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Qualitative assessment of the probability of introduction and onward transmission of lumpy skin disease in Ukraine

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A R T I C L E I N F O

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A B S T R A C T

Lumpy skin disease (LSD) is a transboundary disease affecting bovine animals, which may result in severe economic implications. Ukraine is considered particularly vulnerable to LSD due to its proximity to regions where the virus is circulating. In addition, its ecological and environmental parameters can sustain, in summer, the spread of the disease in case it entered the country.

This qualitative risk assessment aimed to investigate the probability that LSD virus is introduced to Ukraine and, if introduced, what would be the probability of onward transmission in the country within the next year. The risk assessment followed the OIE import risk analysis for animals and animal products guidelines and was undertaken with the support of local experts via an expert elicitation workshop. A modified Delphi approach was used to gather experts inputs.

The illegally traded cattle was the pathway considered to have the highest probability of LSD introduction; however the probability was estimated to be low. When assessing the probability of an animal being exposed to the virus and further onward transmission in Ukraine, the highest probability estimate was related to flying vectors (high probability). During the expert opinion workshop, the Delphi approach helped to increase the agreement between experts and to assess the uncertainty related to some of the probability estimates.

Throughout the risk assessment, some data gaps were identified and highlighted. The lack of reliable data on animal movements and biosecurity in Ukraine were emphasized. Based on the elicited probability estimates, the local experts generated recommendations for risk management practices. To our knowledge, this is the first risk assessment performed on LSDV in Eastern Europe and the conceptual framework adopted can help other countries willing to do a risk assessment in a similar data scarce environment.

1. Introduction

Lumpy skin disease (LSD) is a transboundary disease of cattle (Bos indicus and B. taurus) and water buffalo (Bubalus bubalis), categorized as notifiable by the World Organization for Animal Health (OIE). LSDV is a virus from the family of the Poxviridae.

Abbreviations: BTV, blue tongue virus; EFSA, European food safety authority; EKE, expert's knowledge elicitation; FAO, food and agriculture organization of the United Nations; GTPV, goat pox virus; IBR, infectious bovine rhinotracheitis; LSD, lumpy skin disease; LSDV, lumpy skin disease virus; OIE, office international des epizooties; PCR, polymerase chain reaction; RA, risk assessment; SSFSCP, state service for food safety and consumer protection of Ukraine; SSPV, sheep pox virus.

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The disease first started to spread among southern African countries in the forties and since then has become endemic in most countries south of the Sahara (Weiss, 1968) (OIE WAHIS). In the following years, the virus spread through the Middle-Eastern region (EFSA Panel on Animal Health and Welfare, 2015; FAO (Food and Agriculture Organization of the United Nations, 2013). It then spread to the European continent entering Greece from Turkey (European Food Safety Authority (EFSA), 2017; Tasioudi et al., 2015). From 2015 to 2016 Bulgaria, Serbia, Montenegro, former Yugoslavia, Republic of Macedonia, Kosovo, Albania and Russia reported the disease.

In 2018 and 2019, outbreaks reported in Europe were in Greece, Georgia and Russia. Worldwide outbreaks continuing into 2020 and 2021 are located in the Middle-East, Southern Africa and South-East Asia. Ukraine remains to this day disease-free (OIE, 2019).

Following the rapid spread of the disease in the Balkans in 2015-2016, the European Commission implemented a large-scale vaccination campaign, vaccinating more than 2.5 million animals. In 2019, the Balkans were declared free from any outbreak in the year 2018 (Calistri et al., 2019), showing that vaccination with homologous strains associated with a stamping out policy is an effective way to control the disease.

LSDV affects cattle, and water buffaloes (Sharawi et al., 2011). Whether the disease affects Asian and European wildlife is still unknown. However, the conclusions of various studies on African wildlife indicate that wildlife does not play a significant part in the spread or maintenance of LSDV (Hedger and Hamblin, 1983; Babiuk et al., 2008). The incubation period after natural infection by cattle is estimated to be between 1 to 4 weeks (Tuppurainen and Oura, 2012). LSDV is believed to be transmitted primarily by arthropod vectors. The transmission between animals through direct contact is inefficient according to experimental and field evidence. However, experimental intravenous transmission was successful, indicating that the natural cases of LSDV are probably spread by blood-sucking arthropods (Weiss, 1968; Carn and Kitching, 1995).

There is only little information about the different arthropod vectors for LSDV in the field. It has not been proven yet that there is any biological arthropod vector for the virus (EFSA Panel on Animal Health and Welfare, 2015). The virus is transmitted mechanically, meaning that there is not any replication of the virus in the arthropod tissues or cells. The transmission occurs via contaminated mouth parts of vectors. The mechanical transmission was demonstrated to be effective by Aedes aegypti, where the infected mosquitoes that had fed upon lesions of LSDV infected cattle could transmit the virus to susceptible cattle over a period of 2-6 days (Chihota et al., 2001). Ticks are also potential vectors of LSDV.

The survival of the virus in fomites, feed, feces, urine and pastures is still unknown, but indirect transmission via those commodities cannot be excluded (EFSA Panel on Animal Health and Welfare, 2015).

Taking into account the geographical localization of Ukraine and its proximity to countries with known recent LSD outbreaks such as Russia and the Balkan, Ukraine was identified as being in an “at-risk” area for the incursion of LSDV (Saegerman et al., 2019, Allepuz et al., 2019). It was demonstrated that the median spread rate of LSDV in the Balkan was 7,43 km/week, but that it also attained a maximum of 543,6 km/week. Vector-associated spread rates were considered to be less than 10-15 km/week, whereas the higher rates were associated with animal movements (Mercier et al., 2018). Considering that the incubation time is assumed to be up to 28 weeks (Tuppurainen and Oura, 2012, OIE, 2017), the disease could stay undetected over long distances, hampering the efforts to detect virus circulation early .

Given how quickly LSDV has spread between 2014 and 2016, assessing the probability of introduction is essential to help veterinary authorities to implement risk-based surveillance strategies and increase preparedness for risk mitigation. Entry of LSDV would lead to economic losses directly, because of the impact of the disease on cattle productivity and indirectly because of the economic impact related to trade restrictions and control measures that could follow. In light of Ukraine’s recent effort to extend its market and sustain its economy through agri-food products, trade restrictions could be devastating, as re-gaining a disease-free status after an outbreak is expensive and takes time (OIE, 2018).

LSD is not currently circulating in Ukraine but given the current situation in neighboring countries and the perceived non-negligible risk of introduction in Ukraine, the veterinary authorities decided to assess the probability of introduction of LSD in Ukraine by means of live animals movement, vectors, or animal products and by products within one year (December 2018-December 2019). The probability of onward transmission to the susceptible animal population if disease introduction were to occur was also assessed. The process allowed the identification of those risk pathways and risk factors more relevant for LSD introduction and spread in Ukraine, and contributed to define risk mitigation strategies against the risks ascertained.

This analysis was conducted as part of the “Milk Safety Project (MSP)” (Milk Safety Project, 2019), a capacity building project implemented by SAFOSO in collaboration with the State Service for Food Safety and Consumer Protection (SSFSCP) in Ukraine in the period 2015-2019. The overall objective of the project is to support the establishment and implementation of a modern risk-based food safety control system in the dairy value chain in Ukraine.

2. Material and methods

2.1. Qualitative risk assessment framework and risk questions

The qualitative risk assessment was based on the framework set by the OIE Handbook on Import risk analysis (OIE, 2010). The framework consisted of an entry assessment, exposure assessment and consequence assessment. The probability estimates of each step in the risk pathways were estimated by Ukrainian experts through expert’s knowledge elicitation (EKE). Details are presented below. The qualitative risk categories used for the experts are defined in Table 1 (Journal, 2006).

Table 1: Definition of qualitative risk categories.

The overall questions of the risk assessment were defined as:

- What is the probability that the lumpy skin disease virus is introduced in Ukraine within the next year?
- In case LSDV was introduced in Ukraine, what would be the probability of onward transmission of the lumpy skin disease virus in the country within the next year?

In this work, “within the next year” is the time period from December 2018 to December 2019. To allow experts to estimate the annual probability of introduction (and further spread) considering this timeframe, information on the number of imports / movements of live animals and products for 2018, along with other information, were provided. The susceptible species considered in this risk assessment are domestic cattle, water buffalo and local wild ruminant species.

2.2. Risk pathways

The entry assessment estimated the likelihood of LSDV introduction in Ukraine via specific pathways with different commodities.

Table 1
Definition of qualitative risk categories (Journal, 2006).

Risk category	Definition
Negligible	The event is so rare that it does not merit to be considered
Very low	The event is rare but cannot be excluded
Low	The event is rare but does occur
Medium	The event occurs regularly
High	The event occurs very often
Very High	The event occurs almost certainly

Commodities considered in the entry assessment were live animals, vectors, milk and meat, hides and skin, semen and other biomaterials (Fig. 1).

