights the importance of identifying which abattoir are most likely to close to assess the robustness of the private kill network. This also determines the distance and complexity of livestock journeys and consequently directly influences the viability of farmers' private kill retail enterprises. This in turn impacts upon the value of the locally finished and slaughtered red-meat supply chain. This section reviews the information needed to allow the random removal of abattoirs to be replaced with more precise information about which abattoirs are most likely to close.

5.1 Abattoir-specific information requirements

Replacing the random removal of abattoirs by the abattoirs most likely to cease trading requires detailed information about their short- and long-term viability. Ideally a census of all trading abattoirs is needed as this would also include abattoirs currently not offering private kill services, but which may expand into this market. However, experience with our abattoir survey shows this information is not likely to be forthcoming. In such a competitive market, many abattoir owners are likely to be wary of sharing the highly confidential financial information that researchers would need for this purpose, such as trends in and annual cash flows, profitability, throughput, level and types of debt, and net worth. Moreover, many abattoirs currently not offering private kill services are unlikely to want to reveal the circumstances under which they would start to do so.

Nevertheless, a sufficient minority of owners might provide somewhat less sensitive, more general business information such as private kill throughput, trend in profitability, past investments, essential future investment requirement, and a subjective assessment of the business's financial stress. This could be used alongside more readily available information (for example, distance from farm to abattoir for all their customers, annual throughput, distance to their nearest private kill abattoirs, range of specialist slaughtering and butchery services offered, and location in relation to areas of livestock production and human populations) to categorize the financial status of similar abattoirs. By identifying failing abattoirs in this way, the robustness of future private kill networks could be more accurately visualized and quantified. However, business and family-specific factors not captured by this approach, such as the opportunity cost of the abattoir's premises, and presence of a successor to take over the business, would result in additional unpredicted closures and consequential changes in services offered.

5.2 Farmer-specific information requirements

If an abattoir ceased trading, the farmers supplying it would need to assess the suitability of alternative abattoirs for their private kill retail requirements. For example, an alternative abattoir would need licenses to slaughter the livestock species and be able and prepared to slaughter the breeds the farmer finishes, offer appropriate butchery services, and be sufficient close to the farm for the private kill enterprise to remain profitable. Private kill farmers tend to make regular trips to abattoirs, taking few livestock at any time and return to collect the offal and carcase/butchered joints, so any significant increase in journey distance may make their private kill retail business unviable.

The less attractive the alternative abattoir is, the more likely the private kill retail business would also close when the abattoir currently used ceased trading. This would reduce throughput, and thereby jeopardize the viability of, locally finished and locally slaughtered red meat supply chains. Therefore, a survey of private kill farmers would be needed to identify which, if any, alternative abattoirs farmers would be willing to use.

5.3 The next steps

This study uses spatial analysis as a visual tool to make private kill network data available to a wider audience to promote discussion and debate. This plays to the key strengths of spatial analysis exploiting its potential for integrated analysis across all scales from the field to farm up to national levels. For example, FAO (2022) use geospatial data to understand local and regional and planetary agricultural trends. However, there are additional spatial analysis techniques that could be used to develop this study, though they would need additional data. For example, spatial analysis can include transport networks to estimate transport time between farm and abattoir based on assumed speeds for each type of road (using the OS Open Roads dataset). To do this, a survey would be needed to ask for farmer's postcodes, information which our survey was not allowed to ask as this information is considered personal information.

Other factors, such as the relationship between the density of livestock and private kill abattoirs (a supply factor) and the density of human population and their wealth (demand factors) could also be included in the analysis. However, the livestock density information that is available is presented by number of head by individual species so would need to be converted into a single LSU density map for all species to link with the measurement used to measure abattoir size.

A back-casting study, looking to see the influence of these factors on recently closed abattoirs, could add to the insights analyses using this information. This may, for example, help develop criteria to help government intervene to help abattoirs on animal welfare grounds. Additional analyses might include the impact on the robustness of the private kill network should existing and newly built abattoirs start offering private kill services.

5.4 Alternative approaches

Thought there is a clear need to monitor the robustness of the private kill network, the data demands to do so are clearly challenging. It may, therefore, be advisable to consider alternative strategies. For example, by making special provisions which help support small and isolated abattoirs. For example, small abattoirs on Sark and Alderney take advantage of "de minimis" derogation (available in EU Directive 853/2004/EU (European Commission, 2004)) to reduce their operating costs. This derogation allows remote rather than in-person supervision of slaughtering by a veterinarian. If applied to the UK's small island abattoirs it would remove the need to transport livestock by sea (Franks and Peden, 2022).

