Spatial distribution of brucellosis in sheep and goats in Sicily from 2001 to 2005

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Summary

Spatial analysis is making an increasingly important contribution to surveillance measures due to its ability to enable immediate visualization of information on the phenomenon studied. The authors describe the spatial distribution of prevalence and incidence of brucellosis in small ruminants in Sicily between 2001 and 2005. The study was conducted by integrating geographic information systems (GIS) technology (MapInfo® Professional 7.0) with SaTScan™ software to perform an epidemiological analysis of the municipalities and to locate problem areas. A comparison between the thematic maps produced for brucellosis in small ruminants on the basis of prevalence and incidence data for each individual year has shown that in terms of prevalence, the area identified as the secondary cluster in 2001 became the primary cluster from 2002 onwards whereas, in terms of incidence, the distribution of the clusters was irregular throughout the entire region during the years studied.

Keywords

Brucellosis, Geographic information system, Incidence, Prevalence, Sicily, Small ruminant, Spatial analysis.

Distribuzione spaziale della brucellosi ovi-caprina in Sicilia dal 2001 al 2005

Riassunto

Nell'ambito dell'applicazione delle misure di sorveglianza l'impiego della analisi spaziale sta assumendo un ruolo sempre più rilevante, grazie alla rapidità di impiego e all'efficacia che deriva dalla visualizzazione immediata delle informazioni sul fenomeno oggetto di studio. In questo lavoro gli autori descrivono l'andamento spazio-temporale della prevalenza e dell'incidenza della brucellosi ovicaprina in Sicilia nel corso degli anni 2001-2005. Lo studio è stato condotto integrando la tecnologia GIS (MapInfo® Professional 7.0) con il software SaTScan™ per la caratterizzazione epidemiologica dei territori comunali e l'evidenziazione di "aree problema". Il raffronto fra le mappe tematiche, realizzate per ogni singolo anno per la brucellosi ovi-caprina sulla base dei dati di prevalenza ed incidenza, ha evidenziato che, relativamente alla prevalenza, l'area individuata come cluster secondario nell'anno 2001 è diventata dal 2002 in poi cluster primario. In riferimento all'incidenza, nel corso degli anni considerati, la distribuzione dei cluster è stata irregolare su tutto il territorio regionale.

Parole chiave

Analisi spaziale, Brucellosi, Incidenza, Ovi-caprini, Prevalenza, Sicilia, Sistema informativo geografico.

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Introduction

Brucellosis in small ruminants caused by *Brucella melitensis* is a highly contagious disease that has a considerable impact in the animal husbandry sector. It is also considered to be the most widespread zoonosis in the world and is a serious human health hazard.

The prevalence of the disease in Italy is currently at very low levels in the northern and central regions of the country but remains critical in some southern regions and in Sicily.

Spatial analysis is making an increasingly important contribution to disease control measures due to its ability to provide immediate visualisation of the distribution of the phenomena under study within the territory. It is commonly used to determine whether a one-dimensional point process is purely random or whether clusters can be detected (3). Rapid detection of emerging geographic clusters due to unexpectedly occurring risk factors can be of great importance for public health (2). In the specific case of this study, this tool was used to determine the spatial distribution of brucellosis in small ruminants in Sicily in order to identify geographic problem areas, defined as groups of municipalities with a higher probability of positive flocks, and to analyse positivity trends in the areas considered between 2001 and 2005.

Materials and methods

SaTScan™ software (M. Kulldorff and Information Management Services, Inc. SaTScan™ v. 3.0: Software for the spatial and space-time scan statistics. Bethesda, National Cancer Institute, 2002) was used for statistical calculations and MapInfo® software was used to represent the results obtained in Sicily in the form of reliable and interpretable spatial images. In our study, each of the 390 municipalities making up the region of Sicily was identified as a centroid. The spatial position of each centroid was identified by geographic coordinates (latitude and longitude expressed in decimal degrees). The analysed data were obtained from the results of official laboratory tests conducted on sheep and goats by the *Istituto Zooprofilattico Sperimentale della Sicilia* between 2001 and 2005 as part of the national brucellosis eradication programme. Table I shows annual data for the number of flocks tested, the number of flocks tested as a percentage of the total present in the region, the number of flocks found to be infected and the number of newly positive flocks.

