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Spatio-temporal patterns of livestock anthrax in Ukraine during the past century (1913–2012)

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A B S T R A C T

Anthrax is a severe, under-reported zoonosis, caused by the bacterium *Bacillus anthracis*, that affects livestock, wildlife, and humans nearly worldwide. Humans most often contract anthrax from animal products, including meat, bones, and hide. In the early 20th century, a large number of livestock anthrax outbreaks in the Russian Empire were in Ukrainian territories. During the past century, as a part of the Soviet Union and as an independent nation, Ukraine has continually experienced livestock and human anthrax outbreaks. Here, we used georeferenced livestock outbreak data from 1913 to 2012 to report spatio-temporal patterns and use spatial analysis to define hotspots of livestock anthrax from historical to contemporary times in Ukraine. We were most interested in comparing changes in anthrax reporting over the past century, and to identify areas where anthrax persists in modern times. Historically (1913–1978), anthrax reporting sites were widely distributed across the country with relatively large hotspots. In the contemporary period (1979–2012), there were 72× fewer initial anthrax reporting sites. Weighted hotspot analysis identified multiple anthrax foci, though these were smaller than historical hotspots. Space time analysis of moving polygons (STAMP) showed that expanding and stable anthrax foci overlapped historical reporting areas, and newly generated foci that were located near recently reported wildlife outbreaks. These findings may help better direct future control and mitigation efforts, and indicate that alternative detection methods (e.g. wildlife surveillance and predictive ecological models) may be helpful.

Introduction

Anthrax, a disease caused by the spore-forming soil bacterium *Bacillus anthracis*, occurs worldwide and has been defined as an undervalued zoonosis that affects livestock, wildlife, and humans (Fasanella, Galante, Garofolo, & Jones, 2010). Annual estimates of human anthrax cases worldwide range from 20,000–100,000 (Swartz, 2001), indicating that it remains a significant public health concern, particularly in agrarian areas. Humans most often contract cutaneous anthrax from handling meat, animal hides, bones, and other materials. Livestock and wildlife likely contract it by ingesting during browsing/grazing (Blackburn et al., 2010), by percutaneous exposure from biting flies (Blackburn, 2010), and possibly spore inhalation. Carnivorous/omnivorous animals usually are infected by scavenging. *B. anthracis* spores are generally considered resistant to many environmental factors. Under certain soil conditions, spores may persist in disease foci and contribute to disease outbreaks for long periods of time, possibly decades (Turnbull, 2008). Following the definition from Soviet times and post-Soviet Russia, a focus can be defined as an area of favorable soil conditions to maintain *B. anthracis* contamination from previous animal cases that can lead to future infections (Cherkasskiy, 1999).

Ukraine, a large agrarian nation in Eastern Europe, has reported livestock outbreaks for more than a century. At the turn of the 20th century, anthrax was a major animal and public health concern in the Russian Empire (which included a large part of Ukraine). From 1900 to 1912, 40,000–60,000 livestock cases were registered annually (total ~623,500 cases), and incident human cases ranged

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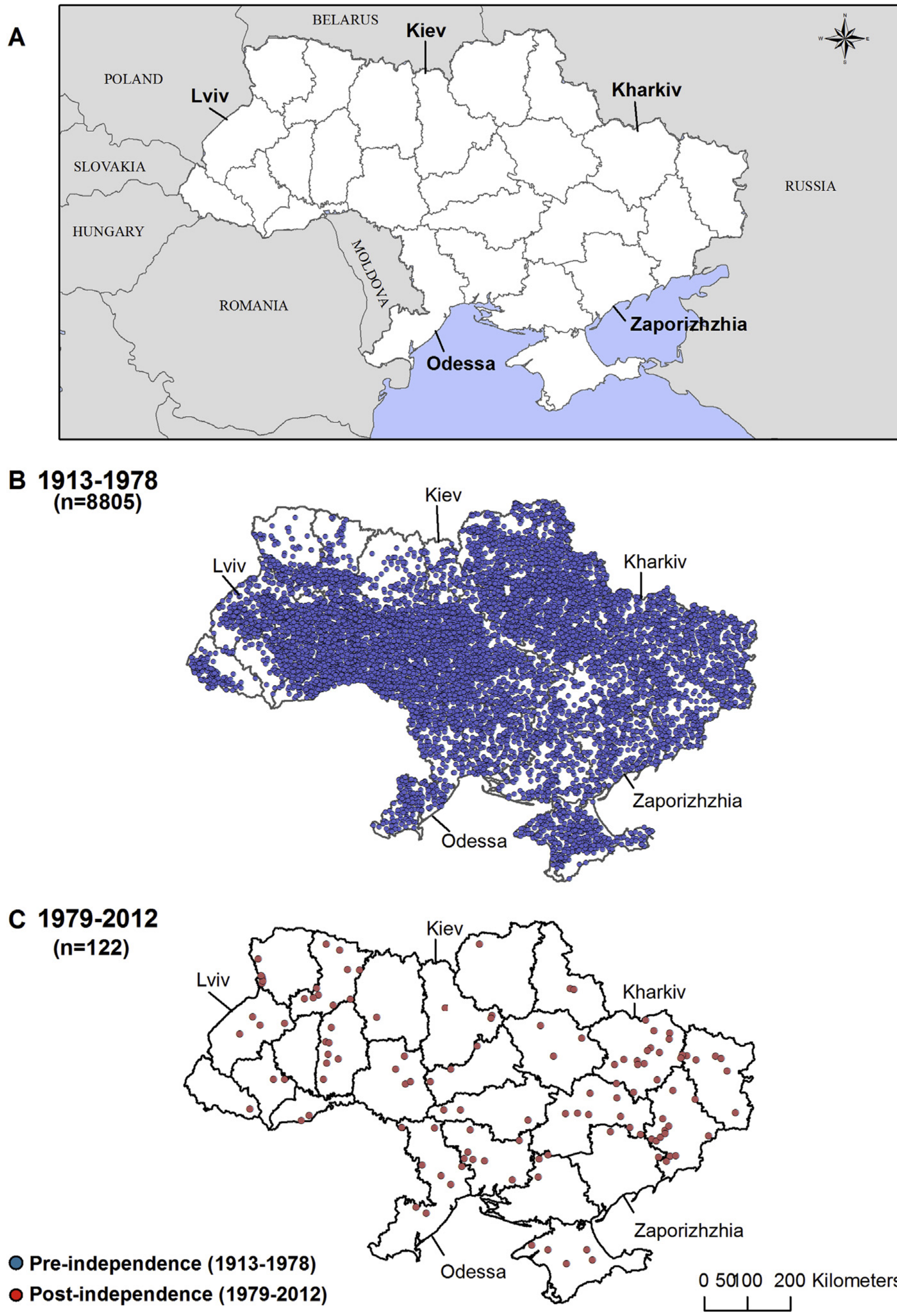

