Modelling the spread of emerging infectious diseases in animal health: case study of lumpy skin disease in the Balkans, 2015–2016

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Abstract

The spatial and temporal study of the spread of emerging infectious diseases is crucial to understand their epidemiology and evaluate the risk of introduction into disease-free areas. In this paper, we present a generic method that models the spread rate of emerging infectious diseases that we applied to Lumpy Skin Disease (LSD), a current epizooty affecting cattle in the Balkans, from May 2015 to July 2016. In the study period, 824 outbreaks of LSD were reported in eight countries. Hotspots of viral transmission were identified mainly south of the Turkish/Greek border, southwest of Bulgaria and south of the Serbian/Bulgarian border. By using Thin Plate Spline Regression (TPSR) to interpolate the week of first invasion, we estimated the spread rate based on the mean duration of time for the infection to spread across a given area (1km). The median spread rate was 7.8km per week, with an interquartile interval of 4.6 to 13.7km and a maximum value reaching 375.6km. The distribution of spread rate indicates two diffusion processes: a localised diffusion covering small distances and suggesting vector transmission, and a diffusion at greater distances possibly due to anthropogenic movement of infected animals. Further research should focus on identifying environmental and socio-economic factors that might influence the spread of LSD to better understand the disease epidemiology and suggest targeted control measures.

Keywords: *Lumpy skin disease, animal health, epidemic intelligence, spread rate*

Introduction

Emerging infectious disease outbreaks are an ever-growing threat to human and animal populations due to globalisation, movement of passengers and international trade, and underline the need for early warning and proactive surveillance systems at international level. The study of the spread of emerging infectious pathogens is crucial to understand the epidemiology of the diseases, and it also allows stakeholders to evaluate the risk of introduction into unaffected territories and implement mitigation measures.

In 2013, the French platform for animal health surveillance (http://plateforme-esa.fr/) set up a multi-institutional group of experts in international epidemic intelligence in animal health (VSI team). The main purpose of the VSI team is to detect, verify, analyse and follow-up early signals for new and emerging animal health risks not present in France, and provide reports to the national institutions for risk assessment (ANSES), risk management (French Ministry of Agriculture - DGAL) and stakeholders.

The VSI team has developed new tools and methods to analyse and interpret disease-related events from both official and unofficial data sources. One of these methods focuses on modelling the spread of emerging diseases. This paper presents an application of this generic method to Lumpy Skin Disease (LSD) in the Balkans from the first introduction to the European part of Turkey in May 2015 to July 2016.

LSD is a viral disease affecting cattle that is caused by a Capripoxvirus from the Poxviridae family. LSD is transmitted by mechanical vectors, but direct/indirect transmission may occur (1). The disease was limited to Sub-Saharan Africa until 1986 when it spread to the Middle East and reached Turkey for the first time in 2013. The LSD virus was first introduced in Greece in August 2015, then in Bulgaria and the Former Yugoslav Republic of Macedonia (FYROM) in April 2016, in Serbia, Kosovo and Albania in June 2016 and in Montenegro in July 2016.

Materials and methods

Epidemiological data on LSD outbreaks was collected from the Animal Disease Notification System (ADNS) of the European Commission and the EMPRES-i database of the Food and Agriculture Organisation of the United Nations (FAO). The information used to characterise the outbreaks was the geographical coordinates (latitude, longitude) and the date of occurrence of the outbreaks. The study area stretched from the European part of Turkey (provinces of Edirne, Kirklareli and Tekirdag) to Greece, Bulgaria, FYROM,

Serbia, Kosovo, Albania and Montenegro. The time period analysed was from the first occurrence of an LSD outbreak in the European part of Turkey 13 May 2015 to 31 July 2016.

To illustrate the density of outbreaks, we applied hexagonal binning as suggested by Carr *et al.* in 1987 (2). The study area was divided into hexagons of 20km and outbreak data was spatially aggregated per hexagon. The spread rate was calculated using a trend surface analysis (TSA) method (3). We first created a raster mask representing the front wave of invasion (i.e. the time of first invasion). We applied an interpolation method, Thin Plate Spline Regression (TPSR), to interpolate the week of first invasion and generated a 1km resolution raster. The TPSR interpolation method was selected as some studies have shown that in combination with TSA, it provided the most robust local spread rate quantification (3-4). A friction index was then calculated as the difference between the week number of each raster cell and the week number of the surrounding cells. In this study, the friction index represents the mean duration of time (in weeks) for the virus to spread from a given raster cell to its neighboring cells (i.e. to cross 1km). All the analyses were performed using the R software and especially the packages 'surveillance', 'raster' and 'fields'(5).

Results

In the study period, 824 outbreaks of LSD were reported in eight countries. Figure 1 reveals the presence of hotspots which correspond to geographic aggregation of LSD outbreaks. The main hotspots are located south of the Turkish/Greek border, south of the Serbian/Bulgarian border, in the southwest of Bulgaria and in the eastern part of Montenegro.

