

Geospatial Health 6(3), 2012, pp. S87-S93

Application of a geographical information system approach for risk analysis of fascioliasis in southern Espírito Santo state, Brazil

Isabella Vilhena Freire Martins¹, Barbara Rauta de Avelar², Maria Julia Salim Pereira³, Adevaire Henrique da Fonseca³

¹Department of Veterinary Medicine, Universidade Federal Espírito Santo, Alto Universitário s/n, Alegre, Brazil;

²Course of Veterinary Medicine, Centro de Ciências Agrárias, Universidade Federal Espírito Santo, Seropedica, Brazil; ³Department of Animal Parasitology, Veterinary Institute, Universidade Federal Rural do Rio de Janeiro, Seropedica, Brazil

Abstract. A model based on geographical information systems for mapping the risk of fascioliasis was developed for the southern part of Espírito Santo state, Brazil. The determinants investigated were precipitation, temperature, elevation, slope, soil type and land use. Weightings and grades were assigned to determinants and their categories according to their relevance with respect to fascioliasis. Theme maps depicting the spatial distribution of risk areas indicate that over 50% of southern Espírito Santo is either at high or at very high risk for fascioliasis. These areas were found to be characterized by comparatively high temperature but relatively low slope, low precipitation and low elevation corresponding to periodically flooded grasslands or soils that promote water retention.

Keywords: *Fasciola hepatica*, fascioliasis, epidemiology, geographical information system, Brazil.

Introduction

Fascioliasis, caused by the trematodes *Fasciola hepatica* and *F. gigantica*, is a zoonosis of mainly veterinary interest. It is a major disease in ruminants, which has resulted in considerable economic loss due to mortality, liver condemnation, weight loss, anaemia, lethargy and reduced quality and quantity of milk production (Reid and Dargie, 1995). Over the last decade, the importance of human and animal fascioliasis in various countries of South America has been emphasised. The infection is considered a neglected disease according to the World Health Organization (WHO, 2012) and where animal cases are reported, human cases generally also exist. In South America, Peru and Bolivia are considered to be hyper-endemic for human and animal fascioliasis with other countries such as Chile, Ecuador, Colombia and Venezuela also affected (Fuentes, 2006; Rinaldi et al., 2012). Although the disease has been reported in

humans in many other parts of the world, including several states of Brazil, it has not been recorded in Espírito Santo (Igreja et al., 2004). Epidemiological knowledge about when, where and at what intensity there is risk of infection by *F. hepatica* is essential for the development of strategic control programmes (Kleiman et al., 2007).

Climatic variables are extremely important to the development of snails that act as intermediate hosts for *F. hepatica*, and as consequence, to its larval stages. The close relationship between climate and fascioliasis enables the development of models to estimate the risk of occurrence of the disease (Fox et al., 2011). Indeed, modelling the dynamics of fascioliasis in different regions with geographical information systems (GIS) have been used in different countries, assisting in decision-making strategies that mitigate the risk of occurrence of fasciolosis (Malone et al., 1998; Yilma and Malone, 1998; Tum et al., 2004; Dutra et al., 2010; McCann et al., 2010). GIS can also be used as an auxiliary tool when building models to estimate endemic, disease-free and potential dispersion areas of diseases. Its use is especially important in areas and types of events for which data are not available and where the development of disease control strategies requires modelling (Yang et al., 2005).

Although fascioliasis in ruminants is prevalent in

Corresponding author:
Isabella Vilhena Freire Martins
Department of Veterinary Medicine
Universidade Federal Espírito Santo
Alto Universitário s/n. Caixa postal 16, Alegre, Brazil
Tel. +55 28 3552 8643
E-mail: isabella@cca.ufes.br

several Brazilian states, epidemiological information on the disease in these areas is still insufficient (Dutra et al., 2010). The disease has only recently been recorded in Espírito Santo, a southern state of Brazil, with a growing trend of observed fascioliasis in cattle at slaughter with an average prevalence of 24.9% during the years 2006-2009 (Bernardo et al., 2011). Alves et al. (2011) reported the distribution and factors associated with fascioliasis in cattle in 10 municipalities of the southern part of Espírito Santo between 2008 and 2009.

Epidemiological analysis of human and animal fascioliasis has been carried out with GIS in different parts of the world (Malone et al., 1992; Yilma and Malone, 1998; Fuentes et al., 2001; Tum et al., 2004; Fuentes, 2006), including Brazil (Dutra et al., 2010). It was felt that this approach would be useful in the geographical context of Espírito Santo, as there is an increase of fascioliasis in the state and the determinants involved in the dynamics of the disease are still unknown. Assessment of the role of determinants responsible for the onset and prevalence of this parasitic disease are needed for this region. Thus, the objective of this study was to identify the determinants and analyse the risk of occurrence of fascioliasis in Espírito Santo, using a geo-environmental analysis system.