This spatial analysis shows the increased distances between abattoirs when a private kill abattoir closes, and is therefore helpful for the development of mobile abattoir businesses. A recent study by Menzies *et al.* (2020) reported 90% of over 600 farmer respondent supported mobile abattoirs in the UK, principally because of "animal welfare (reducing the haulage distances)" and "the desire to create more local meat sales businesses" (Menzies *et al.*, 2020: p 49). Whilst mobile abattoirs face considerable challenges, related to farmer commitment, waste management, hygiene regulations and cost control (Menzies *et al.*, 2020), they may be a more efficient and economical way to replace lost private kill services (Fisher *et al.*, 2004; Lambooij *et al.*, 2011; Babb and Kennedy, 2012; Wood, 2019; Menzies *et al.*, 2020).

6 Conclusions

The further closure of private kill abattoirs will result in longer and more complex livestock journeys from farm to abattoir. The extent to which this will be detrimental to animal welfare and undermine farmers' private kill retail enterprises, which would in turn threaten the locally-finished and -slaughtered red meat supply chain, will depend on the location and number of abattoirs that close and the geographical distribution of those remaining in business.

Although there is provision in the Agriculture Bill to provide grant-funded assistance to abattoirs, no study has examined how support instruments can be targeted to maintain and expand the private kill network of abattoirs to offset these adverse impacts. This proof of concept study is a first step in doing so. It has shown how combining farmer and abattoir survey data, spatial analysis software and Monte Carlo simulations can estimate the change in geographical coverage of the private kill abattoir network and help target interventions to offset the worst effects of abattoir closures.

To be of more practical use for policy makes, it would be necessary to replace the random removal of abattoirs created using Monte Carlo simulations with survey-based information able to estimate the likelihood of individual abattoirs closing. This additional information could be used with transport network analysis to establish the relationships between the number and location of private kill abattoirs that cease trading, the change in distance and complexity of the resulting livestock journeys from farm to abattoir, and the number of private kill retail farmers who continue to supply the local-finished and -slaughtered supply chain and therefore the impact of abattoir closures on the size of that supply chain. Should this information not be available, then spatial analysis can help to identify the geographical areas of the UK that would most likely benefit from the introduction of mobile abattoirs.

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[1] A small abattoir is defined in this report as having a throughput below 5k livestock units/yr., where 1 livestock unit (LSU) is 1 cattle, or 2 pigs, or 5 sheep, or 3 deer.

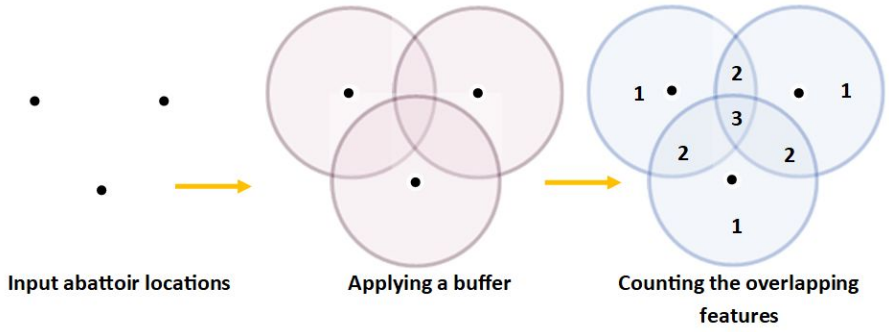
[2] These broad estimates assume *inter alia* that respondents to the abattoir survey are representative of the underlying population of private kill abattoirs. As respondents were self-selecting, this will clearly not be the case. Therefore these estimates must be treated with considerable caution.

[3] The survey received internal ethical approval from the Human Ethical Review Committee at Newcastle University. Informed consent was obtained from all participants.

[4] One interviewee believed a third abattoir in Northern Ireland offered private kill services. However, this was not confirmed by the company's manager, therefore the abattoir was not recorded as a provider of private kill services.

1

2 *Figure 1. Stages of spatial analysis used by GIS*



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4

To	Dr Robert Hamlin (Editor British Food Journal)
From	Dr Jeremy Franks, Dr Jess Hepburn and Dr Rachel Peden
Subject	**A spatial analysis of the robustness of the private kill abattoir network in the UK: proof of concept study (BFJ-01-2022-0081.R1).** (Resubmission deadline: 25-Oct-2022).
Date	11th October 2022

To the Editor British Food Journal

Dear Dr Robert Hamlin

Many thanks for your comments and decision regarding this paper. My apologies for omitting to respond to the point made by Reviewer 1 (below), I am not sure how I came to overlook it. The point is copied below and our responses immediately below that.

The unaddressed comment.

"It is more common to have large numbers of iterations in Monte Carlo simulations to thoroughly assess the variability of potential outcomes. The greater number of runs would enable a more thorough exploration of the solution space and allow richer statistics to be reported on the spatial distributions. In any case, choosing only seven simulation runs requires better justification. Does this not generate a small sample problem? Would the results be notably different with a larger MC sample size?"

I would be grateful if the authors could provide some additional clarification/justification for the choice of only seven replications in the Monte Carlo simulations.

