Foot-and-mouth disease in wildlife
Risks and risk management proposals for Europe

François Moutou

Introduction
The real importance of many wildlife species in foot-and-mouth disease (FMD) epidemiology is quite often addressed but the answers are not so easy to find or to use. The questions are many, combining free-ranging or captive species and animals, but also items like passive carrier, active carrier, biological reservoir, as well as receptivity, susceptibility, clinical expression, long-term carrier, for many different species belonging to quite distinct zoological groups. The possible differences in the answers depending of the virus types or sub-types involved must not be forgotten.

Depending of all these items, the possible risk linked to any species, under any circumstance, could be important to evaluate. The easiest approach however is to ask the questions following zoological groups. Short synthesises are here proposed, written following the references mentioned in the bibliography. For each situation, the conclusions should be read through their own context: free-ranging species, farmed species, and zoological gardens species. The arguments here proposed are those of a risk management point of view, linked to known FMD outbreaks identified in a European country, and possibly involving “non classical species”. The proposals could be included in contingency plans. This is not a review on FMD in wildlife in Europe.

It must be noted that owners of some of these species when captive, or even managers of native wild species, may be less informed than farmers on FMD risks, consequences and policy. Their reactions will also be different. Other elements that just economical factors could be used and this could make the discussions more difficult.

1 - Backgrounds
Classically, FMD is associated with mammalian species of Artiodactyla order but textbooks still give a rather longer and rather heteroclite list of susceptible species. In fact, many references still in use are rather old and are often just linked to clinical observations. Not always is or was a confirmation performed with FMD virus isolation and identification mentioned. This does not mean that all is to be rejected but certainly a more critical review should be necessary and the data revisited. This was clear during the 2001 European outbreaks when some zoological gardens managers or exotic species (camelidae for instance) breeders were asking for derogations (for instance vaccination or non-culling strategies) to the actual European legislation for their own animals. So the point here is also to imagine suggestions adapted to these situations within the frame of the application of 2003/85/EC directive, as it is possible.

The order of presentation of the zoological groups is rather linked to systematics than to their real or possible epidemiological importance. It must be added that free ranging species may, as least in theory, act as passive vectors of the virus during an outbreak, but this is not only true for wildlife. This will only be mentioned with birds.

2 – Birds
It may be a little surprising to speak of birds, as they do not seem to be at all susceptible to FMD virus. In fact, this question had already been asked for many years, birds being seen then just like passive carriers of the virus, possibly over long distances.
Speaking of migratory birds, it is possible to say that billions of them are crossing twice a year the Mediterranean Sea, both ways. Not a single outbreak of FMD linked to SAT types virus ever occurred in Europe or in northern Asia after the spring migration. During the British epidemic of 2001, racing pigeons were indeed forbidden over the Channel but this was more for global biosecurity reasons.

Researches have been conducted on this topic however not recently (Eccles 1939) and were not conclusive. A quite recent document tries to revisit this hypothesis but the references and the arguments are using typical bird-adapted virus like West Nile virus or orthomyxoviridae, when FMD virus is clearly not an avian-adapted virus (Koch et al. 2001). It does not seem that this manuscript has been published.

So, it is sufficient to say here that, up to today, it has been possible to handle all documented FMD outbreaks without any specific action against bird life.

3 – Hedgehogs (Mammals Insectivora)
Insectivora mammals, in fact mainly the Western European hedgehog (Erinaceus europaeus), are often mentioned as being able to carry FMD virus locally around an outbreak. An ancient citation (McLaughlan and Henderson 1947 [not seen]) speaks of animals naturally infected closed to outbreaks in Great Britain. In 2001, the survey forms used in British infected premises had a specific question to address the point of hedgehogs known to be present, or not, on the farm. This argument is in use nowadays in some USA states to ban any hedgehog as pets (Riley and Chomel 2005). In this case it must be recalled that hedgehogs are only known in the Old World, so, in the USA, they have to be imported from somewhere else. Apparently, commercial hedgehogs farms do exist there, but probably not with the European species. The most common one should be an African Hedgehog, Ateletix albiventris, locally called « pygmy hedgehog » as it is a little smaller than the European species. It is however possible to find exotic (Africa, Asia) hedgehogs species, including this one, on sale in pet shops in Europe. Law in Europe protects both native species, the Western and Eastern European hedgehogs.

