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Economic impact of lumpy skin disease and cost effectiveness of vaccination for the control of outbreaks in Ethiopia

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Abstract

Lumpy skin disease (LSD), an infectious viral disease of cattle, causes considerable financial losses in livestock industry of affected countries. A questionnaire survey with the objectives of determining direct economic losses of LSD (mortality loss, milk loss, draft loss) and treatment costs (medication and labour cost) per affected herd, and assessing the cost effectiveness of vaccination as a means for LSD control was carried out in the central and north-western parts of Ethiopia. From a total of 4430 cattle (in 243 herds) surveyed, 941 animals (in 200 herds) were reported to be infected. The overall morbidity and mortality at animal level were 21.2% and 4.5%, and at herd level these were 82.3% and 24.3%. There was a significant difference in animal level morbidity and mortality between categories of animals. Over 94% of the herd owners ranked LSD as a big or very big problem for cattle production. A large proportion (92.2%) of the herd owners indicated that LSD affects cattle marketing. A median loss of USD 375 (USD 325 in local Zebu and USD 1250 in Holstein-Friesian local Zebu cross cattle) was estimated per dead animal. Median losses per affected lactating cow were USD 141 (USD 63 in local Zebu cows and USD 216 in Holstein-Friesian local Zebu cross cows) and, USD 36 per affected ox. Diagnosis and medication cost per affected animal were estimated at USD 5. The median total economic loss of an LSD outbreak at herd level was USD 1176 (USD 489 in subsistence farm and USD 2735 in commercial farm). At herd level, the largest component of the economic loss was due to mortality (USD 1000) followed by milk loss (USD 120). LSD control costs were the least contributor to herd level losses. The total herd level economic losses in the commercial farm type were significantly higher than in the subsistence farm type. The financial analysis showed a positive net profit of USD 136 (USD 56 for subsistence farm herds and USD 283 for commercial herds) per herd due to LSD vaccine investment. It should be noted that only the noticeable direct costs and treatment costs associated with the disease were

considered in the study. Generally, vaccination is economically effective and should be encouraged.

Keywords: LSD outbreak; morbidity; mortality; economic loss; vaccination; Ethiopia.

1. Introduction

Lumpy skin disease (LSD) is a severe systemic disease of cattle caused by the lumpy skin disease virus, which belongs to the genus *capripoxvirus,* family *poxviridae*. It is characterized by fever, nodular lesions on the skin and mucous membranes and lymphadenopathy (Murphy et al., 1999; Radostits et al., 2007). The morbidity during LSD outbreaks varies greatly from 5% to 100% depending on the immune status of the host and the abundance of arthropod vectors (Woods, 1988; Tuppurainen and Oura, 2012). LSD mortality is generally low (usually less than 5%) but occasionally may reach 20% (Woods, 1988; Babiuk et al., 2008; OIE, 2010). LSD is associated with reduction in milk production, temporary or permanent sterility in bulls and cows, weight loss, draft power loss, abortion, damage to hides and death. Disease control and eradication measures such as vaccination campaigns, removal of affected animals, biosecurity are costly (Woods, 1988; Radostits et al., 2007; Babiuk et al., 2008; OIE, 2010; Tuppurainen and Oura, 2012). For example in Israel the control of the initial LSD outbreak costed USD 750,000, and the indirect financial loss associated with compulsory animal movement restrictions was also significant (AU-IBAR, 2013). The economic importance of the disease is also due to convalescence of several months (Murphy et al., 1999). The World Organization for Animal Health (OIE) categorized LSD as a notifiable disease because of its substantial economic impact (Tuppurainen and Oura, 2012; OIE, 2015). Because of these considerable financial losses and the international trade restrictions on live animals and their products, LSD is one of the most important infectious diseases in countries where it is endemic.

Livestock is an important sector in Ethiopia’s economy as it contributes 35.6% to the agricultural Gross Domestic Product (GDP), equivalent to 16.5% of the national GDP (Metaferia et al., 2011), and 37 to 87% to the household incomes (GebreMariam et al., 2010). The contribution of livestock to the annual foreign exchange earnings amounts to 12% (NBE, 2014). Households keep cattle for multiple purposes: milk production, draft power, beef production, manure for fuel and fertilizer, and breeding (GebreMariam et al., 2010; Negassa et al., 2011). The total cattle population of Ethiopia is estimated to be about 57 million heads (CSA, 2015). The benefit that cattle could have for the country is not attained for several reasons and one important reason is animal disease. LSD stands among the major diseases that limit the productivity of the cattle population (Gari et al., 2011; APHRD, 2012).

LSD was restricted to Africa and Middle East countries for decades, but recently it is spreading unusually beyond its territory into Europe and other Asian countries and increasingly becomes a risk for the livestock industry in these continents (Tuppurainen et al., 2015; Tasioudi et al., 2016; WAHIS, 2016). In Ethiopia, LSD was first observed in 1981 in the north-western part of the country (Mebratu et al., 1984). However, it has now spread to almost all regions and agro-ecological zones of the nation with seroprevalence ranging from 23-31% at animal level and 26-64% at herd level (Gari et al., 2010; Gari et al., 2012). The infection was reported to cause 33.93% and 13.41% morbidity and 7.43% and 1.25% mortality in Holstein-Friesian cross bred and local Zebu cattle, respectively (Gari et al., 2011).

Knowledge of disease impact is essential when deciding on the level of expenditure that can be justified for a disease control programme (Knight-Jones and Rushton, 2013). The economic impact of LSD can be largely influenced by the methods used to control and eradicate outbreaks. In general, LSD prevention and control programmes are based on one or more of the following three elements: routine vaccination, stamping-out and movement restriction (Davies, 1991; Carn, 1993; Horst et al., 1999). The main LSD prevention and control scheme in Ethiopia is through vaccination. Vaccination costs depend on the number of animals vaccinated, vaccine cost, vaccination frequency, and labour and distribution costs (Horst et al., 1999). In Ethiopia, vaccination cost is borne by the government, i.e. vaccines are provided free of charge to the livestock owners.

Disease impacts are generally easy to identify but may be difficult to quantify. Disease outbreaks often have broad, long-term effects on livestock industry. The costs of animal disease can roughly be divided into direct costs, which include losses related to animal illness, death and less immediate impacts such as reduced fertility, and indirect costs, which encompass control costs, losses in trade and other revenues (Rushton, 2009; Oxford-Analytica, 2012). Understanding the impact of animal disease and assessing its losses is useful for policy makers and farmers who may weigh the losses against the costs of disease control each at their own level (Pritchett et al., 2005). There has been very limited work carried out on the financial analysis of herd-level control of LSD. Therefore, the objectives of this study were to determine the direct financial losses of LSD related to milk loss, draft power loss, mortality and indirect losses due to treatment, and to assess the cost effectiveness of vaccination as a means of LSD control.

2. Materials and methods

2.1. Study design and population

A questionnaire survey targeted to assess the economic impact of LSD was carried out in the central and north-western parts of Ethiopia (Figure 1). In central part, it was undertaken in Ada'a, Sebeta Hawas, Ambo, Dendi, Debrelibanos, Kuyu and Hidabu Abote districts in Oromia National Regional State. In north-western part, the data were collected from Dejen, Gozamen, Hulet Ejju Enessie and Jabitenan districts in Amhara National Regional State. Furthermore, another five commercial dairy farms (Selale Dairy Development PLC at Muketuri, Aser at

Ecoefobabo, Sululta; Selam Children Village in Addis Ababa, Holeta dairy cattle genetic improvement nucleus farm and Holeta agricultural research centre farm at Holeta) were included in the study.

The livestock production systems in the study area can be classified into two broad categories: subsistence crop-livestock production and commercial dairy production. In the subsistence production system the small holding farms are mainly kept for draft power, milk and meat production (Mengistu, 2003) and the composition of the herd is dominated by local Zebu cattle. The commercial dairy farms are market oriented and include medium (10-50 animals) to large-scale (>50 animals) farms of crossbred Zebu with Holstein-Friesian. They are mostly located around peri-urban and urban areas practicing intensive and semi-intensive production (Mengistu, 2003). Milk and calf production are the main source of income.

