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Detection of major climatic and environmental predictors of liver fluke exposure risk in Ireland using spatial cluster analysis

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ABSTRACT

Fasciolosis caused by *Fasciola hepatica* (liver fluke) can cause significant economic and production losses in dairy cow farms. The aim of the current study was to identify important weather and environmental predictors of the exposure risk to liver fluke by detecting clusters of fasciolosis in Ireland. During autumn 2012, bulk-tank milk samples from 4365 dairy farms were collected throughout Ireland. Using an in-house antibody-detection ELISA, the analysis of BTM samples showed that 83% ($n = 3602$) of dairy farms had been exposed to liver fluke. The Getis-Ord Gi* statistic identified 74 high-risk and 130 low-risk significant ($P < 0.01$) clusters of fasciolosis. The low-risk clusters were mostly located in the southern regions of Ireland, whereas the high-risk clusters were mainly situated in the western part. Several climatic variables (monthly and seasonal mean rainfall and temperatures, total wetdays and raindays) and environmental datasets (soil types, enhanced vegetation index and normalised difference vegetation index) were used to investigate dissimilarities in the exposure to liver fluke between clusters. Rainfall, total wetdays and raindays, and soil type were the significant classes of climatic and environmental variables explaining the differences between significant clusters. A discriminant function analysis was used to predict the exposure risk to liver fluke using 80% of data for modelling and the remaining subset of 20% for post hoc model validation. The most significant predictors of the model risk function were total rainfall in August and September and total wetdays. The risk model presented 100% sensitivity and 91% specificity and an accuracy of 95% correctly classified cases. A risk map of exposure to liver fluke was constructed with higher probability of exposure in western and north-western regions. The results of this study identified differences between clusters of fasciolosis in Ireland regarding climatic and environmental variables and detected significant predictors of the exposure risk to liver fluke.

1. Introduction

Fasciolosis caused by *Fasciola hepatica* (liver fluke) can account for major economic losses in cattle farms worldwide (Kaplan, 2001) and is strongly influenced by climatic conditions (Mas-Coma et al., 2009). The association of climatic and environmental parameters with the exposure risk to liver fluke indicates an apparent spatial component in the epidemiology of fasciolosis (Selemetas et al., 2015a). Therefore, the observed temporal pattern of the disease can be elucidated using climatic and environmental variables in order to develop a detailed predictive risk model for fasciolosis (McCann et al., 2010a).

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Several studies have been performed to examine the spatial distribution of fasciolosis in Europe, mainly in England and Wales (McCann et al., 2010a,b), Belgium (Bennema et al., 2011), Germany (Kuerpick et al., 2013) and Ireland (Selemetas et al., 2015a). The use of geographical information systems (GIS) and geospatial tools and the incorporation of spatial statistics aiming to detect high-risk regions of a disease can contribute to a better understanding of the geographical pattern, transmission, and potential risk factors of fasciolosis (Weisent et al., 2011). Spatial cluster analysis belongs to this category of tools that try to detect hotspots (clusters) or regions presenting higher density of spatio-temporal disease occurrence (Fritz et al., 2013).

Studies investigating high-risk regions of fasciolosis through the use of cluster analysis are limited. Rinaldi et al. (2009) found clusters of fasciolosis in water buffaloes farms in Italy; Bennema et al. (2011) detected spatial clusters of the disease in dairy cow farms in Belgium, and Selemetas et al. (2015b) identified high-risk and low-risk regions of fasciolosis in Munster province of Ireland. However, a national-scale cluster analysis of the disease in dairy farms has not yet been conducted in Ireland to detect high-risk regions of fasciolosis and specific infection patterns. The objectives of the current study were (i) to detect clusters of fasciolosis in dairy farms in Ireland, and (ii) to develop a predictive risk model for the disease by identifying significant climatic and environmental predictors of the exposure risk to liver fluke.

2. Materials and methods

2.1. Study area and sampling strategy

The study was conducted in Ireland between September and November 2012. The Irish climate is mild without temperature extremes and with higher rainfall levels in the western part of country (Walsh, 2014). Several dairy cow farmers across Ireland participated in the current study, including those farmers ($n = 1292$) that took part in the study on cluster analysis in Munster province by Selemetas et al. (2015b). In total, 4365 dairy farms throughout Ireland were sampled by an Irish private company on cattle breeding services, collecting bulk tank milk (BTM) samples from all its dairy farmer customers and a small creamery in County Donegal. BTM samples each containing a single preservative tablet of 0.3 mg Natamycin and 8 mg Bronopol (Broad Spectrum Microtabs II; Advanced Instruments, Inc., USA) were sent to the Veterinary Parasitology Laboratory of University College Dublin. Samples were then left to stand for 4 days at 4 °C to allow the separation of lipid layer before being tested. The addresses of farms were at townland level.

2.2. Detection of liver fluke antibodies

The exposure to liver fluke was determined using an in-house antibody-detection enzyme-linked immunosorbent assay (ELISA) on BTM samples, as described by Selemetas et al. (2014). The antibody levels of each sample were expressed as per cent positivity (PP) based on the optical density (OD) of BTM samples, according to the following equation:

$$\text{PP Value} = \frac{\text{OD of test sample}}{\text{mean OD of positive controls}} \times 100 \qquad (1)$$

2.3. ELISA cut-off value

The cut-off value of the ELISA test that used to classify dairy farms into positive and negative classes was determined using the algorithm of expectation-maximization (EM) of the normal mixEM function of the Mixtools package (Benaglia et al., 2009) in R3.0.3 statistical language environment (R Core Team, 2013).

2.4. Climatic and environmental variables

Several climatic and environmental variables (Table 1) were tested to explain possible dissimilarities in the liver fluke exposure between dairy farms in high-risk and low risk regions, including: climatic variables and environmental variables.

2.4.1. Climatic variables

Gridded weather datasets (Table 1) at 1 km resolution for Ireland for the year 2012 were provided by Met Éireann (the Irish National Meteorological Service) and were projected on the Irish Grid Reference System (TM75/Irish Grid). The main categories of climatic variables included mean monthly and seasonal temperatures (°C), total rainfall (mm), total raindays (daily rainfall ≥ 0.2 mm), and total wetdays (daily rainfall ≥ 1 mm). The seasonal datasets denoted the following 3-month periods: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). All weather datasets were converted to raster files using the R3.0.3.

2.4.2. Environmental variables

Satellite images of enhanced vegetation index (EVI) and normalised difference vegetation index (NDVI) at a spatial resolution of 250 m × 250 m from January to September 2012 were derived from MODIS Terra and were post-processed by Avia-GIS (Zoersel, Belgium) according to Scharlemann et al. (2008). Soils Maps for Ireland at a resolution of 10 km × 10 km were provided by the Environmental Protection Agency (Daly and Fealy, 2007). Using ArcGIS version 10.1 (ESRI, Redlands, CA, USA) and its Zonal Statistics tool, the values of every dataset in each electoral division were calculated and summarised in a table as either the average value for all numerical (climatic, NDVI, EVI) variables or the majority value for the categorical soil variables.

2.5. GIS mapping and georeferencing

The analysis of spatial data and GIS mapping was conducted using ArcGIS version 10.1. The dairy farms were georeferenced as described previously (Selemetas et al., 2015a) using their townland location.