Qualitative assessment of the entry of capripoxviruses into Great Britain from the European Union through importation of ruminant hides, skins and wool

P. Gale [1], L. Kelly [1,2] and E.L. Snary [1]

[1] Department of Epidemiological Sciences, Animal Health and Veterinary Laboratories Agency, New Haw, Addlestone, Surrey KT15 3NB, UK

[2] Department of Mathematics and Statistics, University of Strathclyde, 26 Richmond St, Glasgow G1 1XH, UK

Correspondence: Dr Paul Gale, Animal Health and Veterinary Laboratories Agency, Weybridge, New Haw, Addlestone, Surrey, KT15 3NB, UK. E-mail: paul.gale@ahvla.gsi.gov.uk

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Abstract

Sheep pox and goat pox (SPGP) virus and lumpy skin disease (LSD) virus belong to the genus *Capripoxvirus* and cause disease with economic impacts in sheep/goats and cattle respectively. In 2013/14, outbreaks of SPGP were reported in sheep in Greece and Bulgaria and LSD outbreaks were reported in cattle in Turkey, Egypt and some countries in the Middle East. Clinical signs for both diseases include pox lesions, papules and scabs on the skin which may contain virus. This, together with the fact that Great Britain (GB) currently imports cattle hides, sheep skins and wool from European Union (EU) countries without the requirement for treatment prior to export, raises concern that capripoxviruses could be introduced into GB. A qualitative assessment presented here concluded that the current risk of entry of SPGP virus into GB through the importation of one untreated sheep skin, hide or wool bale from an EU Member State (MS) with similar flock prevalence to that in sheep in Greece in 2013/14 is *low*. In terms of SPGP virus levels, those infected sheep skins/hides entering GB are more likely to be from infected animals with normal skin (i.e., not showing lesions) and hence carrying lower levels of virus than those from animals showing papules and scabs which contain very high virus levels and are easier to detect. The predicted risk of importation of LSD virus per cattle hide/skin is also *low* (assuming LSD were to emerge in an EU MS with similar herd prevalence to that reported for SPGP in Greece in 2013/14). The levels of LSD virus on an infected cow's hide, if imported, may be very low. It is recommended that the risks for entry of capripoxviruses are recalculated if outbreaks occur elsewhere within the EU.

Introduction

Lumpy skin disease (LSD), sheep pox and goat pox are pox diseases of cattle, sheep and goats, respectively. They are characterised by fever, nodules on the skin, internal lesions, enlarged lymph nodes and sometimes death [1,2,3,4]. The diseases are of economic importance as they cause damage to hides and can result in death due to secondary bacterial infections [2] together with resulting disruption of trade in livestock and livestock products [1]. LSD can cause a temporary reduction in milk production in cattle and sterility in bulls [2] with subsequent production impacts. The World Organisation for Animal Health (OIE) has categorised LSD and sheep pox and goat pox as notifiable diseases [4,5].

OIE consider sheep pox and goat pox to be a single disease entity [5], referred to here as sheep pox and goat pox (SPGP). The viruses causing these diseases are members of the *Capripoxvirus* genus of pox viruses (family *Poxviridae*) and are clinically indistinguishable. Strains of sheep pox virus (SPPV), goat pox virus (GTPV) and lumpy skin disease virus (LSDV) cannot be differentiated serologically [5]. There is close genetic relatedness of capripoxvirus isolates, which average no less than 96% nucleotide identity between strains of SPPV, GTPV and LSDV [1].

LSD is currently present throughout most of the continent of Africa, with only Libya, Algeria, Morocco and Tunisia in the north still considered free [4]. It has spread out of the African continent into the Middle East with the first cases in Israel in 1989 after the disease appeared in Egypt the previous year [4]. LSD outbreaks have been reported in the Middle Eastern region since 1990 including Kuwait, Lebanon, UAE, Israel and Oman. Tuppurainen and Oura [4] write that there are no geographical or epidemiological reasons why LSD cannot spread further north into Turkey and Europe, or further east into Asia and they cite the impact of climate change on the abundance and distribution of mechanical vector populations as possible reasons for this. Indeed, outbreaks of LSD occurred in south eastern Turkey in 2013/14 [6].

SPGP is found in Africa north of the equator, the Middle East and Asia including India, Nepal and parts of China [5]. It has spread into Europe on several occasions [5], with outbreaks reported in sheep in Bulgaria and Greece in 2013/14 [7]. Distinct host preferences exist with most strains of SPPV and GTPV causing more severe disease in the homologous host [1] and new introductions are generally only identified in one of the two animal species concerned (i.e. goats or sheep) depending on the strain introduced [5]. For example, goat pox was introduced into Bangladesh in 1984 from India, and sheep pox has caused occasional outbreaks in Italy (1983), Greece (1988, 1995, 1996, 1997, 1998 and 2000) and Bulgaria (1995 and 1996) having spread from Turkey, probably in illegally imported animals [5].