Fig. 2 shows the risk pathways for entry assessment for live animals. The rest of the entry pathways can be found in Supplementary Material A. The exposure assessment assessed the likelihood of exposure of livestock to LSDV assuming a first virus incursion in Ukraine. Commodities considered in the exposure assessment are live animals, vectors, milk and meat, hides and skin, semen and other biomaterials. Fig. 3 shows the exposure pathway for live animals. The rest of the exposure pathways can be found in Supplementary Material A. The probability of exposure was estimated as the probability of infection of a first holding after the virus was introduced in Ukraine. "First holding" describes the first Ukrainian holding where an animal gets infected for the first time. The consequence assessment (Fig. 4) assessed the likelihood of further spread via specific pathways before being detected. The consequence assessment assumes virus incursion and exposure have already occurred. The pathways taken into account were live animals, farm workers, vectors, fomites, vehicles, insemination, by products (manure, dead animals) or unhygienic practices (iatrogenic). In agreement with the local Ukrainian authority, the consequence assessment was limited to assess the likelihood of further spread to other holdings and did not evaluate the impact of the disease (i.e. in terms of morbidity, production losses and economic consequences). Additionally, the risk assessment framework did not aim to identify geographical areas or regions at higher risk of introduction and spread. However, when relevant, probability was differentiated between intensive production and backyard production.

2.3. Live animals

This route considers domestic cattle and water buffalo, which are known to transmit LSDV. Local European wild ruminants species were also considered, following the indications of the local authorities, even though there is currently no information or evidence that they are susceptible to LSDV, nor that they can transmit it. The probability of introduction was estimated via five different routes, considering both legal and illegal import. The probability that at least one infected animal is imported into Ukraine was estimated by considering the following factors: the countries currently exporting cattle to Ukraine and the number of animals imported, their quarantine policy, implementation of vaccination programs, the possibility of vaccine conversion and whether the animal could survive the journey while remaining infectious. It was also considered whether post-import testing is implemented and what local quarantine and surveillance programs are in place. To assess the probability of introduction of LSDV through wild ruminants crossing the border, data on wild animal movements and surveillance systems in place were gathered.

When assessing the probability of further transmission within Ukraine, the risk pathways were split in two main categories: direct and indirect transmission. Direct transmission occurs directly through livestock and indirect transmission occurs through contaminated vectors or environment.

For this route, movements of live animals were considered, as well as their legal requirements and if biosafety measures were taken regarding newly traded animals.

2.4. Vectors

This route considers whether an infected vector (ticks or blood-sucking flying insects) could cross the border, directly or indirectly through, for example a vehicle. The data studied included for each vector species were as follow: presence in Ukraine and in areas close to the borders, how long they can fly or survive while remaining infectious. The species of vectors present in Ukraine and at its border depends on environmental conditions, such as the temperature, the humidity, the wind and the season. When assessing the probability of further transmission within Ukraine, local biosafety measures against vectors and

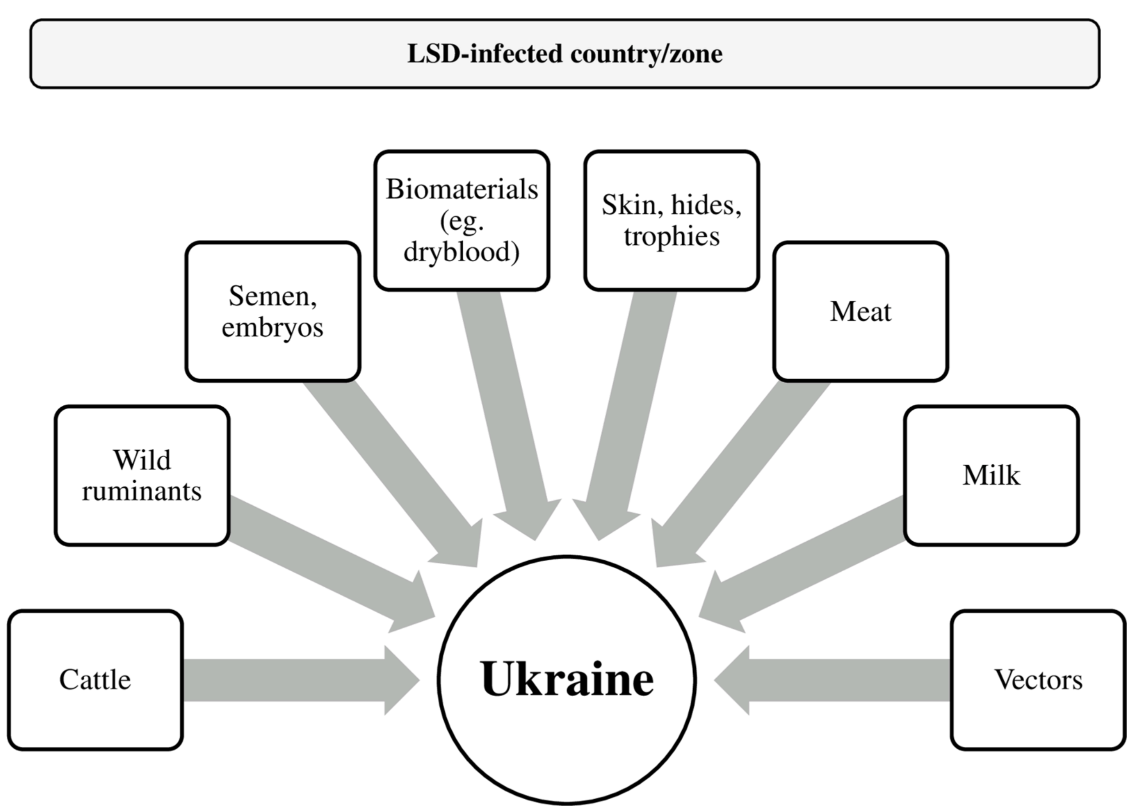

Fig. 1. Commodities assessed for the probability of introduction of LSDV in Ukraine.

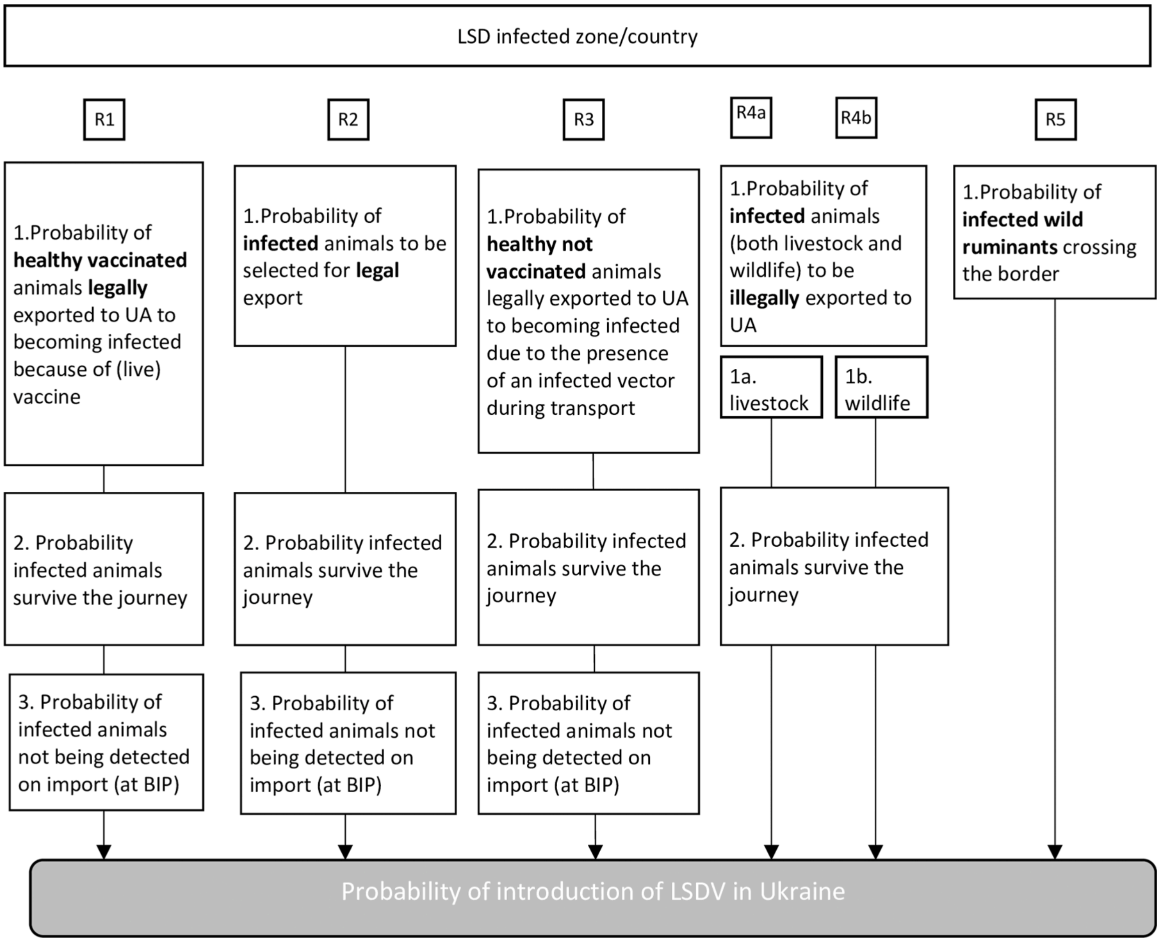

Fig. 2. Risk pathway for the introduction of LSDV via live animals.

density of farms and households on the local Ukrainian territory were considered.

