Use of geographic information systems to identify areas at risk of introducing *Amblyomma variegatum* and *A. hebraeum* to Italy

Ilaria Pascucci, Annamaria Conte & Massimo Scacchia

Summary
Tick-borne diseases are one of the most important obstacles to the development of livestock breeding in Africa. Among these diseases, heartwater is of significant importance, second in rank to East Coast fever. Heartwater affects wild and domestic ruminants and is caused by a micro-organism belonging to the order *Rickettsiales*, previously called *Cowdria ruminantium* and recently renamed *Ehrlichia ruminantium*. The disease is transmitted solely by ticks. Although the aetiology and the clinical signs have been known for a long time, epidemiology presents many aspects that have yet to be understood. Among these, the biology of the vectors, ticks of the genus *Amblyomma*, present many features linked to environmental conditions that affect the likelihood of disease occurrence in free countries. Sporadic reports of the presence of *Amblyomma variegatum* in the Mediterranean are probably due to the introduction of these ticks by migratory birds. A predictive geographic information systems (GIS) model was built using temperature and land use as predictors that influence the risk of survival in Italy of infected *Amblyomma* ticks possibly carried by migratory birds. The model predicts Sardinia, Sicily and the south-western part of the Italian peninsula as being the most suitable areas for the presence of *A. variegatum* and *A. hebraeum* presence. The use of GIS could be an effective tool to estimate the risk of introduction and establishment of infected *Amblyomma* ticks.

Keywords
Amblyomma, Geographic information system, Heartwater, Italy, Land use, Survival, Temperature, Ticks.

Uso dei sistemi informativi geografici per identificare le aree a rischio per *Amblyomma variegatum* ed *A. hebraeum* in Italia

Riassunto
*Le malattie trasmesse da zecche nel continente africano rappresentano uno dei maggiori ostacoli allo sviluppo dell'allevamento del bestiame. Tra queste patologie heartwater è per importanza seconda solo all'*East Coast fever. Heartwater *colpisce i ruminanti domestici e selvatici ed è causata da un microrganismo appartenente all'ordine* Rickettsiales, *precedentemente chiamato* Cowdria ruminantium *e recentemente rinominato* Ehrlichia rumiantium. *Questa patologia è trasmessa esclusivamente da zecche. Sebbene l'eziologia e la sintomatologia clinica siano conosciute da lungo tempo, l'epidemiologia presenta ancora numerosi aspetti non ben conosciuti. Tra questi la biologia del vettore, le zecche del genere* Amblyomma, *presenta numerose caratteristiche legate alle condizioni ambientali che influiscono*

Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise 'G. Caporale', Via Campo Boario, 64100 Teramo, Italy
i.pascucci@izs.it

sulle probabilità di insorgenza della malattia in paesi indenni. Le sporadiche segnalazioni della presenza di Amblyomma variegatum *nell'area Mediterraneo sono probabilmente dovute all'introduzione di queste zecche mediante gli uccelli migratori. Un modello predittivo basto sull'utilizzo dei sistemi informativi geografici (GIS) è stato costruito considerando le temperatura ed uso del suolo come indicatori di previsione condizionanti il richio di sopravvivenza di esemplari di* Amblyomma *infetti eventualmente introdotti da uccelli migratori in Italia . Il modello individua la Sardegna, la Sicilia e l'Italia sud-occidentale come le più idonee all'insediamento di* A. variegatum *ed* A. hebraeum. *L'utilizzo dei GIS può risultare uno strumento efficace nella stima del rischio di introduzione ed insediamento di zecche infette appartenenti al genere* Amblyomma.

Parole chiave

Amblyomma, Heartwater, Italia, Sistema informativo geografico, Sopravivvenza, Temperatura, Uso del suolo, Zecche.

Introduction

Tick-borne diseases are one of the most important obstacles to the development of livestock breeding in Africa. Among these diseases, heartwater ranks second only to East Coast fever. Heartwater affects wild and domestic ruminants and is caused by a micro-organism that belongs to the genera *Rickettsiales*. It was previously called *Cowdria ruminantium* and has recently been named *Ehrlichia ruminantium*. It is transmitted solely by ticks of the genus *Amblyomma* (*Ixodoidea, Ixodidae*) (Fig. 1).

Amblyomma ticks are also capable of inflicting substantial direct losses to livestock breeding; wherever these ticks prevail, they represent a serious threat to livestock production (9).