Material and methods

Study area

The current study focusses on the southern part of Espírito Santo situated between latitudes 20°27' S and 21°03' S and longitudes 41°00' W and 41°78' W, which represents zone 24 according to the universal transverse Mercator (UTM) geographic coordinate system. Its grid position 204,217-309,154 m W, 7,642,859-7,760,032 m S comprises an area of approximately 900,000 ha (Fig. 1). The climate in the region is described by the Brazilian Institute of Geography and Statistics (IBGE, 2008) as predominantly humid and subtropical, with high annual precipitation. The topography is dominated by plains and mountainous areas with numerous streams.

Analytic approach

The modules “*create*”, “*assessment*” and “*environmental signature*” of the Geo-environmental Analysis System (Vista Saga, 2007) from the Federal University of Rio de Janeiro (LAGEOP, 2007) were used to cre-

ate the dataset and the analyses. A bibliographic survey on the major factors involved in the fascioliasis epidemiology was done and the factors deemed relevant selected. The determinants were subjectively weighted according to their perceived relative importance (Table 1) before combining them for the construction of the fascioliasis risk-map.

For each determinant, a digital theme map was created in raster format based on theme maps in tiff format of Espírito Santo provided by Instituto Estadual do Meio Ambiente (IEMA), i.e. the State Environmental Institute. Together they formed a 150 x 150 km rectangle at 25 x 25 m resolution, totalling 36,000,000 pixels, georeferenced in UTM, datum SAD 69 (IBGE, 2005). The theme maps for temperature and precipitation correspond to the historical averages of the last 30 years. The determinant “*hydrography*”, although graded as relevant on its own, was represented in conjunction with land use given that the 1:25 m scale necessary to represent the study area could not portray details important for the occurrence of fascioliasis in a theme map, e.g. small



Fig. 1. The situation of the study area in the state of Espírito Santo and in Brazil.

Table 1. Weights and grades assigned to the epidemiological status of *Fasciola hepatica*.

Determinant	Weight	Category		
		8-10	4-7	1-3
Land use	24%	Pasture/wetland	-	Forest/agriculture/urban
Altitude	19%	<800 m	800 – 1,700 m	>1,700 m
Slope	19%	<0%	10 – 15%	>15%
Rainfall	17%	<1,600 mm/year	>1,600 mm/year	-
Soil type	13%	Alluvials/podzol	Latosol/podzol	Brunizem/cambisol*
Temperature	8%	15-25 °C	10-14.9 and >25 °C	6-9.9 °C

* Soils with incipient soil formation

streams, wetlands and irrigated areas discussed by other authors (Tum et al., 2004; Durr et al., 2005; Kleiman et al., 2007).

For the assessment of fascioliasis risk, weightings were assigned to determinants according to their assumed relevance to the occurrence of the disease. Categories not used in the analysis, but present on the maps, were blocked. Relevance grades ranging from 1 (low) to 10 (high) were assigned to the determinants (Table 1). Risk areas, obtained through the assessment process and represented by grades, were classified and grouped into the following categories: low risk (grades 1-4), moderate risk (5-6), high risk (7-8) and very high

risk (9-10). The representative risk-map was submitted to signature and the results presented and discussed.

Results

Theme maps of the risk factors associated with fascioliasis used in the analyses are shown in Fig. 2, and the spatial distribution of the risk areas in southern Espírito Santo is shown in Fig. 3. The results indicate that over 50% of southern Espírito Santo is either at high or at very high risk for fascioliasis (Table 2).

