The Use of Risk Assessment to Decide the Control Strategy for Bluetongue in Italian Ruminant Populations

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The affiliation, assessment and management of risks is a traditional part of veterinary medicine. In the past, veterinary services involved in this type of activity usually assessed risks qualitatively. However, since the 1990s, quantitative methods have become increasingly important. The establishment of the World Trade Organization in 1994, and the promulgation of its Agreement on the Application of Sanitary and Phytosanitary Measures (the “SPS Agreement”) led to an increased application of import risk analysis and to significant improvements in the methodology of risk analysis as applied to international trade policy for animals and animal products. However, there was very little development of risk analysis in veterinary fields other than international trade and management of health risks to consumers of animal products and little has been published on its use in the choice and definition of control or prophylaxis strategies for animal diseases. This article describes a quantitative risk assessment, which was undertaken in Italy to help choose an appropriate national response strategy following an incursion of bluetongue, an infectious disease of sheep and goats. The results obtained in this study support the use of risk analysis as a tool to assist in choosing an appropriate animal disease management strategy. The use of risk analysis in the evaluation of disease management strategies also offers advantages in international trade. It makes easier the comparison of different strategies applied in the various countries, and thus facilitates the assessment of equivalence of the guarantees provided by different strategies.

KEY WORDS: Bluetongue; control strategy; infectious disease; risk assessment; veterinary medicine

1. INTRODUCTION

The assessment and management of risks is a traditional part of veterinary medicine. In the past, veterinary services involved in this type of activity usually assessed risks qualitatively. However, since the 1990s, quantitative methods have become increasingly important. The establishment of the World Trade Organization in 1994, and the promulgation of its Agreement on the Application of Sanitary and Phytosanitary Measures (the “SPS Agreement”),(1) led to the formal recognition of the Office International des Epizooties (the world organization for animal health)(2) as being responsible for developing the standards and guidelines for safe international trade in animals and animal products.

The SPS Agreement states that sanitary or phytosanitary measures in international trade may be applied only to the extent necessary to protect human, animal, or plant life or health and must be based on scientific principles. The agreement also identifies risk

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analysis as the tool to ensure that scientific principles are applied in the choice of measures to be applied in international trade.

The increased application of import risk analysis,(3) which followed the adoption of the SPS Agreement, led to significant improvements in the methodology of risk analysis as applied to international trade policy for animals and animal products.(4) However, there was very little development of risk analysis in veterinary fields other than international trade and management of health risks to consumers of animal products. Nevertheless, it is apparent that the techniques of quantitative risk assessment could have a wide range of veterinary applications. Risk analysis is a tool for decision making in the face of uncertainty and provides numerical estimates of the probabilities and consequences associated with particular scenarios. Risk analysis allows a quantitative evaluation and comparison of various scenarios ranging from no safeguards to combinations of various safeguards. It facilitates the communication of risks and their consequences to stakeholders and decision-makers and allows decision-makers to choose appropriate safeguards in a transparent fashion. However, little has been published on its use in the choice and definition of control or prophylaxis strategies for animal diseases.

This article describes a quantitative risk assessment, which was undertaken in Italy to help choose an appropriate national response strategy following an incursion of bluetongue (BT), an infectious disease of sheep and goats. BT appeared for the first time in Italy in August 2000, probably as a result of the wind-borne introduction of infected insect vectors (the most important of which is the midge Culicoides imicola) from North Africa. The main epidemiological features of BT are summarized in Box 1.

The choice of the strategy was made after assessing the range and magnitude of consequences of implementing or not implementing a vaccination program of all susceptible domestic livestock (cattle, sheep, and goats) in the affected regions, or just the sheep and goats.

The relevant regions had already been defined in a European Commission Decision dated February 9, 2001, which set BT protection and surveillance zones in the Community.(5) This decision declared all provinces of Sardinia, Sicily, Calabria, and Basilicata, and one province of Campania, Salerno (Fig. 1) as protection zones, within which a vaccination program should be implemented.

