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Remotely sensed vegetation moisture as explanatory variable of Lyme borreliosis incidence

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ABSTRACT

The strong correlation between environmental conditions and abundance and spatial spread of the tick *Ixodes ricinus* is widely documented. *I. ricinus* is in Europe the main vector of the bacterium *Borrelia burgdorferi*, the pathogen causing Lyme borreliosis (LB). Humidity in vegetated systems is a major factor in tick ecology and its effects might translate into disease incidence in humans. Time series of two remotely sensed indices with sensitivity to vegetation greenness and moisture were tested as explanatory variables of LB incidence. Wavelet-based multiresolution analysis allowed the examination of these signals at different temporal scales in study sites in Belgium, where increases in LB incidence were reported in recent years. The analysis showed the potential of the tested indices for disease monitoring, the usefulness of analyzing the signal in different time frames and the importance of local characteristics of the study area for the selection of the vegetation index.

1. Introduction

Lyme borreliosis (LB) is a widespread disease caused by the spirochete *Borrelia burgdorferi* (*Bb*) and transmitted to humans by bites of infected ticks of the *Ixodes* genus. The main vector in Europe is *I. ricinus*; other tick species like *I. hexagonus* and *I. uriae* can also convey the pathogen to humans (Gern and Humair, 2002). LB is the most common tick-borne disease in Europe (EUCALB, 2011; Rizzoli et al., 2011; Smith and Takkingen, 2006) and incidence growth has been reported in several European countries during the last decade (see for example Hofhuis et al., 2006; Semenza et al., 2009; Smith and Takkingen, 2006).

Ticks feed on a wide range of hosts including mammals, birds and reptiles (Lindgren and Jaenson, 2006) being some of them competent to act as reservoir of *Bb*. In that case, *Bb* is transmitted from one organism to the other during blood meals. Host organisms (reservoir or not) are also important vehicles for the spatial distribution of ticks.

LB incidence and spatial spread is greatly dependent on environmental conditions impacting habitat, demography and trophic interactions of ticks and ticks' hosts. Landscape configuration is also a major determinant of tick habitat conditions and influences the fashion and intensity of human interaction with vegetated areas. Therefore, monitoring vegetated environments has become a public health concern as climate change may induce alterations in the severity of outbreaks and the spatial distribution of LB and other vector-borne diseases (Semenza et al., 2009).

The growing concern about environment-related vector-borne diseases has given an impulse to the exploration of data sources and monitoring techniques that offer the possibility of exploring changes in vector habitat conditions along the temporal and spatial dimension. In this respect, significant contributions have been provided by early works where both airborne (Wilson et al., 2003) and spaceborne (Brownstein et al., 2005; Eisen et al., 2005; Estrada-Peña, 2002; Kalluri et al., 2007; Kitron and Kazmierczak, 1997; Randolph, 2001) remote sensing (RS) have proven useful to study the connection between vegetation-related features and vector demography and/or disease incidence. The most commonly used RS product for these applications is the Normalized Difference Vegetation Index (NDVI).

Several studies report on the importance of humidity as one of the abiotic factors determining tick abundance (Estrada-Peña, 2001; Greenfield, 2011; Jensen et al., 2000), questing behavior (Mejlon and Jaenson, 1997) and preference for humid woodlands

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with abundant undergrowth and a thick litter layer (Lindgren and Jaenson, 2006). A positive correlation between humidity indicators and the number of LB reported cases has also been found (Bennet et al., 2006; Subak, 2003). In the light of these evidences, this study dwells into the question of whether the observed LB epidemiological pattern could be related to reflectance in remotely sensed segments of the electromagnetic spectrum (EMS) that are sensitive to humidity.

The objective of this study was to assess the correspondence between time series of a RS-based parameter with sensitivity to vegetation greenness and moisture – the Normalized Difference Water Index (NDWI) – and officially reported LB annual incidence in areas that have experienced notorious increments in LB incidence in recent years. Stated otherwise, we aimed at testing the potential of a remotely sensed indicator of vegetation moisture as explanatory variable in the modeling of LB incidence. The test was based on reflectance data captured by the MODerate Resolution Imaging Spectroradiometer (MODIS) sensor during the period 2000–2010 and the study focused on two areas of great epidemiological relevance in Belgium.

2. LB in Belgium

Belgium is located in Western Europe and its climate is temperate with warm summer and without a dry season. As temperature rises in the spring, the host-seeking activity of ticks is intensified after a period of low activity during the cold months. In addition, warm weather encourages outdoor activities and, therefore, the chance of encounters between infected ticks and humans increases. The combined effect of more active ticks and more human exposure to tick bites in spring and summer has shaped an annual pattern in LB occurrence, as shown in Fig. 1.