At present, thirteen species of *Amblyomma* ticks are known to be able to transmit heartwater in natural or experimental conditions. In addition to the African vectors, three American species of *Amblyomma* have been shown to be capable of transmitting *E. ruminantium*: *A. cajennense* experimentally, although only transmission from larval to nymphal stages has been proved while transmission from nymphs to adults failed, *A. maculatum* has high vectorial capacity and *A. dissimile* (2, 3, 7, 12). These species are distributed widely in the Western hemisphere. Furthermore, the successful establishment in Florida of an exotic vector of *E. ruminantium* and *A. marmoreum* through the importation of foreign wildlife has been reported. In another survey of reptiles imported into Florida, *A. sparsum* ticks infected with *E. ruminantium* were detected on leopard tortoises (*Geochelone pardalis*) imported from southern Africa (4, 5).

Figure 1
Male *Amblyomma* tick

Five species of *Amblyomma* are natural vectors and are spread only in Africa, with the exception of *A. variegatum.* Of these, *A. hebraeum* and *A. variegatum* are the principal vectors. The first is only present in southern and East Africa, whereas the second prevails in Central Africa and also in the Caribbean and Yemen (3, 7). The establishment and the spread of *A. variegatum* (tropical bont tick, or TBT) in the Caribbean is a serious concern and efforts to control the disease have been coordinated in an international eradication programme (Caribbean *Amblyomma* Programme). From 1994 to 2005 the United States Department of Agriculture (USDA), French government, Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), Inter-American Institute for Cooperation on Agriculture (IICA), and the island nations of the Caribbean strived for the eradication of the TBT in the Caribbean. During this period, the TBT was eradicated from Anguilla, Montserrat and St Vincent. Furthermore, levels of infestation of the tick on Barbados, St Kitts, Nevis, Dominican Republic and St Lucia were greatly reduced, but in December 2005 it was realised that eradication of the TBT from the Caribbean region was not attainable, so the eradication programme was transformed into a region-wide TBT control programme. This programme will focus on surveillance and capacity building.

Amblyomma variegatum is still present in the Caribbean and the climatic and ecological conditions are favourable for its colonisation of parts of Argentina, Brazil, Central America, Colombia, Mexico, Paraguay, Venezuela and the United States. Moreover, the role of cattle egrets *(Bubulcus ibis)* in disseminating the TBT throughout the Caribbean has been demonstrated; marked egrets from Antigua and Guadeloupe were shown to migrate as far as the Florida Keys (6).

Figure 2 shows the distribution of the principal African vectors of heartwater. In this map, *A. gemma* is not present; it prevails mainly in the tropical areas of East Africa.

Although the aetiology and symptoms of heartwater have been known for a long time, the epidemiology of the disease is not yet fully understood. The biology of the vectors (genus *Amblyomma*), presents many features linked with the environmental conditions that affect the likelihood of occurrence of the disease in disease-free countries. On the other hand, sporadic occurrence of *A. variegatum* in the Mediterranean Basin (Sicily and Greece) could probably be linked to the introduction of these ticks by migratory birds, which are one of the suitable hosts of the immature stages of the tick (1, 8).

This study focuses only on *A. hebraeum* and *A. variegatum*, using a predictive model based on a geographic information system (GIS) to identify area at risk of *A. variegatum* and *A. hebraeum* spreading in Italy.

Materials and methods

Data on optimal environmental conditions for *A. variegatum* and *A. hebraeum* were collected from the literature: the more suitable land uses and the seasonality for each species were noted (10, 13).

Based on the literature (3, 10, 13) the land use obtained from Corine land cover (250 mt resolution) was classified into three risk categories (low, medium and high) for the survival and establishment of *A. variegatum* and *A. haebraeum*. High-risk areas were those rich in moisture and protected by UV. The land-use classification is presented in the Table I.