**BOX 1.**

BT is an infectious disease of ruminants transmitted by insect vectors and, although all ruminants are susceptible to infection, clinical signs are seen mainly in sheep and goats.(10) The etiological agent is a virus, of which 24 serotypes are known. Their pathogenicity is variable and immunity (naturally acquired after infection or induced by vaccination) against one serotype is often ineffective in case of infection due to a different serotype.

In the past, BT was endemic in the eastern Mediterranean basin with sporadic spillover in Europe (Cyprus, Greece, Spain, and Portugal) that never led to an establishment of the infection. In December 1999, BT was notified in Tunisia, along the eastern coast of the country. New outbreaks appeared in the whole northern part of Tunisia during the summer of 2000. During summer and autumn 2000, Italy experienced the largest bluetongue epidemics in Europe. Three regions were involved (Sardinia, Sicily, and Calabria), inhabited by 54.7% of the entire Italian sheep and goat population. In the early fall of 2000 the disease has been also identified in Spanish Balearic islands and French island of Corsica.

BT virus is transmitted by midges (mosquito-like insects of the genus Culicoides), and the disease is generally considered to be present, or potentially present, in a zone between the 40° parallel North and the 35° parallel South, where climatic and environmental conditions are suitable to the vector’s life cycle. In reality, these limits are theoretical, since insects can spread beyond such boundaries under appropriate meteorological conditions.(10) Once infected by the vector, an unvaccinated animal undergoes a long viraemic period, lasting up to 45–60 days, during which the virus can be transmitted to the midges, thus assuring survival of infection during the cold season. Non-infectious virus RNA can be detected for as long as 220 days after infection. From an epidemiological point of view, particular attention must be paid to bovine animals, which are presumed to be viral amplifiers, even though they do not show any clinical signs of the disease.

Factors regulating vector presence have an influence on the disease spread. Therefore, its pattern is strictly seasonal. The first cases of BT usually occur late in the summer, with the highest incidence at the end of that season; the disease then tends to disappear at the beginning of winter, with night temperatures below 12°C. Adult Culicoides are active during night hours (from dusk to dawn) and bite animals to feed on their blood. Insects become infected by feeding on infected animals during viraemia and remain infected for the rest of their lives. Virus vertical transmission (from one generation to another) in midges has not been proved. In order to reproduce, Culicoides need fresh water; eggs are laid in humid transitional areas at the edge of water ponds. Here the insect goes through its growth cycle (larva and pupa) and becomes an adult. The adult midges are able to actively fly in an area of a few hundred meters while wind can transport them for over 300 km.
The purposes of BT vaccination in the protection zones are:

- To reduce losses due to BT mortality in sheep and goats; and/or
- To reduce the likelihood of the disease spreading from Calabria (Southern Italy, Fig. 1) to other Italian territories by creating a belt of animal population resistant to infection; and/or
- To attempt, in the long-term, eradication of BT from Italian territory by interrupting virus transmission.

2. METHODS

The assessment was carried out by answering the following questions:

1. What is the likelihood of BT spreading from areas of southern Italy infected during the year 2000 (Calabria) without a vaccination program?
2. What are the effects of vaccinating either sheep and goats or sheep, goats, and cattle for BT in the regions involved on the spreading
of the disease and on eradication of BT from Italy?

The overall risk assessment was conducted on a qualitative basis by evaluating the likelihood of each event occurring, while some specific problems were analyzed also on a quantitative basis, by computer models.

In the following sections, methods used to answer each question are described.

2.1. What is the Likelihood of BT Spreading from Infected Areas of Southern Italy Without a Vaccination Program?

In order to determine the likelihood of BT spreading, qualitative and quantitative risk assessments were conducted. In the quantitative assessment, the weekly infection probability in municipalities of Calabria was calculated.

The model’s input variables were chosen by a multiple logistic regression performed on geographical features of the municipalities analyzed (unpublished data). The study area analyzed in the multiple logistic regression was the whole of Sardinia region, the first and most widely affected Italian region. Variables considered in the logistic regression were the mean height above sea level, cattle population density, and sheep and goat population density. The dependent variable was the presence or absence of BT outbreaks in each municipality. The model including the mean height above sea level of the municipal territory (variable affecting climatic conditions and water stagnation due to the soil gradient; both characters are important to the vector biology), and sheep and goat population density per square kilometer had a significant Hosmer and Lemeshow chi-square test and was used to build the deterministic model for the likelihood of BT spreading from infected areas.