Spread of capripoxviruses can occur through trade of infected animals and their products such as wool and hides [8]. Such products may be treated or untreated. Untreated hides and skins are defined in Regulation (EU) No 142/2011 [9] as cutaneous and subcutaneous tissues that have not undergone any treatment, other than cutting, chilling or freezing. There is currently no requirement for treatment of these products imported to GB from within the EU. Under Regulation (EU) No 142/2011 [9] fresh hides and skins must, however, comply with the animal health conditions for fresh meat laid down under Council Directive 2002/99/EC [10]. Thus, skins and hides must not come from slaughterhouses in which animals infected with sheep pox and goat pox virus (SPGPV) or LSDV were present during the slaughtering or production process. This is important because it means that if a positive animal is detected at the farm or slaughterhouse in the EU then the whole batch (including other infected animals which may have been missed) is condemned.

Given the ongoing outbreaks of SPGP in south-eastern Europe and LSD in Turkey, there is potential for further spread of these capripoxviruses to and/or within Europe. This, together with the fact that GB currently imports cattle hides, sheep skins and wool from European countries without the requirement for treatment prior to export, raises concern that capripoxviruses could be introduced into GB. This paper describes a qualitative assessment of the risk of importation of one infected product (i.e. skin/hide or bale of wool) through legal trade into GB.

Methods

Risk question and scope

The specific risk question was: *What is the probability that an individual whole skin/hide or bale of wool legally imported from an EU Member State (MS) with an ongoing outbreak is infected with capripoxvirus at the point of entry into GB?* Thus, following the OIE Terrestrial Animal Health Code definition [11], an entry assessment was undertaken. SPGPV and LSDV are very similar and each step of the risk assessment considers both viruses together, while highlighting any subtle differences that warrant a separate consideration in terms of risk. The products (skins/hide/wool) are considered collectively. Trade levels to GB and transmission/spread, once within GB, were not considered. An infected product was defined as one that contains one or more infectious virus particles.

Risk pathway

The risk pathway has four component steps: (i) the herd/flock from which an animal comes is infected (with probability P_1), (ii) an individual animal is infected with the virus (with probability P_2), given the herd/flock is infected, (iii) the infected skin/hide/wool bale enters the export chain (with probability P_3), and (iv) the virus survives packaging and transport of the skin/hide/wool to GB (with probability P_4). The probabilities P_2, P_3 and P_4 are conditional probabilities and the overall probability of virus entry (R) is given by:

$$R=P_1P_2P_3P_4 \quad (1)$$

Although the level of virus is not explicitly considered as an output from the assessment (virus entry is defined as one or more infectious virus particles), it is important for the estimation of some of the pathway probabilities. In particular P_3 and P_4 are dependent on the levels of the virus in the skin of infected animals. For this reason, virus level was considered.

Levels of virus on skins/hides of infected animals

A distinction was made between skins/hides from infected animals showing clinical signs (i.e. pox lesions, papules or scabs) and those from infected animals with normal skin (i.e., skin with no apparent gross pathology) and no clinical signs. This distinction was made because most virus is found in the skin papules about six days after their first appearance [5]. Bowden et al [1] estimated that the normal skin of goats experimentally infected with GTPV has $10^{3.0}$ to $10^{4.4}$ tissue culture infectious dose 50% ($TCID_{50}$) per gram between 8 and 13 days post inoculation (dpi) while the papules have loading ranges over 100-fold higher than the normal skin at $10^{5.2}$ to $>10^{7.2}$ $TCID_{50}$ per gram over the same time scale. Similarly, genomic copies of SPPV in normal sheep skin were 4-$\log_{10}$ (per 100 ng total DNA) at 8 dpi compared to 6.5-$\log_{10}$ for the secondary skin nodules [1] with a >5 $\log_{10}$ difference at 13 dpi. In experimentally infected sheep, SPPV titres of 10^7 $TCID_{50}$ per gram of skin (at sites where virus was inoculated) were detected by day 7 to 8 [12]. In cattle experimentally infected with LSDV through the jugular vein, skin nodules contained high levels of virus [13] with 5.1 and