2.5. Animal Products

For this route,the products taken into consideration were skin, hides, hunting trophies (parts of animals kept as trophies after hunting), chilled meat and milk products. To assess the probability whether an infected product could be consigned or exported to Ukraine, several factors were evaluated: amount of items traded, if and how long the virus can survive in those products, and if it could be detected upon arrival in Ukraine. Both the legal and illegal routes were considered. To assess the probability of onward transmission, it was assessed if there was a probability of contact between the cattle and the animal products, direct or indirect (via vectors).

2.6. Biomaterials

Biomaterials were defined as semen, embryos or other biological products such as dry blood. To assess the probability of introduction, it was assessed the probability of crossing the border while remaining infectious and undetected upon arrival. Both legal and illegal routes were considered. For the semen and embryos, it was assessed under what conditions the products must have been collected, quarantine requirements and testing for the import to Ukraine.

To estimate the probability of onward transmission, the storage conditions and processing of the biomaterials were considered.

2.7. Data collection and parametrization

The data necessary to assess the likelihood of each step of the pathway were gathered by members of the SSFSCP and the local project team. Data were gathered through literature research, access to national database and statistics, or from international organizations (FAO, OIE, EFSA). Relevant parameters considered for each risk pathway are presented below (Table 3). In few cases no data were available.

Table 3 Key Data used for the risk assessment.

2.8. Expert knowledge elicitation

The expert knowledge elicitation (EKE) was conducted during four workshops implemented in Kiev, Ukraine in the period June 2018 to January 2019. In the first workshop the risk pathways and data needed to estimate the probabilities of entry, exposure and consequence components were identified by local experts. Data were collected by staff of the SSFSCP in the period gap between the 1st and the 2nd workshop. In the 3rd and 4th workshop, respectively in December 2018 and January 2019, the participants presented the data collected for each risk pathway and, complemented by their local expertise derived the probability estimates for all individual steps and for the combined probability estimates.

The expert knowledge elicitation was conducted through a Delphi approach to increase the agreement between the experts. The local project team facilitated the workshops and coordinated the data collection but did not contribute to the estimation of probabilities. The group of experts participating in the elicitation process consisted of 26 members of the Risk assessment team established during the

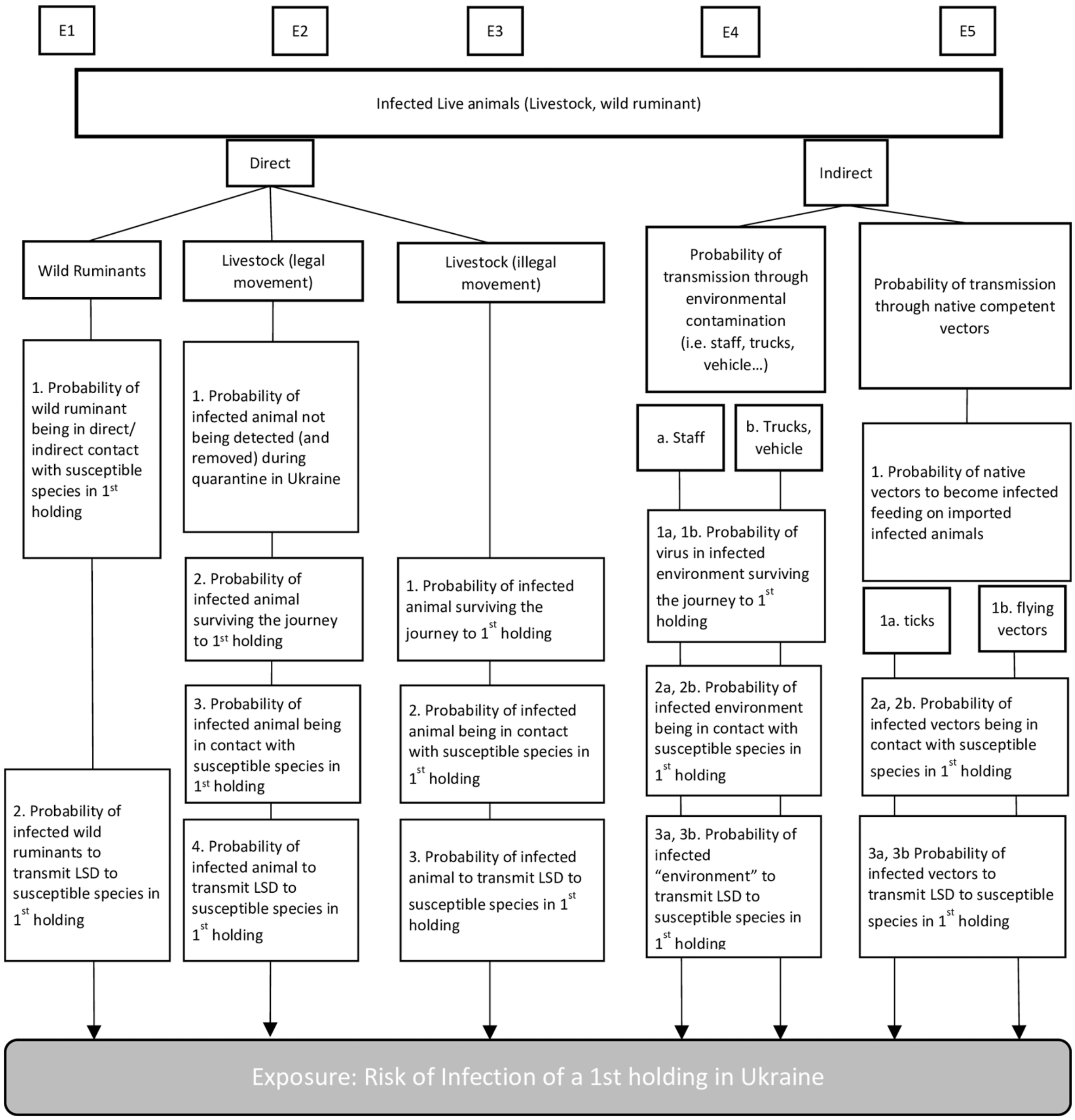

Fig. 3. Exposure pathways for live animals.

implementation of the Milk Safety Project. Experts were selected from departments and units of the State Service on Food Safety and Consumer Protection of Ukraine with different expertise and background necessary including field veterinarians, professors of infectious diseases and state veterinarians from Animal Health and Animal Welfare, Food Safety and Epizootiology departments.

The EKE was implemented using a three step approach. First, the gathered data were presented to the experts and doubts clarified. Printouts of presentations of data were given to each expert to be able to reflect on the data presented. The experts were then asked to derive qualitative probability estimates for each step in the risk pathways through an online voting tool (i.e. Mentimeter) that provides immediate feedback about the results, while keeping the anonymity of the participants. The questions asked to the experts were identical to the text described in the boxes in the risk pathway shown in this paper. To avoid individual experts being influenced by other experts' answers, the results were only shown and discussed in plenum once all answers were collected. The discussion of the first round of votes was coordinated by an independent workshop facilitator. In order to reduce bias, the facilitator would intervene in case the discussion was driven out of context or views were imposed by specific participants. Similarly, attention was paid to prevent potential anchoring or overconfidence biases. After the plenary discussion, a second round of voting was performed. For each step in the risk assessment, the mode of the second voting round was used as the final likelihood estimate. When all experts agreed on the same estimate or the level of agreement was already very high after the first round of votes, then, experts were asked if they agreed to skip the second round and upon their consensus, the second round was not asked. This process was repeated for each specific step of each pathway.

2.9. Combination matrix

To combine the qualitative estimates obtained from each step of the pathways in the risk assessment components, a conditional matrix was used (Table 2). In each pathway, given that each step is fully conditional to the previous ones, the principle of conditional probabilities applies, and the increase of the combined probability is not possible. This matrix was taken from risk matrices reported elsewhere (Wieland et al., 2011, Gale et al., 2010).