These input variables and the average rate of spread observed in a reference area (i.e., an area where the infection spread is less affected by the presence of mountains) of the region of Calabria have been used to estimate the weekly risk of infection of each municipality of the part of southern Italy where a significant presence of *C. imicola* (the main vector) has been detected by entomological surveillance. The model shown in Table I generates values between 0 and 1 that rank the risk of infection (*p*) of the municipality in a given week. In order to evaluate the results in the validation of the model and to compare them with the observed data, it was decided that values ≥0.5 for *p* indicated that the municipality was predicted to be infected, values below this threshold of 0.5 indicated that the municipality was predicted to be not infected. The threshold 0.5 was chosen to be consistent as far as possible with the classification table of the logistic regression from which the model derived. Classification tables of logistic regression usually employ the value of 0 of the logit of probability (i.e., log(*p*/(1 − *p*)), corresponding to 0.5 probability, as breakpoint.

The structure of the model is presented in Table I. The deterministic model was developed using MS-Excel 1997.

### Table I. Structure of the Model on BT Spread

For each municipality and each week, the probability of infection entering the municipality was calculated as follows:

\[
\forall d/v \leq w \Rightarrow p = 1 - (1 - p_0)^{\text{int}(w - d/v) + 1},
\]

\[
\forall d/v > w \Rightarrow p = 0,
\]

where *p* is the probability of municipality becoming/remaining infected in a given week; *d*, the distance of municipality centroid from the nearest centroid of primarily infected municipalities (in km); *v*, the average weekly rate of spread (in km); *w*, the number of weeks from the beginning of the new epidemic; *p₀*, the probability of municipality infection, based on results of logistic regression.

*p₀* was calculated as follows:

\[
p₀ = \frac{1 + \exp(0.3694 - 0.00625 \times h + 0.00262 \times s)}{1 + \exp(0.3694 - 0.00625 \times h + 0.00262 \times s)},
\]

where *s* is the sheep population density in the municipality, *h* is the average height of municipality territory above sea level.

2.2. What Are the Effects of Vaccinating Sheep, Goats, and Cattle for BT in the Infected Regions on the Spread of the Disease and on Eradication of BT from Italy?

Qualitative and quantitative risk assessments were conducted to determine the probability of stopping the circulation and spread of virus.

For the quantitative assessment, based on a simulation model, the following scenarios were considered:

- Absence of (any form of) vaccination in susceptible populations.
- Vaccination of 75% of domesticated susceptible populations (sheep, goats, and cattle).
- Vaccination of 80% of domesticated susceptible populations (sheep, goats, and cattle).
Control Strategy for Bluetongue in Italian Ruminant Populations

- Vaccination of 85% of domesticated susceptible populations (sheep, goats, and cattle).\(^4\)
- Vaccination of 75% of sheep and goat population.
- Vaccination of 80% of sheep and goat population.
- Vaccination of 85% of sheep and goat population.

For each scenario, the probability of infection spread was estimated by simulating the number of secondary cases expected after a month from the onset of 1, 10, 50, 100, and 200 primary cases (animals already infected before the start of vaccination campaign or infected animals introduced in the area).

Input variables were:

1. Susceptible population, equal to 8,010 animals, 14% of which are cattle and 86% of which are sheep and goats (average number of animals in municipalities where the epidemic occurred in 2000), minus the number of vaccinated animals of each specific scenario.

