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

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32 1. Introduction

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

43 Few social and environmental risks are not calculated and represented in
44 spatial form ([Haughton and White, 2018](#)). For [Dransch et al. \(2010\)](#) and
45 [Hagemeyer-Klose and Wagner \(2009\)](#), the spatial representation of risk in maps
46 has an important role in communicating risk, so long as maps are designed
47 appropriately and match public understandings of risk. This focus on ‘map
48 effectiveness’ ([Robinson et al., 1995](#)) is challenged by attempts to reveal the
49 values and power relations embedded within maps ([Harley, 1989](#); [Kitchin and](#)
50 [Dodge, 2007](#); [Wood, 1992](#); [Pickles, 2004](#)). Critiques of the map effectiveness
51 model address its reliance on a deficit model of risk communication that
52 assumes supplying the public with more information results in a reduction in
53 risk-taking. Participatory approaches to risk management seek to address
54 these problems by addressing the twin challenges of collaboration between
55 experts and local communities, and capacity-building by developing and
56 acknowledging new sources of knowledge ([Maskrey et al., 2019](#)). Thus, uses of
57 participatory mapping seek to reduce the gap between the public and experts
58 ([Lane et al., 2011](#); [Brandt et al., 2019](#)), and incorporate and develop new forms
59 of expertise in the planning, management and representation of risks ([Cadag](#)
60 [and Gaillard, 2012](#); [Gaillard and Mercer, 2012](#); [Chambers, 2008](#)). Whilst some
61 question the extent to which participatory approaches to risk mapping produce
62 new forms of knowledge ([Haughton et al., 2015](#)), participatory approaches
63 presume that ‘non-expert’ understandings of risk differ from those of scientific
64 experts. Yet comparisons of subjective and objective understandings of risk can

65 show little difference ([Wright et al., 2002](#)) with the public demonstrating
66 surprisingly good and nuanced understandings of risk, even if their behaviour
67 suggests otherwise ([Davison et al., 1991](#)).

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

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

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96 2. Comparing Expert and Non-expert Risk Mapping

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

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

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

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

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

153 These studies paint a mixed picture in relation to the similarities between expert
154 and non-expert geographical imaginations of environmental risks. However,
155 they also highlight four inter-related dimensions which also help explain how
156 these differences are created and sustained. Firstly, these studies suggest that
157 the technicalities of mapping may contribute to tensions in geographical
158 imaginations. This may refer to aspects of colour and presentation as identified
159 by Soane et al (2010). Alternatively, ecological fallacies created by aggregating

160 individual data or using different areal units may contribute to these differences
161 in geographical imagination. Secondly and relatedly, 'lived experience' and
162 local knowledge may provide a contextual understanding of risk phenomena,
163 prompting more nuanced rather than distant and universal geographical
164 imaginations (cf. Bickerstaff and Simmons, 2004). Thirdly, as Harley (1989)
165 suggests, mapping is political and choices made in producing maps reflect
166 different political positions. Whilst expert maps of risk phenomena may reflect
167 institutional choices, maps that ignore contextual or local phenomena may
168 represent attempts to protect disciplinary boundary ([Gieryn, 1983](#)). Finally,
169 following [Kitchin and Dodge \(2007\)](#), it may also be possible that these binary
170 positions breakdown as maps are used in practice. Rather than differences
171 between map users and producers, more nuanced positions may emerge
172 reflecting a more complex engagement between experts and non-experts
173 geographical imaginations.

174 **3. Spatial Measures of Animal Disease Risk**

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

191 Surveillance of bTB incidence, however, is well established. Cattle herds are
192 tested regularly, and data are stored in a national dataset that is used to analyse
193 annual disease trends at different spatial scales ([APHA, 2015](#); [Lawes et al.,
194 2016](#)). Cattle that test positive to the test used to diagnose bTB are known as
195 'reactors', and a herd incident commonly referred to as a 'breakdown'.
196 Historically, these incidence data were used to set the frequency of cattle
197 testing in parishes - known as the parish testing interval (PTIs) - which were
198 mapped and communicated to farmers ([Defra, 2013](#)). For farmers, the PTI map
199 came to represent a map of disease risk, demarcating the boundaries of 'clean'
200 and 'dirty' zones, and has been used by policy makers as a means to try to
201 communicate disease risks and encourage farmers to adopt biosecurity
202 practices ([Enticott and Higgins, 2016](#)). However, whilst the PTI map might serve
203 the needs of policy makers, they are not ideal epidemiological zones. They are
204 not of uniform size or shape, and do not account for stocking densities or
205 changes to farm practices such as the use of discontinuous parcels of land.