Table 2: Combination matrix two probability estimates established

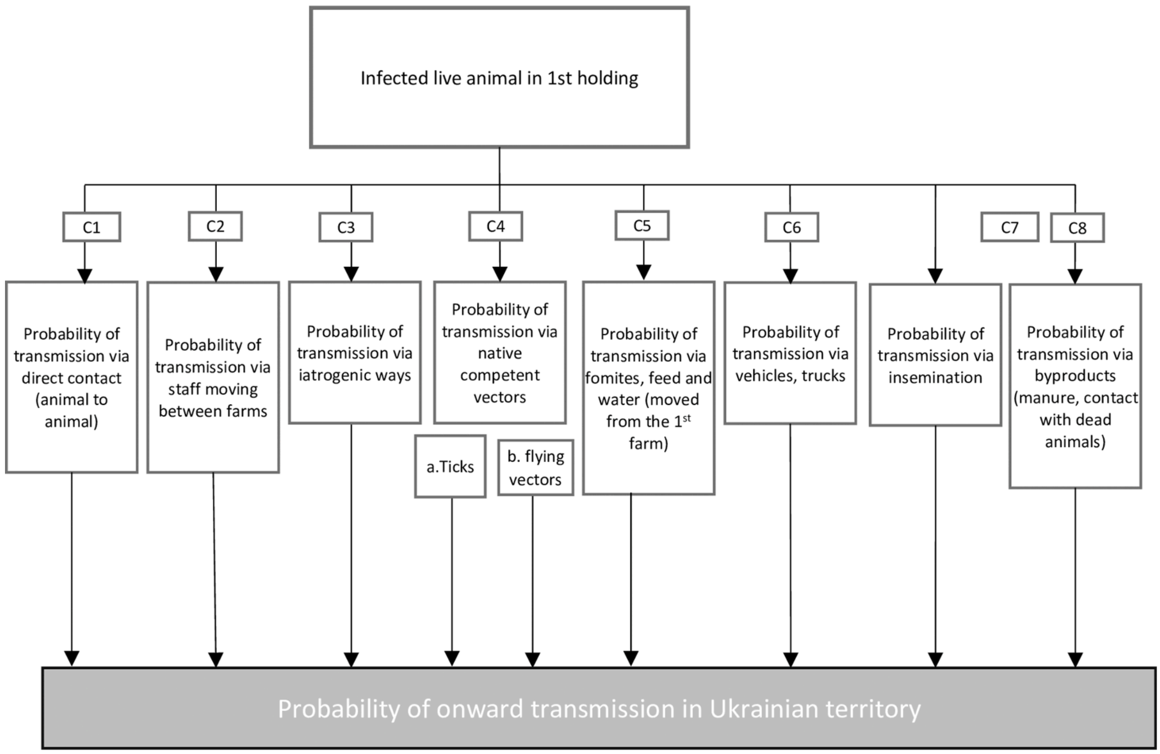

Fig. 4. Consequence pathway for each commodities.

Table 2
Combination matrice two probabilities estimates established on the hypothesis that the second event is entirely conditional to the previous one (Gale et al., 2010).

Event 1	Event 2	Negligible	Very Low	Low	Medium	High	Very High
Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	
Very low		Negligible	Very Low	Very Low	Very low	Very low	Very low
Low		Negligible	Very Low	Low	Low	Low	Low
Medium		Negligible	Very Low	Low	Medium	Medium	Medium
High		Negligible	Very Low	Low	Medium	High	High
Very high		Negligible	Very Low	Low	Medium	High	Very High

on the hypothesis that the second event is entirely conditional to the previous one

2.10. *Uncertainty assessment*

The level of disagreement between experts was assessed during the EKE process and used as an indicator of uncertainty. A quantitative score was assigned to each qualitative probability estimate (where “negligible” = 1 and “very high” = 6) and the average of the absolute difference of individual quantitative probability estimates to the mode was calculated. The resulting average absolute differences to the mode ranged from 0.00 to 1.47. They were then ranked and split into quartiles (Q1=0.35; Q2=0.52; Q3=0.76), allowing identifying four categories of uncertainty (“low”, “medium”, “high” and “very high”). A similar approach was used in Wieland et al. (2015).

The chosen approach aimed to facilitate the consensus among experts and reduce the uncertainty. To assess if this approach proved right, the average absolute differences to the mode related to the 1st and the 2nd round of votes were compared with the underlying hypothesis that the agreement would increase between the two rounds (64).

The uncertainties estimated along each pathway were not combined in a single estimate, however, the largest uncertainty on the pathway has been indicated in the result tables (Tables 4–7) to express the overall uncertainty of each specific pathway.

2.11. *Definition of risk management strategy*

At the end of the last workshop, the experts were asked, using their local expertise, to generate recommendations for risk management practices based on the elicited probability estimates. Experts were organized in separate working groups and outputs from each group were presented and plenary approved. The risk management strategies defined through this process are available in the supplementary documentation (Supplementary Material C).

3. Results

To better contextualize the choices of experts, the information and data presented during the workshops that helped the experts to express their judgements are described here (Table 3). Relevant aspects are also discussed in the discussion. To allow conciseness, only pathways that were estimated to have a non-negligible probability are described in detail.

3.1. *Entry assessment of LSDV*

A total of eighteen (R1-R18) different entry pathways were considered to assess the probability of introduction of LSDV in Ukraine. Table 4 shows the results for live animals. The rest of the result tables can be found in the Supplementary Material B (Tables B.1–B.7). The overall

Table 3
Key Data used for the risk assessment.

Data requirements	Estimate	Source
Countries (that export to Ukraine) consigning cattle fromLSD affected countries in 2018	None	Ukrainian State Statistic
Countries exporting meat to Ukraine in 2018	Australia, Belarus, Belgium, Germany, Netherlands, New Zealand, United States	Ukrainian State Statistic
Amount of meat exported to Ukraine in 2018	See table II.h in supplementary documentation	Ukrainian State Statistic
Countries exporting milk and dairy products to Ukraine in 2018	Belarus, Belgium, Denmark, Finland, France, Germany, Poland, Romania, United States	Ukrainian State Statistic
Amount of milk and dairy products exported to Ukraine in 2018	See table II.i in supplementary documentation	Ukrainian State Statistic
Countries exporting sperms and embryos to Ukraine in2018	Canada, Czech Republic, France, Germany, Hungary, Netherlands, Norway, Switzerland, United States	Ukrainian State Statistic
Amount of sperms exported to Ukraine in 2018	See table II.j in supplementary documentation	Ukrainian State Statistic
Countries exporting susceptible species to Ukraine	Germany, Poland, Hungary, Denmark, Netherlands, Czech Republic	Ukrainian State Statistic
Number of live animals of susceptible species exported to Ukraine in 2018	See table II.k in supplementary documentation	Ukrainian State Statistic
Countries exporting trophies to Ukraine in 2018	No data	
Amount of trophies exported to Ukraine in 2018	No data	
Countries exporting unprocessed hides to Ukraine in 2018	Germany, Hungary, Italy, Latvia, Moldova, Poland, Romania, Serbia, Slovakia,	Ukrainian State Statistic
Amount of unprocessed hides exported to Ukraine in 2018	See table II.l in supplementary documentation	Ukrainian State Statistic
Countries in Europe vaccinating against LSDV	Albania, Bosnia et Herzegovina, Bulgaria, FYROM, Greece, Kosovo Montenegro, Serbia	European Food Safety Authority (EFSA) (2017)
Countries that reported an LSD outbreak in 2018	Georgia, Russia, Turkey	OIE Wahid
Countries vaccinating against LSD exporting to Ukraine	None	Ukrainian State Statistic
Duration of quarantine in exporting country	28 days	Order of the Ministry of Agrarian Policy and Food of Ukraine N° 553 (Ministry of Agrarian Policy and Food of Ukraine et al., 2021)
Duration of quarantine in Ukraine	30 days	Order of the Ministry of Agrarian Policy and Food of Ukraine N° 553 (Ministry of Agrarian Policy and Food of Ukraine et al., 2021)
Homologous live vaccines side effects	Side effects constated in 0.19% of farms, 0,09% of the animals, loss of 0.024% of animals.	Ben-Gera et al. (2015)

Table 3 (*continued*)

