Mapping the Geography of Disease: A Comparison of Epidemiologists' and Field-Level Experts' Disease Maps

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1. Introduction

A common saying amongst veterinarians and epidemiologists is that 'disease knows no boundary'. Yet this narrative is frequently undermined by the geographical work veterinarians and epidemiologists undertake in attempting to control animal disease. On the one hand, the national and international governance of animal disease creates spatial zones and boundaries, fixed rules and procedures (Higgins and Dibden, 2011; Enticott and Franklin, 2009). On the other hand, veterinary epidemiologists rely on mapping the incidence of animal disease, its prevalence and spread. Like maps of any other risk, these spatial representations of animal disease can have an effect, invoking new policy prescriptions and altering farmers' behaviour.

Few social and environmental risks are not calculated and represented in spatial form (Haughton and White, 2018). For Dransch et al. (2010) and Hagemeier-Klose and Wagner (2009), the spatial representation of risk in maps has an important role in communicating risk, so long as maps are designed appropriately and match public understandings of risk. This focus on 'map effectiveness' (Robinson et al., 1995) is challenged by attempts to reveal the values and power relations embedded within maps (Harley, 1989; Kitchin and Dodge, 2007; Wood, 1992; Pickles, 2004). Critiques of the map effectiveness model address its reliance on a deficit model of risk communication that assumes supplying the public with more information results in a reduction in risk-taking. Participatory approaches to risk management seek to address these problems by addressing the twin challenges of collaboration between experts and local communities, and capacity-building by developing and acknowledging new sources of knowledge (Maskrey et al., 2019). Thus, uses of participatory mapping seek to reduce the gap between the public and experts (Lane et al., 2011; Brandt et al., 2019), and incorporate and develop new forms of expertise in the planning, management and representation of risks (Cadag and Gaillard, 2012; Gaillard and Mercer, 2012; Chambers, 2008). Whilst some question the extent to which participatory approaches to risk mapping produce new forms of knowledge (Haughton et al., 2015), participatory approaches presume that 'non-expert' understandings of risk differ from those of scientific experts. Yet comparisons of subjective and objective understandings of risk can show little difference (Wright et al., 2002) with the public demonstrating surprisingly good and nuanced understandings of risk, even if their behaviour suggests otherwise (Davison et al., 1991).

These issues are highly relevant to the management of infectious animal diseases. Despite the origins of epidemiology in the mapping of public health, there are no critical studies of the way animal health risks are constructed and represented in maps. However, the publication of animal disease risk maps not only represents a method of communicating disease risks, but also a way of encouraging farmers to employ farming practices that keep farms 'disease free'. Whilst some research has suggested that farmers develop their own understandings of the spatial transmission of disease (Enticott, 2008), there is no research which examines the extent to which these understanding of disease are different to objectively defined epidemiological calculations contained within disease maps used by policy makers. This has important implications, potentially allowing a broadening of the notion of epidemiological expertise to include farmers and field-level veterinarians in order to develop disease maps that are culturally compelling.

The aim of this paper is therefore to examine the extent to which 'official' epidemiological understandings of animal disease risk differ from 'field-level experts', specifically farmers and veterinarians. To do this, the paper draws on a series of participatory disease risk mapping exercises with farmers and veterinarians. The paper describes an attempt to objectively define the spread and endemicity of bovine tuberculosis (bTB) in England and Wales. It then analyses farmers' and veterinarians definitions of endemicity and compares these spatial representations of endemic bTB (defined by Thrusfield, 2007: as constantly present in a population) to those of epidemiological experts. The policy implications of using disease risk maps to influence farmer behaviour is discussed in conclusion.

2. Comparing Expert and Non-expert Risk Mapping

In this section we review existing studies that have sought to reveal different spatial imaginations between official or expert accounts, and those of the public and/or field-level experts. Studies from human geography, environmental psychology and sociology frequently point out variations between subjective and objective accounts of risk (Rowe and Wright, 2001). For example, disparities between subjective and objective assessments of health are widely recognised (see Baker et al., 2004). Explanations of these disparities often rely on the suggestion that population subgroups use different thresholds when assessing their health despite having the same level of true health (Lindeboom and van Doorslaer, 2004).

Others studies point to the significance of lived experience and local knowledge to explain variations in risk assessment. In assessing levels of criminal behaviour, Klinger (1997) and Herbert (1997) suggest that police officers, through their day-to-day activities, build a mental map of their beats and the location of high volume crime areas but which differ to official crime statistics (Rengert, 1995; Rengert and Pelfrey, 1997). For example, Paulsen (2004) found that police officers' perceptions rarely matched mapped official crime data and providing them with official crime maps had little effect on their perceptions (see also Ratcliffe and McCullagh, 2001). Paulsen (2004) attributes this limited impact to the failure to involve officers in map-making.

Disparities between objective and subjective risk perceptions may also be due to understanding risks at different spatial scales. Nasar and Fisher (1993) suggest that crime hotspots can be understood at macro (i.e. neighbourhood) and micro (i.e. proximate) scales. The significance of proximate features is diluted by mapping at macro scales, missing site-specific and situational features. For environmental risks, Cidell (2008) explains how local experience contributes to challenges to noise maps. In this case, residents argued that their local experience of noise was different to that represented by noise contours on maps. In echoes of the map communication model, Hagemeier-Klose and Wagner (2009) note that the public's understanding of flood maps depends on the colours used to depict flood risk areas (see also Soane et al., 2010).

However, despite these studies, public perceptions of risk may not always differ from expert or scientific risk assessments. Rowe and Wright (2001) reviewed studies comparing risk assessments by experts and the public, finding no evidence that experts judged risks differently to non-experts, or that experts' judgements were in some way more accurate (see also Wright et al., 2002). In studies of public health, failure to follow official advice on healthy living may be taken as a sign that the public requires more information on health risks because they do not fully understand the implications of their behaviour. However, this behaviour may disguise compatibility between lay understandings of risk and their official/scientific equivalents. For example, Davison et al. (1991) find that whilst official public health advice is rejected by the public, lay theories of illness demonstrate good knowledge of the various risk factors suggested by public health officials.