2. Secondary attack rate for each primary case during the following month (equal to 0.166%, average detected in the year 2000 on all involved municipalities) in the absence of vaccination. This is the main input variable to simulate the expected number of secondary cases; therefore, the uncertainty in the estimate of the secondary attack rate may heavily influence the predictions of the model. Nevertheless, the uncertainty was considered negligible because the secondary attack rate was estimated on the basis of the clinical surveillance performed on a total population of more than 2,700,000 susceptible animals living in the involved municipalities, integrated by a serological survey (aiming at the estimation of the sensitivity of the clinical surveillance) involving a sample of animals in clinically infected flocks, and a sample of the entire sheep, goats, and cattle populations, based on the random testing of three sheep or goats and three cattle/km\(^2\) (i.e., the overall testing of more than 70,000 animals).

3. The decrease in vector capacity of *C. imicola* when a portion of the population is vaccinated\(^7,8\) calculated as follows:

\[
\Delta S \propto \left[ \frac{\nu v}{\nu u} V + 1 \times (1 - V) \right].
\]

Where *S* is the susceptibility of the entire population; \(\nu v\), the duration of viraemia in vaccinated animals; \(\nu u\), the duration of viraemia in unvaccinated animals; *V* is the proportion of vaccinated animals in the population;

- the susceptibility of vaccinated population is proportional to the decrease in the duration of viraemia following the challenge of vaccinated animals;
- the susceptibility of the unvaccinated population remains unchanged;
- therefore, the susceptibility to infection in the entire population is proportional to:

\[
\Delta C \propto \left[ \frac{\nu v}{\nu u} V + 1 \times (1 - V) \right]^2.
\]

The uncertainty in the ratio was considered using a truncated normal distribution with mean equal to the mean number of days of viraemia in the vaccinated and control groups, standard deviation equal to the standard errors of the mean in the same two groups, and ranges equal to 0–60 for the unvaccinated animals and 0-duration of viraemia in unvaccinated animals for the vaccinated group.

The structure of the model is described in Table II. The simulation model was developed using @Risk software (Palisade Corporation, New York/London) version 3.5.2. Five thousand iterations were performed using a Latin hypercube sampling.

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\(^4\) The range of vaccination coverage considered by the model (75–85%) is the one most frequently achieved by well-conducted mass vaccination campaigns in animal populations.
### Table II. Structure of the Simulation Model on the Ability of Vaccination to Stop Spread of Infection

<table>
<thead>
<tr>
<th>Variable</th>
<th>Distribution Used</th>
<th>Parameters of the Distribution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Total number of susceptible sheep, goats, and cattle</td>
<td>8,010</td>
<td>Mean number of ruminants in municipalities infected during year 2000, surveillance data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cattle = 14%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sheep and goats = 86%</td>
<td></td>
</tr>
<tr>
<td>2. Number of primary cases</td>
<td>Truncated normal 5 scenarios: 1, 10, 50, 100, 200 primary cases</td>
<td>µ = 0.375, σ = 0.183, Range 0–Variable 4</td>
<td>Ref. (9)</td>
</tr>
<tr>
<td>3. Mean number of days of viraemia in vaccinated animals after challenge</td>
<td>Truncated normal</td>
<td>µ = 6.5, σ = 0.289, Range 0–60</td>
<td>Ref. (9)</td>
</tr>
<tr>
<td>4. Mean number of days of viraemia in nonvaccinated animals after challenge</td>
<td>Truncated normal</td>
<td>µ = 0.375, σ = 0.183, Range 0–Variable 4</td>
<td>Ref. (9)</td>
</tr>
<tr>
<td>5. Proportion of vaccinated eligible population</td>
<td>Truncated normal</td>
<td>µ = 0.375, σ = 0.183, Range 0–Variable 4</td>
<td>Ref. (9)</td>
</tr>
<tr>
<td>6. Decrease in vector capacity of C. imicola following vaccination</td>
<td>Truncated normal</td>
<td>µ = 6.5, σ = 0.289, Range 0–60</td>
<td>Ref. (7) Ref. (8)</td>
</tr>
<tr>
<td>7. Secondary attack rate in the absence of vaccination</td>
<td>Truncated normal</td>
<td>µ = 6.5, σ = 0.289, Range 0–60</td>
<td>Ref. (7) Ref. (8)</td>
</tr>
<tr>
<td>SAR = SC / PAR × PC</td>
<td></td>
<td></td>
<td>2000 epidemics</td>
</tr>
<tr>
<td>where SAR is the secondary attack rate; SC, the number of secondary cases; PAR, the population at risk; PC, the number of primary cases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Number of expected secondary cases in the absence of vaccination</td>
<td>Binomial</td>
<td>n = Variable 1 – Variable 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>p = 1 – (1 – Variable 7) Variable 2</td>
<td></td>
</tr>
<tr>
<td>9. Number of expected secondary cases following vaccination</td>
<td>Binomial</td>
<td>n = Variable 1 – Variable 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>p = 1 – (1 – Variable 7) Variable 2</td>
<td></td>
</tr>
</tbody>
</table>