Here too, it is possible to say that documented FMD outbreaks were put under control without any specific actions against hedgehogs. Of course, in what is called « neighbourhood risk », if cats as dogs or domestic pigeons are included, then why not hedgehogs or domestic sparrows?

4 – Elephants (Mammals Proboscidae)
Elephants do not belong to European fauna but on one hand lesions linked to FMD were described in both species, Asian as well as African elephants, and on the other hand these animals are often presented in zoological gardens or even in circuses in Europe. It can be added that they represent a real value, not only just economical.

FMD clinical descriptions are more numerous for the Indian elephants (Elephas maximus), which may be not only linked to the fact that they can be domesticated and tamed but also to a higher specific susceptibility (Pyakural et al.1976, Hedger and Brooksby 1976). The Asian species seems to be able to do a natural disease even if viral transmission from a sick elephant to any other animal does not seem to have been documented. However, transmission between elephants is possible. In Africa, most of the data for natural situations come from South Africa. Out of 3535 elephants from Kruger National Park (RSA) culled and examined during 4 years during the 1960s and 19670s, none was showing a single lesion or even a sign looking like FMD when it is well known that the virus is present and circulating in local wildlife (African buffaloes) in this National Park (Hedger and Brooksby 1976). At the end, thousands of wild elephants have been culled and examined between 1968 and 1994 with the same negative results, and thousands of serologies have also been performed, all negative (ProMED 20001123.1908). The only description of an apparently spontaneous clinical disease in an African elephant came for the years 1970s, in an Italian circus. In fact, it could have been an Asian elephant instead, as the other species is really rare in circus (ProMED 20001123.1908)!
Under laboratory conditions, the African elephant (*Loxodonta africana*) may show severe lesions when the virus is experimentally inoculated to a young animal, but the species does not seem to be able to transmit nor to carry the virus. It makes no antibody and cannot get infected by contact with sick cattle. A young elephant which received a SAT2 virus strain in its tongue in 10 different places showed no reaction, neither clinical nor serological and it has not been possible to re-isolate the virus afterwards. The initial viral concentration of the inoculate is not known (Hedger *et al.* 1972). Another study describes a clear clinical disease in young elephants after they were infected by the virus (Howell *et al.* 1973 [not seen], Pinto and Hedger 1978, ProMED 20001123.1908).

So, elephants have only a very low epidemiological importance, knowing also that a recently described herpes virus in these species gives lesions looking like those of FMD in captive individuals and may have been responsible of some of the lesions associated with FMD, at least in captivity.

### 5 – Suidae (Mammals Artiodactyla)

As the wild boar is the wild ancestor of domestic swine, it is true that they share receptivity and susceptibility to quite a lot of pathogens. However, the recent FMD outbreaks that occurred within Europe have shown that the transmission of the virus between the wild and the domestic stocks was not so common. In 2001, out of 208 free ranging wild boars tested in the Netherlands, all gave a negative serological result (Elbers *et al.* 2001). If there have not been so many papers published on this topic in the UK, it may be linked to the fact that the species vanished from the country some centuries ago. Today, reintroductions are on with also some escapes from farms in the Southwest of the country.

So, without going much further, a conclusion could be that contamination of wild boars by domestic ruminants presents a low probability of occurrence, just like the contamination of domestic ruminants by wild boars (Elbers *et al.* 2001). The question of viral transmission from domestic pig to wild boar may be different, specifically in outdoor farming situations. Wild boar farms are to be seen as places where animal really receptive and susceptible to the virus are bred.

Wild exotic suidae in zoological gardens are more to be seen and managed as exotic bovidae (*cf infra*). Under laboratory conditions, peccaries (collared peccary), which belong to the tayasuidae family, so distinct from suidae family, seem to be susceptible to FMD.