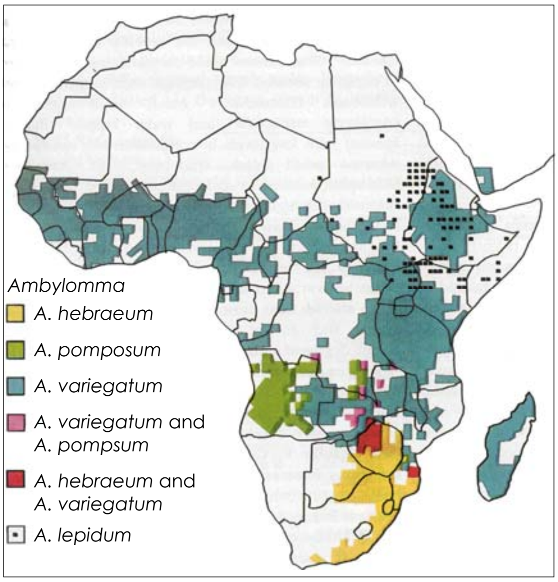

Figure 2
Distribution of the principal African vectors of heartwater
Source: *Infectious diseases of livestock, with special reference to southern Africa* (3)

Average temperatures registered during the spring (March-May is the risky period in Italy for *A. variegatum* and *A. hebraeum* introduction due to bird migration from southern Africa) by 102 Italian Air Force meteorological stations were been recorded and analysed by geo-statistic interpolation (ordinary kriging) (Fig. 4). These values were compared to the temperatures registered in different African areas during the peak activity period of the tick (www.bbc.co.uk/weather/world/country_guides/).

Table I
Land-use classification based on the risk of survival and establishment of *Amblyomma variegatum and A. hebraeum*
This classification enabled the development of the map given in Figure 3

Land-use classification		
Low risk	Medium risk	High risk
Continuous urban fabric	Road and rail networks and associated land	Permanently irrigated land
Discontinuous urban fabric	Green urban areas	Vineyards
Industrial or commercial units	Unirrigated arable land	Fruit trees and berry plantations
Port areas	Rice fields	Pastures
Airports	Olive groves	Land principally occupied by agriculture, with significant areas of natural vegetation
Mineral extraction sites	Annual crops associated with permanent crops	Agro-forestry areas
Dump sites	Complex cultivation patterns	Broad-leaved forest
Construction sites	Coniferous forest	Mixed forest
Sport and leisure facilities	Beaches, dunes, sands	Natural grasslands
Bare rocks	Intertidal flats	Moors and heathland
Burnt areas		Sclerophyllous vegetation
Glaciers and perpetual snow		Transitional woodland-shrub
Sea and ocean		Sparsely vegetated areas
		Inland marshes
		Peat bogs
		Salt marshes
		Salines
		Water courses
		Water bodies
		Coastal lagoons
		Estuaries

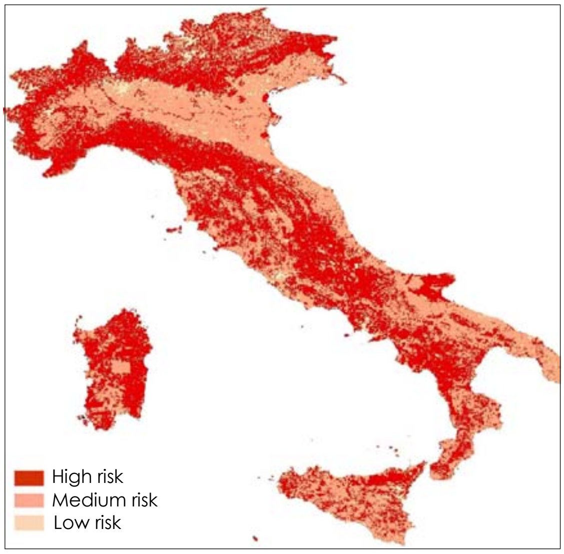

Figure 3
Reclassification of Corine land use into areas at risk

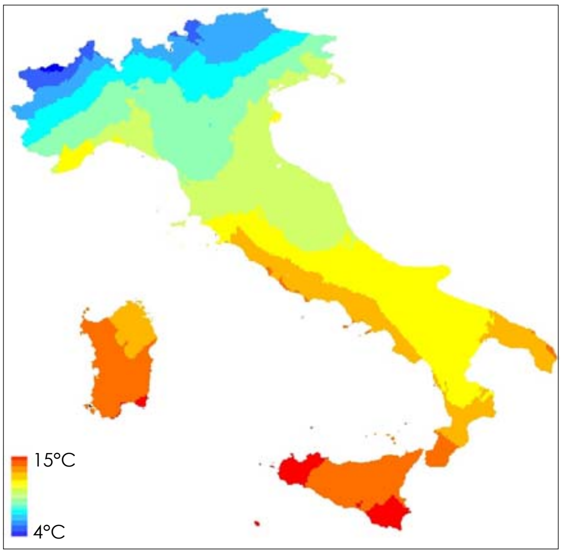

Figure 4
Average temperatures recorded in spring in Italy

It should also be noted that the hot temperatures of the summer will increase the probability of survival of ticks that may be carried by migratory birds.