Table I
Brucellosis in small ruminants: tests conducted in Sicily, 2001-2005

Year	No. of flocks checked	No. of positive flocks	No. of newly positive flocks	Flocks covered (%)
2001	7 507	1 802	794	75.60%
2002	8 219	1 854	874	92.40%
2003	8 636	1 777	672	98.73%
2004	8 666	1 560	603	99.80%
2005	8 775	1 471	623	99.68%

A flock is considered infected (or positive) if it contains at least one animal that tests positive to the official serological tests for brucellosis. 'Newly positive' flocks are those that are found to be infected or positive after testing negative the previous year. The number of flocks located in each municipality in the region was defined as the population. For each year, we analysed 'cases' within this population (all flocks testing positive for brucellosis, i.e. prevalence) and 'newly positive' flocks (those that had become positive during the year, i.e. incidence).

The principal objective was to establish whether events (cases of infection) occur randomly throughout the Sicily region or whether clusters can be identified. For this purpose, the purely spatial method of SaTScan™ software and the Poisson probability model were used. The distribution of cases throughout the region was assumed to be random, in other words, there were no areas with a higher probability of flocks becoming positive.

To describe the spatial distribution of brucellosis in small ruminants, the Sicily region was partitioned into cells corresponding to municipalities. For each municipality, the coordinates of geographic centroid, number of flocks and number of cases of disease were considered. The SaTScan™ software created circular windows within the area, identifying each municipality as the centre of the circle (the centroid). The software included a gradually higher number of municipalities surrounding the centroid by increasing the radius from zero (corresponding to one municipality) to a maximum limit. At this maximum limit, the window contained a percentage of cases out of the total number of flocks in the region that was lower than or equal to the values of regional prevalence or incidence for each year. Each window therefore differed from the others in terms of its position and radius. Finally, clusters inside the circles were identified by SaTScan.

For each window, we constructed a hypothesis system to verify whether the probability of the disease occurring inside the window was equal to the probability of the disease occurring outside the window (1). To do this, we let *G* be the geographical space (Sicily region) and *Z* the set of all circular zones $z \subset G$ (1). We considered a point (z, p, q) in the parameter space where p and q vary from 0 to 1 and z is used to denote a vector made by the centroid coordinates and the radius of circle and also to denote the zone it describes (1). The hypothesis system is as follows:

$H_0 : p = q$
- $H_1 : p > q$
- p : probability of a case occurring in the municipalities inside the circular window
- q : probability of a case occurring in the municipalities outside the circular window
- $\lambda = \dfrac{\left(\dfrac{c(z)}{\mu(z)}\right)^{c(z)} \left(\dfrac{c(G)-c(z)}{\mu(G)-\mu(z)}\right)^{c(G)-c(z)}}{\left(\dfrac{c(G)}{\mu(G)}\right)^{c(G)}}$.

To test the hypothesis system we used the likelihood ratio test (4) where:
- $c(G)$ = total number of cases observed in the region
- $c(z)$ = number of cases inside the circular window z
- $\mu(z)$ = expected number of cases inside the circular window z
- $\mu(G)$ = expected number of cases in the region.

To solve the equation, we performed a simulation using the Monte Carlo technique with 9 999 iterations (3).

For example, in 2005 each replicate involved choosing 1 471 flocks at random from the total number of flocks (8 775) and labelling these as cases.

The windows in which the null hypothesis can be rejected (*p*-value less than or equal to 0.05) can be defined as clusters.

Results

The prevalence in the region during 2005 was found to be 17% (95%, with a confidence interval [CI] of 16-18%) and this was taken as the upper limit for the radius. Table II gives the results obtained from the simulation of the equation. The incidence in the region in 2005 was 7% (95%, CI: 6.56-7.64%) and this was taken as the upper limit for the radius. Table III gives the results obtained from the simulation of the equation considering the new cases. Tables IV and V give the results of the simulations for 2001-2004.

Prevalence in the entire region fell slightly over the five year period (Fig. 1).

Cluster analysis revealed that the first cluster measured in 2001 became the second cluster from 2002 to 2005 with a smaller radius (in terms of kilometres), covering fewer municipalities. The second cluster measured in 2001 became the first cluster from 2002 onwards with an almost constant radius. The third cluster measured in 2001 contained gradually fewer municipalities in subsequent years with the exception of 2004 when the situation was similar to that of 2001. Lastly, in 2005 a further cluster was observed that was not present in previous years with its centroid in the municipality of Montallegro (Figs 2, 3, 4, 5, 6).