2.2. Data collection

The questionnaire survey was undertaken from October 2014 to May 2015. The time span for the financial analysis was one year i.e. May 2014 to April 2015. A total of 243 herd owners from 15 districts (comprising 34 kebeles and 5 farms) enrolled in the study, a number close to numbers used in comparable studies (Jemberu et al., 2014; Jibat et al., 2016; Chenais et al., 2017). Kebele is the smallest administrative division in Ethiopia. The districts were selected based on the occurrence of an LSD outbreak and three kebeles were randomly selected from each of 10 districts, four kebeles from one district, 2 farms from 1 district and 1 farm each from the other 3 districts. From each kebele, five to eight herd owners that were willing to participate were interviewed. The data were collected by face to face interview using the local language.

An oral consent to use the data for scientific research was obtained from each participating herd owner before the interview started.

The questionnaire was designed primarily to record the magnitude of production losses, mortality, and cost of control for LSD in several categories of bovines in a herd (a group of cattle owned by a household or an organization), and perception of farmers on livelihood impact and its influence on cattle marketing during the outbreak period. The farmer's ability to identify LSD infection was cross-checked by enquiring about the main epidemiological and clinical features of LSD. If the herd owner's description was consistent with the classical clinical signs and epidemiologic features of LSD (nodular lesions on skin and mucosal surface, enlargement of superficial lymph nodes, swelling of the limb or the lower body, discharge from eyes, nostrils and mouth, reduced milk production in lactating cows, depression, morbidity varying from 5-45% and mortality less than 10%) (FAO, 2010), they were considered to know the disease and the interview was continued. Farmers were also asked to estimate the daily milk production of their cattle before and after infection, the duration of infection, the milk price per litre, the renting price of an ox, the market value of animal, labour time lost for an animal getting treated and wage of a daily labourer. Commercial farms and some of subsistence herd owners estimated the volume of the daily milk produced in litres. However, the majority of subsistence herd owners estimated the volume of milk produced by each LSD affected cow using the local container (gourds or bucket) which normally is used for milking. This was later converted to litre after filling the container with water to the level indicated by the owner and measured using a graduated jug. Additional information such as treatment and vaccination cost were collected from veterinary practitioners. Financial information was collected first in Ethiopian currency (Birr) and later converted to USD at an exchange rate of 20 Birr = USD 1 (8 October, 2014).

2.3. Estimation of economic losses

The economic impact of LSD was determined by an estimation of the direct (visible) production losses such as milk loss, mortality loss, and draft power loss, and indirect impacts like control costs (Knight-Jones and Rushton, 2013) using the method described in Jemberu et al. (2014). However, due to information paucity, impacts of the other direct losses due to reduced bodyweight, abortion, infertility, culling, and poorer hide quality were not considered in this study. Only affected herds were included in the calculations. All costs are expressed as median costs as the distribution is not Normal.

2.3.1. Mortality loss

The mortality loss was set equal to the market value of the animal that died. Thus, the economic loss due to mortality per herd was calculated by considering the seven categories of animals (calf, bull, heifer, dry cow, pregnant cow, lactating cow, and ox) that died and their corresponding market price (Formula 1).

$$MLSD_i = \sum_{j=1}^{7} NMC_{ij} * PC_{ij} \qquad [1]$$

Where $MLSD_i$ represents the economic losses due to LSD induced death of herd i; NMC_{ij} is the number of animals that died in each category j of herd i and PC_{ij} is the price of that animal.

2.3.2. Milk loss

LSDV infections in lactating cows cause milk yield reduction or cessation of milking for the duration of the illness and sometimes beyond. The economic loss per herd due to loss of milk production was estimated based on Formula 2.

$$MilkLSD_i = NLSDcow_i * D_i * QMilkL_i * PMilk_i \qquad [2]$$

where $MilkLSD_i$ represents the economic losses due to milk loss for herd i; $NLSDcow_i$ the number of LSD infected lactating cows in herd i; D_i the average duration of illness in days of affected lactating cows; $QMilkL_i$ the average quantity of milk lost in litres per affected cow per day, and $PMilk_i$ the price of milk per litre for herd i.

2.3.3. Draft power loss

In Ethiopia, the traditional agricultural system depends heavily on animal draft power to cultivate crops. A diseased draft ox cannot plough or provides less draft power. The loss from draft power reduction can be captured from effective working days lost (Formula 3).

$$DraftLSD_i = NoxenLSD_i * DDraft_i * PDraft_i * \frac{65}{365} \quad [3]$$

where $DraftLSD_i$ represents the economic loss due to draft power loss for herd i; $NoxenLSD_i$ the number of oxen affected in herd i, $DDraft_i$ the average duration of illness in days of an affected ox, $PDraft_i$ the price of draft power rent of an ox per day and 65/365 is an adjustment factor for effective working days - a draft ox in Ethiopia works for about 65 days in a year (Goe, 1987). Farmers whose draft oxen are affected with LSD have to rent, purchase a replacement ox or borrow animals for cultivation. An ox can be rented from a farmer owning surplus oxen on cash or grain basis.

2.3.4. LSD control costs

LSD control costs were considered to consist of vaccination, diagnosis and medication costs and extra labour costs for seeking treatment for sick animals. Many herd owners in Ethiopia use public veterinary services to get their animals vaccinated which is free of charge for contagious and transboundary animal diseases like LSD. However, clinical treatment of LSD affected animals was at the farmers' own expense. Hence, the economic cost of LSD treatment is calculated as per Formula 4.

$$TrCost_i = (NTr_i * PTr_i) + (NhoursL_i * Pdl_i) \quad [4]$$

where $TrCost_i$ represents the treatment cost for affected herd i; NTr_i the number of animals treated; PTr_i the average per head expenditure to LSD treatment; $NhoursL_i$ the average number of working hours lost for seeking treatment for sick animals, and Pdl_i the average payment rate of a replacement labourer per hour in the locality of herd i.

2.3.5. Total economic losses

The total economic costs (TEC) due to LSD infection per affected herd were obtained by adding losses arising from draft power loss, milk production loss, mortality and treatment expenditure (Formula 5).

$$TEC_i = MLSD_i + MilkLSD_i + DraftLSD_i + TrCost_i \quad [5]$$

2.4. Partial budget analysis for LSD vaccine use

The cost effectiveness of LSD control through vaccination was evaluated using partial budgeting analysis technique, which quantifies the economic consequences of a specific change in farm procedures (Dijkhuizen et al., 1995). The economic concept of partial budgeting is important for cost–benefit analysis of disease control measures (Rushton, 2009). A partial budget format with four parts (additional returns gained, reduced costs, returns foregone, and extra costs experienced as a consequence of the change) was employed as described by Dijkhuizen et al. (1995) and Dijkhuizen and Morris (1997). Costs were estimated in scenarios with and without vaccination. The base plan was no vaccine use by the herd owners, and the alternative plan was LSD vaccine use. The cost for purchase and administration of the LSD vaccine was considered the extra cost of the alternative plan, though it is borne by the government. The profitability of vaccine use in LSD control was calculated on a herd basis using Formula 6.

$$Net\ Profit = (Additional\ returns + Reduced\ costs) - (Returns\ foregone + Extra\ costs)[6]$$

A positive net result indicates that LSD vaccination is desirable from an economic point of view (Dijkhuizen et al., 1995; Dijkhuizen and Morris, 1997; Young et al., 2013). Moreover, the marginal rate of return (MRR) was calculated as the net benefit divided by the total cost incurred due to vaccine use to further scrutinize the adoption of the change (Gari et al., 2011).

2.5. Statistical analysis

Descriptive statistics were used to calculate the morbidity and mortality at animal and herd level. A Chi-square test was used to evaluate the differences in morbidity and mortality between categories of animals and between districts. Kruskal–Wallis equality-of-populations rank test was used, as the economic losses were not normally distributed, to compare the differences in herd level economic losses among districts and between farm types. A p-value less than 0.05 was considered as significant. Stata version 14 was used for all analyses.