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

215 A key dimension of these calculations is a threshold for disease proximity and
216 recurrence. Epidemiological calculations of endemicity can be validated by
217 comparing different thresholds to disease incidence in so-called 'Stevenson
218 districts' ([Stevenson et al., 2005](#)). In this case, two thresholds were set in
219 defining endemicity. The first endemic threshold was the number (n) of nearest
220 incidents in order to produce a consistent core endemic area and reduce the
221 influence of isolated cases. The second threshold was the maximum distance
222 (measured in kilometres) of the n^{th} nearest bTB incident. Both thresholds affect
223 the appearance of the spatial distribution and rate of spread of bTB when

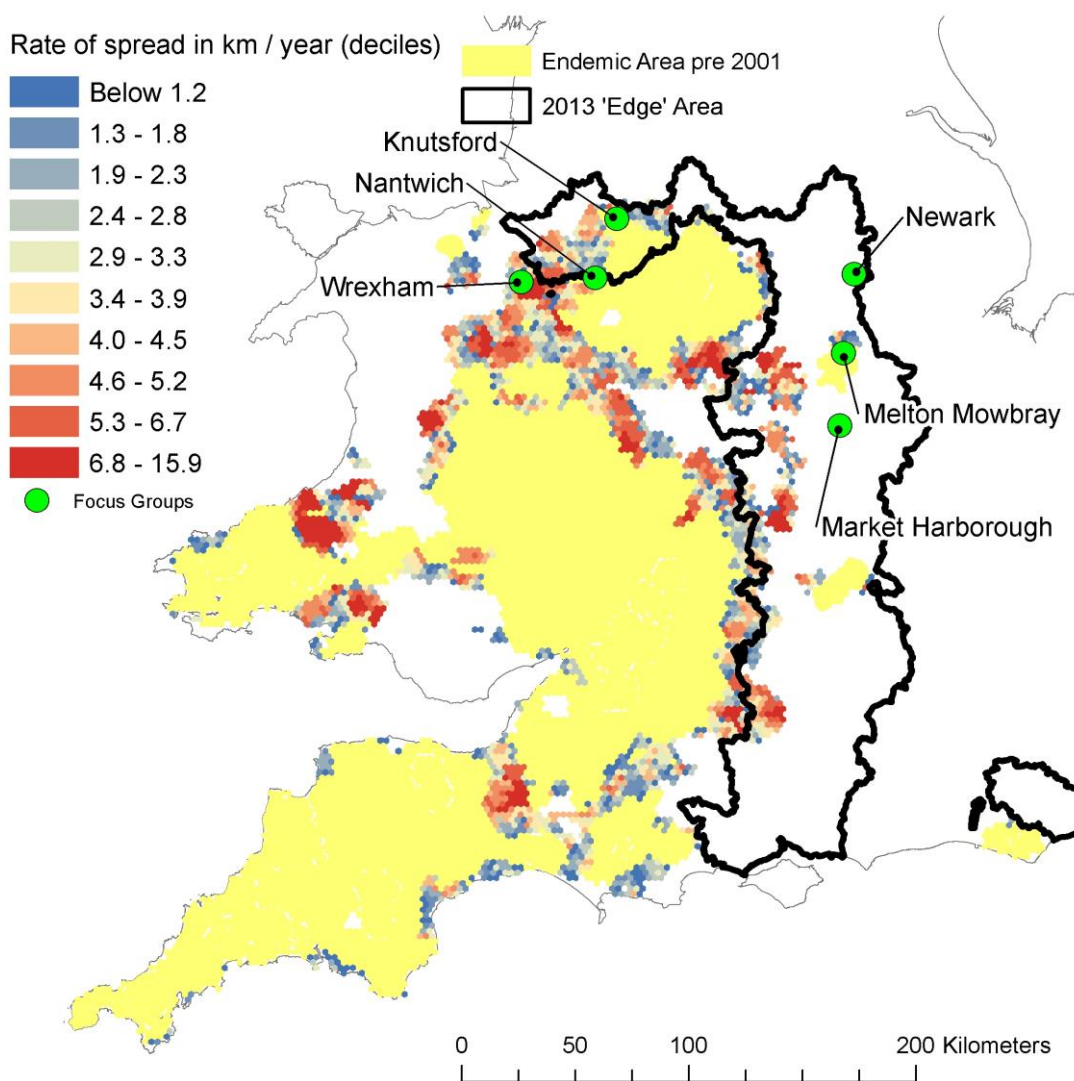
224 mapped. Following a workshop with veterinarians working for APHA, and
225 epidemiologists responsible for calculating endemicity, the 3rd nearest incident
226 was set as the first threshold and its distance threshold was set at 7km and
227 used in subsequent attempts to calculate and map endemic bTB.