### 6 – Camelidae (Mammals Artiodactyla)

South American camelidae (llamas, alpacas, guanacos and vicunas) like Old World species (two-humped camel and dromedary) are susceptible to FMD but their epidemiological importance seems to be really low, without being totally ruled out. For instance, not so long ago, an FMD outbreak involving cattle, sheep, goats and camels has been described from Mongolia in 2000 (OIE Mai 2000). Although camelidae chew their cud, they are not classified within Ruminantia by within Tylopoda suborder. In the International Animal health Code, OIE, 2005 edition, they are however included with ruminants for the purpose of FMD chapter (2.2.10, article 2.2.10.1). Nearly all these species may be seen in Europe, especially llamas, alpacas and dromedary, all considered as domestic animals and being bred in a few farms.

In the case of South American camelidae, it is possible to say that llamas and alpacas are susceptible if infected in the laboratory, but that they do not seem to have any natural importance in the local outbreaks (Labroth *et al.* 1990, Fondevila *et al.* 1995, Fondevila *et al.* 1996). It is even possible that animals showing clinical signs are unable to transmit the disease to any other animal (Fondevila *et al.* 1995). In this last work, out of 30 animals exposed to the contact of pigs, which had been inoculated, only 3 made the disease. The experiment was performed with 6 pigs, organized in three groups of 2 animals, each group inoculated with a different FMD virus strain (A, O and C respectively). The llamas were put into contact with the pigs, 10 llamas per group of 2 pigs, in distinct and isolated cabinets. Only in a single cabinet (the one with O strain) two animals presented light lesions associated with a seroconversion and a third animal of the same group was discovered seropositive without lesion. In the other two groups and on the other seven animals of the first group, nothing was
noticed. A calf was associated to each group. It became infected and made a clinical disease in every case, like the pigs. In experimental conditions as in Lubroth et al. (1990) an inoculated llama was able to contaminate 3 pigs out of 3 put at its contact, an other inoculated llama did contaminated (light clinical form) a single llama in contact out of two and an inoculated cattle contaminated (clear lesions) one out of two llamas in contact.

The transmission risk of FMD virus through embryo transfer in llamas seems to be really lows: $3^{-08}$ (Sutmoller and Taylor, manuscript, no date).

In the case of the two and one-humped camels, literature is quite contradictory (Richard 1975, Leforban et al. 1996, Schneegans 2001). A recent review presents FMD in camels (Wernery and Kaaden 2004). Animals appear however as being susceptible but most of the time, clinical signs are very mild. It seems possible for the one-humped camel as for the two-humped species to transmit the virus to cattle when, in the opposite way, under laboratory condition, virus transmission looks difficult or even impossible. However, being able to transmit the virus means that it has been acquired from somewhere, as these species are not biological carrier or reservoir of the virus.

So, here too, considering these two groups of species, it is clear that their epidemiological importance is not a major one but it is difficult to pretend that there is absolutely no risk. A good management of their numbers, by breeding them away from any other domestic stocks, could be a positive way to protect them. Documented situations in which they really had an epidemiological importance in FMD outbreaks are very few. In South America, the FMD contingency plans only concern ruminants and pigs (Cancino Valenzuela 1988).

7 – Cervidae (Mammals Artiodactyla)

The 2001 FMD epidemic was another occasion to ask about susceptibility of deer to this virus as European populations of red deer (Cervus elaphus) and of roe deer (Capreolus capreolus) have seen their figures and geographical distributions really increasing these past years, just like wild boar on the continent (Table I). It must be mentioned that precise estimations of their populations are difficult to get. The only solid figures are those of hunting bags, which have also been increasing since the first year when data were collected (in France, 1973-1974 season, figures coming from French hunting agency ONCFS).

Estimations of population figures are just made for red and roe deer and the confidence intervals, not mentioned, are certainly very wide. In France, red deer population could have grown from 38,600 in 1985 to about 117,800 in 2000 and their could be now between 1.5 et 2 millions of roe deer in the country (ONCFS).