5.3 $\log_{10}$ plaque forming units (pfu) per gram at 12 and 15 dpi, respectively [13]. In contrast to sheep and goats in the study of Bowden et al [1], infectious virus was absent from normal skin of LSDV-infected cattle [13]. Furthermore, while levels of viral DNA in the skin nodules of cattle were very high between 4.6 and 8.6 $\log_{10}$ copies per μg tissue, levels of viral DNA in normal skin of LSDV-infected cattle were in general undetectable [13]. Based on these data, it was assumed that the titre of virus on a hide/skin is directly proportional to the number of lesions or papules on that hide/skin and the time since infection. The papules and scabs are likely to contain very high levels of virus, while normal skin from SPGPV-infected goats and sheep is likely to contain medium levels of virus. Normal skin from LSDV-infected cattle contains very low levels of virus.

Levels of virus in wool from infected animals

There is little information on levels of SPPV or GPPV in wool. Following experimental intradermal inoculation, the virus replicates in the cells of the dermis and glandular hair cells at the base of the hair follicles [15]. Unlike skin, the virus will not be able to replicate within the wool itself, and therefore any virus present will be due to contamination of the wool with skin fragments, including fragments of scab material. In this respect the wool could contain fragments of lesion with high loadings of virus. The papules may cover the whole body or be restricted to the more hairless or woolless parts of the skin [1,5]. In lambs and kids naturally infected in the Duhok area of Iraq, the presence of pox lesions occurs in areas of the hide with less wool and hair [14]. Similarly in sheep in Iran, the gross lesions in adults occurred in woolless or sparsely wooled areas of skin [15]. However, the gross lesions were all over the skin and in some internal organs in lambs [15]. It was assumed that wool from infected adult sheep contains low levels of infectivity while wool from lambs contains medium levels of infectivity. This reflects the fact that in some lambs lesions occur all over the skin rather than in the woolless areas observed in adults.

Qualitative probabilities

The entry assessment describes the probability of entry of the virus into GB through the importation of one product item from other regions of the EU. Following the European Food Safety Authority (EFSA) definitions, the probabilities in Equation (1) are expressed qualitatively as *negligible*, *very low*, *low*, *medium*, *high* or *very high* [16,17]. The definitions of these terms were taken from [16] namely, *negligible*: so rare that it does not merit to be considered; *very low*: very rare but cannot be excluded; *low*: event is rare but does occur; *medium*: event occurs regularly; *high*: event occurs very often; and *very high*: event occurs almost certainly. To estimate the risk of release, R, the qualitative probabilities were combined as in Equation (1) using the reasoning described previously [18]. In summary, as each qualitative probability P_1 to P_4 can be considered quantitatively as taking a value between 0 and 1, it follows that the product R will be at most, the minimum of P_1 to P_4. The qualitative value of R is thus set as the minimum of the qualitative values of P_1 to P_4. The probability definitions given above apply to all the qualitative probabilities within the risk assessment, i.e. R, P_1, P_2, P_3 and P_4.

Estimation of P_1: Probability that a herd/flock is infected

Data on the recent outbreaks in Greece were used to estimate P_1. Hadjigeorgiou et al [19] reported that there are around 9,200,000 sheep and 5,600,000 goats in Greece on about 300,000 farm units. Counting the units with more than 10 adult female animals, this equates to about 155,000 farms. OIE [7] give data on the number of farm units in which outbreaks occur. Between Aug 2013 and January 2014 (six months), outbreaks of SPGPV were reported in sheep in Greece in 82 farm units [7]. Over a period of one year, therefore, double that number of outbreaks, i.e. 164, might be expected. This would represent about one in a thousand of the 155,000 goat and sheep farms in Greece. LSDV has never been reported in Europe [4], and it is assumed here P_1 would be similar to that for SPPV in Greece.

Estimation of P_2: Probability that an individual animal within a positive herd/flock is infected

Data from the recent outbreaks of SPGPV in sheep in Greece and Bulgaria were used to estimate this probability. Between Aug 2013 and January 2014, a total of 1,472 cases (250 deaths) of SPGPV were reported in Greece in 17,735 susceptible sheep in 82 infected flocks (Figure 1) [7]. The OIE definition [23] of susceptible animals is, “Animals present in the outbreaks at the start of the period in question”. Thus the number of susceptible animals recorded by OIE [6, 7] includes all animals on the farm which are susceptible to the virus whether infected or not. Therefore the average within-flock prevalence in sheep may be calculated as 1,472/17,735 = 0.083. The range of within-flock prevalences was from 0.0035 (1 case in 284 susceptible sheep) to 1.0 (13 cases in 13 susceptible sheep) with 5th and 95th percentiles of 0.007 and 0.552 respectively. Linear regression analysis of the data for 82 infected sheep flocks in Greece [7] showed that there is a statistically significant relationship between decreasing within-herd prevalence and increasing herd size, ($P<0.001$) (Figure 1). There is uncertainty associated with why this relationship could occur, but one possibility is that this represents an under-reporting in larger flocks because once a single case is detected the whole flock is condemned, and there is little point in looking for every last case in a large flock.