3. Results

3.1. Herd size and structure

A total of 243 herds with 4430 heads enrolled in the study. The study population comprised 18.4% calves, 22.7% heifers, 8.9% bulls, 37.1% cows and 12.9% oxen. Herd size varied from

1 (n=3) to 643 (n=1) animals. About 90% of the herds consisted of less than 25 animals. The mean herd size in commercial farms was 56 heads and 10 heads in the subsistence farms. The majority of the farms (81.9%) involved in the study were small holder subsistence farms, but they hold only 44.3% of the study animals; 78.6% of the herds were managed extensively.

3.2. LSD morbidity and mortality

All herd owners approached were able to describe LSD in terms of its key epidemiologic features and symptoms. Based on the farmer's response, a total of 941 out of 4430 (21.2%) animals and 200 out of 243 (82.3%) herds were declared affected by LSD (i.e. they had at least one LSD positive animal) in the period May 2014 to April 2015. Mortalities at animal and herd level were 4.5% (198/4430) and 24.3% (59/243), respectively. Case fatality amounted to 21.0% (198/941). In most herds in which animals died it was restricted to 1 (n=36 out of 59) or 2 (9 out of 59) dead animals, however in one large herd (331 heads) 40 animals died. Differences in morbidity and mortality between study districts, at both animal level and herd level, were statistically significant ($P<0.05$). The highest animal level morbidity (37.9%) and mortality (12.1%) were recorded in Jabitenan district and Selale dairy Dev. PLC, respectively (Table 1). The morbidity per animal category varied from lowest 15.0% in dry cows to 26.9% in oxen, whereas the mortality varied from 2.2% in dry cows to 6.0% in pregnant cows (Table 2). The difference in animal level morbidity and mortality between categories was significant ($P<0.05$).

3.3. Perception of herd owners on LSD impact

From 243 herd owners interviewed in this study, 229 (94.2%) ranked LSD as a serious or very serious disease. Economic losses most frequently mentioned were death, milk loss, draft power loss, weight loss, abortion and hide quality loss (Figure 2). 224 (92.2%) of the herd owners indicated that LSD outbreaks affect cattle marketing. A large proportion (n = 217, 89.3%) of them witnessed that cattle selling is practiced during LSD outbreaks. Almost all herd owners do not sell sick animals and 32 (13.2%) of them would like to sell unaffected animals from their herds during LSD outbreaks mainly due to fear of the disease (n=30, 93.8%).

3.4. Financial losses of LSD outbreaks

The financial losses related to mortality, milk reduction, draft power loss, and control cost per affected individual animal are presented in supplementary Tables 1–4, respectively. The overall median financial loss per dead animal was estimated at USD 375; however, it was USD 325 for local Zebu and USD 1250 for Holstein-Friesian local Zebu cross cattle. Category wise, the median loss per head varied from USD 150 for calves to USD 1181 for milking cows, whereas from breed perspective the highest loss (USD 2250) was recorded in cross breed cows and the lowest (USD 59) in local Zebu calves. District wise, the median loss per dead animal varied from USD 125 in local Zebu in Debrelibanos district to USD 1966 in cross breed cattle in Holeta (Supplementary Table 1). Besides to the mortality loss, additional costs were incurred for carcass disposal. For this a cost of USD 11.9 (ranging USD 5-20) per carcass was required, but this was not included in the economic loss estimation due to the fact that expenditure for this purpose is required in rare occasions as usually the carcasses are disposed or buried by the villagers.

Almost all (n=240, 98.8%) of the herd owners knew the effect of LSD on milk production. According to the information obtained from the herd owners, milk production reduced by 74%

for a period of about 2.5 months. The overall daily milk loss per affected milking cow was 4.0 litres. Breed wise, it was 1.7 litres in local and 7.2 litres in cross bred cows. Financially, the overall median milk production loss per affected milking cow was USD 141, which was USD 63 in local Zebu cow and USD 216 in Holstein-Friesian local cross cow. The lowest and the highest milk loss per milking cow reported were USD 27 in local cattle and USD 906 in cross cow in Hulet Ejju Enessie and Debrelibanos districts, respectively (Supplementary Table 2).

Almost all (n=241, 99.2%) interviewees responded that LSD affects the traction power of animals. The median number of effective working days lost per affected ox was 10 days (range 1–32 days) resulting in an overall median loss of USD 36 per affected ox (Supplementary Table 3).

More than 80% of LSD affected cattle got treated for secondary complications. The overall median diagnosis and medication cost per affected animal was USD 5 (Supplementary Table 4). The cost of time lost for seeking treatment per affected animal could not be estimated as it was common practice that a herd owner took several animals to a veterinary clinic at a time to seek treatment and this complicated the estimation of per head cost.

The median total economic loss of an LSD outbreak at herd level was USD 1176. This figure is based on 193 herds as in 7 herds the LSD positive animal(s) were not productive and were not treated. A statistical analysis with Kruskal–Wallis equality-of-populations rank test revealed significant differences ($P < 0.05$) in total economic loss among districts. The highest and lowest economic losses were recorded in Selale dairy farm and in Sebeta Hawas district, respectively (Table 3). At herd level, the largest component of the economic loss was due to mortality (USD 1000) followed by milk loss (USD 120) and draft loss (USD 48). LSD control costs were the least contributor to herd level losses (Table 3). The median economic loss by farm type was USD 489 and USD 2735 in subsistence and commercial farms respectively per affected herd ($P < 0.05$; Table 3).

3.5. Partial budgeting

The majority of the input parameters for the partial budget analysis were obtained from data collected in this study; however, the remaining key parameters were taken from other sources (Supplementary Table 5).

The results of the partial budget analysis indicated a positive net profit of USD 136 (USD 56 for subsistence farm herds and USD 283 for commercial herds) and marginal rate of return (MRR) of 15.14 (11.29 in subsistence and 10.10 in commercial herd) per herd by vaccinating the animals for LSD (Table 4). Thus, investment in vaccination to control LSD would reduce the overall financial loss due to the disease by 11.6% per herd.

4. Discussion

The animal level morbidity (21.2%) and mortality (4.5%) recorded in this study is close to the 22.9% and 26% morbidity and 2.3 and 1.9 % mortality reported in central Ethiopia (Ayelet et al., 2013) and Jordan (Abutarbush et al., 2015), respectively. However, it is much higher than the 7.4% animal level morbidity reported in north-eastern Ethiopia (Hailu et al., 2014), 8.7% in Greece (Tasioudi et al., 2016), 11% in Israel (Brenner et al., 2009), and 0.65% in Turkey (Ince et al., 20016). Significantly different morbidity and mortality was observed between animal categories with oxen showing the highest level of morbidity (26.9%). This might be attributable to the stress and fatigue created during ploughing. The highest mortality was observed in pregnant cows (6%) which might be related to physiological conditions of pregnancy that make the animal more susceptible to disease (Kehrli et al., 2009). Generally, LSD morbidity varies from as low as 5% to 100% (Woods, 1988) and mortality is generally low (usually less than 5%) but may sometimes reach 20% (Woods, 1988; OIE, 2010). Thus, the animal level as well as the LSD morbidity and mortality levels per animal category reported in this study are within the limits reported in previous works. Furthermore, a significantly different morbidity and mortality was present between districts with highest morbidity in Jabitenan district (37.9%). This might be related to the presence of many rivers, irrigated areas and higher temperature, making the conditions in the district suitable for the replication of arthropods and propagation of LSD (Davies, 1991).

Interview results indicated that LSD is a serious problem for cattle producers in the study area as more than 94% of the interviewees considered LSD as a threat for their cattle. According to the herd owners, the disease induces weight loss, reduced milk production, draft power loss, mortality, market instability, infertility, abortion, culling, and hides quality losses. These observations are in line with the impacts of LSD described in previous works (Woods, 1988; Davies, 1991; Kumar, 2011; Abutarbush et al., 2015). The impacts of LSD in domestic as well as international cattle market is complex and generally go beyond the immediate effects on affected producers (Otte et al., 2004). In this study, more than 92% of the herd owners reported that LSD outbreaks affects cattle marketing at domestic market in numerous ways including lowering the demand and price of cattle during the outbreak period.