228 Figure 1 illustrates the rate of spread of bTB for each 6.25km² hexagonal cell
229 that formed the base resolution for the study in the 24-month interval in which
230 spread occurred (anytime between September 2001 and August 2012). Rate of
231 spread was calculated as the distance between the endemic areas for 24 month
232 intervals two years apart (e.g. September 2003 - August 2005 compared with
233 September 2001 - August 2003), divided by the period of time elapsed ([for
234 complete details, see: Brunton et al., 2015](#)). Subsequently, figure 1 was
235 converted to a contour map showing smoothed areas of endemicity for each of
236 the 24-month intervals from September 2001 until September 2012 (see figure
237 2).

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

251 A series of expert opinion workshops (EOWs) was subsequently organized to
252 compare the representations of disease endemicity in the disease map with
253 farmers' and veterinarians' perceptions of disease endemicity. By involving
254 farmers and local veterinarians in the EOWs, the purpose was to capture their
255 geographical and occupational expertise thereby reflecting calls for a broader

256 notion of expertise ([Landström et al., 2011](#)). Table 1 shows the number of
 257 participants in each EOW. Locations of each EOW were chosen to reflect
 258 different 'endemic fronts' - specifically a northern and eastern front (see figure
 259 1). Participants were selected across the width of these endemic fronts. For
 260 example, the Nantwich EOW recruited farmers from the southern verge of the
 261 northern endemic front whereas the Newark EOW recruited farmers who
 262 farmed closer to the outer boundary of the eastern front. Dairy and beef farmers
 263 were enrolled into the EOWs with the help of local veterinary practices, farming
 264 organisations, and snowball sampling.



265

266 Figure 1: Map illustrating the hexagons where endemic bTB (defined by the presence of
 267 three confirmed bTB incidents within 7km) spread between 2001 and 2012. Rate
 268 of spread in km per year is calculated for the two-year time period during which endemic
 269 bTB first passed through the hexagon. Hexagons which were classed as endemic prior to
 270 2001 are coloured yellow and are considered to be the 'core' endemic area.

271

272 The EOWs were organised around three participatory mapping exercises
273 (PMEs) and conducted by research team's social scientists (GE and KW).
274 Participatory approaches to mapping are well established in critical cartography
275 studies ([Haklay and Tobón, 2003](#); [Elwood, 2002](#)) and rural development
276 ([Chambers, 1994](#)). In the first PME, participants were provided with A0 maps of
277 their area and asked to annotate the areas they considered to have endemic
278 bTB. Secondly, participants discussed meanings of endemicity and
279 vulnerability in relation to their annotated maps. Thirdly, participants were
280 presented with maps produced by APHA using different thresholds to calculate
281 endemicity. The thresholds referred to the optimal distance between recurrent
282 breakdowns: four threshold maps covering participants' local area were
283 presented (3km, 5km, 7km, and 10km. See figure 2). Participants engaged in a
284 consensus exercise to agree which threshold most closely represented the
285 endemic area. Finally, participants took part in another consensus exercise to
286 agree on risk factors for bTB (not reported in this paper). For each activity,
287 participants were split into groups depending on the size of the EOW (see table
288 1).