Fig. 1. Maps of A) Ukraine and sites according to the year of initial anthrax outbreak report during B) historical (1913–1978) and C) contemporary (1979–2012) time periods. Oblast (state) names are in bold in A. Each time interval includes villages organized by the year of initial reported anthrax outbreaks.

from 11,600–19,800, annually (Korotich & Pogrebniak, 1976). Many of those cases occurred within the Ukrainian territory; for example, the southeastern half of modern Ukraine reported ~36.4% of total registered human anthrax cases for the Russian Empire in 1903 and >1000 livestock cases occurred in a single province in 1907 (Korotich & Pogrebniak, 1976). As a result, after the Russian October Revolution of 1917, the Soviet government established a surveillance system for livestock diseases, with a particular focus on anthrax and other highly consequential livestock diseases and zoonoses. Widespread anthrax epizootics (~20,000 livestock anthrax cases in 1923–1924 in Ukraine) led to responses such as a massive government-lead vaccination campaign in 1924–1925, where more than 2 million animals were inoculated (Korotich & Pogrebniak, 1976). Although there are records of mass vaccination in the 1920s, recurrent, prophylactic anthrax vaccination was not mandated until 1953 (Tretyakov, 1973).

Examining the historical epizootiology of a disease can identify the geographic extent of environmental foci, define areas prone to repeat outbreaks, and lead to a better understanding of natural disease cycles. Recent studies have been exploring the historical geography of diseases, in order to evaluate previous disease control and response measures and better inform current animal and public health interventions (Kracalik et al., 2011; Morris et al., 2013; Trevelyan, Smallman-Raynor, & Cliff, 2005a, 2005b). Here, we analyze a century of livestock outbreak data (1913–2012) to describe historical spatial patterns and temporal trends in livestock anthrax across Ukraine. Specifically, we examine the following questions: What were the overall spatial and temporal patterns of sites reporting anthrax outbreaks in Ukraine during the past century? Where are the areas of high anthrax outbreak concentration in current times? Are there regions in Ukraine with persistent or emerging anthrax?

Materials and methods

Ukraine is a large country located between Europe and Asia (Fig. 1A). Ukraine has reported anthrax outbreaks throughout the Soviet Period and since independence in 1991. During the Soviet regime (pre-1991), livestock cases and outbreak data were collected by the Soviet Veterinary Service. Post-1991, these data have been collected by the Veterinary Service of Ukraine (VSU). The VSU has stations in each rayon (district) and oblast (state). Outbreaks were reported to these offices by each village or settlement (sites) within their administrative boundaries. Surveillance officials responded to outbreaks with decontamination efforts and vaccination. Data on livestock outbreaks were available back to 1913, prior to the advent of this well-organized surveillance system. To map these data, we constructed a geodatabase in ArcGIS 10.1 (ESRI, Redlands, California) with data on epizootic sites, total number of anthrax outbreaks, and cases per animal species. A report of one or more anthrax cases per site was considered an outbreak. Here sites correspond to the geographic coordinates (latitude/longitude pairs) of specific villages or settlements.

During the past century, Ukraine used two different livestock anthrax reporting schemes. From 1913 to 1978, records for each site contained the first and last year an outbreak was detected at a site, and the number of outbreaks and cases that occurred during that time interval (without linking specific outbreaks to specific years). From 1979 to 2012, records for each site include the number of outbreaks and cases (by livestock group) annually. For ease of description here, 1913–1978 is considered the "historical" period, while 1979–2012 is defined as the "contemporary" period.

To enable comparisons between reporting of outbreaks during the historical and contemporary periods, we mapped the geographic coordinates of each site by the year of the first reported anthrax outbreak (initial outbreak) (Fig. 1B and C). We graphed those data over time to illustrate the number of sites initially reporting anthrax on an annual basis, and completed unweighted hotspot analysis on reporting sites for these two time periods using kernel density estimation (KDE; see *Spatial analysis* below).

During the contemporary period, Ukraine obtained national independence when the Soviet Union dissolved in 1991 – a major socio-political change. For this study, we subdivided the contemporary period to correspond to pre-independence (1979–1991) and post-independence (1991–2012), as responsibility for anthrax surveillance and outbreak response shifted from the Soviet Veterinary Service to the VSU. As there were annual records of outbreaks and cases for the time period of 1979–2012, we were able to map the number of outbreaks per outbreak year and site and complete weighted hotspot analysis during these two time periods (see *Spatial analysis* below).

Statistical analyses

Descriptive statistics were calculated for each time period. The two sample *t*-test with equal variances was used to compare outbreaks during each the pre- and post-Soviet period. Statistics were calculated in Microsoft Excel 2010 (Redmond, Washington, USA).

Spatial analyses

Anthrax hotspots were identified using kernel density estimation (KDE). The spatial distributions of villages reporting anthrax during the historical and contemporary periods were compared using unweighted KDE. Here, we were interested in identifying the areas with the highest concentration of sites reporting anthrax in each time period. Because of the reporting style of the historical period (includes first and last year a site experienced an outbreak, and the number of outbreaks within that time span), there was no way of knowing when the outbreaks occurred during the reported time interval (some of the time intervals were >50 years). Because of this limitation, we categorized the sites into "historical" and "contemporary" using the year in which a village initially reported anthrax outbreaks as the classification criteria.