During the period 1993–2009, LB incidence in Belgium has exhibited a remarkable increase ranging, according to official statistics (Ducoffre, 2010), from 0.9 cases/100,000 inhabitants in 1996 to 16.2 cases/100,000 inhabitants in 2005. Due to the heterogeneous distribution of vegetated environments in the country, local incidence values deviate strongly from the country level figures. This becomes clear when examining the plots in Fig. 2 where the incidence values for a number of districts are presented.

The plots in Fig. 2 illustrate the local differences in LB incidence in terms of temporal pattern and incidence severity as compared to national values. Plots in Fig. 2A and B show the incidence values along the Franco-Belgian border where LB incidence is considerably higher than the average country incidence. Especially the last years of the period, when more than 200 cases/100,000 were reported in the district Neufchâteau (Ducoffre, 2010). LB has also been increasing in the northern part of the country as is the case in the district of Turnhout (Fig. 2C).

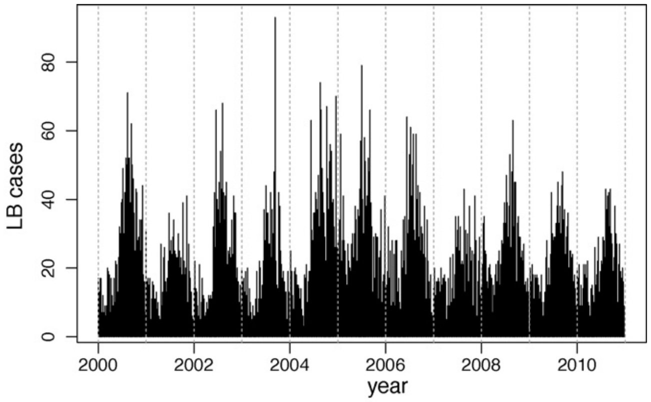

Fig. 1. Weekly records of LB cases for the period 2000-2010 in Belgium.

3. Materials and methods

3.1. Study area

Given the increasing trend in LB incidence detected in the north-east and south-west parts of the country and shown in the plots of Fig. 2, nine vegetated areas were randomly selected there as sample sites. The geographical position of the sample sites is presented in Fig. 3. This figure also shows the land cover classes in the surroundings of the sample sites according to the CORINE land cover map (European Environment Agency, 2009). Fig. 3 illustrates the difference in landscape configuration between the areas along the southern Franco-Belgian border (A) and those in the north (B) in terms of forest patchiness and urbanization.

3.2. Spaceborne data

The sensitivity of the short wave infrared (SWIR) region to changes in vegetation moisture has been widely documented (Ceccato et al., 2001; Gao, 1996; Zhang et al., 2010) and has been implemented in the form of a number of spectral indices. The most well known moisture related vegetation indices are computed as normalized differences between the near-infrared (NIR) reflectance and the SWIR and are commonly referred to in literature as Normalized Difference Water Index (NDWI). In this work, the NDWI was selected as indicator of vegetation moisture because it expresses the contrast between the sensed reflectance in the SWIR, which diminishes as vegetation water content increases, and the NIR reflectance, which increases in function of foliar density and canopy greenness and is indifferent to moisture content. An alternative approach could be the use of vegetation indices sensitive to chlorophyll content. Such approach would rely on the assumption of a direct relation between chlorophyll and water content. However, as shown by Ceccato et al. (2001) and Gond et al. (1999) and others, this assumption does not hold for all ecosystems as chlorophyll content can be also affected by factors different from water content.

The Terra satellite was launched in 2000 and orbits the earth on a daily basis. It carries the MODIS sensor that captures reflected energy on 36 EMR canals or bands with a huge potential for studies concerned with epidemiology and public health (Tatem et al., 2004). Two of these bands are located on the SWIR region and may be used for the computation of NDWI. In MODIS terminology, these bands are referred to as Band 5 and Band 6 and measure the reflectance in the ranges 1230–1250 and 1628–1652 nm, respectively. NDWI is mathematically expressed as shown in Eqs. (1) and (2).

$$NDWI_5 = \frac{\varphi_{841-876\,\mathrm{nm}} - \varphi_{1230-1250\,\mathrm{nm}}}{\varphi_{841-876\,\mathrm{nm}} + \varphi_{1230-1250\,\mathrm{nm}}} \tag{1}$$

$$NDWI_6 = \frac{\varphi_{841-876\,\mathrm{nm}} - \varphi_{1628-1652\,\mathrm{nm}}}{\varphi_{841-876\,\mathrm{nm}} + \varphi_{1628-1652\,\mathrm{nm}}} \tag{2}$$

where φ represents the reflected energy in the range indicated by the subscript. The MODIS data were obtained from the Land Processes Distributed Active Archive Center (LP DAAC) (USGS-Land Processes Distributed Active Archive Center, 2011) and are contained in the MOD09A1 product. This product comprises reflectance data on seven spectral channels oriented to study land surface processes. This product is issued every 8 days and includes a pixel quality assessment layer.

The pixels corresponding to the sample sites shown in Fig. 3 represented forested areas and were extracted from the datasets after having reprojected the images to the Lambert Azimuthal Equal Area