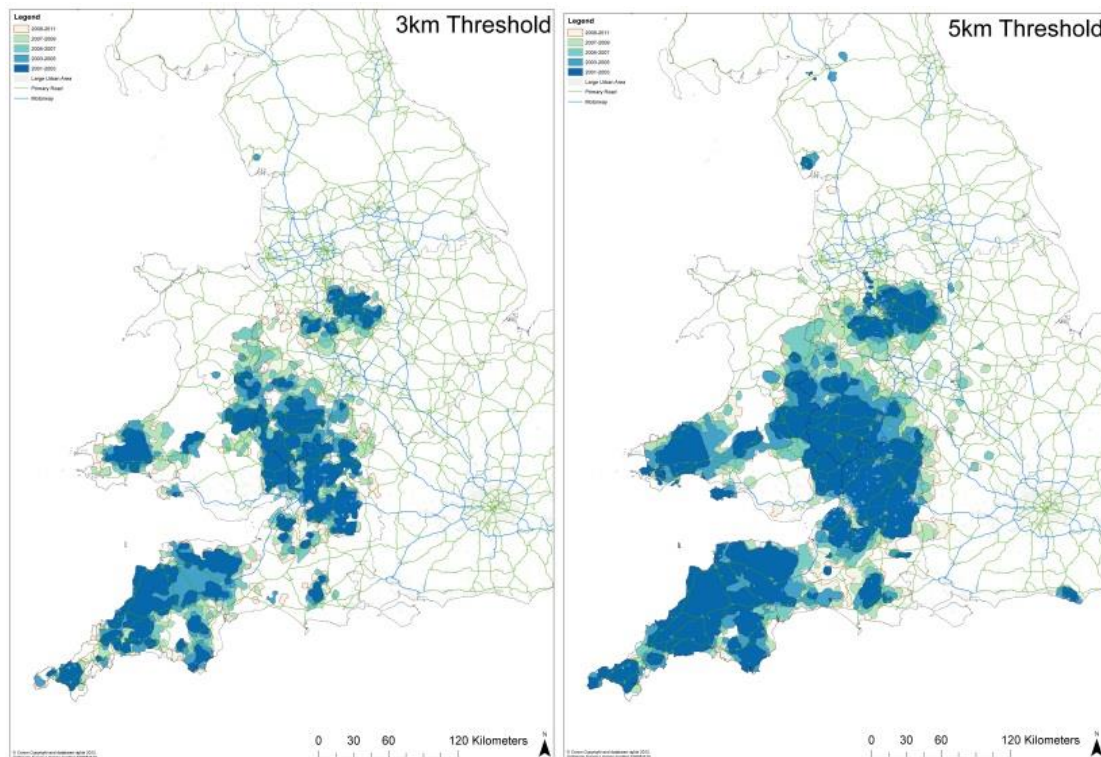
Table 1: Number of participants in expert opinion workshops.

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

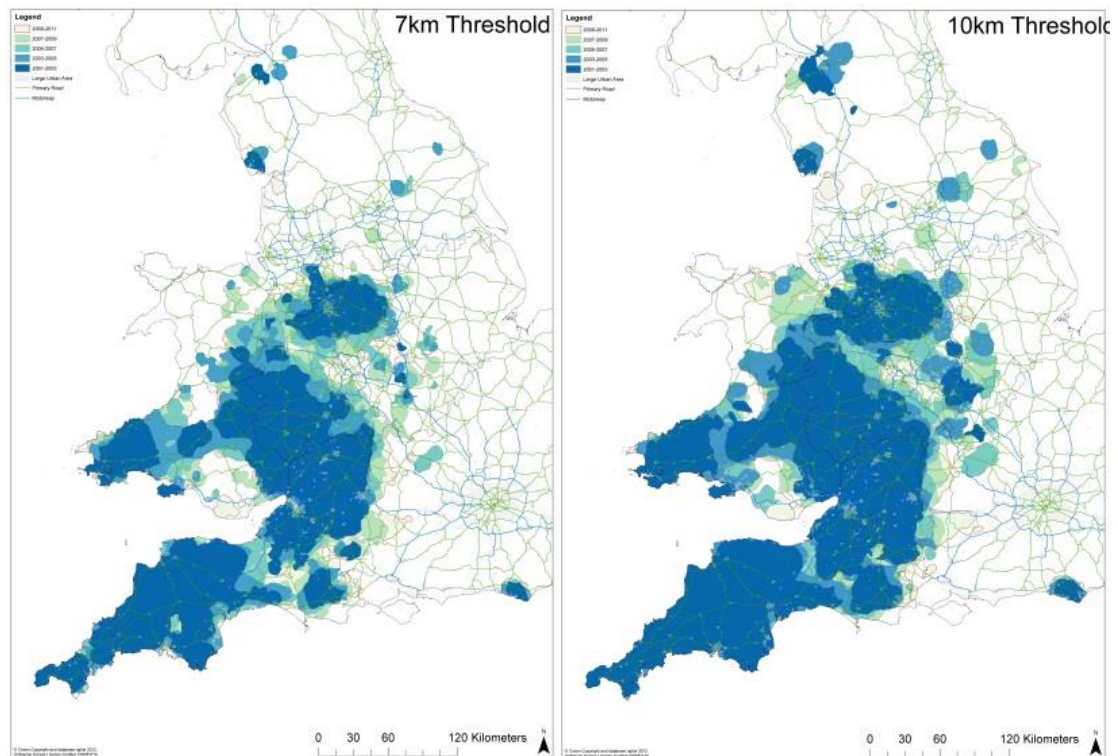
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290 Ethical approval was provided by Cardiff University's Social Research Ethics
291 Committee, and focus group schedules and activities were approved by the
292 funders (Defra). All participants received information sheets on the aims of the
293 project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