In Bulgaria there were three outbreaks in 2013 [7], with a total of 37 cases in 558 susceptible sheep giving an average within-flock prevalence of 0.066. The reported outbreaks from Greece and Bulgaria give estimates of the mean within-flock prevalence (P_2) to be between 0.066 and 0.083. Pox lesions, however, may be missed due to their restricted distribution on some sheep [8]. Thus, the true within-flock prevalence may be higher than these values. In terms of disease symptoms between individual animals, SPGPV typically exhibits a uniform range of responses in the respective host species [8] such that infected animals typically show symptoms. However in the case of cattle, not all animals infected with LSDV exhibit clinical signs thus potentially hindering detection of cases on farm. In 21 outbreaks in Turkey between Nov 2013 and Feb 2014 [6], 837 LSD cases were reported in 21,829 susceptible cattle giving an average within-herd prevalence of 0.038 and roughly half that of SPGP reported in sheep in Greece and Bulgaria. According to Tuppurainen and Oura [4], only 50% of LSDV-infected cows are likely to show clinical signs, even though the majority of experimentally infected cows become viraemic. The observed within-herd prevalence of LSDV was therefore multiplied by factor of two for the purpose of this risk assessment. Thus the estimated within-herd prevalence for a LSDV-positive herd in Turkey is around 0.076 and comparable to that reported for SPGPV-positive sheep flocks in Greece and Bulgaria. The range of within-flock prevalences for LSDV-positive herds in Turkey was from 0.0007 (1 case in 1,372 susceptible cattle) to 0.67 (2 cases in 3 susceptible cattle). Linear regression analysis of the data for 21 LSDV-infected cattle herds in Turkey between Nov 2013 and Feb 2014 [6] showed that there is a statistically significant relationship between decreasing within-herd prevalence and increasing herd size, (P=0.002) (data not shown).

Estimation of P_3: Probability that infected skin/hide/wool bale enters the export chain

The probability P_3 relates to the detection of an infected animal and therefore whether the infected hide is prevented from being exported, rather than whether the animal was slaughtered for domestic consumption or export. With reference to the risk question (see above) it is given that the hide has been legally imported into GB and therefore comes from an EU farm registered to export where EU 142/2011 is enforced. The probability P_3 depends on the probability that an individual infected animal/skin is not detected either on the farm or at the approved slaughter house. In the 82 reported outbreaks of SPGPV in sheep in Greece between Aug 2013 and Jan 2014, flocks with as few as one case in 284 susceptible sheep were reported [7]. This suggests that some farmers/slaughter house operators are good at spotting low frequency occurrences of clinical cases in a large number of animals although it is not known how many cases were present in that flock of 284 sheep and were thus missed. It would seem unlikely that the remaining 283 susceptible sheep in that flock were tested to confirm they were negative. However, at the other extreme, 270 cases were reported in a flock of 390 susceptible sheep, suggesting that the probability of detecting an infected animal with clinical symptoms is relatively high. To estimate P_3 it was assumed that the probability of detection of an infected animal at an approved slaughter house or on a farm is directly proportional to the number of lesions on that animal (i.e. the more papules the greater the chance that the farmer or slaughterhouse worker will see one). Therefore, those animals with high titre hides/skin/wool have a high probability of being detected, while the lower titre animal hides from infected animals without lesions are more likely to be missed. For SPGPV, the distribution of pox lesions in the skin can be widespread with over 50% of the skin surface affected [8] facilitating detection of cases. However, more commonly in enzootic areas, the lesions in sheep and goats are restricted to a few nodules under the tail and are thus only detected on close examination [8], increasing the probability of not detecting a case. Furthermore some animals in the slaughterhouse may be at a stage where infection has taken place in the skin but clinical symptoms have not yet developed. Thus, virus was detected in normal skin of sheep at 4 dpi [1] while macules did not develop before 5 dpi. Moreover the number of SPGP viral genomic copies was ~4-$\log_{10}$ in normal skin in sheep at 6 dpi when macules faded on exsanguination prior to necropsy [1]. Thus macule detection efficiency could be reduced at slaughterhouses, while significant levels of virus are present in normal skin and in the macules themselves. The macules enlarge and develop into papules within 1 to 2 days and then to scabs within the following week [1]. Papules and scabs are less likely to be missed. For LSDV-infected cattle, only half of those infected show symptoms (discussed above).