	Immunity duration of 1 year.	
Illegal Import of hides from infected countries	No data	
Incubation period	up to 28 days	OIE Terrestrial animal code
Morbidity rate	2-50%	European Food Safety Authority (EFSA) (2017)
Mortality	<10%	Davies (1991)
Vector species involved	Aedes Aegypti, Culicoides spp, Stomoxys Calcitrans, Ticks: Ripicephalus spp. and Amblyomma spp., Unknown for other species	Tuppurainen et al. (2018)
Presence of clinical signs	50% of animals	Weiss (1968)
Presence of susceptible vector species in Ukraine	Aedes spp, Culicoides spp., Rhipicephalus spp., Stomoxys Calcitrans	
Presence of susceptible wild ruminants in and nearUkraine	No data on the susceptibility of local wild ruminant species	
Prevalence of LSDV in exporting countries	All countries are free from LSDV	OIE Wahis
Prevalence of LSDV in wild ruminants near Ukraine	No data, unknown	
Survival time in vector	Stomoxys calcitrans and Aedes aegypti up to 6 days after feeding, Rhipicephalus spp possibility of transstadial and transovarial transmission, survives overwintering, other species: no data	Chihota et al. (2001) Tuppurainen et al. (2013), Lubinga et al. (2014)
Susceptible species	Cattle, water buffalo	Sharawi et al. (2011)
Tests used on imported animals	No test for LSDV at the quarantine in Ukraine. Diseases tested: leukemia, IBR, brucellosis, tuberculosis	Order 14.06.2004 No. 71, Ukrainian Legislation
Vector spread rate of LSDV	< 10-15 km/week	Magori-Cohen et al. (2012)
Viremia	up to 2 weeks	OIE (2017)
Virus inactivation	55°C for 2 h; 60°c for 30 min	OIE (2017)
Virus sensible to	20 Solution Ester; 1% solution of formalin ; 2% Phenol ; 2-3% Hypochlorite Sodium ; Chloroform	OIE (2017)
Virus survival time at 4°C	6 months	OIE (2017)
Virus survival time in dried crusts in skin	up to 33 days	Weiss (1968)
Virus survival time in fresh semen	42 days (longer if frozen)	Irons et al. (2005)
Virus survival time in hides	minimum 18 days	Weiss (1968)

estimates of the risk pathways ranged from “negligible” to “low” probability of introduction and the uncertainty of different steps in the risk pathways ranged from “low” to “very high”.

Table 4 Probability of introduction via live animals.

Table 5 shows the estimates of all entry pathways according to the probability. Ten pathways were considered negligible by the experts, and so neither considered in the entry assessment, nor shown in the result tables. Negligible pathways can be found in the full tables included in the supplementary documentation (Supplementary Material B).

Table 4
Probability of introduction via live animals.

Steps of pathway	Healthy vaccinated cattle (R1)		Healthy not vaccinated (R3)		Infected a) cattle b)wildlife (illegal) (R4)	
	Probability	Uncertainty	Probability	Uncertainty	Probability	Uncertainty
1. Probability of infected animal coming to/being exported to Ukraine	Very low	High	Very low	High	a) Low b) Very Low	a) High b) Medium
2. Probability infected animal survives the journey	High	Very High	High	Medium	a) High b) High	a) Very High b) Very High
3. Probability of infected animal not being detected on import (BIP)	Very low	Very High	Very low	Very High	N/A	
Probability of introduction of animal infected with LSDV	Very low	Very High	Very low	Very High	a) Low b) Very Low	a) Very High b) Very High

Table 5
Summarizing the probabilities estimates of each pathway.

Probability estimate	Probability of introduction	Probability of exposure	Probability of onward transmission
High		Indirect contact with livestock via flying vector (E5)	Indirect via native flying vectors (C4b)
Low	Illegal import of infected cattle (R4a)	Direct contact with vectors in vehicle (E9)	Indirect via iatrogen ways (C3)
Very Low	Legal import of healthy vaccinated cattle (R1)	Direct contact with legally imported livestock (E2)	Direct contact between livestock (C1)
	Legal import of healthy not vaccinated cattle (R3)	Direct contact with illegally imported livestock (E3)	Indirect contact via people (C2)
	Illegal import of wildlife (R4b)	Indirect contact with livestock via people (E4a)	Indirect via native ticks (C4a)
	Entry of ticks (R6)	Direct contact with ticks (E6)	Indirect via fomites, feed, water (C5)
	Entry of flying vectors (short distance) (R7)	Direct contact with flying vectors (E7)+ (E8)	Indirect contact via vehicles (C6)
	Entry of vector transported through vehicles (R9)		Direct contact via insemination (C7)
	Legal import of hides (R10)		Indirect contact via byproducts (C8)
	Illegal import of hides (R11)		
Negligible	Legal import of infected cattle (R2)	Direct contact with wildlife (E1)	
	Infected wildlife crossing the border (R5)	Indirect contact with livestock through vehicles (E4b)	
	Entry of vector transported through wind (R8)	Direct contact with hides (E10a)	
	Legal import of trophies (R12)	Indirect contact with hides via vector (E10A)	
	Illegal import of trophies (R13)		
	Import of meat (R14)		
	Import of milk (R15)		
	Legal import of semen (legal) (R16)		
	Illegal import of semen (R17)		
	Legal import of biomaterials (R18)		

3.2. *Live animals*

For the risk posed by the movement of live animals (livestock and wild animals) (R1-R5), the pathway with the highest probability was considered the illegal import of infected cattle (R4a). The probability was assessed as “low”, but with uncertainty levels ranging from “high” to “very high”. There are no official estimations on illegal animal movement through the Ukrainian borders. However, during the workshops, experts claimed the existence of uncontrolled animal movement in the Oblast of Donetsk, due to the current conflict. Donetsk Oblast is close to the Russian border, which is currently LSDV infected. Despite being unsubstantiated by evidence, illegal animal movements from Russia to Ukraine are regularly reported (Workshop Participant, personal communication). The extent of these illegal movements (in terms of number of animals and frequency) is not known.

With regards to the introduction of LSDV via vaccinated healthy animals (R1), Ukraine does not allow the import of cattle from countries vaccinated against LSDV. However, according to the Ukrainian experts, there is a non-negligible possibility that a country free from the disease would import livestock from an LSD vaccinating country and that the vaccinated animal is not declared as such when exported (to Ukraine). Because it has already happened in the past with other diseases such as the Blue Tongue Virus, experts predicted that there is a non-negligible probability that a LSDV-vaccinated animal enters the country unknowingly as LSDV is not tested during the quarantine period. However, the probability that the imported vaccinated animal becomes infectious due to the vaccine is also unlikely according to available evidence. In a study from 2016, the presence of adverse effects after vaccination with live vaccine ranged between 0.03% and 25%, the highest percentage being from unofficial, unbranded and unknown vaccines sold on the black market. Official vaccines show a very low rate of adverse effects (Abutarbush et al., 2016). However, in a study from 2018 investigating an outbreak of LSDV in Russia, vaccine-like LSDV virus was detected both in cattle and in houseflies (M. domestica), but with no evidence that they are able to mechanically transmit the disease (Sprygin et al., 2018). For all of these reasons the probability that vaccinated cattle is imported to Ukraine and becoming infected was estimated to be “very low”. The probability that it would survive the journey was estimated “high”, because the disease is known to have a low rate of mortality, up to 10%. The probability that the infected animal would then not be detected upon arrival in Ukraine was estimated “very low” with a “very high” uncertainty. Checks are based on clinical signs and not serological, the awareness of official inspectors regarding LSDV was estimated good enough by the experts.

Pathways R2 (probability of introduction of infected cattle with LSDV in Ukraine) and R5 (probability of introduction of LSDV through infected wildlife) were considered to be both negligible but with different level of uncertainty. The uncertainty related to the negligible pathway R2 was low since, according to the Ukrainian legislation, only countries free from LSDV and with a surveillance and control system in place are allowed to export cattle to Ukraine. According to the national legislation (Order of the Ministry of Agrarian Policy and Food of Ukraine dated November 16, 2018 № 553)(27), cattle must be kept in quarantine in special premises and under supervision of state veterinarians of the exporting country at least in the last 28 days before entering the Ukrainian territory. The uncertainty related to the pathway R5 was considered to be high due to the scarcity of data on the circulation of the disease in wild ruminants in Ukraine (and in Europe in general), on the surveillance efforts targeted at these species and on wild animals density and movements across the borders. Furthermore, experts disagreed on the susceptibility of local wild ruminants to LSDV since evidence on the role of wild animals in the epidemiology of the disease in Europe and Asia are poor; studies confirming very low seroprevalence of LSDV targeted only African wild ruminant species (Tuppurainen and Oura, 2012). In addition, the more recent outbreaks in Russia were reported only in regions far from the Ukrainian border, with too long distances for the wild animals to cover

3.3. Vectors

For the probability of introduction through vectors (either ticks or flying vectors) (R6-R9), the probability of introduction of LSDV through ticks was considered to be "very low" (R6). The probabilities associated with vectors transported through wind and flying short distances (R7 and R8) were estimated to be "negligible". Ticks can enter Ukraine mostly through imported animals (both livestock and wildlife), and as previously mentioned, Ukraine does not import livestock from LSDV affected countries. That said, the probability that the virus survives in the ticks and that they remain infectious is "high", because ticks are known to be able to survive up to three years. Under experimental conditions, the virus could remain infectious and stable in a tick cell culture at 28°C for 35 days (Tuppurainen et al., 2015). It was also experimentally demonstrated that some ticks species could transmit the disease trans-stadial or trans-ovarian, and staying infectious over wintering periods of two months. (Lubinga et al., 2015, 2014, 2019, 2013). With regards to the probability associated with flying vectors, both on short flying distance (R7) and long (via wind) distance (R8) the overall probability was considered "negligible". Aedes aegypti can fly up to 14km at optimal weather conditions (Rowley and Graham, 1968), Culicoides spp. up to 2 km/day and for Stomoxys up to 45 km with wind (European Food Safety Authority (EFSA), 2017). It was demonstrated in one study in Israel from 2012 that vector transmission of LSDV could occur, but only in short (< 10-15 km) distances (Magori-Cohen et al., 2012). There is currently little information on how long a vector could remain infectious after feeding, except for Stomoxys and Aedes spp. where it could be up to 6 days (Chihota et al., 2001). The current outbreaks are far from Ukraine, located in Russia near Kazakhstan border (flying distance of round 1000km), too far for the vectors to travel and remain infectious.