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<tbody>
<tr>
<td>Red deer</td>
<td>6,573</td>
<td>8,824</td>
<td>9,358</td>
<td>13,001</td>
<td>18,592</td>
<td>32,349</td>
<td>49,844</td>
</tr>
<tr>
<td>Roe deer</td>
<td>58,563</td>
<td>62,487</td>
<td>98,445</td>
<td>156,948</td>
<td>285,319</td>
<td>395,657</td>
<td>461,689</td>
</tr>
<tr>
<td>Wild boar</td>
<td>45,333</td>
<td>57,218</td>
<td>88,413</td>
<td>104,875</td>
<td>211,586</td>
<td>343,628</td>
<td>442,466</td>
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Table I : Evolution of hunting bags for red deer, roe deer and wild boar in France. The year mentioned means that of the closing of the hunting season. * Last season published: 2002-2003 (from ONCFS).

The review by Fletcher (2004) points to the famous FMD epidemic on white-tailed deer (Odocoileus virginianus) described in 1924 from California, USA, and regularly reported. It could indeed have been caused by an adenovirus.
Species Population estimations

<table>
<thead>
<tr>
<th>Species</th>
<th>1970 years</th>
<th>1990 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red deer</td>
<td>190,000</td>
<td>360,000</td>
</tr>
<tr>
<td>Sika deer</td>
<td>1,000</td>
<td>11,500</td>
</tr>
<tr>
<td>Fallow deer</td>
<td>50,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Roe deer</td>
<td>200,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Chinese barking deer</td>
<td>5,000</td>
<td>40,000</td>
</tr>
</tbody>
</table>

Table II: estimation of the trends of British deer populations evolution over thirty years (Fletcher 2004)

In France, many blood samplings were realised during capture sessions of red deer, roe deer and wild boars by the National hunting agency (ONCFS). These animals were used to repopulate different regions where their density was then low. These blood samples were made by Afssa Nancy and tested by Afssa Alfort and have always been negative and have not been published.

Under laboratory conditions there is a publication, which presents experimental viral (C type) contaminations in the tongue of all 5 species of deer present in the UK, and transmission between them as well as with cattle and sheep as contacts (Gibbs et al. 1975). Sika deer (Cervus nippon), fallow deer (Dama dama) and Chinese barking deer (Muntiacus reevesi) have been introduced in the British islands. Concerning receptivity, roe and barking deer are clearly quite susceptible to the diseases with lethal forms, sika deer shows a less severe clinical disease and the two other species (red and fallow deer) just exhibit a sub-clinical disease. Red deer but mainly sika and fallow deer could become carriers over 28 days. Viral excretion is similar with what is seen in domestic ruminants and under these experimental conditions the virus passed from one species to the others. However, the authors of the paper mention the fact that the conditions of the experiments (close cabinets, high density, small spaces) are not natural conditions. So, the epidemiological importance of deer may be less important than that of domestic ruminants.

The serological survey realised in The Netherlands after the 2001 epidemic on 140 free-ranging wild red deer gave 140 negative results (Elbers et al. 2003). In the same time not a single positive case has been notified in the UK on any of the 5 deer species when the growth of the local populations during the second half of the XX\textsuperscript{th} century had also been real there (Table II).

The conclusion could be that contamination of wild deer by domestic ruminants represents a low probability of occurrence and that the contamination of domestic ruminants by wild deer seems nearly impossible. However, deer farms are to be managed like ruminants farms i.e. breeding species whose receptivity and susceptibility is real but rather lower than those of domestic ruminants.

8 – Bovidae (Mammals Artiodactyla)

This is the zoological family to which domestic ruminants are belonging, so it is clear that even if all species have not been tested in laboratory conditions, it is possible to suppose that all are receptive and susceptible and that some of them may become carriers even if we do not know which ones, nor for what types of viruses. In our countries they are found in zoological gardens, with a few American bison (Bison bison), water buffaloes (Bubalus bubalis) or even yak (Bos grunniens) bred in farms. The detail of all the research realised in the field, in Africa or in Asia, as well as the analysis of the outbreaks described in zoological gardens is very rich but can be partly ignore here (Urbain et al. 1938, Hedger et al. 1972, Pinto and Hedger 1978, Shimshony et al. 1986, Hedger 1981, Fowler 1986).

African buffalo seems to be live-carrier of SAT FMD virus types and different antelope species can be infected to its contact, some with mild clinical disease some with severe and even lethal clinical forms.