The results of the signatures carried out on the rep-

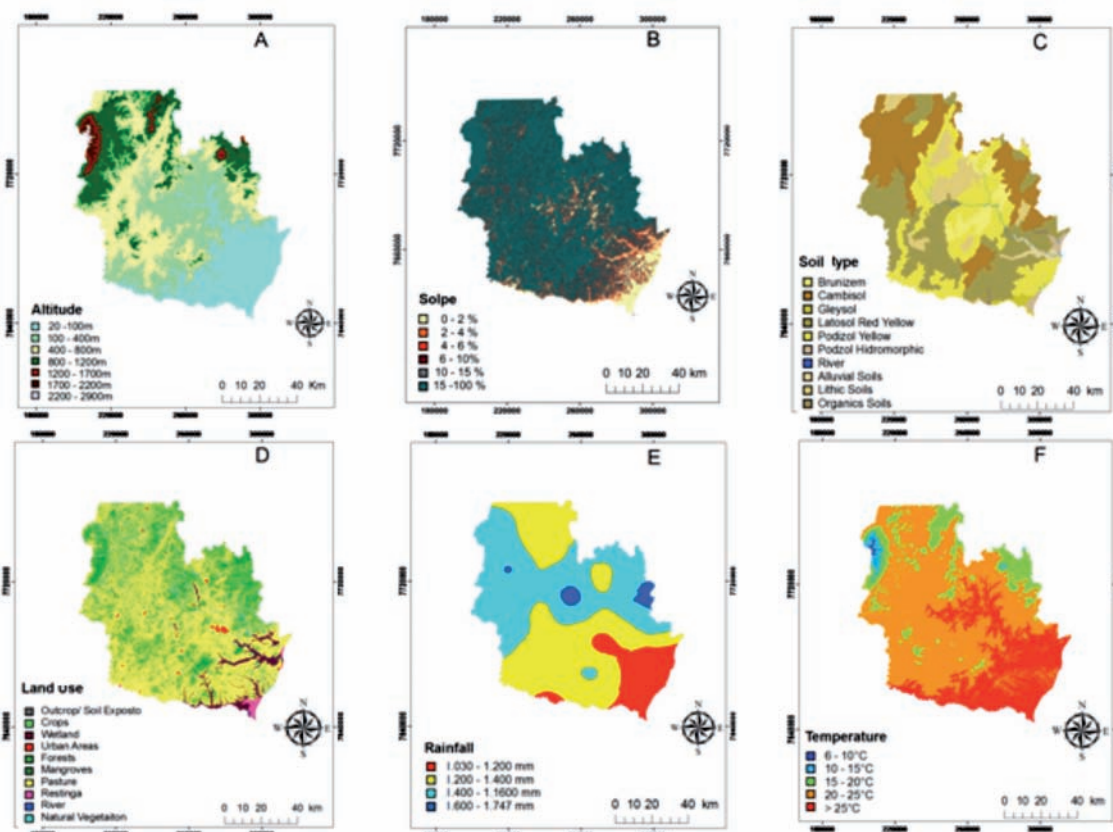


Fig. 2. Theme maps: land use (A); slope (B); rainfall (C); altitude (D); soil type (E) and temperature (F).

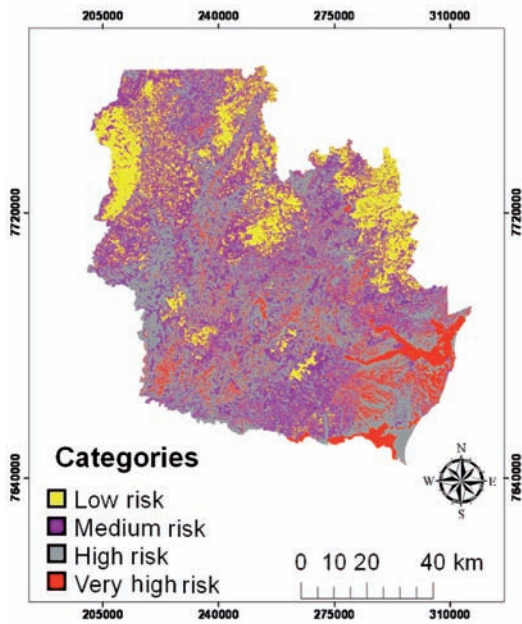


Fig. 3. The distribution of risk for fascioliasis in South Espírito Santo, Brazil.

Table 2. Size of the different risk areas for fascioliasis in South Espírito Santo, Brazil.

Risk category	Area (%)	Area (ha)
Low risk	16.1	145,937
Medium risk	29.1	263,257
High risk	47.4	429,151
Very high risk	7.4	66,906

Table 3. Fascioliasis risk in South Espírito Santo state, Brazil, stratified by city*.