An overall median financial loss of USD 375 per dead animal recorded in this study is a big loss for a farmer whose livelihood depends on crop-livestock or livestock production. The mortality loss per head was highly variable between breeds, animal categories and districts. The per head mortality loss of local Zebu cattle was low (USD 325) as compared to Holstein-Friesian local cross cattle (USD 1250). The median loss per head categories varied from USD 150 for calves to USD 1181 for milking cows. These differences can be mainly attributed to the high production potential of cross bred animals and animal's purpose.

The milk production loss of 74% for the period of about 2.5 months recorded in this study is almost comparable to what has been reported in previous studies (Woods, 1988; Kumar, 2011; Abutarbush et al., 2015). The median daily milk loss of 4.0 litres per affected animal is a big loss for a nation that is an importer of dairy products (Negassa et al., 2011) by aggravating the product scarcity. In most cases the affected milking cows did not produce milk for months. For cows restarting milk production, it took months to regain their normal production level while in some cases, especially for local cows, LSD caused complete drying off. LSD caused an overall median loss of USD 141 per affected cow, being USD 216 in Holstein-Friesian local cross and reduced to USD 63 in local Zebu. The loss indicated here is greater than the loss induced by foot and mouth disease (FMD), which was USD 29 per affected cow in crop-livestock production system and USD 26 in pastoral system (Jemberu et al., 2014).

In the current study the herd owners reported that LSD affected draft animals were not available for field work for an average period of 59 days (ranging 7-180 days) which resulted in a median loss of about 10 (ranging 1-32) effective working days. The lost working days, in turn, lead to reduced crop production, either through reduced area that can be cultivated, or through lower yields due to late planting (McDermott et al., 1999). The effective working days lost estimated in this study is smaller than the 16 days reported by Gari et al. (2011). A farmer whose ox is affected by LSD has to borrow, rent, or purchase replacement ox or request assistance from relatives for cultivation. The translation of the effective working days lost into financial loss by considering the daily renting price (cash basis) of an ox gave an overall median loss of USD 36 per affected ox, which is greater than the loss reported due to FMD (Jemberu et al., 2014). This loss would have been larger if we had used 100/365 as adjustment factor (Yilma et al., 2011) instead of 65/365.

The median total economic loss of USD 1176 per LSD affected herd recorded in this study is a huge loss for a producer in a country with a gross domestic product per capita of USD 316 (Trading-Economics, 2015) and per capita income of USD 550 (World-Bank, 2015). Even the median loss per affected herd in subsistence crop-livestock system (USD 489) is six times higher than what Jemberu et al. (2014) reported for FMD, a disease which is on the top list for its devastating economic impact worldwide (Knight-Jones and Rushton, 2013; Junker et al., 2009). This supports the reports stating that LSD is economically more important than FMD in some countries such as South Africa (Murphy et al., 1999). The reason for this is that mortality in FMD is low and it occurs mainly in young age categories while LSD mortality is relatively high compared to FMD and occurs in all age categories. Of all costs, 85% is due to mortality although LSD induced mortality is low in cattle population as a whole (Woods, 1988). The median total economic losses per affected herd of USD 2735 for the commercial farm were significantly higher than the loss of USD 489 for the subsistence farm type. The higher loss in affected commercial herds is the reflection of larger herd size, higher market value and productivity potential of cross-bred animals.

As the study is undertaken retrospectively after certain months of LSD occurrence in the herd, recall bias in relation to the duration of infection, the amount of milk produced during sickness, working days lost and others might happened. Furthermore, the number of animals and herds affected were reported based on the owners declaration and this might also lead to biased number of cases. The recall bias and the diagnosis bias might have influenced the estimation of the financial losses reported to some extent and can be taken as the weakness of the study.

Routine vaccination, stamping-out and movement restriction are important methods in LSD control (Davies, 1991; Carn, 1993). Each control measure acts by reducing the transmission of the agent in the population. However, Ethiopia is applying mainly vaccination to control the disease. The economic benefit gained from controlling LSD with vaccination was measured by taking the reduction in economic loss from the disease into account by comparison with the level of expenditure for its vaccination. The result of the cost benefit analysis showed that a net loss of about USD 136 per herd would be avoided and marginal rate of return (MMR) of 15.14 gained by using LSD vaccination. The estimates revealed that LSD control with vaccination is economically beneficial by reducing the loss by 11.6% per herd. This result is less cost effective as compared to the findings of Gari et al. (2011) who reported a positive net benefit of USD 680.71 and a MRR of 34 for LSD vaccine intervention. However, the existing LSD vaccine provides incomplete protection against the disease (Ayelet et al., 2013). The vaccine is efficacious in only 28% of the vaccinated animals (unpublished data) which was taken into account in the partial budget analysis. More effective vaccines are needed to gain more from the intervention. The partial budget analysis was restricted to the direct benefits arising from the mortality and morbidity losses avoided and savings in the cost of LSD treatment. We did not consider other control options like movement control due to their practical limitation in Ethiopian situations.

It should be noted that only the noticeable direct costs and treatment costs associated with the disease were considered in the study. The indirect impacts of the disease such as under exploitation of the animal potential, animal welfare, international trade etc., were not considered. Also the visible direct costs were not fully captured mainly due to information paucity and difficulty to measure the loss in precise economic terms. Thus, the economic loss estimation presented here should be seen as a conservative estimate of the loss due to LSD.

Conclusion

The LSD impact in terms of production losses and control costs was high, a median total economic loss of USD 1176 (USD 2735 in commercial and USD 489 in subsistence herd) per LSD affected herd. The losses were mainly from morbidity and mortality of cattle and were the greatest in highly productive animals. The largest component of the economic losses was due to mortality loss followed by milk loss and draft loss at both animal level and herd level losses. LSD control costs were the least contributor for the herd level losses. Commercial farms which hold more productive and more susceptible animals were more severely affected economically than the subsistence crop related farms. Vaccination was found to be economically and practically feasible choice to control LSD. The cost benefit analysis was restricted to the direct benefits arising from the mortality and morbidity losses avoided and savings in the cost of LSD treatment. Generally, vaccination is economically beneficial and should be encouraged.

Conflicts of interest: None

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5. References

Abutarbush, S.M., Ababneh, M.M., Al Zoubi, I.G., Al Sheyab, O.M., Al Zoubi, M.G., Alekish, M.O., Al Gharabat, R.J., 2015. Lumpy skin disease in Jordan: disease emergence, clinical signs, complications and preliminary-associated economic losses. Transbound. Emerg. Dis. 62, 549-554.

APHRD, 2012. Ethiopia animal health yearbook 2011, Animal and Plant Health Regulatory Directorate (APHRD), Addis Ababa, Ethiopia.

AU-IBAR, 2013. Lumpy skin disease. In: (AU-IBAR), A.U.-I.B.f.A.R. (Ed.) CAB International.

Ayelet, G., Abate, Y., Sisay, T., Nigussie, H., Gelaye, E., Jemberie, S., Asmare, K., 2013. Lumpy skin disease: preliminary vaccine efficacy assessment and overview on outbreak impact in dairy cattle at Debre Zeit, central Ethiopia. Antivir. Res. 98, 261-265.

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

Brenner, J., Bellaiche, M., Gross, E., Elad, D., Oved, Z., Haimovitz, M., Wasserman, A., Friedgut, O., Stram, Y., Bumbarov, V., Yadin, H., 2009. Appearance of skin lesions in cattle populations vaccinated against lumpy skin disease: statutory challenge. Vaccine 27, 1500-1503.

Carn, 1993. Control of capripoxvirus infections. Vaccine 11, 1275-1279.

Chenais, E., Boqvist, S., Emanuelson, U., von Bromssen, C., Ouma, E., Aliro, T., Masembe, C., Stahl, K., Sternberg-Lewerin, S., 2017. Quantitative assessment of social and economic impact of African swine fever outbreaks in northern Uganda. Prev. Vet. Med. 144, 134-148.