KDE is a technique for calculating weighted densities of events over a gridded surface within a kernel, or spatial filter (Fotheringham, Brunsdon, & Charlton, 2000). KDE was performed with the Spatial Analyst Extension for ArcGIS 10.1. ArcGIS employs the quadratic kernel function described in Silverman (1986, p. 76, equation (4.5)):

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)$$

where h is the bandwidth, $x - X_i$ is the distance to each outbreak site i. K is the quadratic kernel function, which is defined as:

$$K(x) = \frac{3}{4}\left(1 - x^2\right), \quad |x| \le 1$$

$$K(x) = 0, \quad x > 1$$

Outputs are raster surfaces of smoothed density values of anthrax outbreaks across the study area. The smoothing function or bandwidth can be selected in several ways and can have an important effect on the level of smoothing. We used the optimal bandwidth function provided in Fotheringham et al. (2000):

$$h_{opt} = \left[\frac{2}{3n}\right]^{\left(\frac{1}{4}\right)} \sigma$$

where n is the sample size (here, sites reporting livestock anthrax) and σ is the standard distance of the outbreak sites. Standard distance was calculated with the spatial statistics toolbox in ArcGIS 10.1. To compare KDE outputs between time periods, it is ideal to use comparable model parameters. We calculated h_{opt} for each time period and used the average as the bandwidth for each KDE analysis, historical and contemporary. The output grid cell size was set to 1 km for all analyses. Hotspots for anthrax were defined as the upper 25%, 10%, and 5% of estimated density values following Nelson and Boots (2008).

As the Ukrainian surveillance system captured annual outbreak data during the contemporary period, we could evaluate outbreak intensity for the pre- and post-independence time periods. We weighted the standard distance calculations for h_{opt} and the KDE analyses by the total number of outbreaks per site per time period. The availability of annual outbreak data in contemporary period allowed us to define hotspots with the highest concentration of anthrax outbreaks, whereas the unweighted KDEs estimated the concentration of reporting villages. These weighted analyses can better define potential contemporary anthrax foci.

Space time analysis of moving polygons

To identify geographic areas where hotspots from the historical and contemporary periods overlapped and where areas overlapped

Table 1
Percentage of anthrax cases by animal species.

Animal species	Overall total by species % (*n*)
Cattle	72.0 (22,348)
Small ruminants	14.9 (4633)
Swine	8.1 (2517)
Horses	4.4 (1374)
Mink	0.5 (167)
Dog	0[a] (1)
Moose	0[a] (1)
Total	100 (31,041)[b]

[a] Only one case; percentage = 3.22×10^{-3} of total cases.
[b] Does not include 42 outbreaks that did not have specific case information.

with the pre- and post-independence periods, we converted hotspots (areas with the upper 25% of KDE values) to polygons and use the space time analysis of moving polygons tool (STAMP) (Robertson, Nelson, Boots, & Wulder, 2007). STAMP is a freely available toolbar extension for ArcGIS v 9.3 (http://www.geog.uvic.ca/spar/stamp/help/index.html).

STAMP works by overlaying polygons from two consecutive time periods and evaluating changes in spatial position and overlap between time intervals. For this study, we employed STAMP to compare the unweighted KDE analysis from the historical and contemporary time periods and again for each weighted KDE analysis within the contemporary period. If polygons from two consecutive time periods overlap, those areas are classified as stable. Polygons from two consecutive time periods that are connected are classified as contraction or expansion, depending on a relative increase or decrease in the size of polygons. Contraction defines the area that was present only in the first time interval, while expansion is defined as any new area identified in the second time interval. Disappearance and generation events are spatially discrete from regions delineated in the first time period. Disappearance defines polygons present in the first time period and absent in the second. Generation defines hotspot polygons only present in the second time period.

Results

A total of 23,468 outbreaks corresponding to 31,603 animal cases were reported in 8927 Ukrainian sites (villages and settlements) from 1913 to 2012. Of the 29,742 villages in Ukraine, ~30.0% experienced livestock anthrax outbreaks over the past century. Cumulative anthrax cases per livestock/domestic species were summarized for outbreaks containing case number information. The majority of cases were domestic cattle (~72.0%) followed by small ruminants (sheep and goats; ~14.9%), with swine, horses, and mink composing the remainder of outbreaks (Table 1). Additionally, there were single cases of a moose and a dog; both occurred in sites reporting cattle cases (Table 1).

During the 66 year historical period, more than 8800 sites experienced outbreaks throughout the country (Fig. 1B). During the 34 year contemporary period, the number of new outbreak reporting sites greatly declined, with 122 sites reporting outbreaks (Fig. 1C). It should be emphasized that despite the overall reduction, these 122 sites were not reported prior to 1979. The contemporary reporting sites were widely dispersed throughout the country. The annual pattern of sites initially reporting anthrax showed an increase in new sites reporting outbreaks in the 1940s, then a decrease in the late 1950s to ~100 new sites reporting outbreaks per year (Fig. 2). During the contemporary period, the number of new sites reporting outbreaks was high in the early 1980s, decreased in the mid-1980s, increased immediately following national independence (1991), but dropped again during the 2000s (Fig. 2 inset).

Unweighted KDE-defined hotspots from the historical period identified three hotspots of reporting sites when considering our least conservative threshold (25%) (Fig. 3A). The largest hotspot stretched over 500 km from Lviv oblast in the west to Kiev oblast in central Ukraine. It also contained two areas with high concentrations of reporting sites (according to the more conservative thresholds [5 and 10%]). Another small hotspot was located in north-western Ukraine (Fig. 3A).