#### 2.2.1. Validation of the Models

Since no vaccination against BT had been conducted in Europe when the models were designed, the only possible validation was that concerning the infection spread model. The model was validated on infection spread data from southern Italy and Sardinia in the year 2000. The data were used to forecast the weekly status of infection or noninfection of each municipality in the two regions and the forecasts were compared with the observed data.

### 3. RESULTS

#### 3.1. What is the Likelihood of BT Spreading from Infected Areas of Southern Italy Without a Vaccination Program?

##### 3.1.1. Results of the Qualitative Assessment

Based on data collected so far from surveillance programs and from available scientific literature:

- *C. imicola*, the principal vector of BT, is also present in the Italian territories north of those infected in 2000 (Fig. 2).
- Climatic conditions and soil types north of infected areas are favorable for *C. imicola* breeding.\(^{(11)}\)
- Sufficient numbers of susceptible animals (sheep, goats, and cattle) are present north of infected areas for the epidemic to spread (Figs. 3 and 4).
- There is a source of BT virus present to initiate the spread of the virus (the last diseased flock in southern Italy was detected on February 1, 2001).
- There are no physical barriers to limit the spread of *C. imicola*.

Therefore, it can be assumed that, without a vaccination program, BT would spread from infected areas of southern Italy with a probability near 100%.

##### 3.1.2. Results of Quantitative Assessment

According to the results of quantitative assessment (Fig. 5), without a vaccination program, the disease could spread to the free regions of Italy within 4–6 months of the beginning of any new epidemic, which might occur in 2001.
3.2. What Are the Effects of Vaccinating Sheep, Goats, and Cattle on the Spread and Circulation of BT Virus in Italy?

3.2.1. Results of Qualitative Assessment

The Onderstepoort Veterinary Institute, South Africa, the manufacturer of the vaccine, claims a 99.4% protection (P. Hunter, Onderstepoort Biological Products, personal communication) based on the ratio:

\[
\frac{\text{Total score of clinical signs in vaccinated and challenged animals}}{\text{Total score of clinical signs in nonvaccinated and challenged animals}} = 99.4\%.
\]

This ratio measures the vaccine effectiveness in reducing economic losses due to mortality and decreased productions caused by the disease.

Reduction of economic losses is not the only purpose of vaccination. By creating a BT-resistant population belt, it aims also to reduce the probability of spread of infection. It is also intended to hasten eradication of the disease in the longer term by interrupting the virus transmission cycle. It must be recognized that existing studies on the efficacy of the South African vaccine are not entirely sufficient. Available data relate mainly to protection against clinical disease, rather than to the effects on intensity and duration of viraemia, which are needed to evaluate the extent to which spread...
of infection is likely to be reduced in vaccinated animals.

According to data on vaccine controls performed by the Onderstepoort Veterinary Institute from 1995 to 1999, none of 60 sheep vaccinated and challenged with virulent virus had fever after the challenge. Since it has been demonstrated that fever is consistently present in postinfection viraemia, the absence of fever suggests an ability of vaccine to prevent viraemia following challenge with virulent virus.

In the simulation model, the expected proportion of vaccinated animals ranged from 75% to 85%. This is because pregnant animals will not be vaccinated and some animals are expected to escape vaccination. It is assumed that the lack of vaccination will be randomly distributed throughout the population.