CSA, 2015. Agricultural Sample Survey, 2014/15 (2007 E.C.), Volume II: Report on livestock and livestock characteristics (Private peasant holdings). Statistical Bulletin 578. Central Statistical Agency (CSA), Federal Democratic Republic of Ethiopia, Addis Ababa.

Davies, F.G., 1991. Lumpy skin disease, an African capripox virus disease of cattle. Br. Vet. J. 147, 489-503.

Dijkhuizen, A.A., Huirne, R.B.M., Jalvingh, A.W., 1995. Economic analysis of animal diseases and their control. Prev. Vet. Med. 25, 135-149.

Dijkhuizen, A.A., Morris, R.S., 1997. Animal Health Economics Principles and Applications. Post Graduate Foundation in Veterinary Science University of Sydney, Sydney South 1235, Australia.

FAO, 2010. Case definition of livestock disease. http://www.fao.org/docrep/014/al859e/al859e00.pdf. Accessed 31 July 2017.

Gari, G., Bonnet, P., Roger, F., Waret-Szkuta, A., 2011. Epidemiological aspects and financial impact of lumpy skin disease in Ethiopia. Prev. Vet. Med. 102, 274-283.

Gari, G., Grosbois, V., Waret-Szkuta, A., Babiuk, S., Jacquiet, P., Roger, F., 2012. Lumpy skin disease in Ethiopia: seroprevalence study across different agro-climate zones. Acta Trop. 123, 101-106.

Gari, G., Waret-Szkuta, A., Grosbois, V., Jacquiet, P., Roger, F., 2010. Risk factors associated with observed clinical lumpy skin disease in Ethiopia. Epidemiol. Infect. 138, 1657-1666.

GebreMariam, S., Amare, S., Baker, D., Solomon, A., 2010. Diagnostic study of live cattle and beef production and marketing: Constraints and opportunities for enhancing the system. http://bdsknowledge.org/dyn/bds/docs/800/Ethiopia-livestock-value-chain-diagnostic-july-201.pdf. Accessessed 15 February 2017.

Goe, M.R., 1987. Animal traction on smallholder farms in the Ethiopian highlands. Department of Animal Science. Cornell University, Ithaca, New York.

Hailu, B., Tolosa, T., Gari, G., Teklue, T., Beyene, B., 2014. Estimated prevalence and risk factors associated with clinical Lumpy skin disease in north-eastern Ethiopia. Prev. Vet. Med. 115, 64-68.

Horst, H.S., de Vos, C.J., Tomassen, F.H.M., Stelwagen, J., 1999. The economic evaluation of control and eradication of epidemic livestock diseases. Rev. Sci. Tech. Off. Int. Epiz. 18, 367-379.

Ince, O., B., Cakir, S., Dereli, M.A., 20016 Risk Analysis of Lumpy Skin Disease in Turkey. Indian J. Anim. Res. 50, 1013-1017.

Jemberu, W.T., Mourits, M.C., Woldehanna, T., Hogeveen, H., 2014. Economic impact of foot and mouth disease outbreaks on smallholder farmers in Ethiopia. Prev. Vet. Med. 116, 26-36.

Jibat, T., Mourits, M.C., Hogeveen, H., 2016. Incidence and economic impact of rabies in the cattle population of Ethiopia. Prev. Vet. Med. 130, 67-76.

Junker, F., Komorowska, J., Tongeren, F.V., 2009. "Impact of Animal Disease Outbreaks and Alternative Control Practices on Agricultural Markets and Trade: The case of FMD", OECD Food, Agriculture and Fisheries Working Paper.

Kehrli, M.E.J., Ridpath, J.F., Neill, J.D., 2009. Immune suppression in cattle: contributors and consequences. In, NMC 48th Annual Meeting Charlotte, North Carolina, 103-112.

Knight-Jones, T.J., Rushton, J., 2013. The economic impacts of foot and mouth disease - what are they, how big are they and where do they occur? Prev. Vet. Med. 112, 161-173.

Kumar, S.M., 2011. An outbreak of lumpy skin disease in a Holstein dairy herd in Oman: A clinical report. Asian J. Anim. Vet. Adv. 6, 851-859.

McDermott, J., Randolph, T.F., Staal, S.J., 1999. The economics of optimal health and productivity in smallholder livestock systems in developing countries. Rev. Sci. Tech. Off. Int. Epiz. 18 399-424.

Mebratu, G.Y., Kassa, B., Fikre, Y., Berhanu, B., 1984. Observation on the outbreak of lumpy skin disease in Ethiopia. Rev. Elev. Méd. Vét. Pays Trop. 37, 395-399.

Mengistu, A., 2003. Country pasture/forage resource profiles. http://www.fao.org/ag/agp/agpc/doc/counprof/ethiopia/ethiopia.htm. Accessed 2 September 2015.

Metaferia, F., Cherenet, T., Gelan, A., Abnet, F., Tesfay, A., Ali, J.A., Gulilat, W., 2011. A Review to Improve Estimation of Livestock Contribution to the National GDP. Ministry of Finance and Economic Development and Ministry of Agriculture, Addis Ababa, Ethiopia.

Murphy, F.A., Gibbs, E.P.J., Horzinek, M.C., Studdert, M.J., 1999. Veterinary Virology Academic Press San Diego. pp. 278-291.

NBE, 2014. National Bank annual report of 2013-2014. National Bank of Ethiopia (NBE), Addis Ababa Ethiopia.

Negassa, A., Jabbar, M., 2008. Livestock ownership, commercial off-take rates and their determinants in Ethiopia. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Negassa, A., Rashid, S., Gebremedhin, B., 2011. Livestock Production and Marketing. ESSP II Working Paper 26. International Food Policy Research Institute/Ethiopia Strategy Support Program II, Addis Ababa, Ethiopia.

OIE, 2010. Manual of diagnostic tests and vaccines for terrestrial animals, chapter 2.4.14, Lumpy skin disease. OIE, Paris. http://web.oie.int/eng/normes/MMANUAL/A_Index.htm. Accessed 26 February 2016.

OIE, 2015. Manual of diagnostic tests and vaccines for terrestrial animals, volume 1, chapter 1.1.6, principles of veterinary vaccine production. OIE, Paris. http://www.oie.int/fileadmin/Home/eng/Health_standards/tahm/1.01.06_VACCINE_PRODUCTION.pdf. Accessed 8 March 8 2016.

Otte, M.J., Nugent, R., McLeod, A., 2004. Transboundary animal diseases: Assessment of Socio-economic impacts and institutional response. Livestock policy discussion paper No. 9. FAO, Livestock information and policy branch, Rome.

Oxford-Analytica, 2012. The Costs of Animal Disease. A report produced for the Federation for International Animal Health. Oxford Analytica Ltd, 1-37.

Pritchett, J., Thilmany, D., Johnson, K., 2005. Animal disease economic impacts: a survey of literature and typology of research approaches. Int. Food Agribus. Man. 8, 23-45.

Radostits, O.M., Gay, C.C., Hinchcliff, K.W., Constable, P.D., 2007. Veterinary Medicine: A Textbook of the Diseases of Cattle, Sheep, Pigs, Goats and Horses. Sounders Elsevier Spain. pp. 1424-1426.

Rushton, J., 2009. The Economics of Animal Health and Production. CABI Oxfordshire, UK. pp. 73-197.

Tasioudi, K.E., Antoniou, S.E., Iliadou, P., Sachpatzidis, A., Plevraki, E., Agianniotaki, E.I., Fouki, C., Mangana-Vougiouka, O., Chondrokouki, E., Dile, C., 2016. Emergence of lumpy skin disease in Greece, 2015. Transbound. Emerg. Dis. 63, 260-265.

Trading-Economics, 2015. Ethiopia GDP per capita 1981-2015.

Tuppurainen, E.S., Oura, C.A., 2012. Review: lumpy skin disease: an emerging threat to Europe, the Middle East and Asia. Transbound. Emerg. Dis. 59, 40-48.