The overall probability related to infected vectors transported through vehicles (R9), was considered to be "very low". As previously mentioned, current outbreaks are located at least about 1500-2000 road km away. For an infected vector to enter Ukraine, it would have to feed on the infected animals during transportation and survive the whole duration of transport. This was considered to be hardly possible, although not negligible.

Uncertainties associated with probabilities determined by vectors range from low to high. This is partially due to the lack of data related to the presence, susceptibility and capacity to transmit the disease of local vector species and length of infectiousness period.

3.4. Animal products

When assessing the probability of entry of LSDV through animal products, the overall probability associated with the majority of the risk pathways considered (R10-R15) were assessed as "negligible" with the exception of probabilities associated to the legal and illegal import of hides (R10 and R11, respectively) which were considered as harboring only a "very low" probability. The legislation in Ukraine prohibits import of hides from territories infected with a notifiable disease in accordance to the OIE guidelines.

Legal and illegal import of hunting trophies (R12 and R13) had a negligible probability of introducing the virus since the chemical and thermal procedures trophies are subjected during the preparation should drastically reduce the probability of virus survival. In addition, hunting trophies can sometimes remain in stores in the exporting country for very long time before being exported which makes these commodities unsuitable for the hazard. For the overall probability associated to chilled meat legally traded (R14), the probability was considered "negligible". Skeletal muscle meat is classified from OIE as a safe product. Probability associated with milk and dairy products (R15) were also considered "negligible", because Ukraine does not import those products from LSDV affected countries or countries that vaccinate against LSDV.

The probability of the introduction of LSD in Ukraine associated to biomaterials (R16-18, semen, other biomaterials) were considered to be "negligible". Biomaterials exported to Ukraine are unlikely to be contaminated with LSDV as most exporting countries are LSDV-free and most of the biomaterials undergo treatments that would inactivate the virus. One example is the importation of bovine semen to Ukraine. According to the Ukrainian legislation only countries officially free from LSDV can export semen to Ukraine.

3.5. Exposure assessment of LSDV

Tables 6 shows the results related to the exposure assessment for live animals. Results related to other commodities are in the tables in the supplementary documentation. Only those means/items harboring a non-negligible probability in the entry assessment were further considered for the exposure assessment. These items included the introduction of the LSDV through infected livestock, vectors and hides. Table 5 shows the estimates of all exposure pathways according to the probability.

Table 6 Probability of exposure via live animals.

The exposure pathway considered to have the highest probability of exposing the local livestock population to the LSDV consisted of indigenous flying vector feeding and becoming infected on newly introduced infected animals (E5). The probability associated to this pathway was estimated as high with the level of uncertainty in each step of the pathway ranging from medium to very high. Some species known to be able to transmit LSDV to cattle are present in Ukraine such as Stomoxys and Culicoides. Regarding ticks, mechanical transmission has been demonstrated for two species: Rhipicephalus appendiculatus and Ambylomma hebraeum (Lubinga et al., 2014; Tuppurainen et al., 2013). In addition, biosecurity measures to protect livestock from flying vectors are not commonly implemented in Ukraine. Considering this, the probability that the native vector would feed on a newly introduced infected animal and becoming infected was estimated "high", and then that it would come in contact with other susceptible animals and transmit LSDV was also estimated as "high".

The risk of exposure and infection of local livestock through legal and illegal movement of infected livestock (E2 and E3) was assessed to be "very low". Livestock that are legally brought into the Ukrainian territory must undergo a quarantine of 30 days. This quarantine takes place either in special quarantine centers, or at the farm on special premises meeting the quarantine requirements. During this quarantine, the animals are clinically examined without laboratory diagnostic being carried out. The incubation time of LSD is up to 28 days (OIE, 2017), and the proportion of subclinical/asymptomatic animals could be up to 50% (Weiss, 1968; Tuppurainen et al., 2013). The subclinically affected animals often show enlarged lymph nodes and fever (Kononov et al., 2019). If the clinical examination at the quarantine is thoroughly executed, even subclinical cases should be detected, the quarantine time being longer than the incubation time, but there is always the possibility of totally asymptomatic cases and violation of quarantine requirements, i.e. insufficient control of the animals or keeping them not separated

Table 6
. Probability of exposure via live animals.

Steps of pathway	Direct Livestock (legal)(E2)		Livestock (illegal)(E3)		Indirect Environment (E4)a) Personal		Native vectors (E5) flying vectors (for ticks see consequence)	
	Probability	Uncertainty	Probability	Uncertainty	Probability	Uncertainty	Probability	Uncertainty
Probability of infected animal not being detected and removed during quarantine in Ukraine	Very Low	Low	N/A		N/A		N/A	
Probability of native vectors to become infected feeding on imported infected animal	N/A		N/A		N/A		High	Very High
Probability of virus in infected animal/environment surviving the journey to 1st holding	High	Low	High	Low	Very Low	Very High	N/A	N/A
Probability of infected animal/environment being in contact with susceptible species in 1st holding	Very Low	Medium	Very Low	Very High	Very Low	Very High	High	Medium
Probability of infected animal/environment to transmit LSD to susceptible species in 1st Holding	Very Low	Medium	Very Low	Medium	Very Low	Low	High	High
Probability of infection of susceptible animal in Ukraine	Very Low	Medium	Very Low	Very High	Very Low	Very High	High	Very High

enough from the rest of the herd. In the case of an illegal import, quarantine restriction would not apply, and the asymptomatic animals would directly enter the herd. Still, direct contact between animals is not an effective transmission route for LSDV, therefore even without the quarantine measures the probability of exposure was assessed to be "very low".

The overall probability of exposure of a susceptible livestock through contact with staff (E4a) was assessed to be "very low". There is currently no data of the survival of virus on clothes or people, and if this can further transmit the disease. This mode of transmission was never reported in the literature. Thus, the uncertainty regarding these estimates was "very high". It is not "negligible" because the virus is known to be stable in the environment (OIE, 2017), and someone being in contact with healthy animals after being with infected animals is unlikely to happen, but still cannot be excluded, particularly in farms where biosafety measures (washing hands, shoes, changing clothes) are not correctly implemented.

The probability of infection of a susceptible animal in Ukraine through infected vectors was considered to be "very low" for direct pathways (ticks (E6) and flying vectors (E7 + E8). The direct pathway with ticks was assessed to be "very low" because the infected ticks would remain in quarantine with the animals and quarantined animals are usually kept far from the other animals of the holding, preventing transmission of the disease. For flying vectors, the probability is considered to be "very low" (although not negligible) because of the time necessary for the infected vector to reach the susceptible livestock is within the infectiousness period of the vector then the probability of successful infection cannot be excluded. It is currently not known for every vector species how long they can transmit the disease but as said for Stomoxys and Aedes it can be up to 6 days after feeding (Chihota et al., 2001, 2003).

The pathway E9 considered the possibility that an infected vector is transported through a vehicle in the farm where it would infect an animal. Due to lack of minimum biosecurity measures in place at farm level the probability of exposure to livestock was estimated to be higher than for the other pathways (E6, E7, E8), as "low".

As for the animal products and biomaterials categories, the only pathways considered by the experts for the exposure assessment were the contamination via hides. The probability of exposure and infection of susceptible animal with LSDV in Ukraine through hides was assessed as "negligible" for both direct and indirect (vector-mediated) pathways (E10a and A). The contact between the infected hides and the live animals (E10a) is considered very difficult if not impossible. In addition, hides do not attract blood-sucking insects (E10_A).