The contemporary period had four, compact concentrations of newly reporting sites based on the 25% threshold; one located on the northwestern border of Ukraine, and three in northeastern

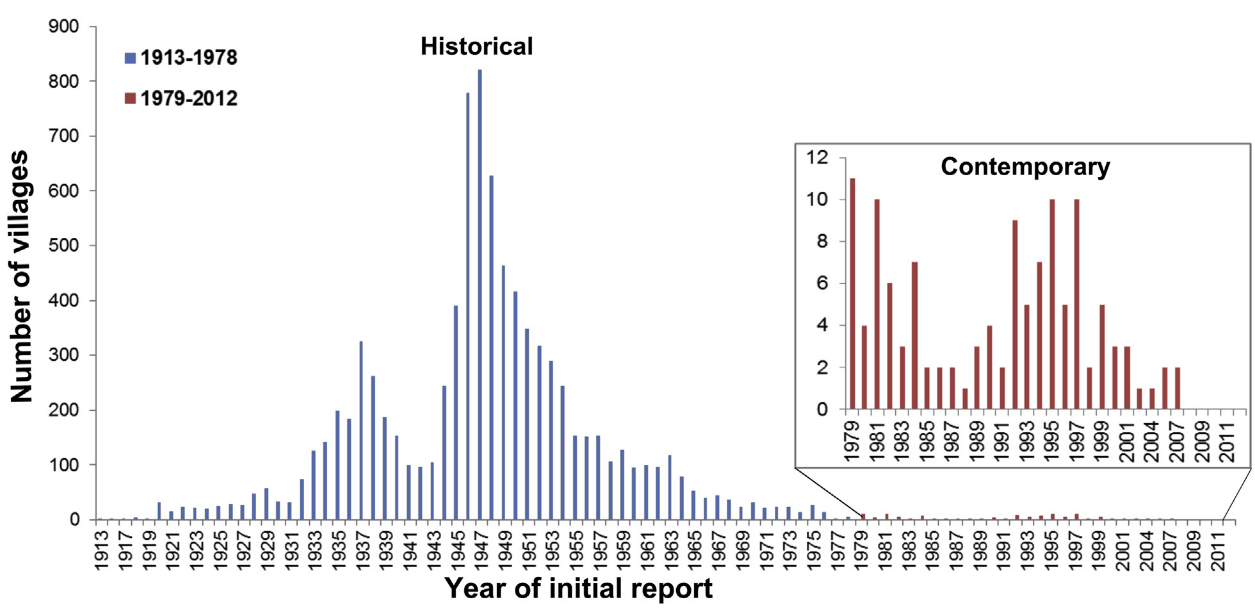

Fig. 2. Annual pattern of sites initially reporting anthrax outbreaks in Ukraine during two periods: historical (1913–1978) and contemporary (1979–2012). Figure inset is a magnified view of the *contemporary* time period.

Ukraine (Fig. 3B). Hotspots of reporting in the contemporary period were independent of historical hotspots based on the unweighted KDE analyses (Fig. 3C). Fig. 4 illustrates the annual number of outbreaks during the contemporary period. A total of 250 sites reported 265 outbreaks during 1979–1991. Most outbreaks occurred along a corridor from east-central to western Ukraine, with scattered outbreaks in the northeastern and southern regions (Fig. 5A). Some sites experienced up to four outbreaks, but most experienced only a single outbreak (Fig. 5A). Following Soviet independence, 197 sites reported 216 outbreaks concentrated in an east to west band across the country (Fig. 5B). As in the pre-independence period, most sites reported single outbreaks. The mean number of outbreaks per year during 1979–1991 (=20.38, SD = 7.40) was significantly higher as compared to 1992–2012 (=12, SD = 9.89) based on a two sample t-test with equal variances ($t_{29} = 2.57$, $p = 0.015$).

Weighted hotspot analyses of the pre- and post-independence periods during the contemporary period illustrated two different spatial patterns. In the pre-independence period, there were seven foci scattered throughout the country using the 25% threshold. There were three in eastern Ukraine, three in central Ukraine, and one in south-central Ukraine (Fig. 6A). In the years post-