Meanwhile, in studies of environmental risk, Siegrist and Gutscher (2006) compared lay people's risk perceptions of flood risks to experts' flood risk maps. Both the lay and expert views of risk were significantly correlated, even when controlling for experience of flooding (see also Kellens et al., 2011: for similar findings). Some studies have raised questions over the reliability of maps created from data contributed by the public (Goodchild and Li, 2012; Goodchild and Glennon, 2010), and questioned the role of these 'citizen science' approaches to data collection and surveillance (Galloway et al., 2006; Marzano et al., 2015). Others are less concerned: Linus' law predicts that volume of correct reports cancels out inaccurate data (Haklay et al., 2010). Thus, Spinsanti and Ostermann (2013) show how maps of forest fires can be accurately sourced from social media by applying filter criteria to ensure data reliability.

These studies paint a mixed picture in relation to the similarities between expert and non-expert geographical imaginations of environmental risks. However, they also highlight four inter-related dimensions which also help explain how these differences are created and sustained. Firstly, these studies suggest that the technicalities of mapping may contribute to tensions in geographical imaginations. This may refer to aspects of colour and presentation as identified by Soane et al (2010). Alternatively, ecological fallacies created by aggregating individual data or using different areal units may contribute to these differences in geographical imagination. Secondly and relatedly, 'lived experience' and local knowledge may provide a contextual understanding of risk phenomena, prompting more nuanced rather than distant and universal geographical imaginations (cf. Bickerstaff and Simmons, 2004). Thirdly, as Harley (1989) suggests, mapping is political and choices made in producing maps reflect different political positions. Whilst expert maps of risk phenomena may reflect institutional choices, maps that ignore contextual or local phenomena may represent attempts to protect disciplinary boundary (Gieryn, 1983). Finally, following Kitchin and Dodge (2007), it may also be possible that these binary positions breakdown as maps are used in practice. Rather than differences between map users and producers, more nuanced positions may emerge reflecting a more complex engagement between experts and non-experts geographical imaginations.

3. Spatial Measures of Animal Disease Risk

Whilst comparisons of subjective and objectively defined risks are found across a range of different policy areas, there are no analogous studies of animal disease. The absence of comparisons between those in the field and experts may be attributable to a lack of data about animal health. Data are not systematically collated for many endemic diseases because they are private interests and not transmittable between farms. The management of the incidence of bovine Tuberculosis (bTB) in England and Wales is one exception. The disease is recognized as one of the most challenging to manage: there is no vaccine and diagnostic tests are compromised by test sensitivity and practicality (Enticott, 2012; Karolemeas et al., 2012). The disease can be transmitted between cattle, but also by badgers - the largest wild mammal in the UK and a protected species (Defra, 2014). The management of bTB has therefore become dominated by arguments over the impact, efficacy and morality of badger culling (Enticott, 2001; Grant, 2009) Different political parties have taken opposing views on badger culling, resulting in an incoherent and ever-changing strategies.

Surveillance of bTB incidence, however, is well established. Cattle herds are tested regularly, and data are stored in a national dataset that is used to analyse annual disease trends at different spatial scales (APHA, 2015; Lawes et al., 2016). Cattle that test positive to the test used to diagnose bTB are known as 'reactors', and a herd incident commonly referred to as a 'breakdown'. Historically, these incidence data were used to set the frequency of cattle testing in parishes – known as the parish testing interval (PTIs) – which were mapped and communicated to farmers (Defra, 2013). For farmers, the PTI map came to represent a map of disease risk, demarcating the boundaries of 'clean' and 'dirty' zones, and has been used by policy makers as a means to try to communicate disease risks and encourage farmers to adopt biosecurity practices (Enticott and Higgins, 2016). However, whilst the PTI map might serve the needs of policy makers, they are not ideal epidemiological zones. They are not of uniform size or shape, and do not account for stocking densities or changes to farm practices such as the use of discontinuous parcels of land.

To resolve these issues, the research team developed an objective measurement of the rate of spread of endemic bTB. To do this, surveillance data held by the Animal and Plant Health Agency (APHA) were used to describe the location and number of bTB incidents in England and Wales. Data were obtained for the period 1st September 2001 to 31st August 2012, and were collated into 24-month intervals. Processing of geographic data and map production was performed using the software ArcGIS 10.0 (ESRI, 2011). The analysis produced two different spatial measurements of bTB: a spatial definition of endemicity, and the rate of spread of the endemic area.

A key dimension of these calculations is a threshold for disease proximity and recurrence. Epidemiological calculations of endemicity can be validated by comparing different thresholds to disease incidence in so-called 'Stevenson districts' (Stevenson et al., 2005). In this case, two thresholds were set in defining endemicity. The first endemic threshold was the number (n) of nearest incidents in order to produce a consistent core endemic area and reduce the influence of isolated cases. The second threshold was the maximum distance (measured in kilometres) of the n^{th} nearest bTB incident. Both thresholds affect the appearance of the spatial distribution and rate of spread of bTB when mapped. Following a workshop with veterinarians working for APHA, and epidemiologists responsible for calculating endemicity, the 3rd nearest incident was set as the first threshold and its distance threshold was set at 7km and used in subsequent attempts to calculate and map endemic bTB.

Figure 1 illustrates the rate of spread of bTB for each 6.25km^2 hexagonal cell that formed the base resolution for the study in the 24-month interval in which spread occurred (anytime between September 2001 and August 2012). Rate of spread was calculated as the distance between the endemic areas for 24 month intervals two years apart (e.g. September 2003 – August 2005 compared with September 2001 – August 2003), divided by the period of time elapsed (for complete details, see: Brunton et al., 2015). Subsequently, figure 1 was converted to a contour map showing smoothed areas of endemicity for each of the 24-month intervals from September 2001 until September 2012 (see figure 2).