3.6. Assessment of the probability of onward transmission (consequence assessment)

Eight pathways were considered for the consequence assessment (Fig. 4). The probability estimates of onward transmission ranged between "very low" and "low", except for the transmission though native flying vectors, which was estimated to be "high". The uncertainty ranged from "low" to "very high" (Table 7). Table 5 shows the estimates of all consequence pathways according to the probability.

Table 7 Probability of onward transmission of LSDV into Ukraine within the next year.

The highest probability to further transmit the disease was associated to flying vectors (C4b) and ranked as "high". In a study modelling the transmission of LSDV, it was demonstrated that indirect transmission (assumed to be via flying vectors) had a basic reproduction number (R0) value of 15.7, whereas the R0 value for direct transmission was 0.38 (Magori-Cohen et al., 2012). This demonstrated how vector-mediated transmission is responsible for the spread of the disease. If introduction were to occur, this would be the most critical mechanism of spread within Ukraine. For ticks to move from one animal to another, they would need to be kept close to each other. Therefore, the estimated probability was considered to be "very low". It was also acknowledged that this transmission pathway is more likely to happen for small households that graze their cows together, and less likely for intensive farming.

Table 7
Probability of onward transmission of LSDV into Ukraine within the next year.

Pathway		Probability of LSDV onward transmission in Ukraine
Direct contact between Animals (C1)	Probability	Very low
	Uncertainty	Low
Moving staff (C2)	Probability	Very low
	Uncertainty	High
Iatrogenic (C3)	Probability	Low
	Uncertainty	High
Native vectors a) ticks b) mosquitoes, flies (C4)	Probability	a) Very low b) High
	Uncertainty	a)Low b) High
fomites, feed, water (C5)	Probability	Very low
	Uncertainty	Medium
vehicle trucks (C6)	Probability	Very low
	Uncertainty	High
insemination (C7)	Probability	Very low
	Uncertainty	Very High
byproducts (manure, dead animals (C8)		
	Probability	
Uncertainty	Very low	
High		

Similarly, in 1995, a study attempted to show direct transmission between diseased and naïve cattle housed together without the presence of arthropods. They could not achieve any direct transmission of LSDV (Carn and Kitching, 1995). Therefore, the probability of transmission between animals (C1) was estimated “very low” with a “low” uncertainty. Animal movements are common between farms, for sale or insemination.

The probability of further spread through iatrogenic transmission (C3) was estimated to be “low” because even if the awareness of veterinarians is currently being raised concerning the risk related to iatrogenic practices, it cannot be excluded that some veterinarians still have unsafe practices. There was no current information on the practice of Ukrainian veterinarians, therefore the uncertainty was “high” on this question. The transmission via fomites, feed or water (C5) has not been sufficiently demonstrated yet. The probability was estimated to be “very low” with a "medium" uncertainty. The virus can survive up to six months at ambient temperature (EFSA Panel on Animal Health and Welfare, 2015). With regards the role of vehicles and trucks (C6) in further spreading the disease, the probability was considered to be “very low”, due to lack of evidence of transmission of the virus this way. Regarding by-products (C8) such as manure and dead livestock animals, the probability was estimated to be “very low”, mostly because the sunlight would inactivate the virus and dead animals are promptly removed from common pastures (EFSA Panel on Animal Health and Welfare, 2015). The probability of transmission via artificial insemination (C7) was estimated as “very low” because, despite being experimentally demonstrated that seminal transmission of LSDV could occur via artificial insemination with fresh semen (Annandale et al., 2014), most of the semen used in Ukraine is imported frozen and there is no data confirming the transmission of LSDV via frozen semen. It has been reported that bulls excrete LSDV in semen, even after having recovered from the disease. With Polymerase Chain Reaction (PCR) detection methods, it could be detected for a maximum of 159 days post infection (Irons et al., 2005).

Both commercial farms and backyard farms use artificial insemination and are at the same risk in Ukraine.

3.7. Agreement level between experts

Overall, in about 43 % of the time the uncertainty level decreased between round 1 and 2. It remained the same 50% of the time. This result confirms that this approach helped experts to agree and reach consensus on their probability estimates.

4. Discussion

This risk assessment contributed to assess the probability of introduction and further spread of LSDV in Ukraine through different commodities and risk pathways. Through this process, relevant data on LSD epidemiology and risk factors in Ukraine were gathered for the first time and data gaps identified and discussed. To our knowledge, this is the first risk assessment performed on LSD in Eastern Europe.

The overall probability of introduction of LSDV into Ukraine was perceived by experts to be "very low" for most of the commodities and risk pathways considered. It was classified as "low" when taking into consideration the illegal import of livestock. The probability of exposure of susceptible species and further spread in Ukraine was considered to be highest for the routes involving vectors. In this case, the highest probability was estimated as "High".

When looking at the overall results of the risk assessment, the likeliest pathways for virus entry and further spread identified by the experts is the introduction of the virus via an infected animal, where vectors could feed on and then further spread the disease in the country. Many pathways were classified as negligible, due to the conditional probability approach (i.e. any pathway with a negligible step ended up being classified as overall negligible). However, the individual probability estimates in single steps helped identifying those steps along the pathways harboring higher risks and therefore indicating critical areas for risk managers.

The risk assessment was based on the OIE Import Risk Analysis framework (OIE, 2010) and structured in 3 different compartments (entry, exposure and consequence). The consequence assessment aimed only to assess the probability of further spread in Ukraine after first infection without attempting to estimate the magnitude of the impact in animal production, hence the economic impact of a potentially vast scale epidemic in the country. We acknowledge this is an important aspect to be further integrated into the risk assessment framework. Lumpy Skin Disease is known to have severe economic consequences. The control measures include vaccination and stamping out, and both are extremely costly. As soon as an outbreak occurs, the animal movements are restricted leading to serious financial loss. Following the OIE guidelines to gain a disease-free status after a case of LSD has occurred; the conditions differ in relation to the surveillance method used to prove the freedom of disease. It can last up to three years without any occurrence of infection with LSDV before regaining a disease-free status (OIE, 2018).

If animals are not culled, the high fever causes a drop in milk yield, some cows can abort, and bulls can become infertile. The convalescence period may last several months, and the cattle may become emaciated and grow less. The lesions in the skin cause permanent scarring that decreases the value of the hides. In a study conducted in Jordan, the observed mean decrease of bodyweight was of 23% and the mean decrease in milk production was 51% (Abutarbush et al., 2015), similarly to what was observed in earlier publications (Woods, 1988). The economic losses are higher in high-production breeds than in local breeds. In intensive farming units, the production losses could be up to 45-65% (Tuppurainen and Oura, 2012).

The risk assessment was implemented qualitatively through the involvement of local experts. The qualitative approach is suitable for most of the import risk assessment and it is particularly useful in a data scarce environment such as the situation in Ukraine. Indeed, the lack of data was a frequent limitation during the implementation of the risk assessment and this aspect is further discussed in other sections of the discussion.

The experts selected a large number of potential risk pathways for each of the three compartments and final probability estimates were generated for each risk pathway within each compartment. The uncertainty level of the probability estimates was also assessed. We didn’t attempt to combine specific probability estimates of the different routes in a unique probability estimate for each compartment; neither had we attempted to combine the entry, exposure and consequence estimates to generate a unique overall probability estimate of introduction and spread. We believe individual probability estimates for each route and the identification and discussion of best risk management strategies of the more important risk routes was a more useful and pragmatic approach. This approach was agreed with the Ukrainian authorities. The current work, despite not providing a final combined probability estimate for each compartment, allowed to identify which pathways were presenting more risk than others, and also to reflect where data and information gaps were more pressing.

The risk assessment was parametrized using a Delphi approach with the aim to increase the consensus on probability estimates between the experts. Experts were presented with the relevant data, asked to vote (1st round), discuss the output of the 1st vote and then eventually to vote again (2nd round). Votes were anonymous. This approach succeeded in improving the consensus between experts since, in more than 40% of cases the uncertainty between experts between round 1 and 2 of votes decreased. However, in about 7 % of cases, the uncertainty increased after the first round of questions. This trend was only related to three specific questions on wild ruminants susceptibility and role in the epidemiology of LSD in Ukraine, vector ecology and illegal trade where missing data was identified. In general, we noted that when data availability was poor, experts were more divided in their opinion. This was partially expected; the Delphi approach facilitated to overcome this limitation.

The experts involved in the risk assessment workshops were members from local research Institutes in Ukraine or from local authorities. The selection of experts was done under the framework of the Milk Safety Project and was based on specific criteria, among others i.e. familiarity with the legal framework in Ukraine, knowledge of the production system and the inner deficiencies (i.e. implementation of biosecurity measures). Few members of the risk assessment team were experts on LSD. Only very few members had some previous experience in risk assessment and, it is acknowledged that some expertise was lacking in the panel of experts, i.e. entomology. However, to overcome this limitation, the project team trained the selected experts on the basic features of the disease based on the most recent evidence. All experts were provided with the same information during the first workshop. In addition, the RA team members were also directly involved in the design of the risk pathways, the identification of the data necessary and the collection and analysis of the identified data. This helped them to build their knowledge on the disease and, in general, on the risk assessment method. This risk assessment was implemented as part of a capacity building activity. The adopted methodology could be relevant in similar settings where competent authorities have basic knowledge in risk assessment and which are characterized by scarcity of data.