The probability P_3 is also related to the number of clinical cases in the flock/herd on the farm or in the slaughterhouse batch (which could include more than one flock or herd). Thus the more clinical cases in an infected flock/batch, the greater the chance that at least one is detected and that all animals in that flock/batch and thus their products are condemned according to EU 142/2011. Analysis of the outbreak data for SPGPV in sheep in Greece [7] showed that the statistical distribution for the number of cases per infected flock is skewed with a significant proportion of infected flocks having a few cases and a small proportion having a large number of cases (Figure 2). Thus, although the average was 18.0 cases per infected flock (1,472 cases in 82 flocks), some 33% of infected flocks had just 1, 2 or 3 cases. The statistical distribution of the number of LSDV cases in infected cattle herds (Figure 2) is even more skewed than for SPGPV based on the data for 21 LSDV outbreaks in Turkey between Nov 2013 and Feb 2014 [6]. Thus of 21 infected herds, 14 (66%) has just one or two cases while three herds had >200 cases.

About 110 fleeces may go into a bale of wool [20]. The shearing process on the farm may expose skin lesions and allow detection of infected animals at an earlier stage. However, although many animals contribute wool to a bale, many infected sheep flocks have few cases of SPGPV (Figure 2).

Estimation of P_4: Virus on wool/hide/skin survives transport to GB.

Although SPGPV is very susceptible to direct sunlight, it can persist for months in dark conditions, such as contaminated animal sheds [5] and has been shown to remain infectious for periods of at least 3 months in scab material obtained from animals which have recovered from the infection [21] LSDV is stable between pH 6.6 and 8.6 and showed no significant reduction in titre after 5 days at 37°C over this pH range [22]. For LSDV in the skin lesions of infected animals, the virus can persist for at least 33 days even though the necrotic portions of skin have completely dried out [22]. Skin/hides and wool are likely to be transported to GB via trucks and ships. Various travel blogs report that the drive from Greece to England requires 4 - 7 days. With temperatures below 37°C and in the dark, it was assumed that little or no inactivation of the virus would occur during this time for transport.

Results

On the basis of 2013/14 data for Greece and taking into account the number of sheep/goat farms in Greece, it was concluded that the probability, P_1, that a herd or flock is infected, is *low*.

Assuming that the data for SPGP in Greece and Bulgaria [7] and LSD in Turkey [6] give a reasonable description of within-flock prevalence for capripoxviruses in any EU country which could potentially have outbreaks or undisclosed infection, it was concluded that P_2 is mostly *medium.* It is noted that smaller flocks appear to have higher within-flock prevalences (Figure 1) (1.0 in two flocks). Thus on a flock to flock bases, P_2 may vary between *medium* and *very high*.

As described previously a SPGPV-infected sheep could be missed because the macules may be localised to areas where they are hidden such as under the tail and a LSDV-infected cow could be missed because it is not showing clinical symptoms. Taking this into account together with the evidence above that virus could be present in skin before macules have developed, the probability of not detecting an SPGPV/LSDV-infected animal is judged to be *medium*. This is at the level of the individual animal. For those flocks/herds with a large number of cases, P_3 was considered to be *negligible* (because at least one case would be detected resulting in condemnation of the whole flock/batch before it could enter the export chain) while for those flocks/herds with lower numbers of cases, P_3 was considered *medium* (reflecting the chance of missing a single case). Since a significant proportion of SPGPV-infected sheep flocks and the major proportion of LSDV-infected cattle herds have only 1, 2 or 3 cases (Figure 2), it was concluded that overall, P_3 is *medium*. This represents a worst case scenario. Although a batch at a slaughterhouse may include more than one flock, it is very unlikely that more than one flock would be positive in a given daily batch because the between-flock prevalence (P_1) is *low*. Thus even those batches at slaughterhouses comprising multiple flocks/herds are still likely to have only a few cases based on Figure 2.

Given that the SPGP/LSD virus in a hide/skin is unlikely to undergo significant decay within the travel time to GB together with the medium initial titres of virus in normal skin of infected sheep and goats, it was concluded that the probability of virus survival, P_4, is *high*.