This method therefore produced an 'official' measure of endemicity and disease spread by the Department for Environment, Food and Rural Affairs (Defra), with vulnerable areas categorised as the 'edge' area and areas either side referred to as the High-Risk Area (HRA) or Low-Risk Area (LRA). These spatial categories subsequently influenced policy choices in Defra's bTB eradication strategy (Defra, 2014). However, these thresholds are arbitrary and reflect the predispositions of those that choose them, rather than necessarily those who might use the resulting maps. The extent to which the assumptions on which official disease maps rest are the same as those amongst farmers or veterinarians who live and work in those areas identified as endemic or experiencing endemic spread is untested. As with other risk maps, without multi-stakeholder validation, expertise remains defined as belonging to veterinary scientists, and risks distancing experts from citizens.

A series of expert opinion workshops (EOWs) was subsequently organized to compare the representations of disease endemicity in the disease map with farmers' and veterinarians' perceptions of disease endemicity. By involving farmers and local veterinarians in the EOWs, the purpose was to capture their geographical and occupational expertise thereby reflecting calls for a broader notion of expertise ([Landström et al., 2011](#)). Table 1 shows the number of participants in each EOW. Locations of each EOW were chosen to reflect different 'endemic fronts' – specifically a northern and eastern front (see figure 1). Participants were selected across the width of these endemic fronts. For example, the Nantwich EOW recruited farmers from the southern verge of the northern endemic front whereas the Newark EOW recruited farmers who farmed closer to the outer boundary of the eastern front. Dairy and beef farmers were enrolled into the EOWs with the help of local veterinary practices, farming organisations, and snowball sampling.

