Applied Geography 45 (2013) 230–240

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Seasonal vegetation variables and their impact on the spatio-temporal patterns of nephropathia epidemica and Lyme borreliosis in Belgium

J.M. Barrios [a,*], W.W. Verstraeten [b,c], P. Maes [d], J.M. Aerts [a], J. Farifteh [a], P. Coppin [a]

[a] KU Leuven Biosystems Department, M3-BIORES, Willem de Croylaan 34, 3001 Leuven, Belgium
[b] Royal Netherlands Meteorological Institute, Climate Observations, PO Box 201, NL-3730 AE, De Bilt, The Netherlands
[c] Eindhoven University of Technology, Applied Physics, PO Box 513, 5600 MB, Eindhoven, The Netherlands
[d] KU Leuven Zoonotic Infectious Diseases Unit, Clinical Virology, Rega Institute for Medical Research, Minderbroedersstraat 10, 3000 Leuven, Belgium

Keywords:
Hantavirus
Lyme borreliosis
Remote sensing
Spatial analysis
Vector-borne
Vegetation

A B S T R A C T

Remarkable outbreaks of various vegetation-related vector-borne diseases have been reported in recent years. Two well-known examples in Western Europe are nephropathia epidemica and Lyme borreliosis. The spatial distribution of these diseases closely follows the geographical distribution of the vegetated areas that are home to the organisms responsible for pathogen transmission. The causal agents of these diseases are the Puumala hantavirus and the spirochete *Borrelia burgdorferi*, respectively. Each disease has a specific transmission mechanism, but there are commonalities in the pathways of these two pathogens. The dynamic nature of vegetated areas and frequent weather anomalies increase the need to understand the links between climate, vegetation and disease. There is a need for innovative ways of monitoring vegetation as determinant of disease risk. This study aims to identify time-variant indicators of vegetation conditions as potential predictors to be used in spatio-temporal disease risk models. The candidate predictors include seasonal growing degree days and vegetation phenology metrics extracted from time series of remotely sensed vegetation indices after the conduction of a wavelet-based multi-resolution analysis. The response variable is a local Bayesian estimator of disease risk, calculated from epidemiological data with consideration of spatial stationarity. The results demonstrate the value of combining meteorological data with georeferenced datasets, like those obtained with remote sensing, which include specific information about the vegetation class of interest and its position with respect to urban centers.

Introduction

The incidence of vector-borne diseases is determined by various processes interacting with one another at different locations and different scales in time and space. The components of the system are factors affecting the ecology of hosts and pathogens, as well as factors of the physical, biological and socioeconomic environment, which determine the exposure of humans to pathogens (Sutherst, 2004). The complexity of these mechanisms makes it difficult to predict the response of the system to changes in its components. Consequently, the assessment of climate change impacts on vector-borne diseases has become a hot topic for the scientific community. The complexity can be addressed by improving the methods and data sources used for disease surveillance (Lindgren, Andersson, Suk, Sudre, & Semenza, 2012) and by implementing concerted initiatives at the supranational level to tackle current and upcoming challenges (Semenza & Menne, 2009).

The dynamics, dimensions and overall conditions of vegetative systems stand out as major determinants of vector-borne disease propagation whenever wild fauna is involved in the transmission mechanism. This is the case for diseases like Lyme borreliosis (LB) and nephropathia epidemica (NE), for which remarkable outbreaks have been reported in Western Europe during the last decade (Clement et al., 2010, 2009; Ducoffre, 2010; Mailles et al., June 2005; Vaheri et al., 2013). The geographical spread of these diseases is closely linked to the spatial distribution of the vegetated areas that serve as habitat for the pathogen hosts. The configuration of the landscape also plays a role, as it affects the environmental conditions in vegetated areas and influences the exposure of humans to the pathogens (Barrios et al., 2013). The annual number of cases has also been shown to be associated with annual or seasonal conditions in the habitat, like the annual seed production of

* Corresponding author. Tel.: +32 479612931.
E-mail address: miguel.barrios@biw.kuleuven.be (J.M. Barrios).