Our response

We agree with the reviewer. On page 18, l 21-23, the existing (unaltered) text stated,

> To be of more practical use for policy makes, it would be necessary to replace the random removal of abattoirs created using Monte Carlo simulations with survey-based information able to estimate the likelihood of individual abattoirs closing.

That is, rather than increasing the number of runs, it would be better to remove the need for a Monte Carlo component to the study altogether. As the paper states, we used Monte Carlo approach to identify abattoirs to withdraw from the population (i.e., to close). What is needed for policy formulation is to move away from this method entirely, and replace it with more detailed -farmer and abattoir specific information.

I have made several minor changes in the text earlier in the paper to emphasise this point.

1 The need to replace the Monte Carlo methodology was alluded to in the original text on page 9, lines 29-34. I have edited the text at this point to add emphasis – the new text is copied below and is coloured mauve.

However, Table II shows that the resulting geographical coverage varies widely depending on which abattoirs are assumed to close, which indicates that additional Monte Carlo runs are needed to deliver more robust distribution and area estimates. However, a more significant improvement for the development of the policies and instruments needed to support the private kill network, would be to use abattoir-specific and private kill retail farmer-specific information to identify abattoirs that are most likely to close rather than using Monte Carlo simulations for this purpose.

2 We have slightly altered the text on page 8, lines 20 – 22 to argue that seven Monte Carlo runs was selected because of our limited resources and because this study is a proof of concept. The new text is copied below.

Given our limited resources, it was decided seven simulation runs would provide sufficient data to prove the value of the concept. Each of the seven runs created a unique data set containing 134 abattoirs.

I hope these minor changes are acceptable to you, but if there is any additional work you think we need to consider, please do let me know.

I was unsure whether you wished me to change the colour of the red text back to black, so thought it best to leave it.4

Yours sincerely

Jeremy Franks
SNES, Newcastle University, England, NE17RU

Figure 2. The cumulative distribution of the percentage of livestock and the distance travelled from farm to abattoir for private kill slaughter.

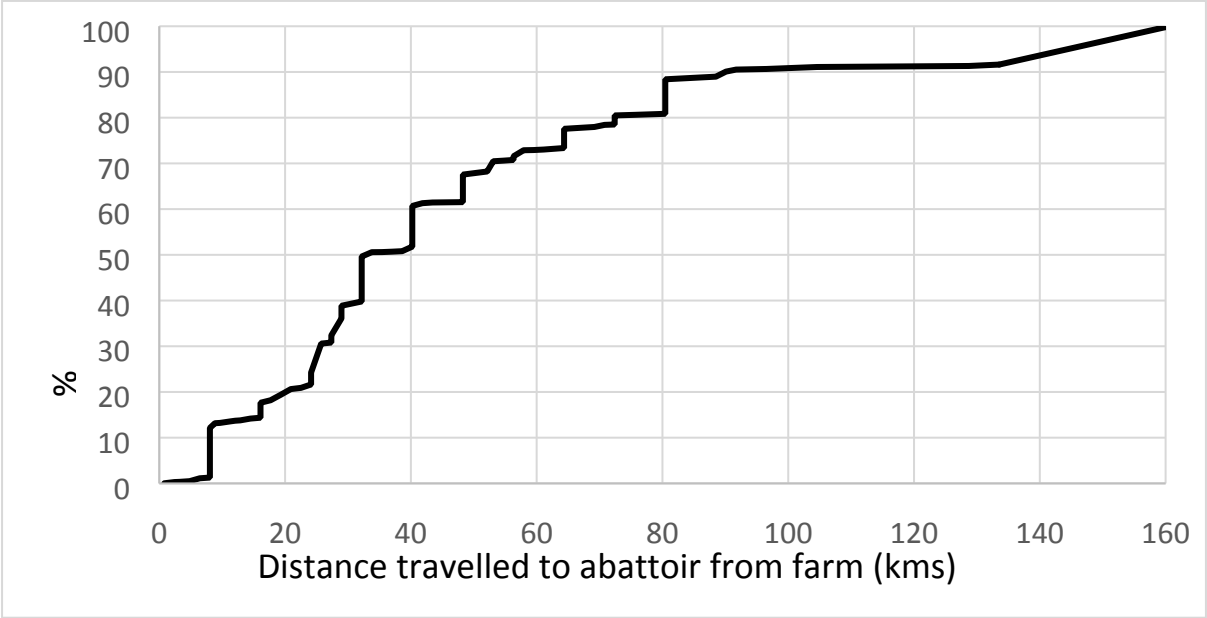

Figure 3. The cumulative distribution of the percentage of farmer and the distance travelled from the farm to abattoir for private kill slaughter.