Nonvaccinated animals entering the vaccination area could further reduce this percentage. According to historical data available from the National Animal Register, the number of nonvaccinated susceptible animals entering a vaccination area will be very low and is not likely to have any substantial effect on overall vaccine efficacy.

Currently, quantitative data from specific experiments on the efficacy of the South African vaccine in suppressing or reducing duration and intensity of viraemia are not available. Some information is available for a different vaccine, apparently less effective than the South African one in reducing the severity of
disease signs. This vaccine is reported as being able to reduce the duration of viraemia after challenge with wild virus to 5.8% of the average duration observed in unvaccinated sheep.\(^\text{(12)}\) Therefore, it is assumed that in field conditions, the level of viraemia suppression following natural infection would be equal to 94% in the worst-case scenario.

Sheep, goats, and cattle are the only important hosts in maintaining the disease. Once recovered, sheep, goats, and cattle are clear of the virus and are immune to infections by the same serotype for at least one year.\(^\text{(13)}\) The expected reduction in the duration of viraemia should be able to significantly reduce the chances for the vector to become infected and spread the infection. Therefore, following vaccination, a significant reduction of the incidence of infection is expected.

3.2.2. Results of Quantitative Assessment

Simulation results, expressed as probability distribution of expected secondary cases following 1 and 200 primary cases after vaccination of sheep, goats, and cattle, are presented in Figs. 6 and 7. Results obtained with 10–100 primary cases were intermediate between these.

These figures show that, if at least 80% of the population is effectively vaccinated, the probability
of a number of secondary cases greater than or equal to primary cases (endemic infection) is always very low, regardless of the number of primary cases triggering the transmission. As a consequence, there is a high probability of having a decrease in the number of cases over the time (and therefore the extinction of the infection in the population) when herd immunity involves at least 80% of the susceptible population. On the other hand, if the herd immunity involves only 75% of the population, the probability of infection extinction is lower (30% in case of a single primary case and 35% in case of 200 primary cases).

Simulation results, expressed as probability distribution of expected secondary cases following 1 and 200 primary cases after vaccination of sheep and goats only, are presented in Figs. 8 and 9.

In these scenarios, the probability of a number of secondary cases greater than or equal to primary cases (endemic infection) is always higher than after vaccination of all ruminants. Moreover, in the case of vaccination of sheep and goats only, even in the case of immunization of 85% of the eligible population, the probability of a number of secondary cases exceeding the primary ones is 40% when the infection is triggered by one single primary case. This probability increases with the number of primary cases, up to more than 65% when the infection is started by 200 infected animals.

3.2.3. Validation of the Model

For the epidemic that occurred in the year 2000, the model of infection spread correctly forecast the
weekly infection status of each municipality of the two regions investigated with a variable probability, generally greater than 70%. The model’s validation results are presented in Figs. 10 and 11. For the validation of the model in Sardinia, the period under investigation was considered to have begun 15 days after the detection of the first case. Since Sardinia was the first region to experience BT, it is probable that around two weeks were necessary for a uniform detection capability to be implemented over the entire region.

3.2.4. Comparison of Model Forecasts with 2001 Epidemics Observed Data

Even though the risk analysis indicated the probable beneficial effects of vaccinating the susceptible livestock, no vaccination program was, in fact,
Fig. 8. Number of secondary cases expected from 1 primary case—vaccination of sheep and goats only.

implemented. Therefore, data collected during the subsequent BT outbreak in 2001 allow further evaluation of the validity of the model used to assess the likelihood of spread from infected areas.

The first BT cases of the 2001 epidemic appeared in Calabria during June, along the Ionian coast. The extension of the epidemic in the region, resulting from movement of livestock, involved also the Tyrrhenian coast, although the number of outbreaks and the time span in which new cases appeared in the latter area remained significantly less than along the Ionian coast. In August 2001, the disease appeared also in the neighboring region, north of the area infected in the 2000 epidemic. Therefore, the forecast of a spread of the disease to free areas within 4–6 months from the beginning of a new epidemic was confirmed. The final