In Europe there are a few native wild bovidae like chamois (Rupicapra rupicapra), isard or Pyrenean chamois (R. pyrenaica), ibex (Capra ibex and C. pyrenaica) and one introduced, the Asiatic mouflon or wild sheep (Ovis orientalis). Today, none of these species ever play any role in any documented FMD outbreak.
9 – Other mammalian species
Here the list may be rather long, but many of the data are most of the time anecdotic.
What to think of the epidemiological importance of the disease described in kangaroos (marsupials),
bears (carnivora), some rodents, tapirs (perissodactyla), hyraxes (hyracoida), either under laboratory
conditions, either in zoological gardens and often quite a long time ago (Urbain et al. 1938,
It is absolutely possible that some of these cases are true and real, just like is true the lesion in the foot
of a Guinea pig after inoculation of a FMD virus strain on the spot, but it may also be true that all
these species have absolutely no epidemiological importance in FMD epidemics. During an outbreak,
actions to be taken around infected premises holding domestic stocks are already quite harsh to realise
and so important to be done swiftly and efficiently that it is worth not to be disturbed by questions
linked to much less important species and topics.

To close this part, it is possible to recall that some old FMD diagnostic methods used inoculation of
the suspected materials to rodents (Guinea pigs and baby mice) and that some vaccines have been
produced, up until very recently, by multiplying the virus in young rabbits (Joubert and Mackowiak
1968). This does not mean however that these species do have an importance in the natural history of
the disease.

Conclusion - Suggestions
Without being exhaustive, this short bibliographical review distinguishes between some anecdotic
situations (zoological gardens) and a whole set of other situations, which potentially may prove to
become more serious (wild boar, camelidae, cervidae). However, it must also be stressed that
laboratory conditions, really important to use and to know, rarely reproduce field conditions. The
analysis and the experience of all previous FMD outbreaks in Europe had shown that a good control of
domestic stock (pigs and ruminants) is enough to handle and to eradicate the disease.

Is it important to suggest new laboratory studies for a better quantification of the susceptibility, the
level of excretion and the possible length of virus carriage, for different virus types and sub-types and
for so many species? May be not for all of them.

The following table reproduces the data here presented (Table III).

<table>
<thead>
<tr>
<th>Zoological groups</th>
<th>Receptivity</th>
<th>Susceptibility</th>
<th>Epidemiological importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birds</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Insectivora</td>
<td>+/-</td>
<td>+/-</td>
<td>No</td>
</tr>
<tr>
<td>Proboscidae</td>
<td>Yes</td>
<td>+/-</td>
<td>No</td>
</tr>
<tr>
<td>Suidae</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>Camelidae</td>
<td>Yes</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>Cervidae</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>Bovidae</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rodentia</td>
<td>Yes</td>
<td>Yes (laboratory)</td>
<td>No</td>
</tr>
</tbody>
</table>

Table III: Review of what is known on receptivity, sensibility and on the epidemiological importance
of the species mentioned in the text. « +/- » means that the known results are contradictory.

Nevertheless, among the possible suggestions it could be proposed to make a census in our countries
of all the different estates and properties holding susceptible species, be they zoological gardens,
native or exotic wildlife parks, fenced hunting properties, farms growing non classical species,
domestic or not, or circuses with animals, as well as the species and their numbers within all these
locations. A good information and knowledge concerning all the animals movements linked to these
estates and properties is also to be expected. Another proposal could be to suggest not to create any
new holding with such species too close from a classical breeding area, region or centre so that domestic stock and captive wildlife shall not be present in the same time at the same location. This may prove to be useful not only for FMD.

When dealing with free-ranging native wildlife, the question is yet another one, but from past experiences, it could be anticipated that these animals should not become the origin of too many troubles. At the legislation level, it must be realised that wildlife, free ranging or even within fenced hunting properties is not seen as domestic stock within a farm.

The two following tables could synthesise suggestions to propose when facing one of these different situations, in the absence of any outbreak: Table IV and recommended measures in case of an outbreak: Table V.