City	Low risk	Medium risk	High risk	Very high risk
Alegre	9.85	30.67	54.49	4.99
Apiacá	2.33	19.90	69.17	8.60
Atilio Vivacqua	2.35	23.06	65.27	9.31
Bom Jesus do Norte	0.31	18.41	72.51	8.77
Cachoeiro de Itapemirim	9.96	26.74	56.99	6.31
Castelo	27.64	37.42	33.19	1.75
Divino de São Lorenço	37.35	36.75	25.90	0.00
Dores do Rio Preto	30.44	44.89	24.67	0.00
Guaçu	7.53	28.91	63.54	0.02
Ibatiba	19.89	42.81	35.46	1.84
Ibitirama	45.79	37.32	16.71	0.19
Irupi	22.86	40.33	35.93	0.89
Itapemirim	0.75	11.40	54.09	33.77
Iuna	31.40	40.36	26.45	1.78
Jerônimo Monteiro	1.17	21.80	68.34	8.68
Marataizes	0.02	6.28	57.80	35.90
Mimoso do sul	6.03	30.85	57.08	6.04
Muniz Freire	29.70	36.87	31.80	1.64
Muqui	5.30	23.26	63.09	8.35
Presidente Kennedy	1.15	13.01	64.57	21.26
Rio Novo do Sul	18.86	38.55	39.77	2.82
São José do Calçado	5.02	18.50	65.23	11.25
Vargem Alta	55.74	33.69	10.44	0.13

* All values are percentage.

representative risk-maps per municipality in southern Espírito Santo are shown in Table 3. The geography of three of the municipalities with >80% area in the high and the very high risk categories is dominated by grassland: Itapemirim (64.7%), Marataízes (67.9%) and Presidente Kennedy (69.3%). In addition, Itapemirim and Presidente Kennedy consist of 39% and 29% wetlands, respectively. The signature carried out on the land use showed that 77% of the areas assigned very high-risk consist of grassland and 22% of wetlands.

In this study, over 90% of the areas assigned very high-risk were found at elevations up to 400 m above the mean sea level (MSL); 100% when including elevations up to 800 m. The municipalities of Iuna, Ibitirama, Dores do Rio Preto and Divino de São Lourenço are situated at higher elevations, with 100% of the areas above 400 m. In addition, 80% of Ibitirama, Dores do Rio Preto and Divino de São Lourenço are above the 800 m elevation line.

The slopes of the areas assigned very high-risk were shown to vary up to 15% with 89% of the land characterized by slopes at 6% or lower. These areas also presented average temperatures above 20 °C with 68% having temperatures between 20 °C and 25 °C.

The soil types in the areas assigned very high risk are latosol (23.9%), podzol (34.6) and alluvial (15.3%). Latosol (oxisol) soils usually have high permeability and are composed of minerals at an advanced stage of weathering, while podzol (ultisol) has lower permeability. Alluvial (fluvisol) soils, consisting of alluvial

sediments, indicate areas where there is risk of flooding (EMBRAPA, 2006). The two first mentioned soil types account for 58% of all soils in the region. They have no particular water retention characteristics but may eventually turn into clay, thereby facilitating water retention.

Discussion

The modelled spatial distribution of fascioliasis risk in southern Espírito Santo indicates that 50% of the study area is at high or a very high risk for fascioliasis. Moreover, no cases of fascioliasis have been discovered in many municipalities situated in the other half of the land shown to have low or moderate risk (Alves et al., 2011), highlighting the good relationship between the model and the data gathered from farms in the region.

The signature carried out on the land use map showed that 77% of the areas of very high-risk are grasslands while 22% are wetlands, supporting the study by Tum et al. (2004), who identified these areas as being at high risk of fascioliasis due to *F. gigantica*.

In this study, over 90% of the areas assigned a very high-risk was situated at elevations up to 400 m above sea level reaching 100% when including elevations up to 800 m. These results are similar to those by Tum et al. (2004), working with *F. gigantica* and by Dutra et al. (2010), working with *F. hepatica*, who assigned areas as high-risk up to 400 m and low-risk above 1,200 m. Few studies have reported the presence of fascioliasis foci in areas situated at high elevation. For example, although Bennema et al. (2011) failed to find a significant relationship between elevation and risk of infection, they felt that a majority of reports support a negative relationship between elevation and infection risk. However, isolated endemic areas of human fascioliasis have been observed in the Bolivian Altiplano from 3,800-4,100 m above sea level (Fuentes et al., 2001). Infection by *F. hepatica* in areas up to 2,560 m above sea level in Ethiopia has also been documented by Yilma and Malone (1998), who argued that the parasite cycle is longer at higher elevations, a fact Malone et al. (1998) and McCann et al. (2010) agreed with. Thus, the fact that 80% of Ibitirama, Dores do Rio Preto and Divino de São Lourenço lie above 800 m elevation, does not necessarily contradict their status as areas carrying risk for fascioliasis.