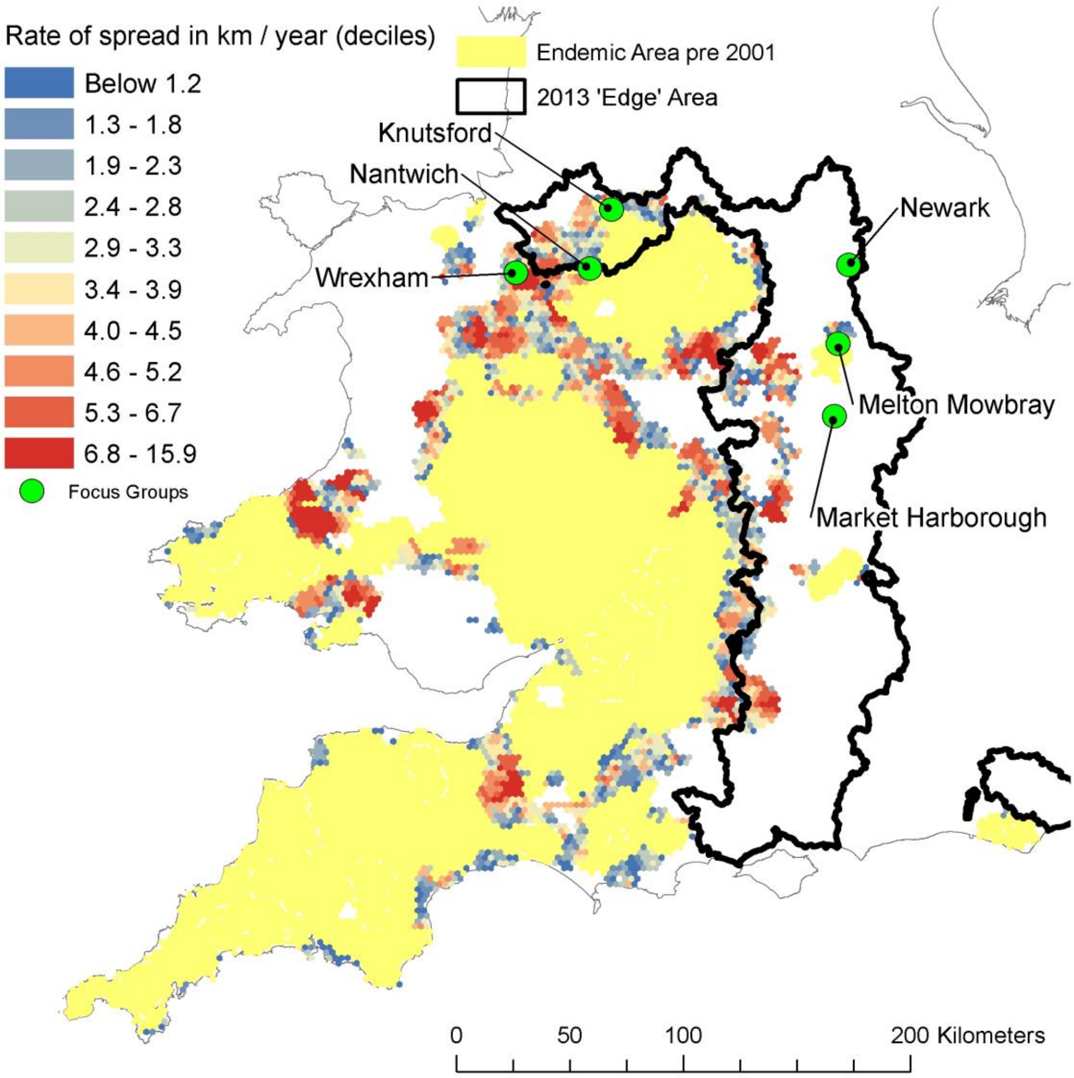


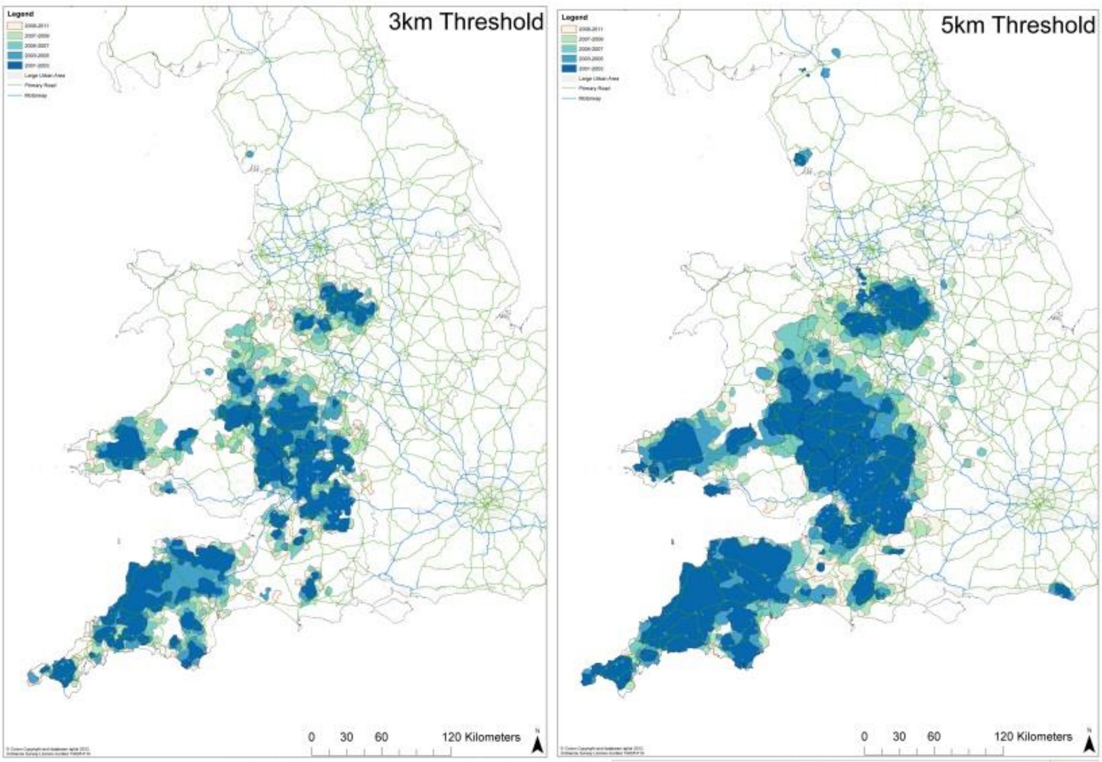
Figure 1: Map illustrating the hexagons where endemic bTB (defined by the presence of three confirmed bTB incidents incidents within 7km) spread between 2001 and 2012. Rate of spread in km per year is calculated for the two-year time period during which endemic bTB first passed through the hexagon. Hexagons which were classed as endemic prior to 2001 are coloured yellow and are considered to be the 'core' endemic area.

The EOWs were organised around three participatory mapping exercises (PMEs) and conducted by research team's social scientists (GE and KW). Participatory approaches to mapping are well established in critical cartography studies (Haklay and Tobón, 2003; Elwood, 2002) and rural development (Chambers, 1994). In the first PME, participants were provided with A0 maps of their area and asked to annotate the areas they considered to have endemic bTB. Secondly, participants discussed meanings of endemicity and vulnerability in relation to their annotated maps. Thirdly, participants were presented with maps produced by APHA using different thresholds to calculate endemicity. The thresholds referred to the optimal distance between recurrent breakdowns: four threshold maps covering participants' local area were presented (3km, 5km, 7km, and 10km. See figure 2). Participants engaged in a consensus exercise to agree which threshold most closely represented the endemic area. Finally, participants took part in another consensus exercise to agree on risk factors for bTB (not reported in this paper). For each activity, participants were split into groups depending on the size of the EOW (see table 1).

Table 1: Number of participants in expert opinion workshops.

Endemic Front	EOW code	Participants	Location	No. Participants	No. Activity Groups
Northern	NF1	Farmers	Knutsford	12	3
	NF2	Farmers	Nantwich	12	3
	NF3	Farmers	Wrexham	8	2
	NV4	Private Veterinarians	From Cheshire and North Wales	9	2
Eastern	EF1	Farmers	Melton Mowbray	7	2
	EF2	Farmers	Market Harborough	6	2
	EF3	Farmers	Newark	3	2
	EV4	Private Veterinarians	From Leicestershire and Nottingham	6	2

Ethical approval was provided by Cardiff University's Social Research Ethics Committee, and focus group schedules and activities were approved by the funders (Defra). All participants received information sheets on the aims of the project and provided consent at the start of each group. All EOWs were recorded using separate digital voice recorders for each breakout group. Audio recordings were transcribed and analysed within Nvivo. Participants had not seen the threshold maps prior to the workshops. Participants were not told which threshold had been used when defining the new Edge, HRA and LRA areas, or what other Expert Opinion Workshops had recommended, although the classifications of the Edge, HRA and LRA was publicly available.