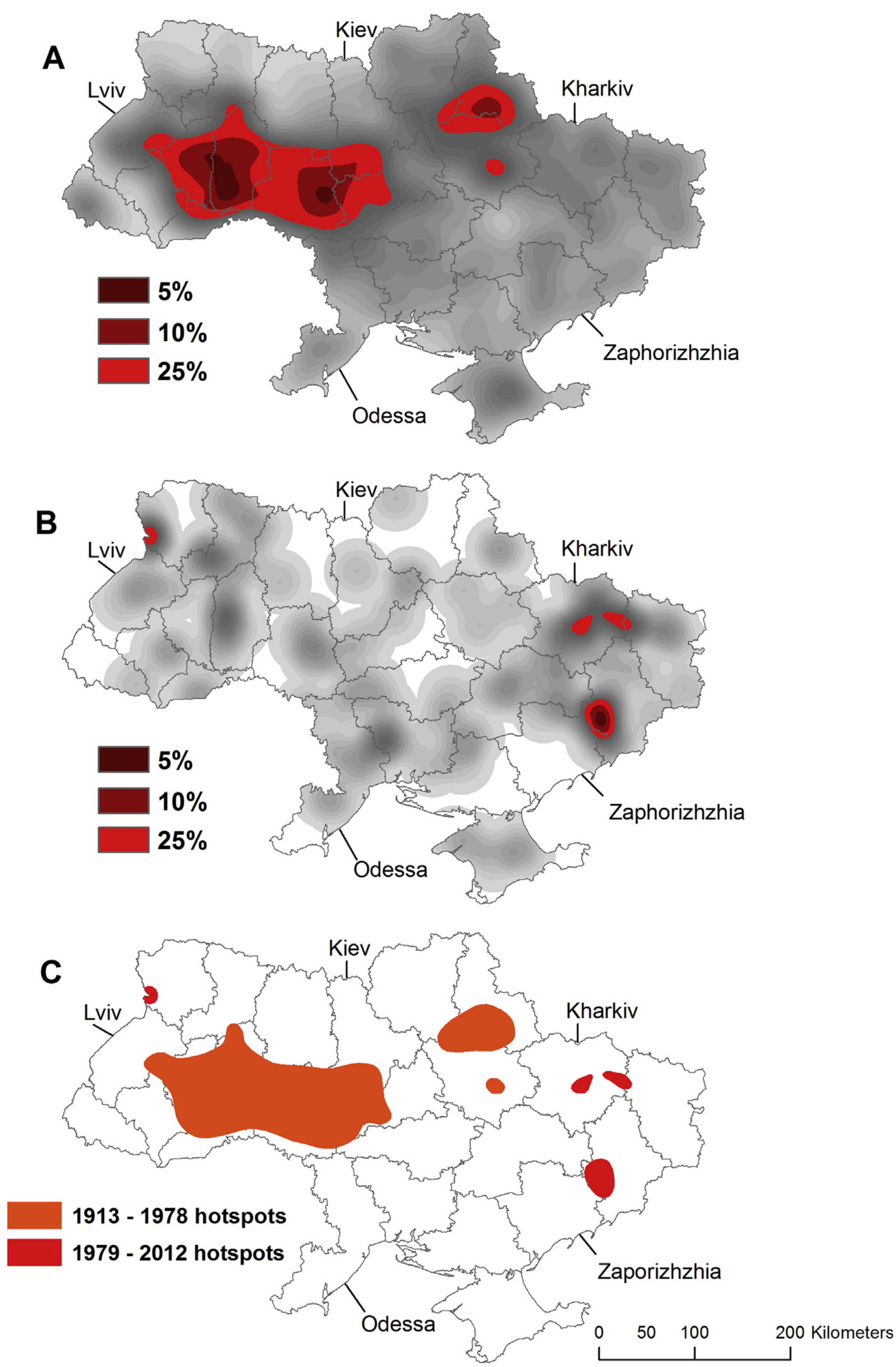

Fig. 3. Livestock anthrax reporting hotspots derived from kernel density estimation at three different thresholds (upper 5, 10, and 25% of density values) during the A) historical and B) contemporary periods. C) Comparison of the hotspots from each period. Each time interval includes villages organized by the year of initial reported anthrax outbreaks.

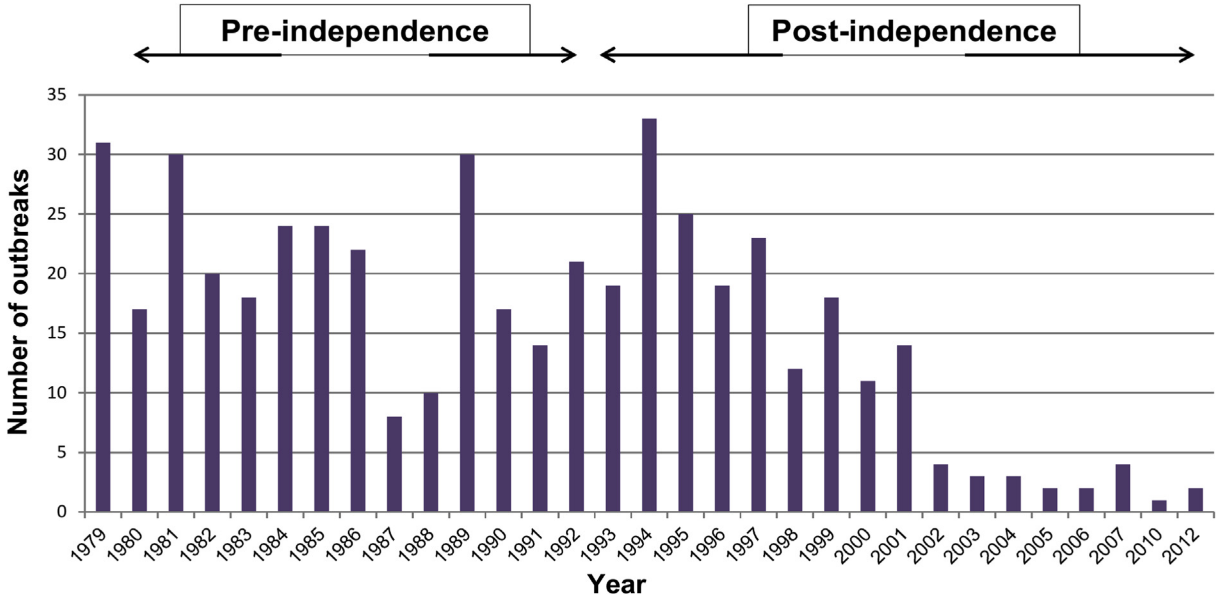

Fig. 4. Number of annual livestock outbreaks pre- (1979–1991) and post- (1992–2012) national independence.

independence, there were four foci, three in eastern Ukraine and one in central Ukraine (Fig. 6B). STAMP analyses identified several changes in the spatial distribution of hotspots between pre- and post-independence. There was one stable hotspot (green area in Fig. 6C, in the web version). This focus also experienced a contraction (shown in gray; Fig. 6C) as compared to the previous time period and an expansion south (shown in orange, in the web version; Fig. 6C). Six foci (three in eastern Ukraine and three in central Ukraine (Fig. 6C)) disappeared during the post-Soviet period, while generation (Fig. 6 illustrated in yellow, in the web version) identified three emergent foci, one in northwestern Ukraine, and two in southwestern Ukraine along the Romanian border.

Discussion

Here, we report trends in the historical and contemporary spatial and temporal patterns of livestock anthrax in Ukraine over the past century. Our primary objective was to examine the spatio-temporal dynamics of the disease and identify areas where anthrax may persist in the present day. We first determined where the highest concentrations of sites reporting anthrax were in the historical (1913–1978) and contemporary periods (1979–2012) and explored spatial differences in reporting between these time periods. We then identified contemporary anthrax foci using hotspot analysis weighted by the number of outbreaks per site. Using STAMP, we determined that there were contemporary anthrax foci that overlaid historical anthrax areas, indicating areas of persistence. There were also recently generated foci, indicating areas of (re-)emerging anthrax risk.