The value of incidence in Sicily in the first two years was approximately 11%, but, as of 2003, it fell to 7% (Fig. 7).

Table II
Geographic prevalence cluster of brucellosis in small ruminants in Sicily obtained by SaTScan simulation, 2005

Clusters	Centroid	Radius (km)	No. of municipalities	Prevalence within the cluster	λ	*p*-value
I cluster	San Cono	49.71	57	36%	136	0.0001
II cluster	Gaggi	35.38	86	33%	52	0.0001
III cluster	Marsala	–	1	69%	34	0.0001
IV cluster	Alcamo	17.94	11	33%	13	0.0006
V cluster	Montallegro	12.19	5	44%	13	0.0007

Table III
Geographic incidence cluster of brucellosis in small ruminants in Sicily obtained by SaTScan simulation, 2005

Clusters	Centroid	Radius (km)	No. of municipalities	Incidence within the cluster	λ	*p*-value
I cluster	Ramacca	33.59	36	18%	36.48	0.0001
II cluster	Naro	12.60	7	36%	27.07	0.0001
III cluster	Cerami	6.39	2	19%	11.14	0.0030
IV cluster	Salemi	19.02	10	14%	9.41	0.0138

Table IV
Regional prevalence of brucellosis in small ruminants and main clusters recorded in Sicily, 2001-2004

Year	Regional prevalence	Prevalence confidence interval (95%)	No. of clusters at greatest risk of brucellosis
2001	24.00%	23.00%–25.00%	3
2002	22.56%	21.65%–23.46%	4
2003	20.58%	19.72%–21.43%	4
2004	18.00%	17.00%–19.00%	3

Table V
Regional incidence of brucellosis in small ruminants and main clusters recorded in Sicily, 2001-2004

Year	Regional incidence	Incidence confidence interval (95%)	No. of clusters at greatest risk of brucellosis
2001	10.57%	9.88%–11.27%	4
2002	10.63%	9.97%–11.30%	3
2003	7.78%	7.22%–8.35%	3
2004	7.00%	6.42%–7.49%	4

Cluster analysis from 2002 to 2005 reveals a shift in the cluster from the province of Palermo to the province of Trapani. In 2004 in particular, it was the primary cluster with a centroid in San Vito Lo Capo. This shift in the cluster was probably due to improved management of brucellosis outbreaks by the veterinary services of the province of Palermo. In 2005, the cluster present in previous years with a centroid in the municipality of San Michele di Ganzaria was not observed. Instead, three new clusters that were not present in previous years were observed (Figs 8, 9, 10, 11, 12).

The procedure was validated through a comparison between the results obtained from cluster analysis applied to prevalence and the theme maps which show the real prevalence data observed in the various municipalities (Figs 13, 14, 15, 16, 17) (5).

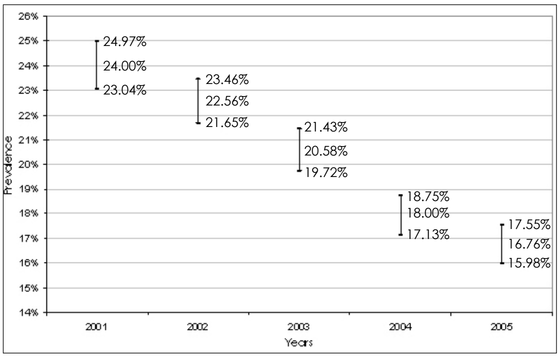

Figure 1
Brucellosis of sheep and goats in Sicily: variation of prevalence, 2001 to 2005