The temperatures for each region of the areas during the period of the peak of activity of *A. variegatum* and *A. hebraeum* are shown in Tables II and III, respectively.

The average temperature grid (250 mt resolution) was reclassified into risk class on the basis of the temperature recorded during the peak period in Africa (<8°C low risk, 8-13°C medium, >13°C high).

A spatial process model, based on temperature and land-use reclassification was developed to identify areas in which *A. variegatum* and *A. hebraeum* are more likely to survive and establish.

Results

The final classification into areas at risk (low, medium, high) is shown in Figure 5.

The model predicts the highest levels of risk in areas of the southern part of the Tyrrhenian coast of Italy, together with the islands of Sicily and Sardinia, where the climate is usually very mild during the winter.

Discussion and conclusion

The model predicts the highest levels of risk in the islands of Sicily and Sardinia, both of which are situated on one of the main flyways

Table II
Temperatures registered into the areal of *Amblyomma variegatum* during peak activity
Minimal and maximal values are highlighted

Place	Peak of activity (season)	Average temperature		Extreme temperature	
		Min.	Max.	Min.	Max.
Tanzania (Dar-es-Salaam, coast)	November-March (rainy season)	24°C	31°C	19°C	36°C
Tanzania (Dodoma, inland)	November-March (rainy season)	18°C	31°C	13°C	36°C
Malawi (Lilongwe, upland)	November-March (rainy season)	16°C	29°C	11°C	34°C
Ethiopia (Harrare, upland)	March-July (spring rains)	14°C	27°C	11°C	31°C
Northern Somalia (climate very hot and dry)	April-May (rainy season)	25°C	36°C	19°C	44°C
Yemen (Red Sea coast)	March-July	25°C	37°C	21°C	41°C
Mozambique (Zumbo, Zambezi Valley)	September-May (rainy season)	15°C	38°C	7°C	49°C
Nigeria (Lagos, Atlantic coast very hot and humid)	May-June (middle of rainy-season) (adult peak)	23°C	31°C	21°C	40°C
Nigeria (Ibadan, central area with less humid climate)	May-June (middle of rainy-season) (adult peak)	22°C	32°C	18°C	35°C
Nigeria (Kano northern area, hot and dry climate)	May-June (adult peak)	23°C	37°C	17°C	44°C
Zimbabwe (Harare, upland)	September-May (rainy season)	9°C	28°C	2°C	35°C

Table III
Temperatures registered into the areal of *Amblyomma hebraeum* during the peak of activity
Minimal and maximal values are highlighted

Place	Peak of activity (season)	Average temperature		Extreme temperature	
		Min.	Max.	Min.	Max.
Mozambique (Zumbo, Zambezi Valley)	September-May (rainy season)	15°C	38°C	7°C	49°C
South Africa (Cape Province)	September-March (spring/summer)	14°C	26°C	1°C	39°C
Zimbabwe (Harare, upland)	September-May (rainy season)	9°C	28°C	2°C	35°C

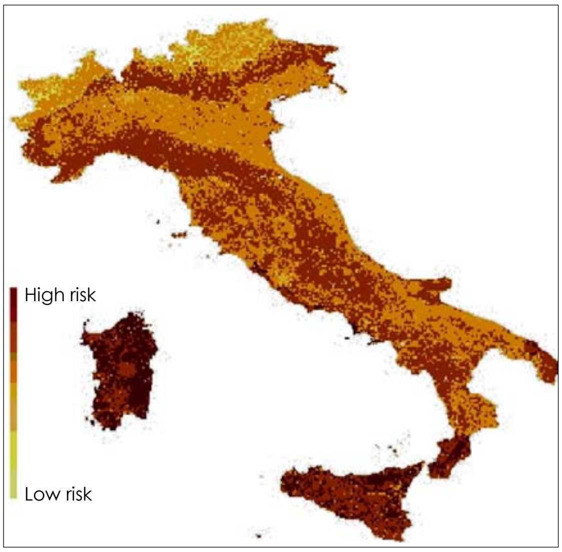

Figure 5
Predictive model of the risk of survival and of establishment in Italy of *Amblyomma variegatum* and *A. hebraeum* ticks

of birds migrating from sub-Saharan Africa to northern Europe. Furthermore, migratory birds stop along the entire Italian peninsula where they usually rest during migration. It must be noted that the model indicates the highest levels of risk in a part of Italy where the mild climate is favourable to breeding in a wild environment throughout the year, providing suitable hosts for the *Amblyomma* ticks that may be introduced.