The individual probabilities and the overall probability R are given in Table 1. The lowest probability is for P_1 (*low*). Thus by combining the qualitative probabilities in Table 1, using the method described by Gale et al [18], it was estimated that the overall probability, R, is *low*. This represents the probability that an individual raw hide/skin or bale of wool is infected with SPGP/LSD virus on legal import to GB from an EU MS with ongoing outbreaks with similar between-flock (P_1) and within-flock (P_2) prevalences to those reported for sheep in Greece in 2013/14.

Descriptions of uncertainty and key assumptions are also presented in Table 1 for each probability term. This process identifies that the risk assessment is highly dependent on the data available from the SPGP outbreak in Greece and there is therefore uncertainty associated with the estimate of risk of another EU country having an outbreak. It is therefore recommended that this risk assessment is revisited if outbreaks occur elsewhere so that the estimates for P_1, P_2 and P_3 and hence the overall estimate of risk can be verified.

Discussion

Outbreaks of SPGP have been reported in sheep in Greece and Bulgaria in 2013/14. LSD outbreaks have occurred in cattle in south-eastern Turkey and there is no reason to assume that LSDV will not spread into Europe at some stage [4]. Given this situation, there is concern within GB that capripoxviruses could be imported via the legal trade of skins/hides and wool from the EU. Using data from the 2013/14 outbreaks of SPGP in Greece and Bulgaria and LSD in Turkey, together with microbiological data from the literature, a qualitative entry assessment was undertaken. It was estimated that the probability of entry of SPGPV/LSDV in a single hide/skin/wool bale imported from a MS with ongoing outbreaks is currently *low*. Entry of infection was defined in terms of importation of one infected product (skin, hide or bale of wool), contaminated with one or more infectious virus particles. Although there are quantitative data available for many of the parameters including P_1, P_2 and P_4, a qualitative approach was adopted here because of the lack of any quantitative data for estimation of P_3.

Viral load was considered to some extent within the assessment although it was not explicitly stated in the probability of entry. While normal skin of SPGPV-infected sheep and goats does contain infectivity, the titres are very much lower than for those in papules and nodules. In view of the inspection processes at approved slaughterhouses, it is considered here that any imported product infected with the virus would most likely have come from an infected animal not yet displaying clinical signs. Alternatively the hide/skin material imported may exclude those regions of the skin (woolless areas or under the tail) where nodules more commonly occur [8]. The viral load on the hide/skin of such an animal is likely to be at a medium level rather than the very high levels found in skins with lesions and papules. The viral levels in wool from an infected bale would also be medium although there may be some variation depending on whether the wool is from lambs or adult sheep. Whether or not this medium level would be important for transmission within GB would depend on several factors including the dose-response relationship and the potential routes of exposure for GB cattle, sheep and goats. SPGPV is spread through aerosols and/or close contact and by indirect means such as contamination of cuts and abrasions (Babiuk et al, 2008a). The high concentration of virus in the skin may also contribute to spread via insect vectors [1] although it is not clear whether this could happen from hides/wool in GB. Normal skin of LSDV-infected cows has very low levels of virus [8]. Thus the capripoxvirus levels on an LSDV-infected cattle skin/hide given it has entered GB from the EU may be much lower than that for SPGPV-infected hides.

The assessment did not consider the volume of trade in skins/hides/wool from the EU. Thus the probabilities of entry per year or per batch were not estimated. There are currently no data available to determine the volume of trade. Should these data become available in the future, the assessment could be extended to include such estimates.

The method used to combine the qualitative probabilities associated with the risk of entry of virus makes use of the fact that these probabilities are conditional; they correspond to a sequential set of events, all of which are necessary for the importation of an infected product. In a comparable quantitative assessment, the rules of probability mean that the conditional probabilities are multiplied to give the joint probability which represents the estimate of risk. The absolute maximum of this joint probability will be the minimum of the conditional probabilities. It is intuitive to consider the same multiplicative process when dealing with conditional probabilities that are qualitative. However, in this case, risk may be over-estimated because no account is taken of where on the qualitative category an individual probability will lie. Furthermore, if all four probabilities P_1 to P_4 were *low*, for example, then R would still be *low* as it would if three were *high* and just one were *low*. Thus, the *low* estimate of virus entry may very well be an over-estimate in this case. As it currently stands, the value of P_1 is the determining probability for R as it is the only probability with a value of *low*. Thus, based on the current data and assessment, the risk of entry of virus depends on the herd/flock prevalence in the countries in which there have been recent outbreaks i.e. Greece and Bulgaria. Should the situation in Greece, Bulgaria or any other EU country change, the estimate of risk would need to be updated.