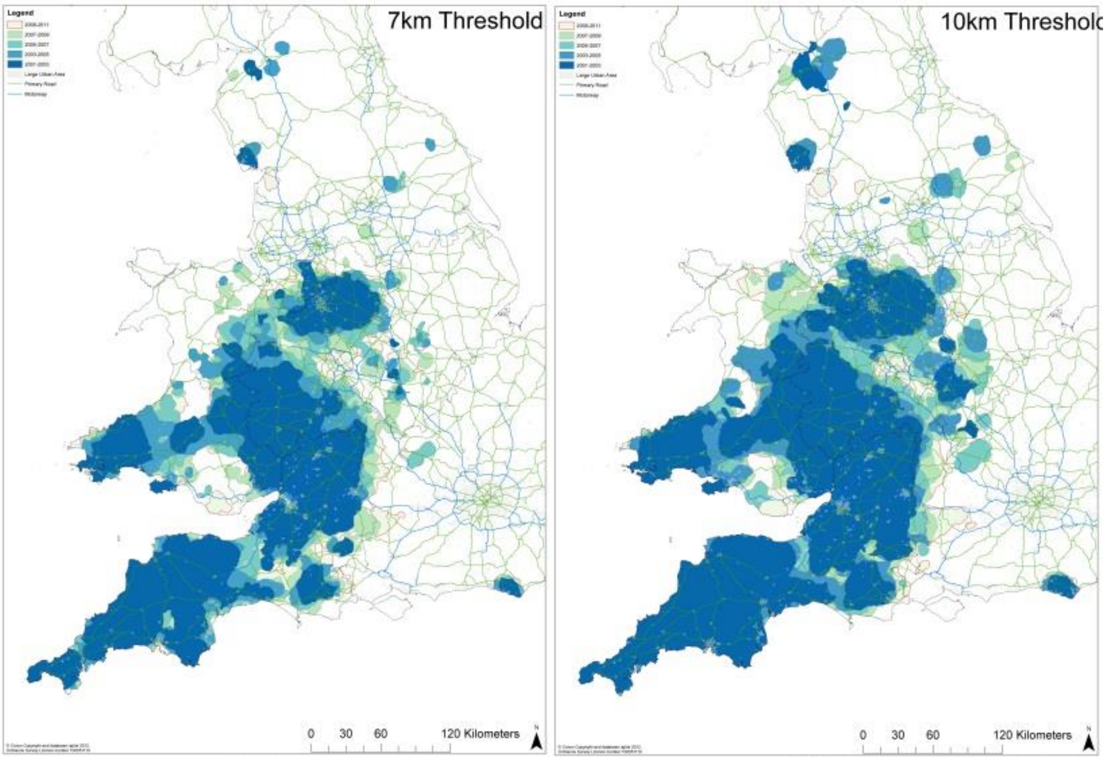


Figure 2: Maps of endemic bTB with different optimal distance thresholds discussed at EOWs.

Due to data protection restrictions, the maps used in the workshops or any other spatial representations of bTB (other than the PTI map) such as the location of bTB incidents were not in the public domain. Since conducting the research, Defra have published maps of incidents of bTB on an interactive website (Enticott et al., 2018). Moreover, even where veterinary professionals have access to other spatial representations of bTB, their use in practice has been hampered by organisational and practical issues (Enticott and Ward, 2020).

4. Comparing Animal Disease Risk Maps

4.1 *Defining 'Endemic' and 'Vulnerable' areas*

In each EOW, participants clearly distinguished between *endemic* and *vulnerable* areas. In relation to 'endemicity' wildlife infection and chronic infection of cattle were identified as the two key determinants. Firstly, farmers and veterinarians in either front associated an endemic area with long-standing infection in wildlife moving between cattle and badgers. This indicated a circularity to the spread of disease as opposed to a linear spread: "*it's in the* *wildlife, it's just circulating; it's just going to re-circle*" (EF1). The relation of endemicity to wildlife infection was also qualified by farmers' perceptions of non-endemic areas with uninfected wildlife populations. The relation of 'endemicity' to wildlife infection was also prominent in the veterinary EOWs on both the eastern and northern endemic fronts. For example, northern front veterinarians described an endemic area as:

> "*being in the wildlife population and unable to be eradicated even if they killed off the cattle in that herd, so if that herd had TB, and you killed off all the cattle, there was a residual infection and TB would still be in that area*" (NV4)

Veterinarians were also more likely to emphasise the presence of chronically infected cattle as a dimension of endemicity. One veterinarian working within the northern front area discussed the importance of chronic infection as a '*defining marker'* of endemicity stating that '*islands*' of chronic infection could be amalgamated to form what he perceived to be an endemic zone:

> "*[there are] some islands of known chronic infection, but really pretty much you can put them all together and say that's an endemic area as well*" (NV4)

Compared to endemicity, vulnerability to bTB involved a greater array of factors. Four key signifiers of vulnerability were discussed by participants during the first mapping exercise, including: cattle movements; pockets and hotspots; uncertainty and hearsay; and emergence of 'new' reactors. The identification of cattle movements was most prominent in the northern front EOWs, the role of hearsay and uncertainty was most prominent in the eastern front EOWs and the emergence of new reactors was most frequently mentioned during the veterinary EOWs. The notion of local 'pockets' or 'hotspots' (and spread from these zones into neighbouring areas) was an identification of vulnerability in all of the EOWs.

For farmers on the northern front, vulnerability was strongly connected to cattle movements in the surrounding area. Referring to their annotated map, one farmer explained what makes an area vulnerable in these terms:

> "*the little orange dots are our farms, the brown circles are where we think it's endemic, but all that area towards [...] is vulnerable just for the amount of places where people take their cattle for summer. Nowhere is really safe we think because the cattle move around so much these days*" (NF1)

The perception of vulnerability to bTB infection due to cattle movements links back to perceived definitions of endemicity and its connection to wildlife infection. For example, one farmer in the northern front said:

> "*The only hope is that if cattle moved, it happens when Lancashire cattle move, they find a TB problem and they get on top of it before it gets into wildlife. So there'll always be these little bits of spread into these clean counties*" (NF1)

Discussion of vulnerability on the northern front was also assesed in spatial terms, where uninfected land around '*pockets*' and '*hotspots*' were perceived to be particularly susceptible to infection. Farmers referred to '*in-filling*' of previously uninfected land with new bTB cases to reflect how vulnerability existed in 'pockets' of infection. Thus, one north Cheshire farmer highlighted vulnerability in the following terms:

> "*what we think is happening is that you get these hotspot areas and then you get infill between them. So we think that all this area is very, very vulnerable. It kind of spreads out, pushes out*" (NF1)

Veterinarians on the northern front also discussed the process of 'infilling' and the identification of vulnerable areas. For example, one veterinarian stated: "*I mean in the past we used to have two intensive clusters, Congleton, Macclesfield, and then around Whitchurch, and now we've had a lot of infilling*" (NF4). Similarly, farmers on the eastern front associated vulnerability with the idea of 'pockets' of infection, annotating them on their maps to show how they were slowly creeping outwards or were connected to cattle movements:

> "*this area here, up the forest and around here, they're getting quite a bit of TB... it's not endemic, but we know there's been pockets sort of here and here*" (EF1).

> "*And here there are little pockets, I know one farm bought in the cows and went down… it's been a problem here…but people buy cattle in… I think its purchase yes, but it's not in wildlife as far as I know, but what I do know, is in the last year the badger population has just exploded*" (EF1).