In the study area, 100% of the area had slopes of up to 15%. Similarly, McCann et al. (2010) documented a negative relationship between slope, soil pH and the spatial distribution of *F. hepatica*, arguing that slope may influence the life cycle of the parasite as strong

slopes are less suitable to the intermediate host due to their increased drainage. Moreover, these authors claimed that slope may interfere with the vegetation cover, land use and soil type and thus have a negative effect on the snails. However, Bennema et al. (2011) found a positive relationship between slope and infection risk, which they attributed to small streams and water collections forming at the base of the hills.

Annual precipitation of up to 1,400 mm was observed in over 95% of the areas assigned a very high-risk. Although precipitation is a risk factor of for fascioliasis, there is no consensus on optimum precipitation levels. Rapsch et al. (2008) considered monthly precipitation of up to 90 mm as the maximum risk of occurrence of fascioliasis, which corresponds to an annual precipitation of 1,200 mm. According to these authors, the risk of infection decreases rapidly above 210 mm per month (2,500 mm annually). However, other authors argue that risk is higher in areas with high annual precipitation, moist soils and surplus water (McCann et al., 2010; Fox et al., 2011). Since Rapsch et al. (2008) attribute the transmission in arid areas to irrigation, rainwater collections and floods, the determinant precipitation alone may be a poor explanatory factor (Durr et al., 2005; Bennema et al., 2011).

Soil moisture has been identified as a key factor in determining year-to-year variation in the transmission of *F. hepatica* (Malone et al., 1984). The most favourable soils are those with high water retention capacity such as alluvial soils (Rapsch et al., 2008) and the transmission of the disease is being associated with poorly drained soils (Malone et al., 1992; Bennema et al., 2011) or loam soils (Charlier et al., 2011). McCann et al. (2010) also found that soils with thin layers of sand were positively associated with infection by *F. hepatica* due to their poor drainage capacity. However, vegetation cover may influence water retention by retaining soil moisture, thereby supporting transmission even in permeable soil types such as latosols and podzols.

All very high-risk areas presented average temperatures above 20 °C. Although Dutra et al. (2010) dismissed temperature as a relevant determinant for fascioliasis, they claimed that temperatures in the range of 10-25 °C would be ideal for the growth of the snails that act as intermediate hosts for the fascioliasis parasite. In contrast, Malone et al. (1998), working with *F. hepatica* and *F. gigantica* in Africa, argued that annual average temperatures above 23 °C represents the limit for maintaining the life cycle in the former snail species. This does not contradict the reported 18 °C optimum temperature for growth of the parasite,

but more studies on the relevance of temperature for the upper limit are warranted.

Although some studies (Dutra et al., 2010; Fox et al., 2011) argue that temperature and precipitation are the main determinants of *Fasciola* transmission efficiency, this is not always the case. While rainfall was a consistent predictor of infection in the many models developed by McCann et al. (2010) for the UK where the climate is temperate, the temperature was a predictor in five of them. On the other hand, as done in the model developed by Tum et al. (2004) for fascioliasis due to *F. gigantica* in Cambodia, temperature and precipitation were excluded, the former because it fluctuates little throughout the year, and the latter because they observed that flooding in the study area was rather caused by melting snow than local rainfall. This fact confirms the hypothesis that the determinants of fascioliasis risk vary with location and that risk factors may interact, e.g. in the UK, temperature had greater impact in areas where average temperature was above 10 °C and there was no rain shortage (Fox et al., 2011). In addition, these authors reported that in areas of high temperature and low precipitation, low soil moisture directly influenced snail development negatively. In Belgium, elevation, slope and soil type were not relevant with only precipitation and management practices being significant predictors (Bennema et al., 2011). The importance of management as a variable explaining the variation in the spatial distribution of *F. hepatica* in dairy farms has also been reported by Charlier et al. (2011). Although management systems were not evaluated in this study for lack of data, farm visits by other researchers have sometimes shown management problems such as grazing in areas suitable for the intermediate host snails (Alves et al., 2011).

Conclusions

Notably, risk factors of fascioliasis vary with geography and climate, factors that directly affect transmission of the disease. The use of GIS tools for the epidemiological study of fascioliasis enables the classification of risk areas and the development of control strategies. In this study, areas at higher risk were characterised by comparatively high temperature and low slope, precipitation and elevation. These areas correspond to periodically flooded grasslands, or with soils that promote water retention and are therefore suitable for the growth of the intermediate snail host.

Epidemiological data for fascioliasis in Brazil are still insufficient and we believe that the different abi-

otic and biotic factors require individualized studies. Therefore, studies on the spatio-temporal variation of the disease are essential for monitoring the transmission patterns in different regions.

Acknowledgements

This research was supported by CAPES (Coordination for the Improvement of Higher Education Personnel) – PROCAD n°093/2007.

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