This predictive model confirms suitable conditions for survival of *A. variegatum* in southern Italy, as described by Sutherst and Maywald in 1985 (11).

In conclusion, by using a GIS, it is possible to confirm the probability of introduction, survival and establishment of two species of *Amblyomma* ticks, the main vectors of heartwater, in the south-western areas of the Italian peninsula, in Sicily and in Sardinia. To improve this model, it will be necessary to extend the knowledge on the tick species introduced by migratory birds.

While international laws succeed in controlling animal movements, it is not possible to control the movements of vertebrate and invertebrate vectors that use natural routes that are affected by environmental conditions such as the wind and temperature variations.

Acknowledgments

The authors would like to thank Giuseppe Di Giulio for collecting and delivering the male *Amblyomma* ticks.

References

1. Albanese B., Smiraglia C. & Lavagnino A. 1971. Notizie sulle zecche di Sicilia con segnalazione di *Hyalomma detritum* e *Amblyomma variegatum*. *Riv Parassitol*, **32**, 273-276.
2. Allan S.A. 1998. Establishment of the tortoise tick *Amblyomma marmoreum* (Acari: Ixodidae) on a reptile-breeding facility in Florida. *J Med Entomol*, **35**, 621-624.
3. Bezuidenhout J.D., Prozesky L., du Plessis J.L. & van Amstel S.R. 1994. Heartwater, Chapter 35. *In* Infectious diseases of livestock, with special references to southern Africa, Vol. 1 (J.A.W. Coetzer, G.C. Thomson & R.C. Tustin, eds). Oxford University Press, Cape Town, 351-370.
4. Burridge, M.J. 2000. Evidence of *Cowdria ruminantium* infection (heartwater) in *Amblyomma sparsum* ticks found on tortoises imported into Florida. *J Parasitol*, **86**, 1135-1136.
5. Burridge M.J. 2000. Introduction of potential heartwater vectors and other exotic ticks into Florida on imported reptiles. *J Parasitol*, **86**, 700-704.
6. Food and Agriculture Organization (FAO) 2007. Caribbean *Amblyomma* Programme 2006. FAO, Rome (www.fao.org/ag/AGAInfo/projects/en/cap/home.html accessed on 29 July 2007).
7. Martinez D. 2003. Cowdriose. *In* Principales maladies infectieuses et parasitaires du bétail (Europe et régions chaudes), Chapter 91. Lavoisier, Éditions Tec & Doc, Cachan, 1111-1131.
8. Papadopoulus B., Morel P.-C. & Aeschlimann A. 1996. Ticks of domestic animals in the Macedonia region of Greece. *Vet Parasitol*, **63** (1, 2), 25-40.
9. Pascucci I. & Pressi G. 2007. Heartwater. *Vet Ital*, Monograph No. 21, 90 pp.
10. Petney T.N., Horak I.G. & Rechav Y. 1987. The ecology of the African vectors of heartwater, with particular reference to *Amblyomma hebraeum* and *Amblyomma variegatum*. *Onderstepoort J Vet Res*, **54**, 381-395.

11. Sutherst R.W. & Maywald G.F. 1985. A computerized system for matching climates in ecology *Agric Ecosyst Environ*, **13** (3-4), 281-299.
12. Uilenberg G. 1982. Experimental transmission of *Cowdria ruminantium* by the Gulf Coast tick *Amblyomma maculatum*: danger of introducing heartwater and benign African theileriasis onto the American mainland. *Am J Vet Res*, **43** (7), 1279-1282.
13. Walker J.B. & Olwage A. 1987. The tick vectors of *Cowdria ruminantium* (Ixodoidea, Ixodidae genus *Amblyomma*) and their distribution. *Onderstepoort J Vet Res*, **54**, 353-379.