In the historical period, there were two apparent sharp spikes in the number of new sites experiencing anthrax outbreaks. The increase of sites reporting anthrax in the late 1930s (peak at 325 in 1937), coincided with the Soviet period of industrialization, which lead to the consolidation of individual peasant farms into large, government-owned collectives (Harrison, 2011). Across the Soviet Union, collectivization of farms resulted in a significant redistribution of livestock and increased herd densities (Robinson & Milner-Gulland, 2003), which may have resulted in large areas of anthrax risk. A very large spike in outbreak reports occurred in the late 1940s; immediately after World War II (WWII), in 1946–1947 (large spike reaching a maximum of 821 sites), which then plummeted during the 1950s (Fig. 2). A similar pattern of increased livestock anthrax post-WWII was also apparent in a recent analysis of historical data from Kazakhstan by Kracalik et al. (2011). The Soviet Union was heavily impacted during WWII with much of the war in Europe fought on Soviet lands (Harrison, 2011). The Soviet Union also experienced a great famine (which was particularly severe in Ukraine) in 1946–1947 (Ellman, 2000). Since Ukraine was occupied by Germany during WWII, there was little to no organized anthrax control or outbreak responses. Many anthrax records were lost (Zaviriuha, Kharchuk, & Trotsenko, 1979). The combination of underreporting during the war and the lack of anthrax control and response measures likely resulted in the observed post-WWII peak in anthrax reporting.

Although the Soviet government had carried out livestock vaccination campaigns as early as the 1920s, annual prophylactic vaccination campaigns did not begin until the post-WWII period (Tretyakov, 1973). In 1953, new national mandates required prophylactic immunization of susceptible livestock and the burning (rather than burying) of anthrax contaminated corpses as a more effective decontamination measurement (Tretyakov, 1973). These revisions in vaccination approaches and outbreak response methodology likely resulted in the decline of sites reporting anthrax through the late 1950s-early 1970s, continuing into the present (Fig. 2; Fig. 3A compared to Fig. 3B). The United States saw a similar reduction in the number of counties reporting anthrax from the 1920s to 1960s, reducing to a few stable foci in Texas, the Dakotas, Minnesota, and Montana, once an efficacious vaccine was widely available and contaminated feed restricted (Blackburn, 2006).

In Urkaine, hotspots of new outbreaks shifted geographically and ultimately decreased over time. A similar pattern was observed in the US in the US (Blackburn, 2006). In the historical time period, outbreak reports were distributed over wide regions (Fig. 5A). In the contemporary period, only 122 new sites reported outbreaks, and individual foci were greatly reduced in size. This represented a 72-fold reduction in sites reporting anthrax in approximately half the time period, when compared with the historical period. Additionally, unweighted hotspots of the new sites reporting outbreaks did not overlap the historical reporting hotspot (Fig. 3C). This

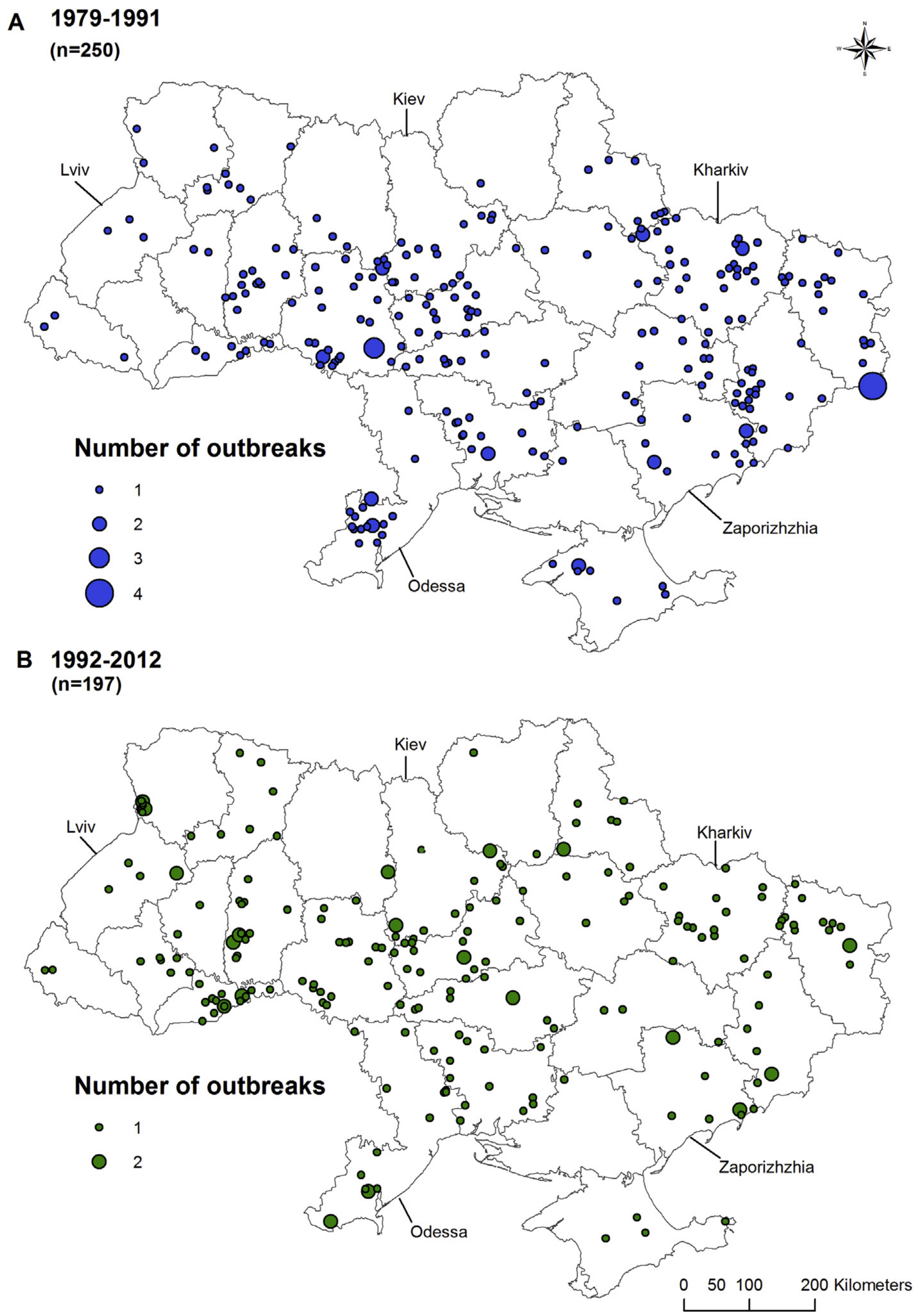

Fig. 5. Map of number of outbreaks at sites during A) pre- (1979–1991) and B) post- (1992–2012) independence.

pattern likely reflects how data were organized. As a large number of sites reported outbreaks in the historical period (>8800 sites), that left a smaller number of new sites that could report anthrax in the contemporary period.