Local 'hearsay' and rumour was important to these mappings of vulnerability. For example, in Leicestershire one farmer identified vulnerable zones as those where one or two outbreaks were known through local knowledge:

> "*we know of outbreaks around there. But we are not being wiped out by them, I know that one, there is two outbreaks there, one nobody knows where it came from, it was a closed herd, he's about a mile away went down this February but don't know where it has come from, or if they do then they have not said*" (EF2)

Though seemingly based on local word-of-mouth these conversations were often key to farmer's identification of vulnerable zones on the eastern front. The significance of one or two breakdowns in the area was enough to signal the increasing vulnerability of the area to farmers:

> "*there have been some people in the Market Harborough area I think. I know there have been one or two problems there, but really we are not privy to enough information to, but I would say that we're quite vulnerable at the moment* "(EF2)

The perception of progression from a vulnerable to an endemic area was often based on hearsay from other local farmers. For example one farmer from the north Melton Mowbray EOW stated "*a couple of the farms that were shut down, I don't know whether they were positive or… it's not endemic here, but we don't know because Animal Health won't give us any information and I don't believe it's endemic*" (EF1). This uncertainty of infection and its link to a feeling of vulnerability was also confirmed on the very edge of the eastern front where one farmer noted that, "*people don't tell you when they're had a TB breakdown unless they're a close friend and you know that they've got a problem*" (EF3).

By contrast, veterinarians relied on their own knowledge of bTB surveillance data and its technical limitations. Firstly, veterinarians pointed to a gradual build up of disease as reflected through the imperfections of bTB testing. Secondly, veterinarians identified the emergence of ‘new’ reactors in ‘clean’ areas as a signifier of vulnerability and the development of vulnerable zones. One veterinarian in the northern EOW explained:

> “*the pattern is usually we get a lot of reactors in a new area and we get no disease. We’ll isolate the organism and we don’t get visible lesions but as time goes on, although we get more breakdowns like that, eventually you do get disease, you get confirmation, visible lesions, so it usually starts off as reactors, no disease, and then eventually, we get disease*” (NV4).

The development of an endemic area was perceived to result from the ‘creep’ of infection into non-endemic areas, subsequently becoming vulnerable areas and eventually endemic areas. The notion of ‘creep’ was discussed in the EOWs as symbolic of the slow but inevitable advancement of endemic TB into their areas: “*it’s creeping, you look over the past 10 years and you can see this disease moving five miles, six miles a year, slowly but surely into what were clean areas, just a slow trickle*” (EV4). Veterinarians associated ‘creep’ with the emergence and increase of inconclusive test results. Similarly, farmers referred to ‘sporadic cases’ as a marker of vulnerability. Farmers meanwhile, particularly on the eastern front, associated ‘creep’ with the movement of badgers into vulnerable areas from the core endemic area.

Both farmers and veterinarians pointed to the role of ‘hard’ boundaries to explain why some areas were vulnerable or had become endemic. Hard boundaries most often appeared during the map annotating in the form of major roads, motorways, canals and urban conurbations. For example, Welsh farmers in the northern front EOW identified the A483 road as demarcating ‘problem’ from endemic areas. Meanwhile, on the eastern front, farmers used the M1 motorway to demarcate between levels of bTB risk. The use of hard boundaries to define vulnerability resonated amongst veterinarians in each area, for example the northern front veterinary EOW explained when discussing their map*: "we're getting a lot of sporadic ones across the whole of Cheshire, I marked on the M56 as a bit of a borderline it's like a corridor I suppose, acts as a bit of a barrier*" (NV4). In this instance, hard boundaries were specifically linked to wildlife with the network of motorways, the Manchester Ship Canal, and urban sprawl between Manchester and Liverpool defining the geographical possibilities of spread, and which areas were considered vulnerable.

4.2 Mapping Thresholds

EOW participants were presented with the maps shown in figure 2. Across all eight EOWs, the 7km threshold map and the 10km threshold map were each chosen four times. The 3km and 5km maps were never chosen. Both veterinary EOWs chose the 7km map regardless of their regional location. However all three farmer EOWs on the northern front choose the 10km threshold map to most accurately represent endemic spread, whereas only one farmer EOW on the eastern front chose the 10km threshold map. The other two farmer EOWs on the eastern front chose the 7km threshold map. All EOWs conducted with farmers on the northern endemic front chose the 10km map as that which most closely resembled their perception of endemic spread and the vulnerable zone. The consensus in all three farmer northern front EOWs was that the 10km map was the most accurate (see table 2). In other words, farmers tended to think that the endemic area was larger than veterinarians did, or the epidemiologists who had made the maps, or indeed the recent definition of the 'Edge' area. In focus groups, these farmers argued that the front had already passed through and the 'real edge' was now further to the East.

Nevertheless, the EOWs revealed a wide range of criticism of the accuracy of the maps in general, including the 10km threshold map that had been chosen as most accurate. Concern was not at the accuracy of the 10km map at *their* local level. Indeed they chose it as being the *most* accurate of the maps presented to them. Rather, there was concern about the maps' ability to reflect the endemic status of distant places such as the southwest of England and the importance of representing 'pockets' of enduring non-endemic areas. Some farmers thought that the threshold maps, particularly the 10km map but not exclusively, supplied the opportunity and/or danger of '*labelling*' all farms within these areas as ‘endemic’. For example, farmers from the northern front complained that:

> “*there is a danger of using the 10k map, again it tells a story but from what they say and I don’t know individually but there are farms in the Southwest that have never had the disease while it’s been all around them and spread out*” (NF1)

> “*as I understand it, even within those endemic areas, what’s now called hot spot areas, still there is at least 40% of herds which have not TB for at least ten years, so they’re using blanket terms to destroy the reputations of everybody in that area and its time they stopped doing that”* (NF2)

This particular quote was made in reference the blanket grading of the south west of England as an endemic area on the larger threshold maps (7km, 10km). Another farmer in the EOW reiterated this point by stating “*we would all love to know why these certain farms have never been affected even though they’re in the middle of Devon, I was talking to a man yesterday and he’s surrounded by it and he’s not had a case for ten years*” (NF2)