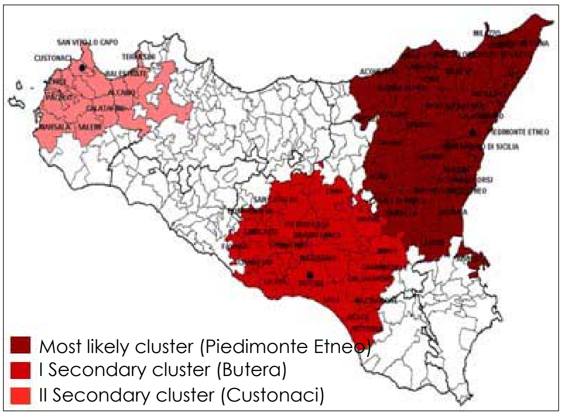

Figure 2
Brucellosis of sheep and goats in Sicily: clusters of prevalence, 2001

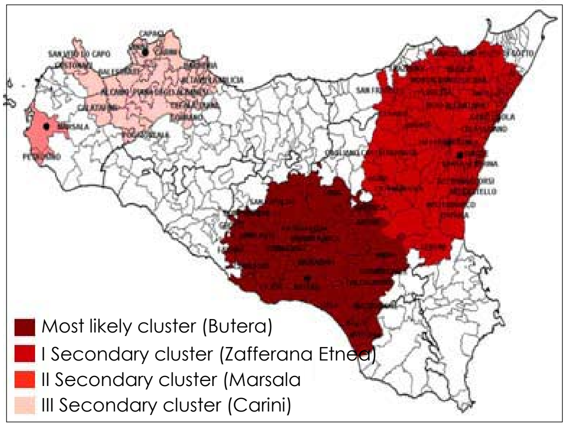

Figure 3
Brucellosis of sheep and goats in Sicily: clusters of prevalence, 2002

These maps were constructed by categorising the seroprevalence of each year on the basis of 25, 50 and 75 percentiles to obtain four different classes for municipalities for each year, as shown in Table VI.

From a comparison between the theme maps describing prevalence and those constructed for validation we found that:

- in 2001, 94% of the municipalities with a prevalence greater than 57% were included in the clusters obtained (Fig. 2)
- in 2002, 94% of the municipalities with a prevalence greater than 51% were included in the clusters obtained (Fig. 3)
- in 2003, 81% of the municipalities with a prevalence greater than 50% were included in the clusters obtained (Fig. 4)
- in 2004, 86% of the municipalities with a prevalence greater than 51% were included in the clusters obtained (Fig. 5)
- in 2005, 83% of the municipalities with a prevalence greater than 51% were included in the clusters obtained (Fig. 6).