During the contemporary period, overall, there was a statistically significant decline in mean outbreaks from the pre-independence to post-independence period. There was a brief increase immediately post-independence (peak of 33 outbreaks in 1994) (Fig. 4) which was likely a result of socio-political instability as the nation transitioned into independence. This was seen in other former Soviet countries (Kracalik, Abdullahyev, et al., 2014). However, the number of anthrax outbreaks in the 2000s decreased to <5 outbreaks a year (Fig. 4), indicating that control and response measures improved during the post-Soviet rebuilding period. In both time periods, most sites experienced one outbreak, although there were sites that experienced more than one outbreak (12 sites with >1 outbreak within 12 pre-independence years, 22 sites within 20 post-independence years). Sites with only one outbreak may be caused by sporadic events, such as contaminated feed or other materials (Fasanella et al., 2013), while repeated outbreaks at a site could be indicative of persistent environmental foci (sites where *B. anthracis* can survive for long periods).

Our weighted hotspot analysis identified seven anthrax foci during the pre-independence period, which decreased to four in the post-independence period, and displayed a spatial shift to the east. In 1991, the Soviet Union collapsed, resulting in massive changes and alterations to the country's infrastructure and livestock production methods, including decollectivization of

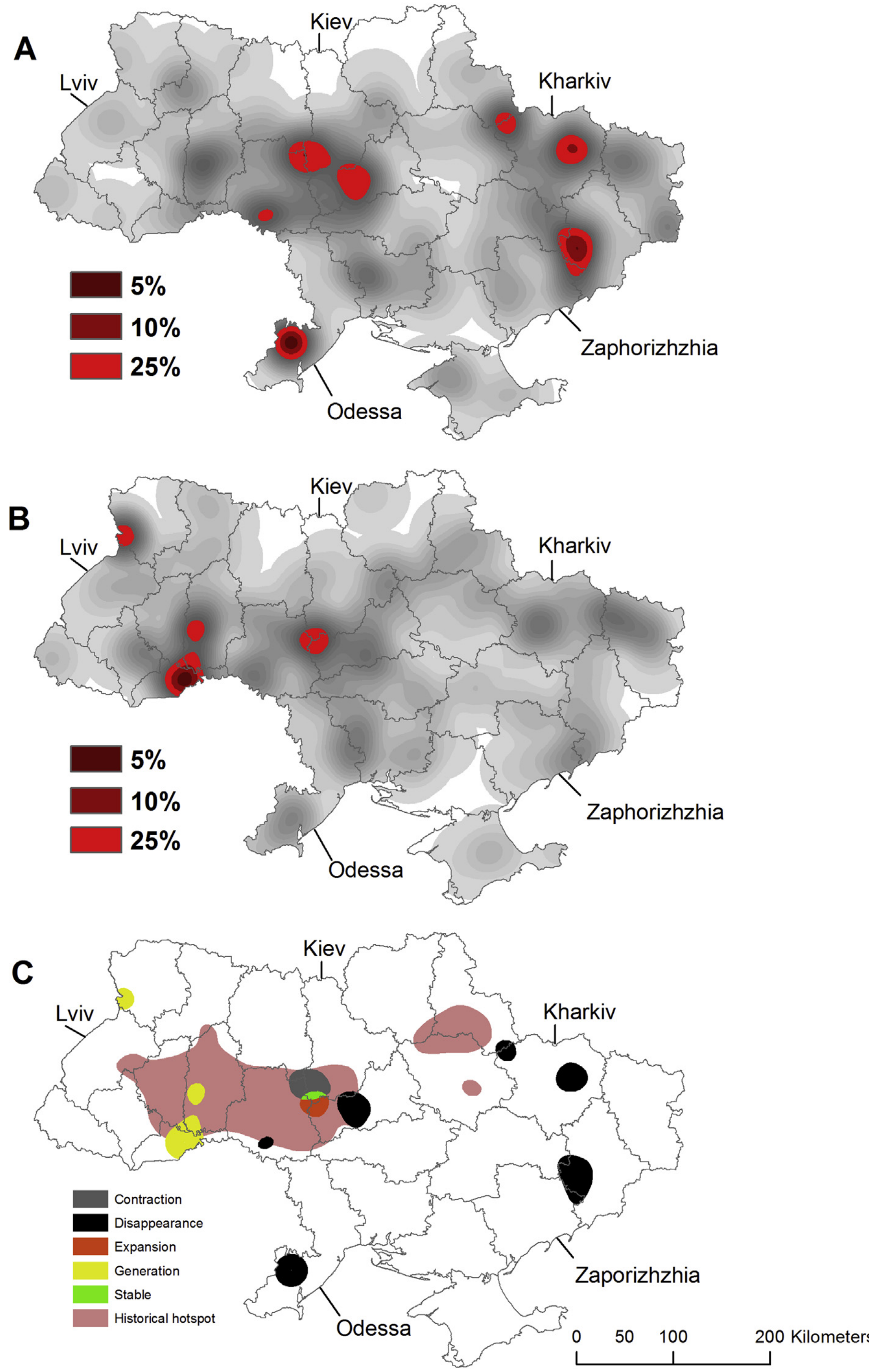

Fig. 6. Livestock anthrax hotspots derived from kernel density estimation at three different thresholds (upper 5, 10, and 25% of density values). A) Pre-independence period (1979–1991); B) post-independence (1992–2012); C) comparison of hotspots during the two periods using space time analysis of moving polygons (STAMP).

farming. The spatial pattern of outbreak hotspots in the post-Soviet period and decrease in number of outbreaks during the 2000s (Fig. 4) may be a result of decollectivization of farms and the subsequent massive decline of livestock (from 24.6 million in 1991 to 4.6 million today) (State Statistic Service of Ukraine, 2013). Currently, livestock in industrial farms are subject to government-sponsored compulsory vaccination. However, the majority of livestock are privately owned by households (in 2013: 3139.4 thousand vs 1506.5 thousand in industrial farms; State Statistic Service of Ukraine, 2013). Unfortunately, individual livestock owners are less likely to vaccinate their livestock. This could lead to an increased risk of anthrax, particularly in areas where the environment supports pathogen survival. Likewise, many cases could go undetected, as it could be more difficult to track disease status across individual farmers. The most recently reported human anthrax case in Ukraine (April 2012), was associated with an individual animal owner slaughtering a pig (GIDEON online: www.gideononline.com).