These concerns show how a technical definition of endemicity contrasts with farmers’ own knowledge of disease and their perceptions of risk at a national level. Indeed, farmers were also concerned that the 10km map could present ‘false’ zones of endemicity, most notably in isolated areas of the Low Risk Area such as Cumbria in north-west England, which they did not perceive to be endemic. For example they stated:

> “*one of the disadvantages on the 10k map is especially the areas up in Cumbria and North Lancashire, what you’ve classed as endemic on there is isn’t necessarily endemic. That’s probably movement related cases that have probably been called back. So labelling those is what is classed as an endemic area is probably a bit false whereas the large block down the South Wales, Southwest is an endemic area in the true sense of an endemic area*” (NF1)

Table 2: Optimal Distance Threshold Choice Agreed at EOWs

	Participants	Optimal Distance threshold			
		3km	5km	**7km**	**10km**
Eastern Front	Farmers	0	0	2	1
	Veterinarians	0	0	1	0
Northern Front	Farmers	0	0	1	3
	Veterinarians	0	0	0	0
All Farmers		0	0	2	4
All Veterinarians		0	0	2	0

On the eastern edge two farmer EOWs choose the 7km map as that which most accurately resembled the vulnerable zone and one group chose the 10km map. One group on the eastern edge selected the 7km map on the basis that the 10km was "*probably over stating the case a little*" and that the 7km map provided a "*more realistic front*". The 10km map was not a realistic representation of endemic spread because participants perceived persistent infection in the wildlife defined endemicity: "*that [10km map] covers a large area and if it were new breakdowns it's not necessarily in the wildlife, it might be in imported cattle, and being dealt with straight away*" (EF3). These discussions also revealed a difference between accuracy and the political use of disease maps. Commenting on the difference between thresholds, farmers in Nottingham referred to the 10k threshold being more "scary" than others. This was a point repeated in the veterinary EOWs in which it was suggested that 10km map was good "*if you wanted to frighten everybody"* (NV4).

Veterinary EOWs perceived the 7km map to be the most accurate representation of endemic spread. In reference to the other maps, veterinarians from the northern front qualified their choice of 7km by labelling the 3km map "*too conservative*". Veterinarians from the eastern front EOW also perceived the 3km map as unrepresentative and too narrow in its catchment threshold for confirmed breakdowns. Their discussion of this point centred on the spatial distribution of cattle farms in the Leicestershire/Nottinghamshire area, explaining that "*if you look at that (3km map) then you miss out all the breakdowns that we are* getting" (EV4). They were concerned that the lower threshold maps would not accurately represent *their region* due to a lower overall number of farm holdings and therefore a wider spatial distribution if breakdowns in their region (compared to somewhere such as Cheshire).

One concern raised about the use of the threshold maps to visualise endemicity was the occasional positioning of farms with chronic TB infection beyond the threshold values (3km, 5km, 7km, 10k). This was presented as a problem in relation to the 7km map in the northern front veterinary EOW. Although choosing the 7km as the most accurate of the maps, vets were concerned that "*the only thing about that one (7km) is that we have a farm that would lay outside of that red line that's had tb for 10 years just south of the M56 and that farm is obviously a major problem, confirmed reactors every 60 days for 10 years*" (NV4). Vets in the eastern edge EOW were also concerned about the situation of some farms outside the threshold. However in their case this was not related to isolated farms with chronic infection but a concern that the spatial distribution of cattle farms in the Leicestershire/Nottinghamshire area was more widely dispersed and hence "*that (3km map) then you miss out all the breakdowns that we are* getting" (EV4).

5. Discussion

The participatory mapping exercises in each EOW raise five key issues relating to the production and use of risk maps. Firstly, broadening who counts as an epidemiological expert in producing disease risk maps reveals the extent to which different experts' views overlap. Previous analyses of the politics of disease eradication have shown distinct differences between locally situated and distant veterinary experts (Bickerstaff and Simmons, 2004). In this case, however, vets who had real-life working experience within those areas judged to be vulnerable to endemic spread agreed with the 7km threshold set by distant epidemiological experts. This does not mean that local vets uncritically accepted the maps. A key issue was the accuracy of the maps in avoiding ecological fallacies – for example, ensuring that the risks associated with isolated outbreaks were still nevertheless represented. However, the agreement that the 7km threshold was most appropriate can be seen to reflect an (albeit limited) acceptance of the imperfections of mapping. As Christley et al. (2013) point out, epidemiological modelling may not be right, but it can nevertheless still be useful. What is interesting, however, is that this critical acceptance is not limited to distant epidemiologists but extends to field-based vets who are usually characterised as dismissive of such veterinary expertise.

Rather than seeking binary classifications of veterinary expertise, these findings direct more attention to the ways in which different knowledge styles can find ways to accommodate and recombine in an epistemic 'borderland' (Hinchliffe et al., 2016; Enticott, 2017). Moreover, whilst there were some differences between veterinarians' and farmers' preferred thresholds, these differences were not large and were in fact similar for 50% of the EOWs. Again, like veterinarians, farmers were not uncritical of the technical limitations of mapping. There were also differences in the ways in which farmers defined endemic areas, choosing to focus more on the disease in wildlife than in cattle (see below). Nevertheless, the similarity of farmers' choice of thresholds with those of other animal disease experts suggests that rather than looking for simplistic binaries between scientific and lay knowledge, attention is better served by examining how the uncertainties of maps are managed in-use. In doing so, it is possible to see how maps are emergent from the process of mapping. Rather than fixed representations, it is only in-use that the meaning of maps emerges through different practices and interpretations (Kitchin et al., 2013).