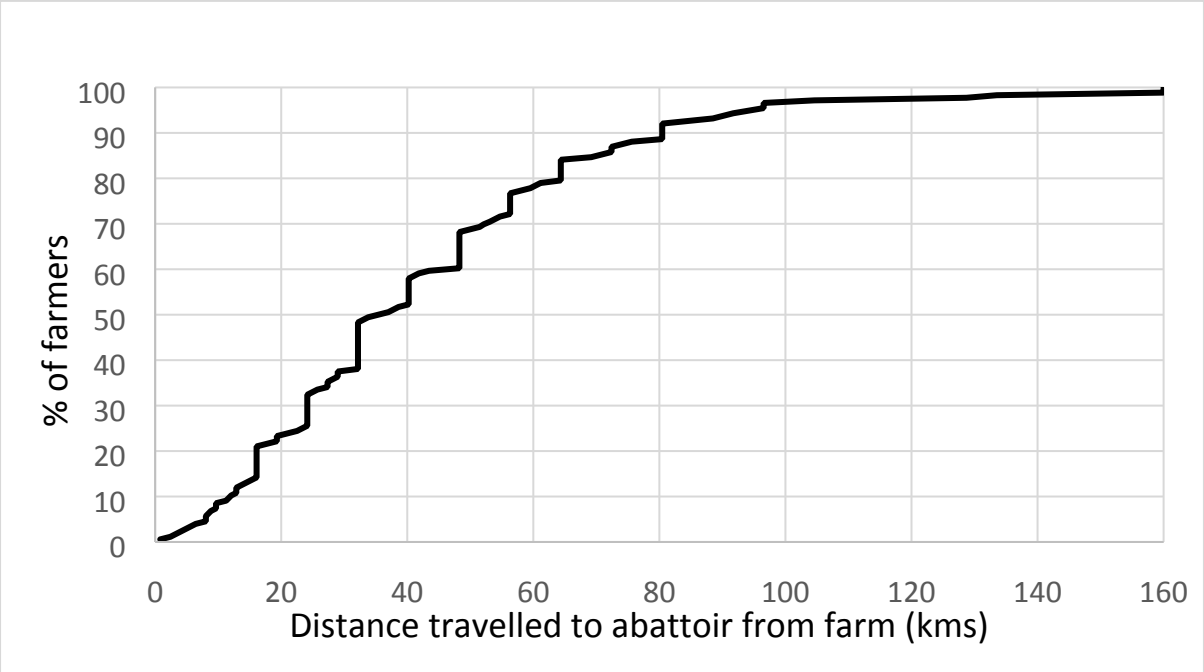

Figure 4. The location of the abattoirs offering private kill services in the UK in August 2020 with 45 km buffer zones.