Tuppurainen, E.S., Venter, E.H., Shisler, J.L., Gari, G., Mekonnen, G.A., Juleff, N., Lyons, N.A., De Clercq, K., Upton, C., Bowden, T.R., Babiuk, S., Babiuk, L.A., 2015. Review: Capripoxvirus diseases: current status and opportunities for control. Transbound. Emerg. Dis. doi:10.1111/tbed.12444.

WAHIS, 2016. Summary of Immediate notifications and Follow-ups. World Animal Health Information System (WAHIS interface). http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/Immsummary. Accessed 18 July 2016.

Woods, J.A., 1988. Lumpy skin disease- A review. Trop. Anim. Hlth. Prod. 20, 11-17.

World-Bank, 2015. Economic over view. World Bank.

Yilma, Z., Emannuelle, G.B., Ameha, S. (Eds.), 2011. A review of the Ethiopian dairy sector. Food and Agriculture Organization of the United Nations, Sub Regional Office for Eastern Africa (FAO/SFE) Addis Ababa, Ethiopia.

Young, J.R., Suon, S., Andrews, C.J., Henry, L.A., Windsor, P.A., 2013. Assessment of financial impact of foot and mouth disease on small holder cattle farmers in Southern Cambodia. Transbound. Emerg. Dis. 60, 166-174.

Table 1. Lumpy skin disease morbidity and mortality in 243 cattle herds in 15 Ethiopian districts (2014/15).

District/Farm	**No. of herds**	**No. of cattle**	**Herd size**	**No. of herds with sick cattle (%)**	**No. of cattle sick (%)**	**No. of herds with death (%)**	**No. of cattle died (%)**
Ada'a	22	421	19.1	15 (68.2)	77 (18.3)	7 (31.8)	23 (5.5)
Sebeta Hawas	17	266	15.7	11 (64.7)	32 (12.0)	1 (5.9)	2 (0.8)
Ambo	15	345	23	11 (73.3)	94 (27.3)	3 (20.0)	26 (7.5)
Dendi	22	243	11.1	16 (72.7)	29 (11.9)	5 (22.7)	7 (2.9)
Debrelibanos	17	139	8.2	14 (82.4)	38 (27.3)	7 (41.2)	11 (7.9)
Hidabu Abote	23	157	6.8	17 (73.9)	30 (19.1)	6 (26.1)	6 (3.8)
Kuyu	18	205	11.4	18 (100.0)	42 (20.5)	3 (16.7)	3 (1.5)
Dejen	20	130	6.5	15 (75.0)	36 (27.7)	2 (10.0)	10 (7.7)
Gozamn	28	497	17.5	26 (92.9)	121 (24.4)	9 (32.1)	16 (3.2)
Hulet Ejju Enessie	31	293	9.5	31 (100.0)	72 (24.6)	3 (9.7)	5 (1.7)
Jabitenan	25	256	10.2	21 (84.0)	97 (37. 9)	9 (36.0)	22 (8.6)
Selam C.Vil.	1	46	46	1 (100.0)	9 (19.6)	1 (100.0)	2 (4.4)
Aser	1	48	48	1 (100.0)	5 (10.4)	0 (0.0)	0 (0.0)
Holeta	2	1053	526.5	2 (100.0)	171 (16.2)	2 (100.0)	25 (2.4)
Selale dairy	1	331	331	1 (100.0)	88 (26.6)	1 (100.0)	40 (12.1)
Overall	**243**	**4430**	**18.2**	**200 (82.3)**	**941(21.2)**	**59 (24.3)**	**198 (4.5)**

Table 2. Lumpy skin disease morbidity, mortality and abortion per bovine category in 243 cattle herds in Ethiopia (2014/15).

Category	**Number (%)**	**Number infected (%)**	**Number died (%)**	**Number aborted (%)**
Milking cow	1047 (23.6)	220 (21.0)	59 (5.6)	2 (NA)
Pregnant cow	364 (8.2)	69 (19.0)	22 (6.0)	12 (3.3)
Dry cow	233 (5.3)	35 (15.0)	5 (2.2)	
Heifer	1006 (22.7)	232 (23.1)	47 (4.7)	8 (NA)
Calf	813 (18.4)	137 (16.9)	37 (4.6)	
Bull	395 (8.9)	94 (23.8)	15 (3.8)	
Ox	572 (12.9)	154 (26.9)	13 (2.3)	
Overall	**4430 (100)**	**941 (100)**	**198 (100)**	

NA = Not applicable, since the denominator is specifically unknown

Table 3. Median total economic costs of lumpy skin disease per affected herd by district/farm and by farm type in USD in 193 cattle herds in Ethiopia (2014/15).

District/farm type	Farm type	Production loss: Mortality losses Median	Production loss: Milk losses Median	Production loss: Draft losses Median	Control expenditures: Medication expenditure Median	Control expenditures: Extra labour cost Median	Total economic cost
Ada'a	subsistence	0	0	46.75	4	8	58.75
	commercial	1750	231	0	72.5	0	2053.5
Sebeta Hawas	subsistence	700	57.75	40.07	5	7	809.82
	commercial	0	0	0	11.5	0	11.5
Ambo	subsistence	150	28.95	66.78	5.88	7.5	259.11
	commercial	18275	1690.5	0	146.25	0	20111.75
Dendi	subsistence	400	82.5	16.03	4.75	0	503.28
	commercial	2200	240	0	88.25	0	2528.25
Debrelibanos	subsistence	400	315	33.72	2.5	1.5	752.72
	commercial	4000	1191.15	119.67	32	15	5357.82
Hidabu Abote	subsistence	150	22.5	46.75	2.5	2.25	224
	commercial	1500	421.88	37.40	8.5	0	1967.78
Kuyu	subsistence	350	60	38.73	1.95	13.63	464.31
	commercial	0	105	0	6.5	0	111.5
Dejen	subsistence	1422.5	84	32.05	1.5	0	1540.05
Gozamn	subsistence	212.5	89.44	80.14	2	3	387.08
	commercial	1611.36	171	53.42	10.75	0	1846.53
Hulet Ejju	subsistence	1000	87.26	41.40	3.15	3	1134.81
Enessie	commercial	0	81	0	14.65	2.5	98.15
Jabitenan	subsistence	425	184.5	105.18	2.53	3	720.21
	commercial	5400	540	0	4.5	0	5944.5
Selam C. Vil.	commercial	1700	1080	50.49	79.2	0	2909.69
Aser	commercial	0	516.38	0	125	0	641.38
Holeta	commercial	19350.48	2377.5	0	791.44	0	22519.42
Selale dairy	commercial	37850	5791.5	0	498.65	0	44140.15
Per farm type	**subsistence**	350	87.26	45.01	3	3.88	489.15
	commercial	2200	421.88	51.96	52.5	8.75	2735.09
Overall		**1000**	**120**	**48.08**	**4.5**	**3.88**	**1176.46**
% of total loss		**85.00**	**10.20**	**4.09**	**0.38**	**0.33**	**100**

Table 4. The cost effectiveness of LSD vaccination per herd in 243 cattle herds in Ethiopia (2014/15).