Secondly, discussions about the thresholds of disease maps reveal the extent to which farmers and veterinarians seek to balance different interests. For farmers, ensuring fair representation was central to their recommended thresholds. They sought to balance what they thought was an accurate representation of disease whilst preventing those who had not had disease from being unduly labelled as 'dirty'. In seeking this balance, farmers privilege some interests over others. Whilst they recognised the ecological fallacies of mapping in some areas where the disease was widespread, these concerns were heightened where they clashed with their own spatial understandings of disease (cf. Nasar et al., 1993). For example, whilst Cumbria had experienced some recent outbreaks of bTB, these were attributed to historical cases arising from cattle movements that falsely labelled the area as endemic. At the same time, farmers and veterinarians recognised the ways in which maps could be used to influence farmers' decisions relating to disease management (see below). Similarly, farmers were also concerned to ensure that their beliefs about the politics of bTB were reflected in these maps. As much as they should be accurate, farmers wanted maps to reflect their sense that the management of bTB was out of control and they had been badly let down by government (cf. Enticott et al., 2014). Thus, maps of endemic bTB needed to reflect where bTB was endemic in wildlife rather than translocated by farmers' trading patterns. Moreover, in the risk assessment exercise that followed the mapping exercises, farmers identified institutional risks (i.e. government (in)action) as their biggest threat, rather than cattle, management or wildlife factors. It was in farmers' interests, then, to ensure disease maps reflected a negative picture as a way of using the disease map to justify their demands for additional resources and policies to tackle bTB, hence their rejection of those maps with lower thresholds. In short, as critical mapping studies suggest (Elwood, 2002), democratising the production of maps does not eliminate the politics of mapping but introduces additional layers of political interests in the production of maps.

Thirdly, and related to the last point, the concepts of vulnerability and endemicity had emotional as well as technical thresholds. Disease maps therefore both reflected and manipulated human emotions, revealing the different uses disease mapping could be put to. Emotions were integral to farmers' own understandings of disease vulnerability. Their reliance on rumour and hearsay to unpick the local disease environment highlighted their own frustrations with the government and agencies responsible for disease control. The emotional dimensions to disease mapping suggest the need for disease management processes to involve farmers in meaningful ways if maps and other advice are to be culturally compelling resources for changing farmers' behaviour (Enticott, 2008). Alternatively, these emotional dimensions highlights the political choices that can underscore disease mapping. As some veterinarians suggested, maps could 'scare' farmers into adapting their farming methods, rather than more accurately reflecting the incidence of disease in their area. Whether or not this would be effective given farmers' own understandings of disease is questionable but reflects how disease maps can become political tools to change behaviour.

Fourthly, the EOWs revealed how the spatial movement of disease was understood differently between veterinarians and farmers. Contoured risk maps are frequently used to map risks, such as flooding. Whilst such debates about contour maps can revolve around their accuracy, the EOWs highlighted how understandings of contours was situated within a spatial understanding of the mobility of disease (cf. Cidell, 2008). Here, two versions of disease mobility, or spread, were described: linear progression and pixellation. Both veterinarians and farmers referred to disease spread by referring to 'creep', but this was not seen as a linear encroachment. Rather, participants referred to a more spatially stochastic process in which areas were seeded with infection ahead of an endemic front and backfilled. This pixellated view of disease spread was shared by farmers and veterinarians, but for different reasons. Farmers referred to cattle movements, or 'unexplainable' cases involving wildlife, whilst veterinarians provided a more technical explanation by referring to the limitations of the bTB testing process.

These discussions show how different spatial imaginations of mobility are invoked when making sense of risk maps. Moreover, they suggest that what is useful in disease mapping is a more general sense of the borderlands of disease spread rather than boundaries. The importance of mobility and borderlands may, however, conflict with initiatives with the UK Government's Open Data initiative (Cabinet Office, 2011) to make data on disease incidence publicly available. This has resulted in the publication of disease incidence data on publicly available website. Whilst this new way of mapping disease incidence may be helpful to farmers, on its own it risks ignoring the more complex understandings of disease risk and mobility articulated by farmers and vets in our research. To capitalize on these knowledges and deliver on the challenge of collaboration and knowledge creation common to participatory risk mapping (Maskrey et al., 2019), we argue that these maps need to capture the mobility of disease rather than a snapshot of disease at any given time. This could be achieved by incorporating or overlaying ‘risk ranges’ rather than risk limits to better reflect farmers’ and veterinarians’ understandings of disease spread. We therefore suggest that disease maps and spatial categories of disease need should encompass both endemic and vulnerable zones, as well as an overlapping ‘creep’ zone to highlight the indeterminate status of this area.

Finally, these discussions revealed some technical issues relating to map-effectiveness. Rather than the appearance of maps and the use of colour, farmers and veterinarians were more concerned with the accuracy of the data used to construct the maps. A frequent concern among farmers was the perceived lack of use of up to date data. Although the use of data couplets (in two-year sequences) was explained, farmers in all EOWs felt up-to-date data must be available for use when mapping the spread of bTB. For one or two farmers the lack of current breakdown data on the maps made them apprehensive about choosing a map among the series which best represented the current situation. Whilst these are important points, they also reflect farmers’ levels of trust in government institutions to manage disease

6. Conclusion

If maps are important tools for risk management, this paper suggests that broadening the expertise used to produce them may benefit the management of animal disease. The approach adopted in this paper has been to involve field-level experts with on-the-ground knowledge of disease and its local transmission – farmers and local veterinarians – in order to contribute to the production of animal disease risk maps. Using participatory mapping exercises, we have shown how farmers and veterinarians understand endemic disease, the factors which make some areas vulnerable and others not, and their understanding of spatial transmission. In doing so, we have shown that these field-level experts’ understandings of disease – as articulated through different thresholds of disease risk – are not significantly different from veterinary epidemiologists producing maps from a distance. These findings challenge previous binary categorisations of veterinary knowledge, suggesting a more complex overlapping relationship between these different styles of knowledge.

This should not legitimise the existing geography of disease map production by distant veterinary epidemiologists. Rather, we have shown that an alternative geography of map production involving local and distant experts can have considerable benefits in the creation of risk maps. It might be possible that broadening the expertise used to map animal disease results in greater 'map effectiveness' – an attractive proposition for policy makers seeking to influence farmers' behaviour. However, we conclude by highlighting how this research shows a continued need to understand how maps are used in practice, the mixing of different epistemic perspectives in map use, and the political choices taken when creating risk maps.

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