The expert knowledge elicitation process may be affected by numerous potential cognitive and motivational biases (Morgan, 2014; Montibeller and von Winterfeldt, 2015; Hagan and Hagan, 2019), among which the anchoring or overconfidence biases are often evident. Anchoring bias consists in the experts starting with an available piece of information, called the anchor. They then insufficiently adjust their judgment, which then results in a judgement biased toward the anchor. Overconfidence biases can happen because experts can be overconfident in their estimation. The methodological approach chosen facilitated the overall debate. The role of the workshop facilitator who intervened to balance the discussions and overcome the mentioned biases and the commitment and participation of the members of the RA team contributed to create an equitable discussion environment, not deviated by overconfident persons or by persons with strong characters who would dominate the discussion and influence others. During the process, it became noticeable that even if some experts would intervene more often, the vote would not always follow the most prominent opinion.

Performing the risk assessment helped identify some relevant data gaps. As expected, official data on illegal animal movement from neighboring countries and regions were missing. However, different experts did not rule out the possibility of uncontrolled animal movement in part of Donetsk oblast, which borders Russia, and illegal movements from Russia and other countries. The project team could not confirm or reject this information that should be therefore treated very carefully. The uncertainty in the probability estimation in these cases was anyway high. Data on illegal import of hides were missing as well.

There is a lack of data on wild ruminants and specifically the paucity of data on local wild species presence, density, and movement across the Ukrainian borders were evident. The susceptibility of European wild ruminants to LSDV is also not completely understood and studied. Despite these doubts, local experts decided to consider wild animals in the risk pathways.

The knowledge on the roles of different vector species in the epidemiology of the LSD (i.e. virus replication, length of infectiousness) is also not sufficiently understood and would require additional experiments. Data on the presence and abundance of vectors in Ukraine was only basic. In addition, the extent to which biosecurity measures that would prevent the transmission of the virus at farm level, had the virus entered the country, are widely implemented in Ukraine is not well known. However, experts were fairly confident that the level of measures implemented in small scale farms is sub-ideal at best. No sufficient evidence is available confirming the transmission through inert objects, vehicles and feces. However, LSDV is remarkably stable, surviving for long periods at ambient temperature, especially in dried scabs. It is very resistant to inactivation and can remain viable for long periods in the environment. The virus, despite being susceptible to sunlight and detergents containing lipid solvents, can persist for many months in dark environmental conditions, such as contaminated animal sheds. Regarding insemination, the uncertainty in probability estimates is “very high” because there is no data confirming the transmission of LSDV via frozen semen, which is the form the semen is mostly imported in Ukraine.

The uncertainty of experts in the probability estimation was calculated and should be considered when interpreting the results. No attempts were made to integrate the uncertainty to the final probability estimate. Instead, the uncertainty level for each step in the risk pathways are presented in conjunction to the results and, in addition, an indication of the overall uncertainty related to each specific risk pathway is also presented. The latter is very often ranked as "Very High" as it reflects the worst-case scenario along the risk pathway.

The approach used to classify the uncertainty provides an indication on the level of disagreement between the experts, which may be due to gaps in data availability in addition to other factors related to expertise and attitude of experts. While expertise and attitude were partially “controlled” by the design of study, i.e. providing same baseline information to all experts and through the role of the facilitator), the lack of data remained an important gap in specific step of the pathways. One limitation in this approach based on quartiles is that while it is useful to easily compare between levels of uncertainties and to easily communicate uncertainties along with the results, it does not shows the overall absolute uncertainty of the whole risk assessment. Alternative approaches may be used in qualitative risk assessment to ascertain uncertainty. One approach could consist in asking the experts directly to express their confidence in the answers provided based on the actual knowledge and their understanding of the situation and context (FAO Food and Agriculture Organization of the United Nations, 2021). In this instance, due to lack of expertise in the country, all experts were presented with the same data before proceeding with the probability estimation, and it was assumed therefore that they shared the same initial knowledge sufficient to express their judgements. The methods used to combine the probability estimates of a single risk pathway is a conditional combination matrix, meaning that the probability resulting can be no more than the lowest probability estimate in the pathway. Thus, when assessing a pathway having a step with a high uncertainty but a low probability estimate, it could easily lead to an underestimation of the probability.

Ukraine is currently free from the disease despite the proximity to regions currently affected. Ukraine has a strong legal framework for LSD and other transboundary diseases that has probably contributed to prevent the entry of LSDV. For example, the probability of introduction via an infected animal was estimated from experts as “negligible” with a “low” uncertainty, mostly because of the current import restrictions in place and the fact that Ukraine is only allowed to import from LSDV-free countries with effective surveillance and monitoring system in place. This is crucial because the results showed that had the disease entered Ukraine, the probability that it would spread in the country through flying vectors was perceived as high especially because of the lack of minimum biosecurity measures implemented at farm level and lack of awareness of famers on the disease.

In this risk assessment, in order to estimate the annual probability of introduction, the number of imports and animal movements were presented to the experts along with other data before asking them to express a judgement. A recent study (Kelly et al., 2018) suggested a valid method based on a graphical reference tool to determine the relation between the probability, the number of imports and the aggregated probability of entry Despite this approach was not used in the current work, it may reduce the ambiguity of a subjective evaluation and, therefore, it is a valuable approach for future works.

Based on the probability estimates generated during the risk assessment, the experts reflected on relevant risk management strategies to reduce the risks identified. This was a first attempt and a more thorough discussion among risk managers is necessary. A number of key points and recommendations were prepared and the full list is provided in the supplementary documentation (Supplementary Material C). The current control strategies for LSD in Ukraine are also built on the findings of this manuscript.

5. Conclusions

This risk assessment showed that the threat of LSDV was not imminent and highlighted the shortcomings of Ukraine related to the disease. However, for some of the risk routes identified, the probability was perceived as not negligible so efforts should be intensified to address those risks. This risk assessment could be improved by including a spatial component, where regions of higher probability of introduction and spread could be identified. During the experts' discussions, some regions were reported to be more at-risk than others, because of the illegal importation of cattle. This would allow for concentration of efforts for surveillance in these specific regions. Furthermore, the Ukrainian legal framework should try to adhere as much as possible to international standards regarding surveillance and control of LSD. FAO, OIE and EFSA have all issued recommendations regarding these matters. Finally, the identified uncertainties in this work helped to identify data gaps and interrogations that need to be addressed through specific research.

Ethics approval and consent to participate

The current risk assessment study did not conduct any research or clinical trials on human subjects, or on vertebrate animals or cephalopods or vertebrate embryos or tissues. Human specimens or tissue samples were not collected from humans or animals. The study implemented an expert knowledge elicitation approach where a group of experts in Ukraine were consulted to provide judgements on specific questions. The participation was voluntary, the judgement from the experts were expressed anonymously and the data were analysed Anonymously. For these reasons, consent from participants and the approval from institutional review board or equivalent committee(s) was not necessary.

Consent for publication

All authors approved and gave consent to the publication

Ethics approval and consent to participate

The current risk assessment study did not conduct any research or clinical trials on human subjects, or on vertebrate animals or cephalopods or vertebrate embryos or tissues. Human specimens or tissue samples were not collected from humans or animals. The study implemented an expert knowledge elicitation approach where a group of experts in Ukraine were consulted to provide judgements on specific questions. The participation was voluntary, the judgement from the experts were expressed anonymously and the data were analyzed anonymously. For these reasons, consent from participants and the approval from institutional review board or equivalent committee(s) was not necessary.

Availability of data and materials

The results presented are based on judgements expressed by experts during elicitation processes which are clearly indicated in the tables in the manuscript and in the supplementary material. Additional datasets used to calculate the uncertainty level is managed by the principal authors of the manuscript and freely available upon request.

CRediT authorship contribution statement

Dima Farra: Formal analysis, Data curation, Writing – original draft. **Marco De Nardi:** Conceptualization, Visualization, Investigation, Formal analysis, Data curation, Writing – original draft. **Viktoria Lets:** Investigation, Writing – review & editing, Conceptualization. **Sergii Holopura:** Investigation, Writing – review & editing, Conceptualization. **Oleksiy Klymenok:** Writing – review & editing, Conceptualization. **Roger Stephan:** Writing – review & editing, Conceptualization. **Oksana Boreiko:** Investigation, Writing – review & editing, Conceptualization.

Declaration of Competing Interest

There are no competing interests of financial or non-financial nature.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mran.2021.100200.

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