Benefits per herd (USD)		**Costs per herd (USD)**		**Net benefit (USD)**	**Marginal rate of return (MRR)**
(1) **Additional returns**	**14.81* (10.96**, 47.94*****)	(3) **Returns foregone**	**0.00**		
Milk loss saved	14.81 (10.96, 47.94)	None	0.00	**136.25 (56.45, 282.80)**	**15.14 (11.29, 10.10)**
(2) **Reduced costs**	**130.44 (50.49, 262.86)**	(4) **Extra costs**	**9.00 (5, 28)**		
Replacement animal	123.46 (43.97, 250.00)	Vaccination cost	9.00 (5, 28)		
Draft power	5.94 (5.65, 5.90)				
Treatment cost saved	0.56 (0.38, 5.97)				
Labour cost for seeking treatment	0.48 (0.49, 0.99)				

*Over all

**Subsistence farm type

***commercial farm type

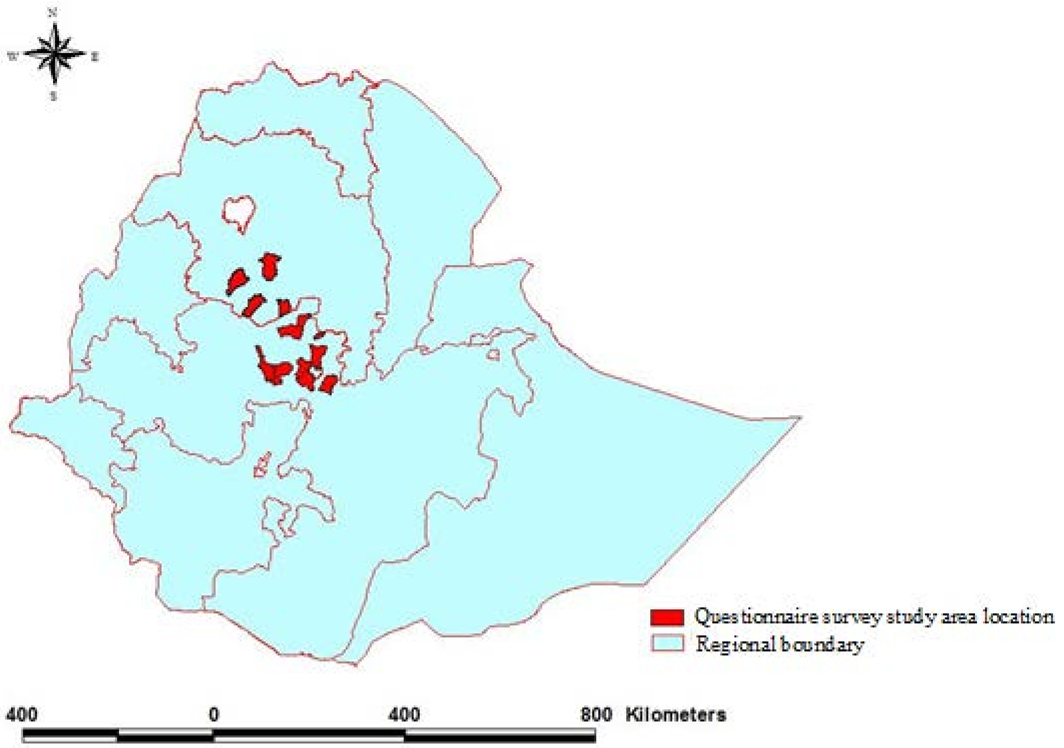

Figure 1. Map of Ethiopia showing the area and the location of 243 cattle farms included in the study of the economic impact of lumpy skin disease (2014/15).

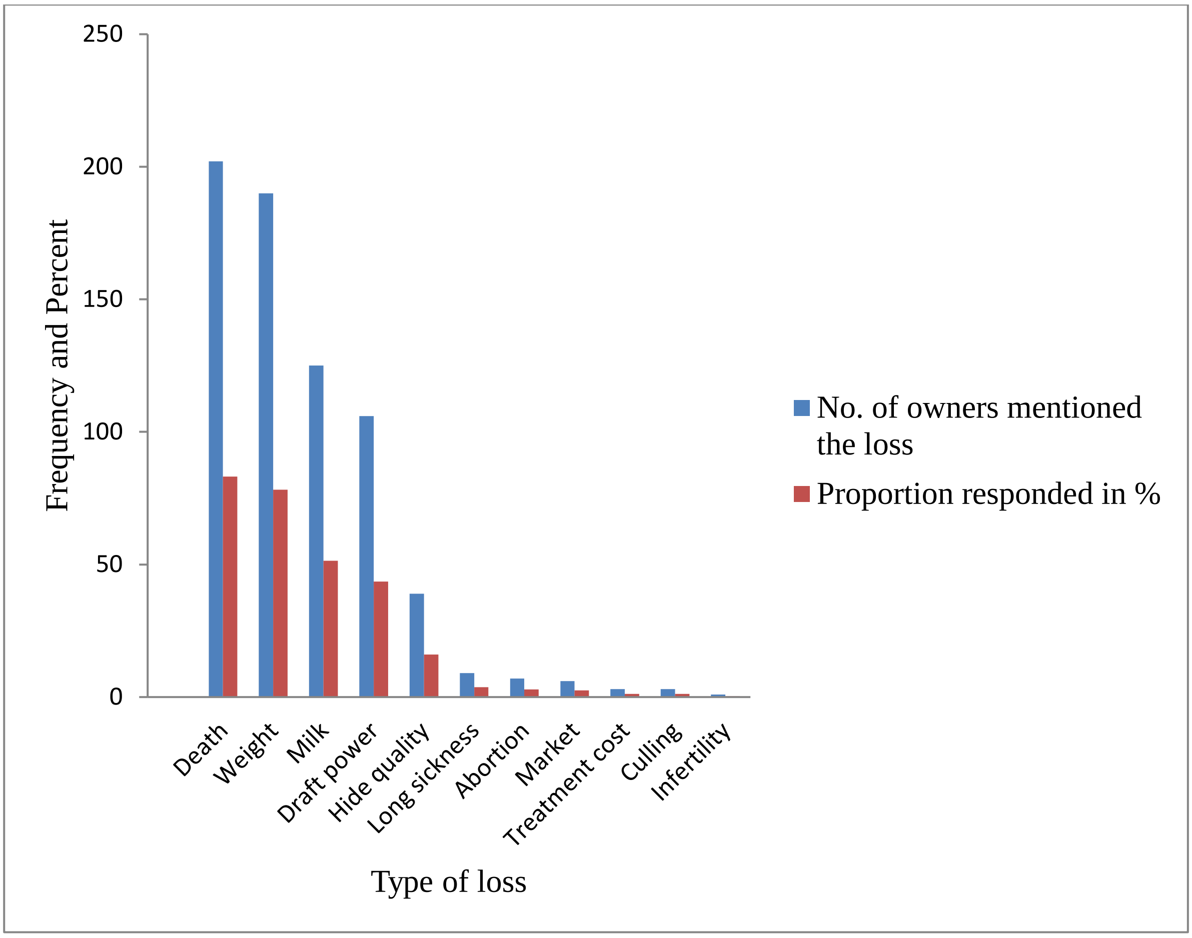

Figure 2. Major losses induced by lumpy skin disease as listed by cattle herd owners (n = 243) in Ethiopia (2014/15).

Supplementary Table 1. Lumpy skin disease financial loss (USD) per head of cattle that died by breed, cattle category and district or farm in 193 herds in Ethiopia (2014/15).

		Category							Median loss per animal
District/Farm	**Breed**	**Milking cow**	**Pregnant cow**	**Dry cow**	**Heifer**	**Calf**	**Bull**	**Ox**	
Ada'a	cross	1481	2000	0	1200	750	0	0	1341
Sebeta Hawas	local	200	0	0	0	0	0	500	350
Ambo	local	0	0	0	0	0	150	0	150
	cross	1700	0	0	1658	133	1000	0	1329
Dendi	local	0	175	0	0	0	0	575	375
	cross	1500	0	0	0	150	0	1250	1250
Debrelibanos	local	200	0	0	0	0	0	400	300
	cross	2042	1667	0	0	0	0	0	1855
Hidabu Abote	local	150	0	0	0	0	100	0	125
	cross	2000	1125	0	0	0	0	1700	1700
Kuyu	local	350	0	0	0	0	0	400	375
Dejen	local	400	400	150	175	60	0	0	175
Gozamn	local	550	250	0	299	57	250	0	250
	cross	1181	0	0	0	200	0	0	691
Hulet Ejju Enessie	local	500	0	0	50	0	0	375	375
	cross	0	0	0	1000	0	0	0	1000
Jabitenan	local	400	350	350	0	0	225	438	350
	cross	1250	0	0	300	50	0	0	300
Selam C.Vil.	cross	0	0	0	850	0	0	0	850
Holeta	cross	1931	2250	2250	1594	233	2000	0	1966
Selale dairy	cross	1600	1750	0	900	400	0	0	1250
Median cost by breed	local	375	300	250	175	58.5	187.5	419	325
	cross	1600	1750	2250	1000	200	1500	1475	1250
Overall cost per animal		**1181**	**1125**	**350**	**875**	**150**	**238**	**469**	**375**

715 Supplementary Table 2. Economic losses (USD) due to milk loss per LSD affected milking cow by breed and district in 193 herds in Ethiopia
716 (2014/15).