Although there is considerable variation in the within-herd prevalence for SPGPV-positive sheep flocks in Greece (Figure 1) (and for LSDV-positive herds in Turkey (not shown)) this range could reflect natural variation, for example due to differences in exposure resulting from the intensity of the sheep/sheep contacts (sheep density), differences in environmental factors between flocks and differences in the susceptibility of individuals/breeds within a given flock (i.e. dose-response). There is a statistically significant relationship between decreasing within-herd prevalence and increasing herd size both for SPGP in sheep in Greece (Figure 1) and for LSD in cattle in Turkey (not shown). As discussed previously, this may relate to some bias within the data due to failure to detect all of the infected animals within a positive herd, particularly in the larger herds. However, using the approaches described above for the combining of probabilities, only a significant decrease in the magnitude of P_2 (such that P_2 is less than P_1) would affect the predicted value of R in this assessment. Under EU 142/2011 all animals in the flock/slaughterhouse batch are condemned if at least one case is detected. Therefore the probability of an infected skin/hide/wool bale entering the export chain (P_3) is dependent on the statistical distribution of the number of cases within an infected flock/herd/batch. Thus the more cases in a flock, the greater the chance that at least one is detected and that the whole flock/slaughter house batch is condemned (under EU 142/2011). An increase in within-herd prevalence or emergence of a more virulent strain which meant fewer infected flocks had just one or two cases, would greatly decrease P_3. Indeed should P_3 decrease in magnitude below *low*, so too would R. While some capripoxvirus-infected animals do not show symptoms (see above) and would not be detected on an individual basis it is unlikely that multiple infected animals in a given flock/herd would all be symptomless at time of inspection. Thus a high within-herd prevalence not only increases the probability of at least one case with symptoms being detected, but also increases the probability of at least some cases displaying detectable symptoms. The statistical distribution of the number of cases within those infected herds/flocks is therefore central to understanding the uncertainty in P_3.

In conclusion, based on the 2013/14 outbreak data for countries in south-east Europe, the probability of entry of SPGPV into GB from the importation of a single hide/skin/wool bale from an EU MS with ongoing outbreaks has been assessed as *low*. The predicted risk is also *low* for LSDV in a single cattle skin/hide should this virus emerge in an EU MS at some stage. These estimates are sensitive to the herd/flock prevalence during an outbreak in the EU.

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References

[1] T.R. Bowden, S.L. Babiuk, G.R. Parkyn, J.S. Copps, D.B. Boyle, Capripoxvirus tissue tropism and shedding: A quantitative study in experimentally infected sheep and goats. Virology 371 (2008) 380-393.

[2] OIE (World organisation for animal health), 2010a: Lumpy skin disease. http://www.oie.int/fileadmin/Home/eng/Health_standards/tahm/2.04.14_LSD.pdf. Accessed 28 March 2014.

[3] OIE (World organisation for animal health), 2010b: Sheep pox and goat pox. http://www.oie.int/fileadmin/Home/eng/Health_standards/tahm/2.07.14_S_POX_G_POX.pdf . Accessed 28 March 2014.

[4] E.S.M. Tuppurainen, C.A.L. Oura, Review: Lumpy Skin Disease: An Emerging Threat to Europe, the Middle East and Asia. Transbound. Emerg. Dis. 59(1) (2012) 40-48.

[5] R.P. Kitching, Sheep pox and goat pox. In: Coetzer, J.A.W., and R.C. Tustin (eds), Infectious Diseases of Livestock, 2nd edn, Volume 2, pp. 1277-81. Oxford University Press Southern Africa, 2004, Capetown.

[6] OIE (World organisation for animal health), 2014: Country Information http://www.oie.int/wahis_2/public/wahid.php/Countryinformation/Countryreports. Accessed 28 March 2014.

[7] OIE (World organisation for animal health), 2014: Sheep Pox and Goat Pox in Greece. Follow up Report No. 11 Ref OIE 14688 Report Date 24.01/2014. http://www.oie.int/wahis_2/temp/reports/en_fup_0000014688_20140124_165829.pdf.

[8] S. Babiuk, T.R. Bowden, D.B. Boyle, D.B. Wallace, R.P. Kitching, Capripoxviruses: An emerging worldwide threat to sheep, goats and cattle. Transbound. Emerg. Dis. 55 (2008) 263-272.

[9] Commission Regulation (EU) No 142/2011, 2011: (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:054:0001:0254:EN:PDF).

[10] Council Directive 2002/99/EC, 2002: Laying down the animal health rules governing the production, processing, distribution and introduction of products of animal origin for human consumption (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:018:0011:0020:EN:PDF).