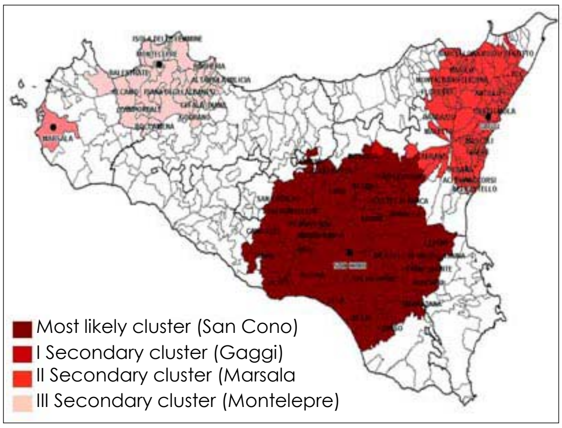

Figure 4
Brucellosis of sheep and goats in Sicily: clusters of prevalence, 2003

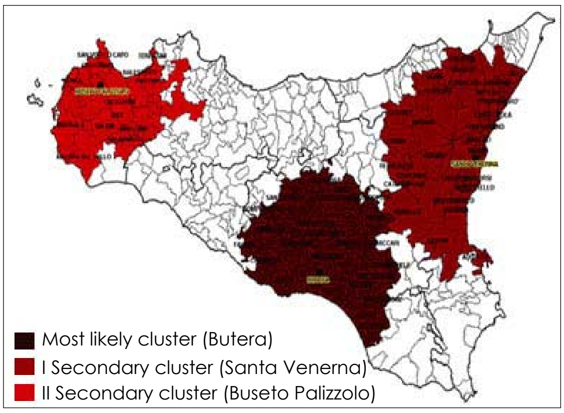

Figure 5
Brucellosis of sheep and goats in Sicily: clusters of prevalence, 2004

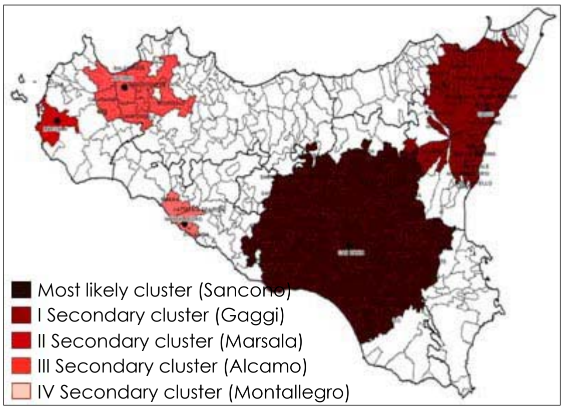

Figure 6
Brucellosis of sheep and goats in Sicily: clusters of prevalence, 2005

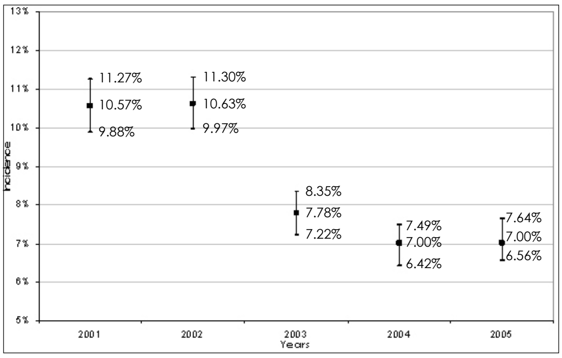

Figure 7
Brucellosis of sheep and goats in Sicily: variation of incidence, 2001 to 2005

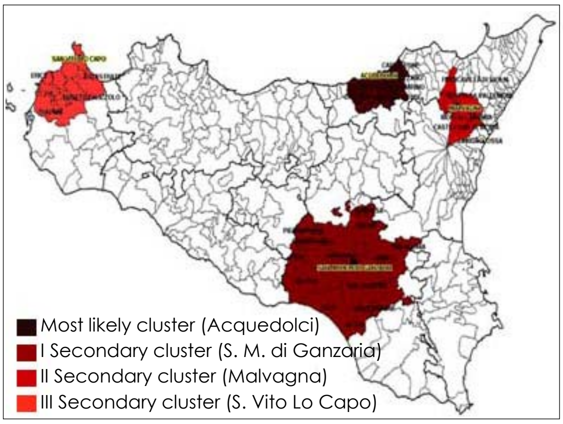

Figure 8
Brucellosis of sheep and goats in Sicily: clusters of incidence, 2001

Discussion

The location of the significant clusters detected by scan statistics generally matched those areas within the highest quartile (Figs 13, 14, 15, 16, 17).