District/Farm	**Bread**	**Daily milk yield (litre) before infection Median (range)**	**Daily milk loss due to LSD (litre) Median (range)**	**Days of LSD illness Median (range)**	**Total quantity milk lost (litre) Median (range)**	**Average milk price per litre Median (range)**	**Economic losses per affected cow in USD Median (range)**
Ada'a	cross	7.59 (6-18)	4.85 (3-18)	83.58 (30-120)	405.38 (90-900)	0.53 (0.5-0.55)	214.85 (45-472.5)
Sebeta Hawas	local	1.33 (1-2)	1.08 (0.5-2)	85 (30-120)	97.5 (15-180)	0.55	53.63 (8.25-99)
Ambo	local	2.08 (1-3)	1.24 (0.7-2)	57 (30-120)	55.8 (30-84)	0.5	27.9 (15-42)
	cross	13.10 (5-16)	9.76 (3.5-12)	30	292.89 (105-360)	0.61 (0.2-0.85)	178.66 (21-234)
Dendi	local	2	1	90	90	0.5	45
	cross	5	4	60	240	0.5	120
Debrelibanos	local	4	2	90	180	0.4	72
	cross	22.89 (9-25)	19.39 (5-25)	106.15 (60-150)	2058.33 (360-2647)	0.44 (0.4-0.45)	905.67 (153-1191.15)
Hidabu Abote	local	2 (2-2.5)	1.6 (1-2.5)	79.5 (7.5-180)	144 (15-375)	0.75	108 (11.25-281.25)
	cross	25	25	22.5	562.5	0.75	421.88
Kuyu	local	2.68 (1-5)	1.89 (0.5-3)	78.41 (7.5-120)	156.14 (7.5-300)	0.5	78.07 (3.75-150)
	cross	12.5 (10-15)	8.5 (7-10)	90 (30-150)	855 (210-1500)	0.5	427.5 (105-750)
Dejen	local	1.38 (1.3-1.5)	1.24 (1-1.5)	97.12 (90-120)	120.43 (117-135)	0.35	42.15 (40.95-47.25)
Gozamn	local	2.08 (1.5-3)	1.90 (1-3)	80.49 (30-150)	152.94	0.6	91.76 (30.6-180)
	cross	8 (7-10)	5.63 (4-10)	46.63 (30-60)	262.5 (240-300)	0.6	157.5 (144-180)
Hulet Ejju	local	2.25 (2-3)	2	30	60	0.45	27
Enessie	cross	5.38 (4-7)	4.63 (3-7)	43.93 (7.5-90)	188.57(45-300)	0.42 (0.38-0.45)	79.20 (40.5-118.61)
Jabitenan	local	2 (1.5-3)	1.86 (1.25-3)	126.01 (60-240)	234.38 (112.5 -480)	0.6	140.63 (67.5-288)
	cross	6.27 (5-8)	3.63 (3-6)	99.17 (60-120)	360	0.64 (0.6-0.75)	230.4 (216-270)
Selam C.Vil.	cross	10	10	60	600	0.9	540
Aser	cross	7	4.5	90	405	0.43	172.13
Holeta	cross	13.82 (8-16)	7.18 (5-8)	52.80 (30-150)	379.18 (240-750)	0.57 (0.5-0.63)	216.13 (120-472.5)
Selale dairy	cross	12	9	90	810	0.55	445.5
Per breed	local	2.04 (1-5)	1.73 (0.5-3)	82.75 (7.5-240)	132.22 (7.5-480)	0.50 (0.35-0.75)	62.82 (3.75-288)
	cross	10.00 (4-25)	7.18 (3-25)	60.00 (7.5-150)	405 (45-2647)	0.55 (0.2-0.9)	216.13 (18-1191.15)
Overall		**5.38 (1-25)**	**4.00 (0.5-25)**	**80.49 (7.5-240)**	**240.00 (7.5-2647)**	**0.53 (0.2-0.9)**	**140.63 (3.75-1191.15)**

Supplementary Table 3. Financial loss from draft power reduction per LSD affected ox by district in 193 herds in Ethiopia (2014/15).

District/Farm	**Duration of LSD oxen stayed out of work in days Median (range)**	**Effective working days lost Median (range)**	**Renting price (USD) for an ox for a day Median (range)**	**Financial loss (USD) from effective working days lost per affected ox Median (range)**
Ada'a	36 (30-60)	6.4 (5-11)	5.8 (5-7.5)	37.4 (26.7-62.3)
Sebeta Hawas	65 (30-120)	11.6 (5-21)	2.5	29 (13.4-53.4)
Ambo	55 (30-90)	9.8 (5-16)	5	49 (26.7-80.1)
Dendi	40 (15-90)	7.1 (3-16)	3	21.3 (8.0-48.1)
Debrelibanos	63 (30-120)	11.2 (5-21)	4.5 (3.5-5.6)	50.7 (21.4-119.7)
Hidabu Abote	56 (30-90)	9.9 (5-16)	3.5	34.7 (18.7-56.1)
Kuyu	42 (7-120)	7.5 (1-21)	3.3 (2.5-5)	24.8 (3.3-71.9)
Dejen	55 (7-90)	9.8 (1-16)	3	29.5 (4-5.1)
Gozamn	61 (30-90)	10.9 (5-16)	5	54.4 (26.7-80.1)
Hulet Ejju Enessie	74 (15-180)	13.1 (3-32)	2.5 (1.8-3.8)	32.2 (8.0-80.1)
Jabitenan	70 (15-120)	12.5 (3-21)	5.7 (5-7.5)	71.6 (15.0-160.3)
Selam C.Vil.	75	13.4	3.8	50.5
Overall	**58.5 (7-180)**	**10.4 (1-32)**	**3.65 (1.8-7.5)**	**36.05 (4-160.3)**

Supplementary Table 4. Costs of treatment for LSD per affected animal by district in 193 herds in Ethiopia (2014/15).

District/Farm	No. of cattle affected	No. of cattle treated (%)	Medication cost per affected animal median (range) in USD
Ada'a	77	74 (96.1)	11.0 (2-50)
Sebeta Hawas	32	31 (96.9)	3.7 (1-10.5)
Ambo	94	83 (88.3)	4.2 (1-12.5)
Dendi	29	26 (89.7)	9.6 (1.3-50)
Debrelibanos	38	35 (92.1)	16.4 (1-34)
Hidabu Abote	30	28 (93.3)	5.4 (0.4-25)
Kuyu	42	36 (85.7)	1.6 (0.5-5.3)
Dejen	36	15(41. 7)	1.1 (0.5-2.5)
Gozamn	121	42 (34.7)	2.4 (0.5-10)
Hulet Ejju Enessie	72	62 (86.1)	2.7 (0.5-15)
Jabitenan	97	56 (57.7)	3.4 (0.7-7.5)
Selam C. Vil.	9	9 (100)	8.8
Aser	5	5 (100)	25
Holeta	171	171 (100)	9.3 (3-15)
Selale dairy	88	88 (100)	5.7
Overall	**941**	**761 (80.9)**	**5.4 (0.4-50)**

Supplementary Table 5. Partial budget input values and their sources.

Inputs	Values	Data source
Total number of animals involved	4430	The current study
Number of herds	243	The current study
LSD prevalence at herd level per outbreak	44%	Gari et al., 2012; Hailu et al., 2014
Average vaccine cost per herd	9 USD	The current study
KS1 O-180 LSD vaccine efficacy	28%	LSD vaccine impact study (unpublished)
Average over all LSD loss per herd	1176.46 USD	The current study
Average milk loss per herd	120 USD	The current study
Average mortality loss per herd	1000 USD	The current study
Average draft loss per herd	48.08 USD	The current study
Average treatment cost per herd	4.5 USD	The current study
Average labour cost for seeking treatment per herd	3.88 USD	The current study