0143-6228/$ – see front matter
http://dx.doi.org/10.1016/j.apgeog.2013.09.019

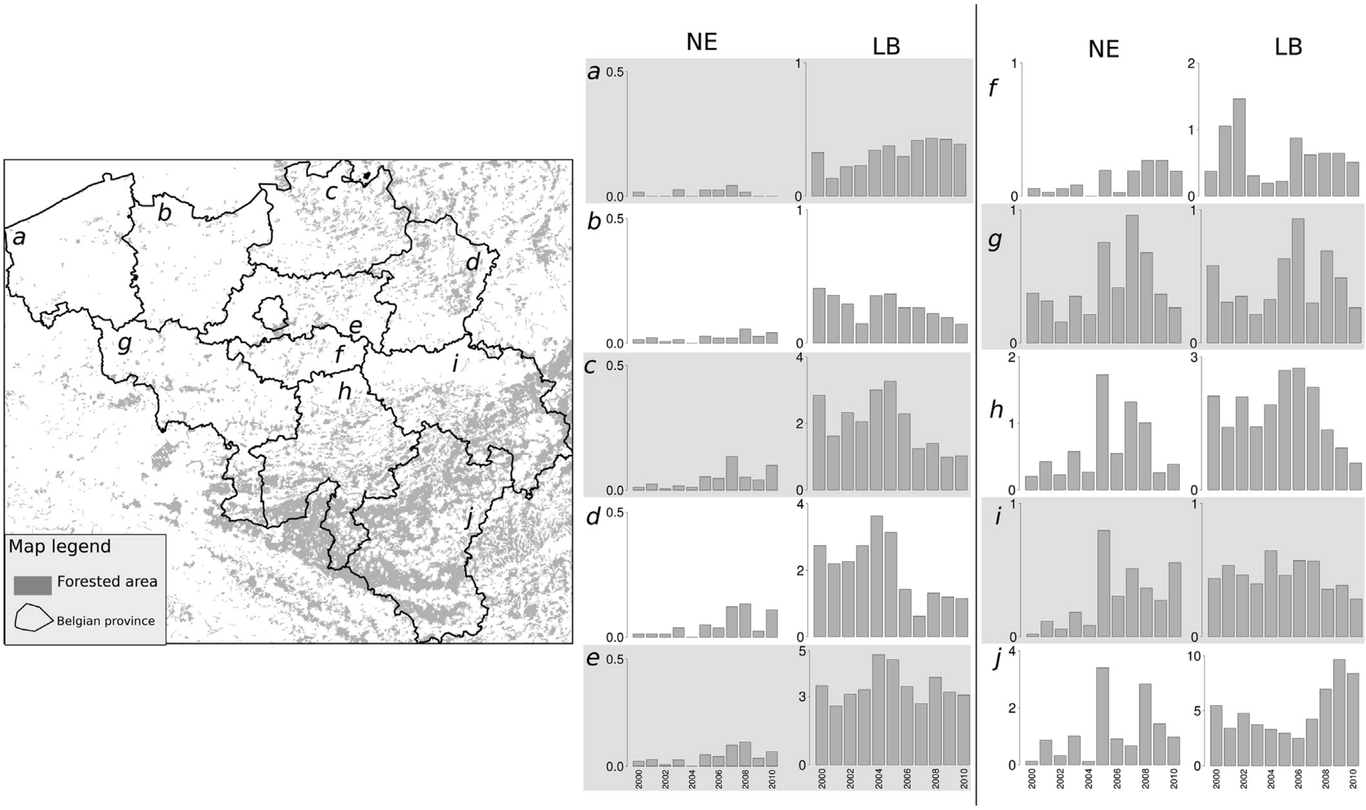

Fig. 1. Map of provinces and forested areas in Belgium and annual incidence of NE and LB per province for the period of 2000–2010. The units in the vertical axis are *cases/10,000 inhabitants*. Note that the scale of the vertical axis is not the same in all plots. The provinces are identified with following letters: *a*. West-Flanders, *b*. East-Flanders, *c*. Antwerp, *d*. Limburg, *e*. Flemish Brabant, *f*. Walloon Brabant, *g*. Hainaut, *h*. Namur, *i*. Liège; and, *j*. Luxembourg. Forested areas were extracted from the CORINE land cover map 18.

masting trees (Clement et al., 2010, 2009), the length of the growing season (Barrios et al., 2010), humidity conditions (Barrios et al., 2012), etc.

The strong connection between disease incidence and landscape and vegetation features suggests that periodic observation of the Earths surface from space has great potential to improve the spatio-temporal analysis of epidemics (Barrios et al., 2013). One of the major goals of observing Earth from space, or spaceborne remote sensing (RS), is the assessment and monitoring of vegetation-related phenomena across time and space. The availability, spatial and temporal resolution and spectral coverage of RS products are constantly improving, creating opportunities to explore new applications. Other important indicators of vegetation activity can be derived from conventional meteorological datasets. For these types of datasets, the concept of Growing Degree Days (GDD) is perhaps the most extensively used parameter that can be correlated with the timing and length of vegetation-related phenomena. GDD is derived from air temperature and represents the cumulative effect of heat units, which are needed to trigger and maintain various biological processes.

In this study, we hypothesized that GDD and remotely sensed data are indicators of the phenomena driving the spatial and temporal patterns of vector-borne disease risk. In particular, the study focused on NE and LB in Belgium in the period of 2003–2010. As mentioned earlier, these diseases have been responsible for major outbreaks in Belgium and other European countries in recent years. In addition, NE and LB disease risk could increase in the future due to climate change (Lindgren et al., 2012). Thus, it is important to consider novel methods of surveillance. As we see it, there are two main objectives: *(i.)* Assess the extent to which vegetation-related RS products and GDD can explain the temporal variability in NE and LB risk. Most studies using RS data for epidemiology focus on deriving risk maps without exploring the potential of improving RS temporal resolution. *(ii.)* Identify indicators of annual vegetation conditions that are suitable for modeling NE and LB propagation. These indicators were derived from time series of remotely sensed data and meteorological data. In the next section, relevant background information is given with regard to NE and LB and the epidemiological records of these diseases for the 2003–2010 period in Belgium.

Background

LB and NE are zoonotic diseases caused, respectively, by the bacterium *Borrelia burgdorferi* and the Puumala virus (PUUV). LB may cause severe complications in the neurological system, heart and joints (Lindgren & Jaenson, 2006), and NE is a mild form of hemorrhagic fever with renal syndrome. The pathways of both pathogens converge in the vegetative system that hosts their reservoirs.

The specific vector of PUUV in Western Europe, the bank vole (*Myodes glareolus*), is a native rodent species that lives in temperate forests. *B. burgdorferi* is transmitted to humans by ticks of the genus *Ixodes*. Aside from its prominent role in the transmission of PUUV, the bank vole is also known to be an important reservoir of *B. burgdorferi*, especially during the ticks larval and nymphal stadia. Other vertebrates, such as rodents, deer, hedgehogs and birds, together with plants form a complex system that influences the interaction between infected ticks and humans (Lindgren & Jaenson, 2006).

There has been a remarkable increase in the number of reported pathological cases in the first decade of this century, and a higher