300



301



302

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

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

312 4. Comparing Animal Disease Risk Maps

313 4.1 *Defining 'Endemic' and 'Vulnerable' areas*

314 In each EOW, participants clearly distinguished between *endemic* and
 315 *vulnerable* areas. In relation to 'endemicity' wildlife infection and chronic
 316 infection of cattle were identified as the two key determinants. Firstly, farmers
 317 and veterinarians in either front associated an endemic area with long-standing
 318 infection in wildlife moving between cattle and badgers. This indicated a
 319 circularity to the spread of disease as opposed to a linear spread: "*it's in the*

320 *wildlife, it's just circulating; it's just going to re-circle*" (EF1). The relation of
321 endemicity to wildlife infection was also qualified by farmers' perceptions of
322 non-endemic areas with uninfected wildlife populations. The relation of
323 'endemicity' to wildlife infection was also prominent in the veterinary EOWs on
324 both the eastern and northern endemic fronts. For example, northern front
325 veterinarians described an endemic area as:

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

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

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

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

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

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

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

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

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

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

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

379 *“this area here, up the forest and around here, they’re getting quite a bit*
380 *of TB... it’s not endemic, but we know there’s been pockets sort of here*
381 *and here”* (EF1).

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

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

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

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

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

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

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

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

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

435 Both farmers and veterinarians pointed to the role of 'hard' boundaries to
436 explain why some areas were vulnerable or had become endemic. Hard
437 boundaries most often appeared during the map annotating in the form of major
438 roads, motorways, canals and urban conurbations. For example, Welsh farmers
439 in the northern front EOW identified the A483 road as demarcating 'problem'
440 from endemic areas. Meanwhile, on the eastern front, farmers used the M1
441 motorway to demarcate between levels of bTB risk. The use of hard boundaries
442 to define vulnerability resonated amongst veterinarians in each area, for
443 example the northern front veterinary EOW explained when discussing their

444 map: “we’re getting a lot of sporadic ones across the whole of Cheshire, I
445 marked on the M56 as a bit of a borderline it’s like a corridor I suppose, acts as
446 a bit of a barrier” (NV4). In this instance, hard boundaries were specifically
447 linked to wildlife with the network of motorways, the Manchester Ship Canal,
448 and urban sprawl between Manchester and Liverpool defining the geographical
449 possibilities of spread, and which areas were considered vulnerable.

450 4.2 Mapping Thresholds

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

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

476 these areas as 'endemic'. For example, farmers from the northern front
477 complained that:

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

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

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

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

499 *"one of the disadvantages on the 10k map is especially the areas up in*
500 *Cumbria and North Lancashire, what you've classed as endemic on*
501 *there is isn't necessarily endemic. That's probably movement related*
502 *cases that have probably been called back. So labelling those is what is*
503 *classed as an endemic area is probably a bit false whereas the large*
504 *block down the South Wales, Southwest is an endemic area in the true*
505 *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