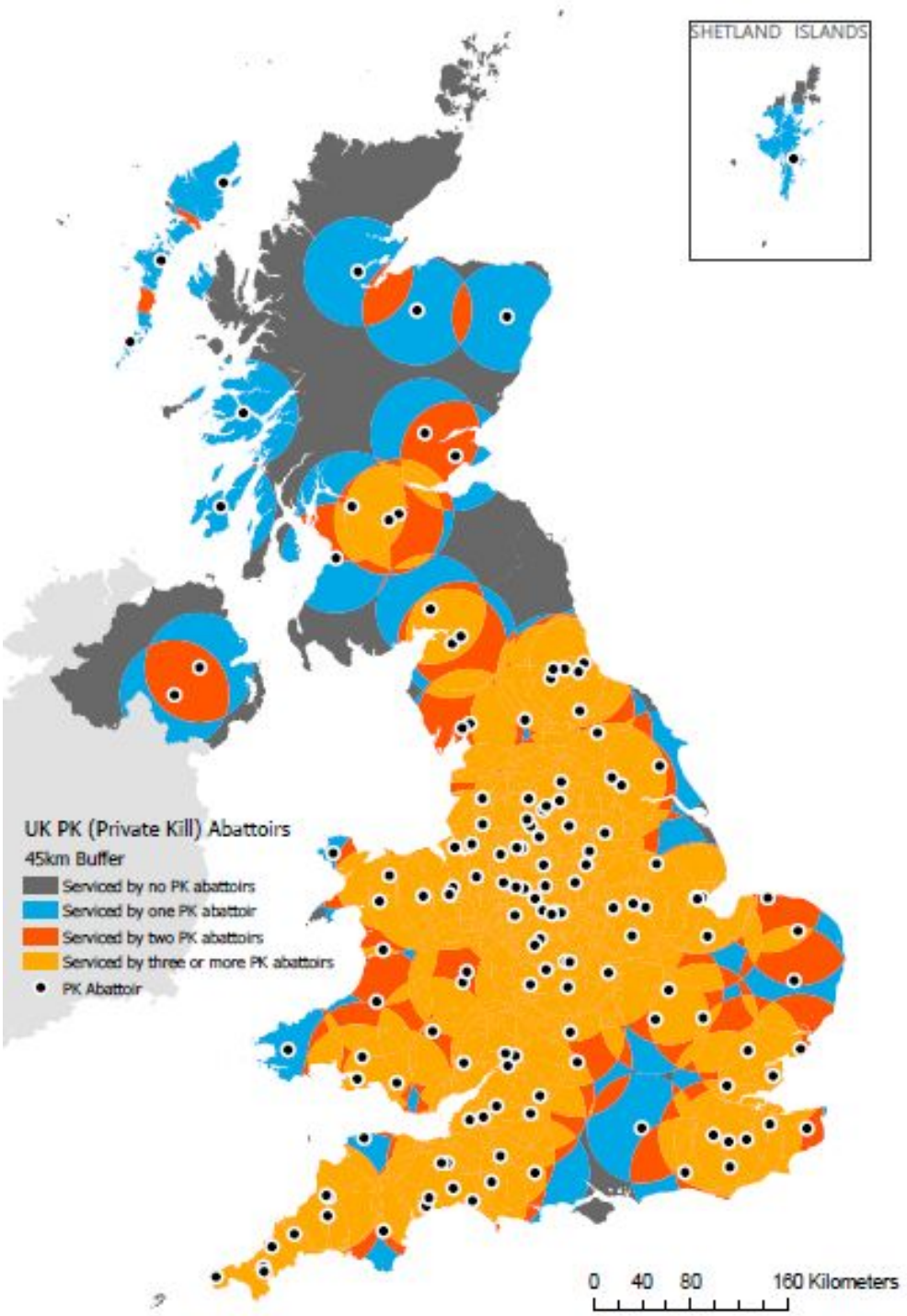

Figure 5. Map showing the smallest area of the UK without any private kill provision (assuming 9% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

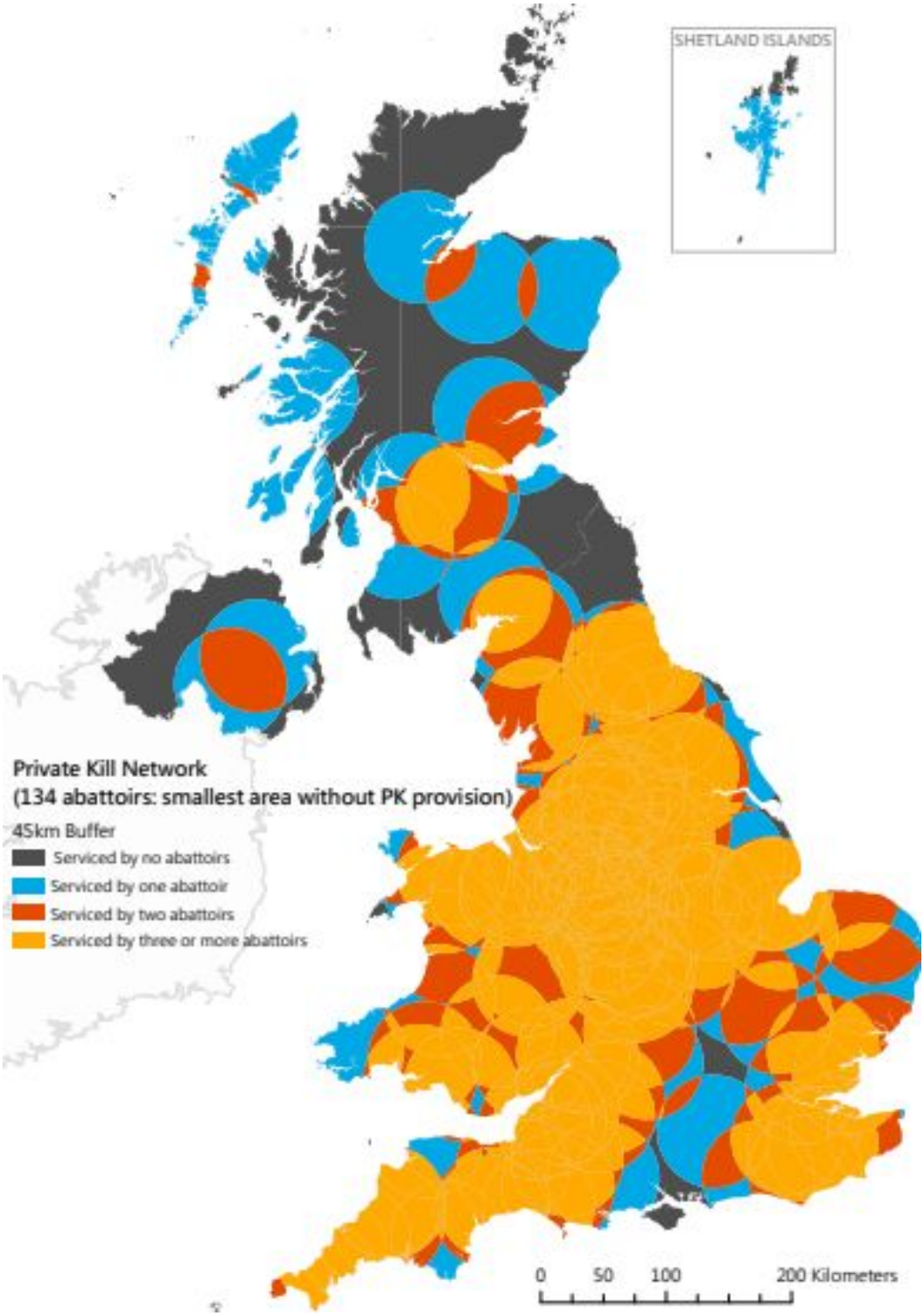

Figure 6. Map showing the largest area of the UK without any private kill provision (assuming 9% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