Fig. 9. Number of secondary cases expected from 200 primary cases—vaccination of sheep and goats only.
extension of BT in Italy on January 28, 2002 is shown in Fig. 12. Since the model was developed on the basis of the 2000 epidemic, due to the serotype 2 of the BT virus and the 2001 epidemic in Calabria was due to the serotype 9, less pathogenic than the serotype 2 (morbidity was 0.38 and lethality was 0.37 times the values observed in 2000), the forecasting ability of the model was rather poor. It was therefore hypothesized that, should the poor forecasting ability of the model be due only to the lower pathogenicity of serotype 9 of the virus, the ranking by the model of the municipalities in terms of their probability of infection would still be correct, but shifted toward excessive values. In order to test this hypothesis, the threshold value of $p$ was increased. The threshold had to be changed to 0.8 in order that the results of the model matched the observed results. The ability of the model to predict the weekly infection status of municipalities in Calabria, using the threshold value 0.8, is shown in Fig. 13.

The vaccination of susceptible animals started in Sicily in October 2001 and in Sardinia in January 2002, while in the continental part of southern Italy vaccination campaigns started in February 2002, but the percent of vaccinated animals was still low by autumn 2002 (Fig. 14). Data from Italian and other infected European regions that have vaccinated sheep and goat populations may give some indication of the ability of vaccination to stop or limit the spread of the disease. Other European regions that experienced a BT epidemic during the summer 2000 and that vaccinated the sheep population were the Balearic Islands of Majorca and Minorca, and Corsica (Table III).
3.2.5. Italy

Two Italian regions achieved the objective of at least 80% vaccination (namely, Sardinia and Tuscany, Fig. 14). During the year 2002, in Sardinia only 24 sheep in six flocks showed signs of BT, compared with the 239,178 diseased sheep in 6,090 flocks during the previous year. Also in Sardinia, in 2002, a further 25 sentinel animals out of 4,393 gave a positive serological reaction. In Tuscany, during the year 2002 no clinical cases of BT were detected in sheep, compared to 693 diseased sheep in 158 flocks during 2001. In Tuscany, five sentinel animals out of 691 gave a positive serological reaction. The geographic distribution of infected municipalities in Sardinia and Tuscany in the years 2001 and 2002 are compared in Fig. 15.

No southern Italian region, apart the province of Trapani in Sicily, vaccinated more than 60% of the susceptible populations (Fig. 14). In these regions BT infection actively spread in the year 2002, with 2,344 sheep in 314 flocks showing signs of BT, compared with 10,360 in 497 flocks the previous year. In particular, the disease was actively spreading in Campania where 1,568 cases were recorded in 238 flocks in 2002, compared with three cases in a single flock the
previous year. The infected municipalities in southern Italy in 2002 are shown in Fig. 16.

3.2.6. Balearic Islands

Two of the four islands, Majorca and Minorca, were involved in the summer 2000 epidemic. The first case of the disease was observed on September 29, and the total number of cases was 5,455. The susceptible animal population of the two islands is 394,524 (347,591 sheep, 15,530 goats, and 31,403 cattle). A vaccination campaign(14) was carried out and by January 15, 2001 a total number of 301,202 sheep had been vaccinated (78.3% of total susceptible population). No further cases of disease were recorded during 2001.

3.2.7. Corsica

This island was involved in the summer 2000 epidemic. The first case of BT was observed on October 18, and the total number of recorded cases was 2,765. There are 129,900 sheep and goats on the island,(15) but data on the cattle population were not available to the authors. A vaccination campaign was carried out and 102,000 sheep (65.1% of the sheep and goat population) were vaccinated between December 15, 2000 and April 30, 2001.(16) A new epidemic started in Corsica in 2001, and a total number of 13,141 cases was recorded between September 2001 and January 2002.

4. DISCUSSION

A comparison of the results of the deterministic model with observed events in 2001 showed that the model was able to predict correctly the time needed for BT to spread from the area that was infected during the previous year. However, the model was unable to classify correctly the infection status of municipalities of southern Italy when used with the same threshold value used for the year 2000. This could be due to a number of reasons.