[11] OIE (World organisation for animal health), 2013: Terrestrial animal health code. Import risk analysis (http://www.oie.int/fileadmin/Home/eng/Health_standards/tahc/2010/chapitre_1.2.1.pdf).

[12] W. Plowright, W.G. MacLeod, R.D. Ferris, The pathogenesis of sheep pox in the skin of sheep. J. Comp. Path. 69 (1959) 400 – 413.

[13] S. Babiuk, T.R. Bowden, G. Parkyn, B. Dalman, L. Manning, J. Neufeld, C. Embury-Hyatt, J. Copps, D.B. Boyle, Quantification of lumpy skin disease virus following experimental infection in cattle. Transbound. Emerg. Dis. 55(7) (2008) 299-307.

[14] I.K. Zangana, M.A. Abdullah, Epidemiological, clinical and histopathological studies of lamb and kid pox in Duhok, Iraq. Bulgarian Journal of Veterinary Medicine 16(2) (2013) 133-138.

[15] A. Khodakaram Tafti, A., I. Namdari, Clinicopathological study of a natural outbreak of sheep pox in Fars Province of Iran. Iranian Journal of Veterinary Research 1(2) (2001) 139-144.

[16] EFSA (European Food Safety Authority), 2006: Opinion “Migratory birds and their possible role in the spread of highly pathogenic avian influenza”. *The EFSA Journal* **357**, 1-46.

[17] FAO/WHO (Food and Agricultural Organization of the United Nations World Health Organisation), 2009: Risk characterisation of microbiological hazards in foods. Guidelines. Microbiological Risk Assessment Series, No. 17.

[18] P. Gale, A. Brouwer, V. Ramnial, L. Kelly, R. Kosmider, A.R. Fooks, E.L. Snary, Assessing the impact of climate change on vector-borne viruses in the EU through the elicitation of expert opinion. Epidemiology and Infection 138(2) (2010) 214-225.

[19] I. Hadjigeorgiou, F. Vallerand, K. Tsimpoukas, G. Zervas, The socio-economics of sheep and goat farming in Greece, and the implications for future rural development. LSIRD BRAY Conference (1998) (http://www.macaulay.ac.uk/livestocksystems/dublin/hadgi.pdf).

[20] Anon, Wool bale (http://en.wikipedia.org/wiki/Wool_bale). Accessed 28 March (2014).

[21] F.G. Davies, Sheep and goat pox. In: Gibbs, E.P.J. (ed). *Virus Diseases of Food Animals, a World Geography of Epidemiology and Control*, 2nd Edition, Volume II, Disease Monographs, pp.733-49 (1981) Academic Press, London.

[22] K.E. Weiss, Lumpy skin disease virus. Virology Monographs 3 (1968) 111-131.

[23] OIE (World organisation for animal health), HANDISTAUS II (http://www.oie.int/hs2/help.asp) Accessed 9 June (2015).

Table 1: Estimated qualitative probabilities for SPGP and LSD.

Probability	**Qualitative probability**	**Key assumptions and uncertainties**
Herd/flock infected (P_1)	*Low*	Data only available for SPGP in Greece, therefore uncertain of probability of a herd/flock being infected elsewhere in the EU. No cases of LSD in EU so assumes P_1 is similar to that for SPGP in sheep in Greece and Bulgaria.
Animal infected, given herd is positive (P_2)	*Medium* to *Very High*	Within-flock prevalence data only available for SPGPV in sheep in Greece and Bulgaria (and LSDV in Turkey), therefore uncertain of the value of P_2 for outbreaks in other EU countries.
Infected skin enters export chain (P_3)	*Medium*	Infected animals with fewer lesions or earlier stages of infection may be missed. P_3 tends to *negligible* for herds with many infected animals.
Virus survival (P_4)	*High*	None
Risk of release for one product item (R)	*Low*	Limited or no data available for likely prevalence of SPGP and LSD within or between flocks/herds in EU countries other than Greece and Bulgaria. Therefore considerable uncertainty associated with the risk of release if an outbreak is reported in another country.

Figure legends

Figure 1: The reported within-flock prevalence for cases of SPGPV-infected sheep decreases with the size of the flock, P = 2.3×10^{-7} (slope $-0.217/\log_{10}$ flock size, 95% c.i. -0.14 to -0.29). Data for 82 SPGPV-infected sheep flocks in Greece between Aug 2013 and Jan 2014 (OIE, 2014b).

Figure 2: Distribution of number of detected cases per infected herd for SPGPV outbreaks in sheep in Greece (OIE, 2014a) and LSDV outbreaks in cattle in Turkey (OIE, 2014b).