506

507 On the eastern edge two farmer EOWs choose the 7km map as that which most
508 accurately resembled the vulnerable zone and one group chose the 10km map.
509 One group on the eastern edge selected the 7km map on the basis that the
510 10km was *“probably over stating the case a little”* and that the 7km map
511 provided a *“more realistic front”*. The 10km map was not a realistic
512 representation of endemic spread because participants perceived persistent
513 infection in the wildlife defined endemicity: *“that [10km map] covers a large area*
514 *and if it were new breakdowns it’s not necessarily in the wildlife, it might be in*
515 *imported cattle, and being dealt with straight away”* (EF3). These discussions
516 also revealed a difference between accuracy and the political use of disease
517 maps. Commenting on the difference between thresholds, farmers in
518 Nottingham referred to the 10k threshold being more “scary” than others. This
519 was a point repeated in the veterinary EOWs in which it was suggested that
520 10km map was good *“if you wanted to frighten everybody”* (NV4).

521 Veterinary EOWs perceived the 7km map to be the most accurate
522 representation of endemic spread. In reference to the other maps, veterinarians
523 from the northern front qualified their choice of 7km by labelling the 3km map
524 *“too conservative”*. Veterinarians from the eastern front EOW also perceived
525 the 3km map as unrepresentative and too narrow in its catchment threshold for
526 confirmed breakdowns. Their discussion of this point centred on the spatial
527 distribution of cattle farms in the Leicestershire/Nottinghamshire area,
528 explaining that *“if you look at that (3km map) then you miss out all the*
529 *breakdowns that we are getting”* (EV4). They were concerned that the lower

530 threshold maps would not accurately represent *their region* due to a lower
531 overall number of farm holdings and therefore a wider spatial distribution if
532 breakdowns in their region (compared to somewhere such as Cheshire).

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

547

548 **5. Discussion**

549 The participatory mapping exercises in each EOW raise five key issues relating
550 to the production and use of risk maps. Firstly, broadening who counts as an
551 epidemiological expert in producing disease risk maps reveals the extent to
552 which different experts’ views overlap. Previous analyses of the politics of
553 disease eradication have shown distinct differences between locally situated
554 and distant veterinary experts ([Bickerstaff and Simmons, 2004](#)). In this case,
555 however, vets who had real-life working experience within those areas judged
556 to be vulnerable to endemic spread agreed with the 7km threshold set by distant
557 epidemiological experts. This does not mean that local vets uncritically
558 accepted the maps. A key issue was the accuracy of the maps in avoiding
559 ecological fallacies - for example, ensuring that the risks associated with
560 isolated outbreaks were still nevertheless represented. However, the
561 agreement that the 7km threshold was most appropriate can be seen to reflect

562 an (albeit limited) acceptance of the imperfections of mapping. As [Christley et](#)
563 [al. \(2013\)](#) point out, epidemiological modelling may not be right, but it can
564 nevertheless still be useful. What is interesting, however, is that this critical
565 acceptance is not limited to distant epidemiologists but extends to field-based
566 vets who are usually characterised as dismissive of such veterinary expertise.

567

568 Rather than seeking binary classifications of veterinary expertise, these
569 findings direct more attention to the ways in which different knowledge styles
570 can find ways to accommodate and recombine in an epistemic 'borderland'
571 ([Hinchliffe et al., 2016](#); [Enticott, 2017](#)). Moreover, whilst there were some
572 differences between veterinarians' and farmers' preferred thresholds, these
573 differences were not large and were in fact similar for 50% of the EOWs. Again,
574 like veterinarians, farmers were not uncritical of the technical limitations of
575 mapping. There were also differences in the ways in which farmers defined
576 endemic areas, choosing to focus more on the disease in wildlife than in cattle
577 (see below). Nevertheless, the similarity of farmers' choice of thresholds with
578 those of other animal disease experts suggests that rather than looking for
579 simplistic binaries between scientific and lay knowledge, attention is better
580 served by examining how the uncertainties of maps are managed in-use. In
581 doing so, it is possible to see how maps are emergent from the process of
582 mapping. Rather than fixed representations, it is only in-use that the meaning
583 of maps emerges through different practices and interpretations ([Kitchin et al.,](#)
584 [2013](#)).