Outbreak prevention and response measures may have helped decrease anthrax in livestock in Ukraine overall, but outbreaks continue to occur, often in previously affected areas. Anthrax foci defined as stable or expanding during the post-independence years (last 20 years), as well as some recently generated foci, directly overlapped the historical hotspot in west-central Ukraine (Fig. 5C). Our results indicate that present day outbreaks are linked to historical anthrax areas and support the hypothesis that the pathogen is persisting in environmental reservoirs that may require further surveillance and control plans. As anthrax was widespread and prolific in the historical period, there likely are a great number of old carcass and burial locations across the Ukrainian landscape. This likelihood combined with inefficient historical decontamination measures and the longevity of anthrax spores indicates that new anthrax cases are likely to occur when livestock are exposed to disturbed ground (e.g. irrigation and construction projects) (Cherkasskiy, 1999). Individuals involved in these types of projects in Ukraine should be made aware of this possibility, so that they may take the proper precautions.

In addition to previously identified anthrax-prone areas, our results indicate new areas with evidence of emerging anthrax. There was generation of new foci in northwestern and western Ukraine during post-independence. The foci along the Romanian border are proximal to areas reporting wild boar outbreaks in the mid-1990s (Volokh, 2002). The data from these wild boar outbreaks were not included in our database, and therefore were not used to determine the contemporary anthrax foci. These outbreaks provide corroborating evidence for anthrax foci in that region, and indicate that surveillance of wildlife can help to determine anthrax risk across the landscape (Bagamian et al., 2014). This is even more relevant, as we had a report of anthrax in a moose (Eurasian elk [*Alces alces*]), that was likely wild, as moose farming is not common in Ukraine. This case co-occurred with a case in cattle, indicating that there is a link between Ukrainian livestock and wildlife, and that other wildlife species, in addition to wild boar, are exposed. Wildlife surveillance (Bagamian, Alexander, Hadfield, & Blackburn, 2013; Blackburn, Asher, Stokke, Hunter, & Alexander, 2014) coupled with predictive modeling of environments that promote pathogen persistence (Blackburn, McNyset, Curtis, & Hugh-Jones, 2007; Joyner et al., 2010), may better inform and direct more efficacious livestock and public health measures.

Ukraine has a long history of human anthrax, and in general, it has declined over the past century (Korotich & Pogrebniak, 1976; Velimirovic, 1984). However, in 2003, the Ukrainian Ministry of Health indicated that anthrax presented a human health concern and continues to pose such a risk today (Ukrainian Ministry of Health Website, 2014). This concern was based on increased reports of human cutaneous anthrax cases. From 1994 to 2001, 105 humans cutaneous anthrax cases were reported, with a mortality of 4.76% (Bobyleva, Mukharska, Nekrasova, & LP, 2001). This was approximately five times higher than during the previous eight years (1986–1993), when only 23 cases were reported. Most cases were quite advanced by the time of diagnosis (Bobyleva et al., 2001). A recent study in the country of Georgia hypothesized that an increase of human cutaneous anthrax in urban areas may be linked to contaminated meat sold in informal meat markets (which have little to no regulation) (Kracalik, Malania, et al., 2014). A similar phenomenon has also been documented in other countries (Chakraborty et al., 2012). In Ukraine, individual household livestock owners often sell contaminated meat along the roadsides; this is an illegal and unregulated enterprise, thereby the meat is not tested and could be contaminated. In a recent case of dog anthrax linked to being fed contaminated beef (Skrypnyk et al., 2014), investigations uncovered that the diseased cow's owners sold the meat to a grocery store and restaurant, although fortunately the meat was recovered before it was used or sold (Ukrainian Ministry of Agriculture, 2012). Future studies should explore the relationship between contemporary human and livestock cases to better define the areas of human anthrax risk, and the practices that contribute to increased human risk.

Using historical data can play a major role in understanding disease patterns and dynamics over time, but use of such data has limitations. Historical records can be lost or incomplete, or suffer from sampling biases. Also, there are likely to be reporting changes over time, as contemporary times are likely to have better records and improved laboratory diagnostics. In addition, different regions of Ukraine may have had different levels of diagnostic capabilities and accuracy, and these factors may have influenced the observed pattern of outbreaks. Here, we assumed that diagnostic capabilities were similar across the country. In this analysis, we did not integrate changes in political boundaries of rayons (districts) or oblasts (provinces); these have changed over the past century. Village coordinates were mapped to historical locations. In spite of these limitations, it is important to understand the history of a disease to better understand the mechanisms and current patterns of transmission, especially for diseases like anthrax that persist or reemerge (Cliff, Haggett, Smallman-Raynor, Stroup, & Williamson, 1997). The organization of the available data limited the type of analyses in this study (as there was no annual outbreak data during the historical period). As a result, we were unable to weight our historical KDE analysis by number of outbreaks per site, and all the sites were treated equally regardless of the number of outbreaks that occurred. However, we were able to weight the KDE analysis by number of outbreaks in the pre- and post-independence years within the contemporary period.

Conclusions

Determining historical hotspots of anthrax activity and relating them to current anthrax foci can help better define areas of increased risk on the landscape. Although vaccination and improved response measures have helped reduce anthrax outbreaks and decrease the size of anthrax foci, these results confirm stable and expanding, as well as emerging, anthrax foci in Ukraine. This, taken with the recent increase in human cases, indicates that further mitigation, such as educational campaigns that encourage livestock vaccination by individual owners and preventing the sale of illegal contaminated meat are necessary. At the same time, we encourage alternative surveillance strategies, such as using wildlife sentinels and predictive ecological models to refine the spatial patterns identified here.

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