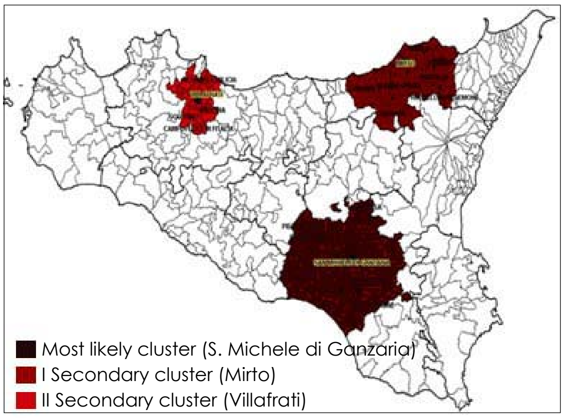

Figure 9
Brucellosis of sheep and goats in Sicily: clusters of incidence, 2002

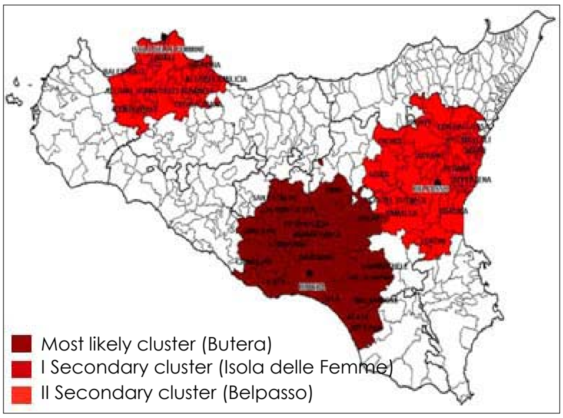

Figure 10
Brucellosis of sheep and goats in Sicily: clusters of incidence, 2003

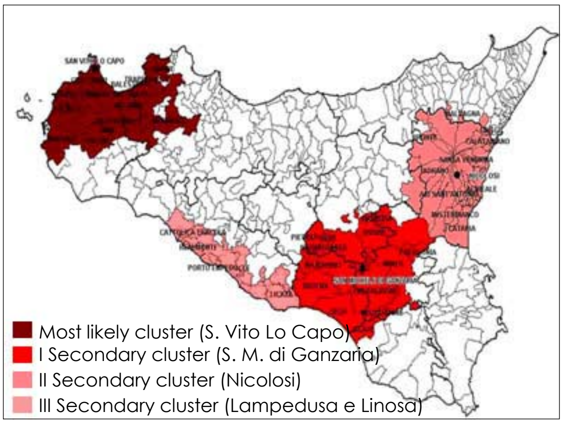

Figure 11
Brucellosis of sheep and goats in Sicily: clusters of incidence, 2004

In this study, some areas of the region were identified as clusters in all five years. Where resources are limited, control activities could be targeted at areas with significant longlasting disease clusters. When a cluster moved from one area to a neighbouring area, the reasons for that shift could also be investigated further.

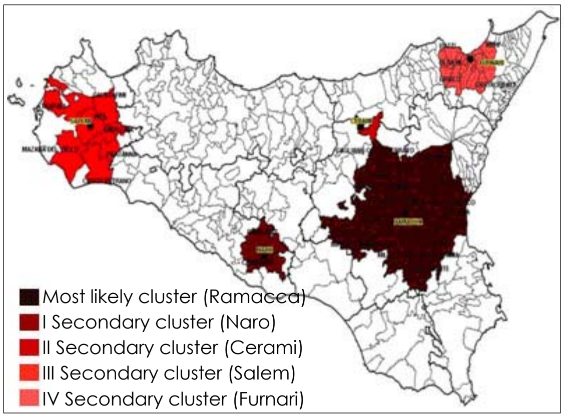

Figure 12
Brucellosis of sheep and goats in Sicily: clusters of incidence, 2005

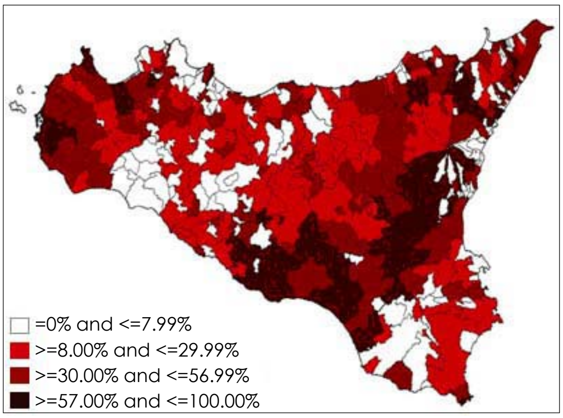

Figure 13
Brucellosis of sheep and goats in Sicily: distribution of prevalence, 2001

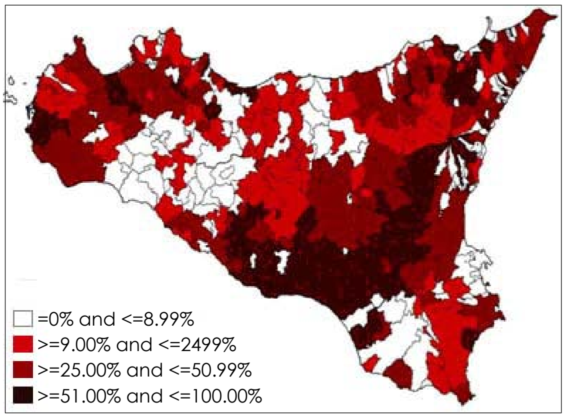

Figure 14
Brucellosis of sheep and goats in Sicily: distribution of prevalence, 2002