1. The numbers of vectors (Culicoides midges) in the year 2001 were significantly lower than numbers recorded in 2000. This lower density of vectors may have resulted in fewer opportunities for transmission of infection in 2001.
2. The type of BT virus responsible for the 2001 epidemic was BTV9 while in the previous epidemic it was mainly BTV2. BTV9 is a less virulent strain than BTV2 and this may have resulted in greater difficulty in detecting new cases.
3. Although the epidemic of 2000 was mainly due to BTV2, a few cases of infection due to BTV9 were detected in the final phases. A serological survey carried out at the end of the epidemic wave indicated that the infection due to BTV9 was more widespread than anticipated on the basis of the distribution of clinical disease attributable to BTV9. This largely unrecognized

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**Table III.** Results of Vaccination Campaigns Carried Out in the Balearic Islands and in Corsica

<table>
<thead>
<tr>
<th></th>
<th>Balearic Islands</th>
<th>Corsica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep population</td>
<td>347,591</td>
<td>159,503</td>
</tr>
<tr>
<td>Goat population</td>
<td>15,530</td>
<td>NA</td>
</tr>
<tr>
<td>Cattle population</td>
<td>31,403</td>
<td>NA</td>
</tr>
<tr>
<td>Total number of</td>
<td>394,524</td>
<td>NA</td>
</tr>
<tr>
<td>susceptible animals at</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the beginning of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000 epidemic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cases in</td>
<td>5,455</td>
<td>2,765</td>
</tr>
<tr>
<td>2000 epidemic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of dead animals</td>
<td>1,991</td>
<td>259</td>
</tr>
<tr>
<td>Total number of</td>
<td>7,706</td>
<td>2,632</td>
</tr>
<tr>
<td>slaughtered animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of</td>
<td>384,827</td>
<td>156,612</td>
</tr>
<tr>
<td>animals remaining at</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the end of 2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>epidemic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vaccinated</td>
<td>301,202</td>
<td>102,000</td>
</tr>
<tr>
<td>animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% vaccinated animals</td>
<td>78.3</td>
<td>65.1</td>
</tr>
<tr>
<td>Number of cases in</td>
<td>0</td>
<td>13,141</td>
</tr>
<tr>
<td>2001 epidemic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not available.
Fig. 15. Infected municipalities in Sardinia and Tuscany in years 2001 and 2002.

Fig. 16. Infected municipalities in southern Italy in 2002.
The presence of BTV9 in the previous year may have been responsible for a partial immunological protection of the population from the resurgence of the disease in 2001.

The ability of the model to predict the status of municipalities after the threshold value was increased shows that the model was nevertheless able to correctly rank the municipalities based on their actual risk of infection. This seems to indicate that the variables chosen are relevant for the epidemiology of BT infection and that, even if unable to produce an exact prediction of the spread of infection, the model is able to indicate the level of risk to which each territory is exposed and, therefore, it could be a useful decision-making tool.

To provide adequate protection against BT, the model predicted that at least 80% of susceptible livestock must be immunized if vaccination is to be effective. Results obtained following the 2002 vaccination campaign in Italy are consistent with the model’s predictions. Data from the Balearic Islands and Corsica also seem to support the projections made by the model. Although only sheep were vaccinated in both areas, in the Balearic Islands, these greatly outnumbered the cattle population and the total number of vaccinated animals was near 80% of the total susceptible population (cattle, sheep, and goats). In contrast, in Corsica fewer than 70% of the total population of sheep and goats were vaccinated. According to what was expected on the basis of the model’s predictions, disease seems to have disappeared from the Balearic Islands while a new epidemic occurred in Corsica in 2001. No cases of BT were detected in Corsica during the year 2002, after a second vaccination campaign.

In conclusion, the results obtained in this study support the use of risk analysis as a tool to assist in choosing an appropriate animal disease management strategy. The use of risk analysis in the evaluation of disease management strategies also offers advantages in international trade. It makes easier the comparison of different strategies applied in the various countries, and thus facilitates the assessment of equivalence of the guarantees provided by different strategies.

REFERENCES
14. Report by the Spanish Government to the EU Standing Veterinary Committee.