585

586 Secondly, discussions about the thresholds of disease maps reveal the extent
587 to which farmers and veterinarians seek to balance different interests. For
588 farmers, ensuring fair representation was central to their recommended
589 thresholds. They sought to balance what they thought was an accurate
590 representation of disease whilst preventing those who had not had disease from
591 being unduly labelled as 'dirty'. In seeking this balance, farmers privilege some
592 interests over others. Whilst they recognised the ecological fallacies of mapping
593 in some areas where the disease was widespread, these concerns were
594 heightened where they clashed with their own spatial understandings of
595 disease ([cf. Nasar et al., 1993](#)). For example, whilst Cumbria had experienced

596 some recent outbreaks of bTB, these were attributed to historical cases arising
597 from cattle movements that falsely labelled the area as endemic. At the same
598 time, farmers and veterinarians recognised the ways in which maps could be
599 used to influence farmers' decisions relating to disease management (see
600 below). Similarly, farmers were also concerned to ensure that their beliefs about
601 the politics of bTB were reflected in these maps. As much as they should be
602 accurate, farmers wanted maps to reflect their sense that the management of
603 bTB was out of control and they had been badly let down by government ([cf.](#)
604 [Enticott et al., 2014](#)). Thus, maps of endemic bTB needed to reflect where bTB
605 was endemic in wildlife rather than translocated by farmers' trading patterns.
606 Moreover, in the risk assessment exercise that followed the mapping exercises,
607 farmers identified institutional risks (i.e. government (in)action) as their biggest
608 threat, rather than cattle, management or wildlife factors. It was in farmers'
609 interests, then, to ensure disease maps reflected a negative picture as a way of
610 using the disease map to justify their demands for additional resources and
611 policies to tackle bTB, hence their rejection of those maps with lower thresholds.
612 In short, as critical mapping studies suggest ([Elwood, 2002](#)), democratising the
613 production of maps does not eliminate the politics of mapping but introduces
614 additional layers of political interests in the production of maps.

615

616 Thirdly, and related to the last point, the concepts of vulnerability and
617 endemicity had emotional as well as technical thresholds. Disease maps
618 therefore both reflected and manipulated human emotions, revealing the
619 different uses disease mapping could be put to. Emotions were integral to
620 farmers' own understandings of disease vulnerability. Their reliance on rumour
621 and hearsay to unpick the local disease environment highlighted their own
622 frustrations with the government and agencies responsible for disease control.
623 The emotional dimensions to disease mapping suggest the need for disease
624 management processes to involve farmers in meaningful ways if maps and
625 other advice are to be culturally compelling resources for changing farmers'
626 behaviour ([Enticott, 2008](#)). Alternatively, these emotional dimensions highlights
627 the political choices that can underscore disease mapping. As some
628 veterinarians suggested, maps could 'scare' farmers into adapting their farming
629 methods, rather than more accurately reflecting the incidence of disease in their

630 area. Whether or not this would be effective given farmers' own understandings
631 of disease is questionable but reflects how disease maps can become political
632 tools to change behaviour.

633

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

649

650 These discussions show how different spatial imaginations of mobility are
651 invoked when making sense of risk maps. Moreover, they suggest that what is
652 useful in disease mapping is a more general sense of the borderlands of
653 disease spread rather than boundaries. The importance of mobility and
654 borderlands may, however, conflict with initiatives with the UK Government's
655 Open Data initiative ([Cabinet Office, 2011](#)) to make data on disease incidence
656 publicly available. This has resulted in the publication of disease incidence data
657 on publicly available website. Whilst this new way of mapping disease incidence
658 may be helpful to farmers, on its own it risks ignoring the more complex
659 understandings of disease risk and mobility articulated by farmers and vets in
660 our research. To capitalize on these knowledges and deliver on the challenge
661 of collaboration and knowledge creation common to participatory risk mapping
662 ([Maskrey et al., 2019](#)), we argue that these maps need to capture the mobility of
663 disease rather than a snapshot of disease at any given time. This could be

664 achieved by incorporating or overlaying 'risk ranges' rather than risk limits to
665 better reflect farmers' and veterinarians' understandings of disease spread. We
666 therefore suggest that disease maps and spatial categories of disease need
667 should encompass both endemic and vulnerable zones, as well as an
668 overlapping 'creep' zone to highlight the indeterminate status of this area.

669

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

681

682 **6. Conclusion**

683

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

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

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887