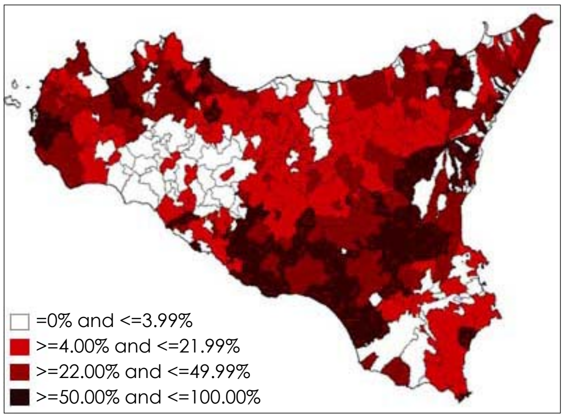

Figure 15
Brucellosis of sheep and goats in Sicily: distribution of prevalence, 2003

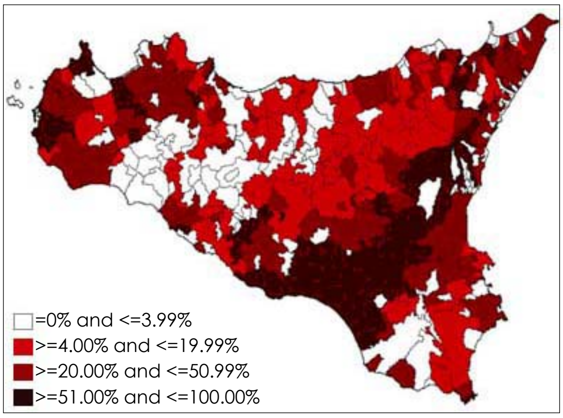

Figure 16
Brucellosis of sheep and goats in Sicily: distribution of prevalence, 2004

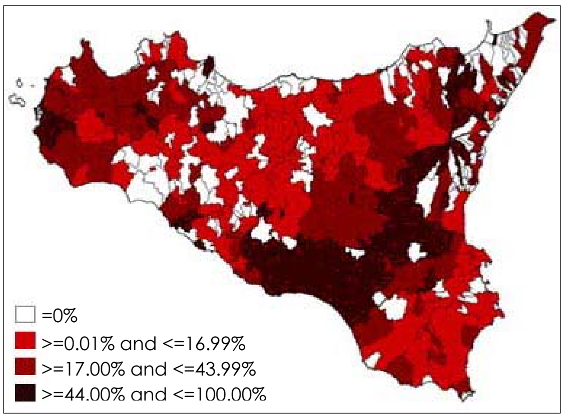

Figure 17
Brucellosis of sheep and goats in Sicily: distribution of prevalence, 2005

Table VI
Prevalence classes on the basis of 25, 50 and 75 percentiles

Class	2001	2002	2003	2004	2005
1	≤7.99%	≤8.99%	≤3.99%	≤3.99%	–
2	≥8% ≤29.99%	≥9% ≤24.99%	≥4% ≤21.99%	≥4% ≤19.99%	≥0.01% ≤16.99%
3	≥30% ≤56.99%	≥25% ≤49.99%	≥22% ≤49.99%	≥20% ≤50.99%	≥17% ≤43.99%
4	≥57% ≤100%	≥51% ≤100%	≥50% ≤100%	≥51% ≤100%	≥44% ≤100%

Observation of the clusters shows that three geographic areas (varying in size during the studied) were at greatest risk in terms of prevalence. These areas are located in the north-east of Sicily (eastern area of the province of Messina and the province of Catania), the central southern area (bordering areas of the provinces of Agrigento, Caltanissetta and Ragusa) and the province of Trapani in the north-west.

In particular, several municipalities (Table VII) displayed a constant level of risk during the period under investigation. During the period 2001-2005, positive flocks located in these municipalities accounted on average for 18% of all the positive flocks located in Sicily. Another municipality that exhibited a constant level of risk was Marsala which, in 2001 and 2004, was located in the third-largest cluster (extending over several municipalities) but in 2002, 2003 and 2005 formed a cluster in its own right.

Table VII
Municipalities at highest risk of brucellosis, 2002-2005

Municipalities at constant risk from 2002 to 2005	
Acate	Mirabella Imbaccari
Aidone	Naro
Barrafranca	Niscemi
Butera	Piazza Armerina
Caltagirone	Pietraperzia
Caltanissetta	Raddusa
Campobello di Licata	Riesi
Canicatti'	San Cataldo
Delia	San Michele di Ganzaria
Enna	Santa Caterina Villarmosa
Gela	Serradifalco
Grammichele	Sommatino
Licata	Valguarnera Caropepe
Mazzarino	Villarosa
Mineo	Vittoria

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