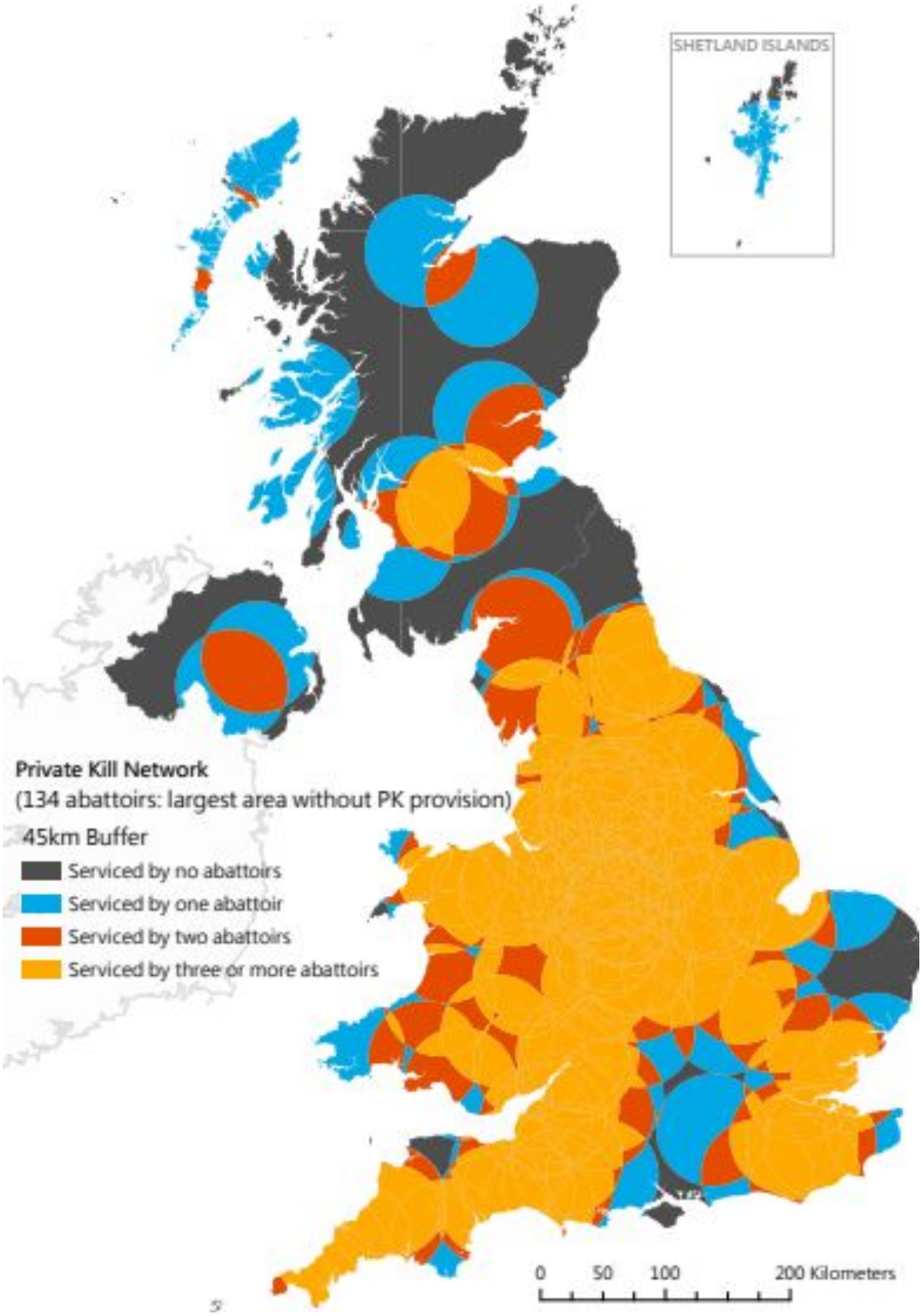

Figure 7. Map showing the smallest area of the UK without any private kill provision (assuming 18% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