Figure 1. Geographic distribution of Lumpy Skin Disease (LSD) outbreaks in the Balkans from May 2015 to July 2016
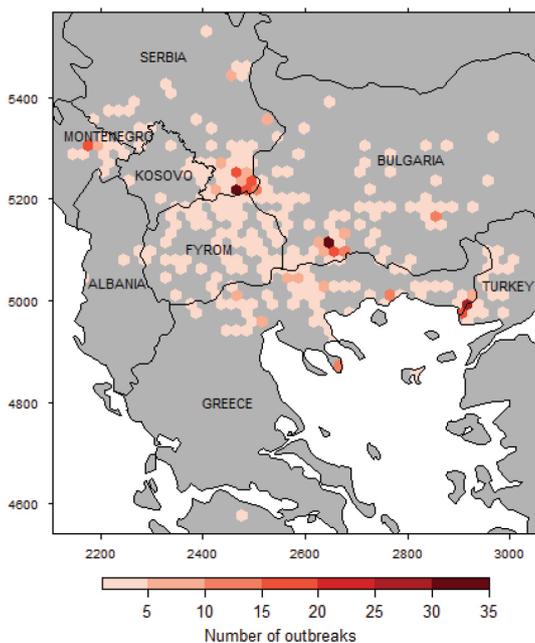
The spread rate model calculated a median spread rate of 7.8km per week, with an interquartile interval of 4.6 to 13.7km per week (Figure 2). The spread rate is therefore below 13.7km per week in 75% of cases. However, the distribution is very heterogeneous and widespread, with maximum values of spread rate reaching 375.6km per week. This is compatible with a hypothesis of two joint diffusion processes of the infection: a localised diffusion covering small distances – more frequent, and a diffusion at greater distances – more rare but important from an epidemiological point of view.

Figure 2. Density probability of spread rate values of Lumpy Skin Disease (LSD) outbreaks in the Balkans from May 2015 to July 2016
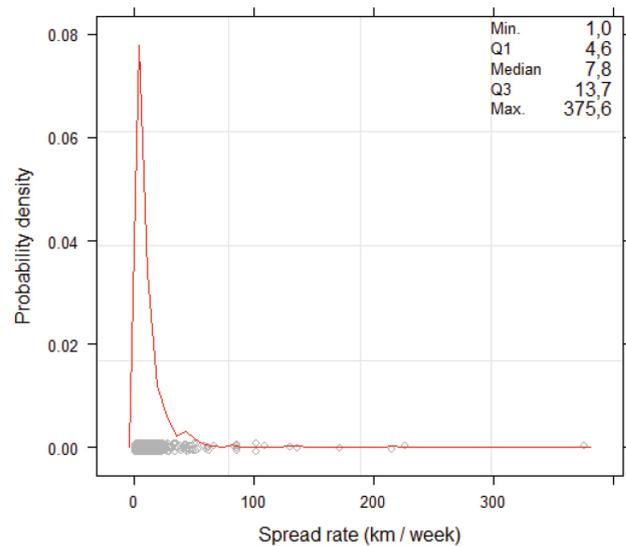
Discussion

The hotspots of LSD outbreaks, observed mainly south of the Turkish/Greek border, south of the Serbian/Bulgarian border and southwest of Bulgaria, may correspond to introduction points around which the virus spreads locally (low spread rates), followed by transmission at greater distances (high spread rates) resulting in hotspots in new areas, from which the virus diffuses locally, and so on. Low spread rates, indicating localised transmission covering small distances, seem to point to a vector transmission of the virus (6) whereas high spread rates, indicating greater distance transmission and outbreak spatial discontinuity, could be linked to animal mobility through anthropogenic transport of infected animal or wind transport of infected vectors (1, 7-8). The emergence of LSD in Greece in August 2015 is likely due to the introduction of the virus in the European part of Turkey a couple of months before. A hotspot of viral transmission formed at the border between Greece and Turkey, from which the infection then spread to Greece and into Eastern Europe.

In this study, we combined several data sources (EMPRES-i, reflecting OIE data, and ADNS) in order to form a more complete dataset *all*owing a better overview of the

epidemiological situation. The data used only reflects the data available to the authors through official sources at the date of analysis. Under-reporting of outbreaks and important delays between outbreak detection and outbreak declaration often lead to incomplete datasets which in turn impact estimators. Extreme values are unstable and strongly depend on available data which is collected during the epizooty and not simultaneously reported or recorded into official databases. For these reasons, we considered the median value of spread rate to be more robust than maximum/minimum and mean values. Even though a limited number of countries report to ADNS, the system presents a strong advantage compared to OIE in that the delays between outbreak detection and reporting are less significant, making ADNS a more reliable and complete data source for the monitoring of emerging infectious diseases in the EU and surrounding regions.

Understanding the spread dynamics of emerging infectious diseases allows a more precise evaluation of the risk of introduction into unaffected regions, which in turn can lead to timely implementation of prevention or control measures. In the case of disease emergence and rapid spread, up-to-date outbreak data is crucial for real-time modelling and monitoring of their spread (9). Understanding the environmental and socio-economic factors that drive this spread is also important. Thus, further research should explore potential influential factors of the spread of LSD, such as climate parameters, land cover or animal densities (1,10-11). Until then, proactive surveillance remains essential to allow early warning and detection of disease emergence in unaffected countries (12).

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