To end, it is possible to go to Council directive 2003/85/EC of 29 September 2003 on Community measures for the control of foot-and-mouth disease repealing Directive 85/511/EEC and Decisions 89/531/EEC and 91/665/EEC and amending Directive 92/46/EEC. Article 2 (a) is written as follows:
« « animal of a susceptible species » means any domestic or wild animal of the suborder Ruminantia, Suina, and Tylopoda of the order Artiodactyla ;
For specific measures, notably in application of Article 1 (2), Article 15 and Article 85 (2), other animals, such as for example of the order Rodentia or Proboscidae, may be considered susceptible to foot-and-mouth disease in accordance with scientific evidence. »

It may be possible to think that rodents have been included because of research laboratories and elephants because of zoological gardens and circuses.

Article 15 (1 and 2) allows to derogate to official control measures (Article 10) even in case of a FMD outbreak if this, or these, outbreak(s) are confirmed « in a laboratory, zoo, wildlife park, and fenced area or in bodies, institutions or centres approved in accordance with Article 13 (2) of Directive 92/65/EEC and where animals are kept for scientific purposes or purposes related to conservation of species or farm animal genetic resources... ». Commercial farms of wild boars, camelidae or cervidae are thus not concerned by this derogating measure. Could fenced hunting areas be assimilated to such a situation when they represent a commercial activity and not a nature reserve?

A good application and practice of these rules mean a good communication as soon as possible, as well as a sensibilisation of the public and an adapted training scheme for all potential actors of the contingency plans.
Table IV: Proposal of preventive measures around situations or properties holding non domestic or non « classical » species without FMD outbreak. The terms of Council Directive 2003/85/EC are presented for comparison.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Free ranging wildlife</td>
<td>Not mentioned</td>
<td>Figures knowledge</td>
</tr>
<tr>
<td>Fenced hunting areas (with susceptible species)</td>
<td>Not mentioned, not considered a farm</td>
<td>Figures and movements knowledge. Checking of the fences and of the quarantine facilities.</td>
</tr>
<tr>
<td>Bovinae other than cattle (bisons, buffaloes, yaks) farms</td>
<td>To be managed like a cattle farm</td>
<td></td>
</tr>
<tr>
<td>Cervidae farms</td>
<td>To be managed like a cattle farm</td>
<td></td>
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<tr>
<td>Camelidae farms</td>
<td>To be managed like a cattle farm</td>
<td></td>
</tr>
<tr>
<td>Suidae farms</td>
<td>To be managed like a pig farm</td>
<td></td>
</tr>
<tr>
<td>Zoological gardens (with susceptible species)</td>
<td>Susceptible species: Ruminantia, Suina, Tylopoda, Rodentia and Proboscidae.</td>
<td>To propose and to apply adapted bio-security rules</td>
</tr>
<tr>
<td>Circuses (with susceptible species)</td>
<td>Not mentioned.</td>
<td>To propose and to apply adapted bio-security rules</td>
</tr>
</tbody>
</table>

Table V: Proposals for management measures in case of confirmed FMD outbreak occurring in one of these situations or properties. The terms of Council Directive 2003/85/EC are presented for comparison.

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<tbody>
<tr>
<td>Free ranging wildlife</td>
<td>Not considered as an outbreak, not mentioned.</td>
<td>No specific action suggested. Hunting seems counter indicated as it could result in large movements of animals and humans.</td>
</tr>
<tr>
<td>Fenced hunting areas (with susceptible species)</td>
<td>Not mentioned so culling not indicated.</td>
<td>Stamping out. Checking of the fence. Monitoring of nearby farms with susceptible species.</td>
</tr>
<tr>
<td>Bovinae other than cattle (bisons, buffaloes, yaks) farms</td>
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<td></td>
</tr>
<tr>
<td>Zoological gardens (with susceptible species)</td>
<td>Susceptible species: Ruminantia, Suina, Tylopoda, Rodentia and Proboscidae. It is possible to derogate to culling.</td>
<td>To close the property, sanitary surveillance, application of biosecurity rules.</td>
</tr>
<tr>
<td>Circuses (with susceptible species)</td>
<td>Not mentioned</td>
<td>Sanitary surveillance, biosecurity rules. Possibilities to derogate to culling.</td>
</tr>
</tbody>
</table>
References