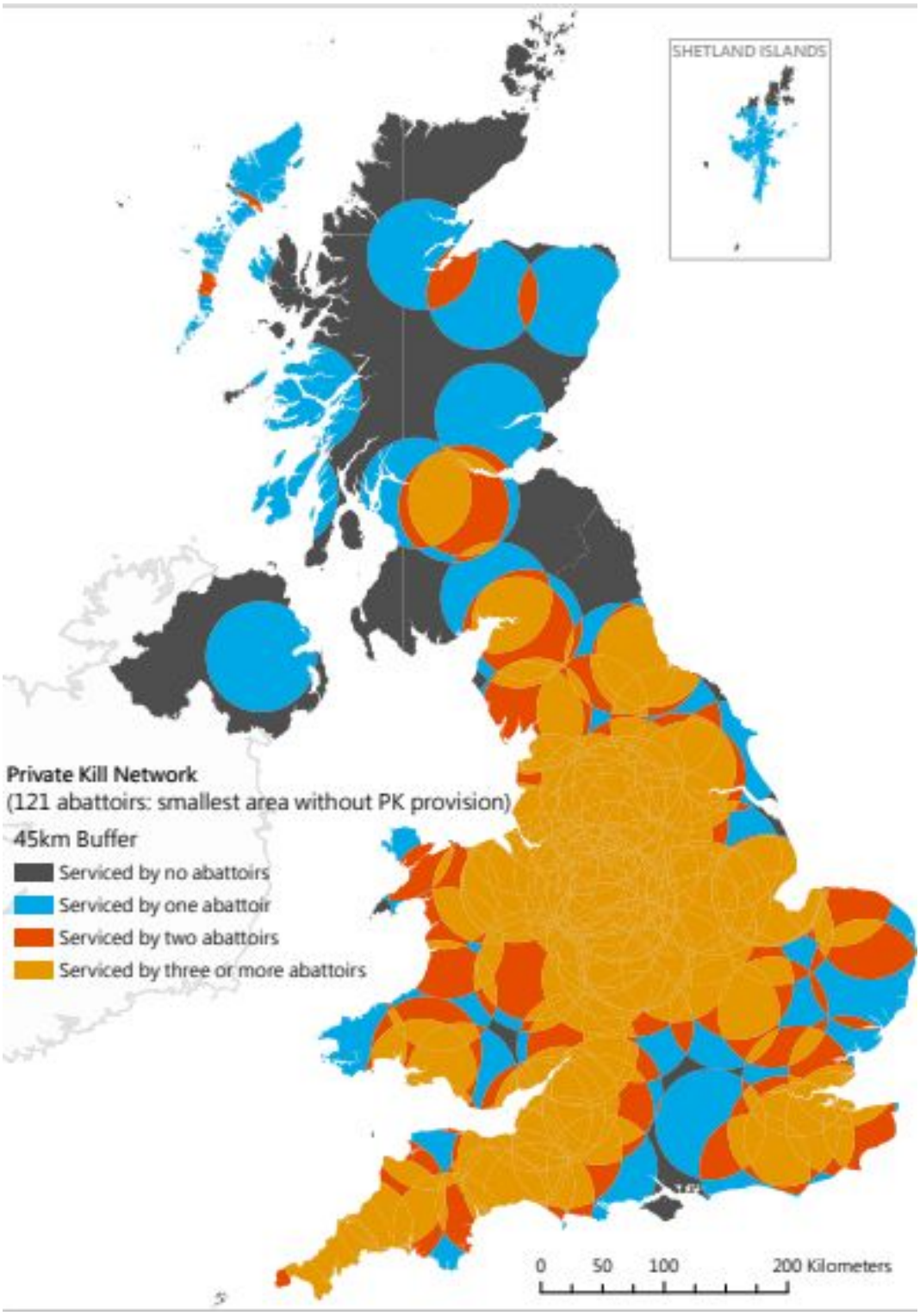

Figure 8. Map showing the largest area of the UK without any private kill provision (assuming 18% of the 147 abattoirs offering private kill services in the UK in August 2020 close and livestock travel no more than 45 kms.)

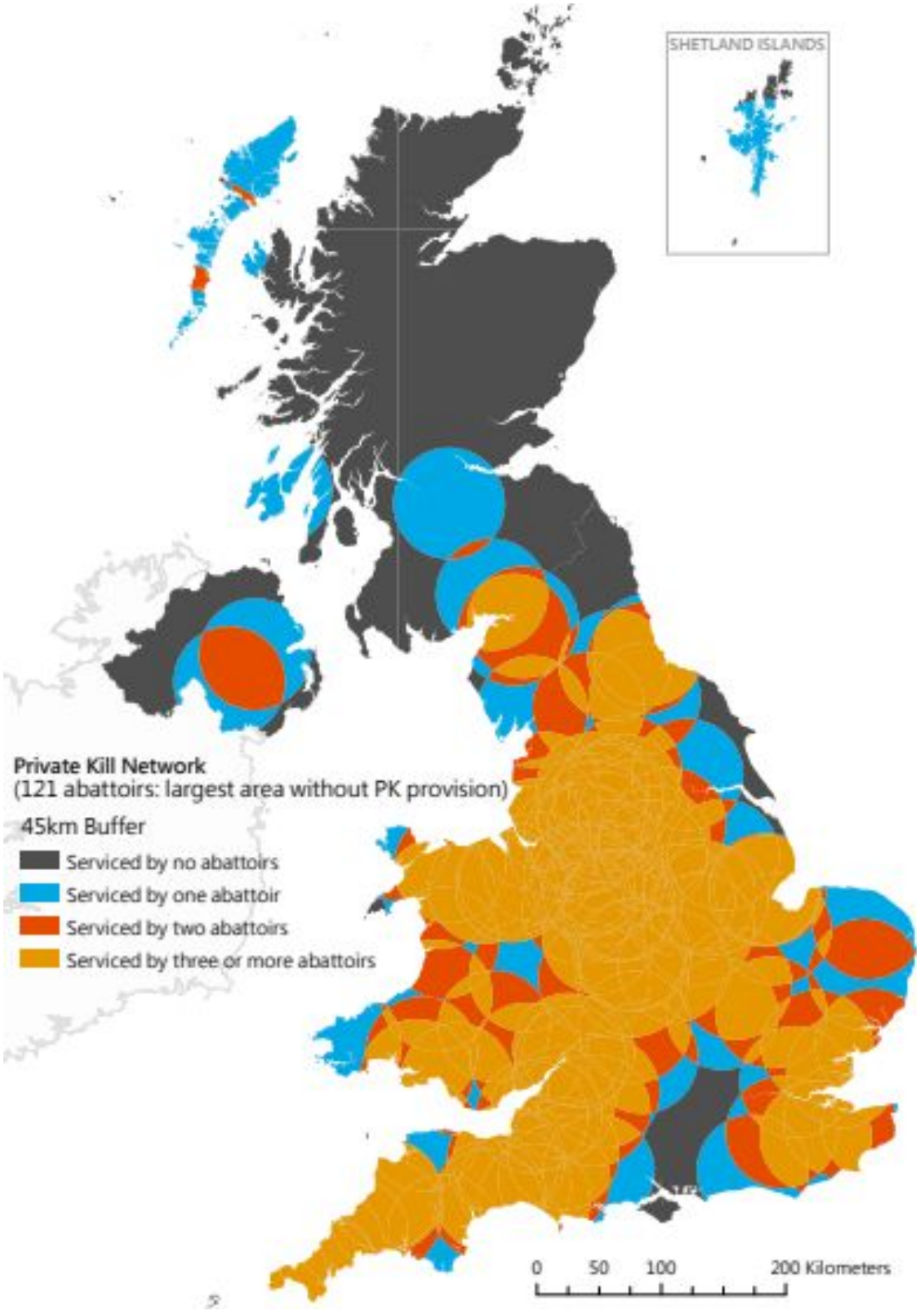

Table I. The area (km^2) and percentage of the UK without private kill abattoir provision, covered by one, two and three or more abattoirs (based on 45 km buffers).

Number of private kill abattoirs	Area covered (km^2)	% of UK covered by the number of abattoirs in column 1
0	44,510	18.2%
1	50,989	20.9%
2	33,809	13.8%
3 or more	114,917	47.1%
Total	**244,226**	**100%**

Table II. The average areas averaged across all seven Monte Carlo simulations, and the simulations that show the smallest and largest areas further than 45 kms from a private kill service.

% of abattoirs randomly removed (number)	Number of abattoirs within 45km	Km coverage			% coverage		
		Average across all seven data sets	Smallest area without coverage	Largest area without coverage	Average across all seven datasets	Smallest area without coverage	Largest area without coverage
9% (13)	0	50,239	45,402	56,309	20.6%	18.6%	23.1%
	1	51,808	48,235	57,591	21.2%	19.8%	23.6%
	2	37,571	34,869	40,377	15.4%	14.3%	16.5%
	3 or more	104,609	101,312	109,550	42.8%	41.5%	44.9%
	Total	**244,226**			**100%**		
18% (26)	0	59,151	49,797	78,991	24.2%	20.4%	32.3%
	1	51,337	37,686	61,499	21.0%	15.4%	25.2%
	2	37,832	28,934	44,790	15.5%	11.8%	18.3%
	3 or more	95,9076	90,034	99,314	39.3%	36.9%	40.7%
	Total	**244,226**			**100%**		

Table III. Change in the geographical area covered by abattoirs following the closure of 9% and 18% of population of private kill abattoirs trading in August 2020.

	% of UK covered			
	Number of abattoirs within 45km			
	0	**1**	**2**	**3 or more**
Baseline (147)	18.2	20.9	13.8	47.1
Removal of 9% of abattoirs (134)	20.6	21.2	15.4	42.8
Removal of 18% of abattoirs (121)	24.2	21.0	15.5	39.3
	Change in % area covered compared to baseline areas			
Closure of 13 abattoirs (134)	2.3	0.3	1.5	-4.2
Closure of 26 abattoirs (121)	6.0	0.1	1.6	-7.8

1