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Modelling the Non-Monetary Societal Burden of Tick-Borne Diseases for Cattle: A Case Study of East Coast Fever in the Traditional Cattle-Keeping Households of Namwala District of Zambia

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https://*Doi:10.53974/unza.jabs.6.2.877*

Abstract

The study aimed at estimating the disease burden of East Coast Fever (ECF) among rural cattle-keeping households of Namwala District of Zambia using Productivity Adjusted Life Years (PALYs). We modified Disability Adjusted Life Year (DALY) equations for humans to PALYs to estimate the societal burden of tick-borne animal diseases. We used a structured questionnaire to collect data on parameters that feed into PALY equations and then coded and entered data from the questionnaires directly into the Statistical Package of Social Sciences (IBM SPSS Version 20). Further, we entered the estimated values of PALY parameters into mathematical calculus software called integral calculator (https://www.integral-calculator.com/). We then used the integral calculator to calculate PALY equations, which we used to estimate the societal disease burden of ECF in cattle. Productivity Adjusted Life Years calculations were done in three categories; PALYs without discounting and age weighting, PALYs with only discounting, and PALYs with discounting and age weighting.

Results revealed that the years of the productivity lost by a cow, bull, and ox that suffered from ECF were estimated at 15, 10, and 15 years, respectively. In the second category, the years of productivity lost by a cow, bull, and ox were seven, six, and seven years, respectively. In the final category, the years of productivity lost by a cow, bull, and ox were five years. East Coast Fever caused a total of 517,165 PALYs in Namwala District. The quality of life reduced in years due to disability (YLD) caused by ECF per cow, bull, and ox was 0.07, 0.07, and 0.02 per cent of their life expectancy, respectively. The estimated values for the years of a lifetime lost due to mortality (YLL) caused by ECF were 35%, 49%, and 35% of the life expectancy per cow, bull, and ox. These results are essential for measuring outcomes of animal health problems in terms of PALYs. The findings are helpful in the future projections for the future burden of any disease and can be used as a basis in policy and decision-making, particularly priorities in animal health research. We recommend that a classification of animal diseases of national economic importance should consider both the societal burden (non-monetary) and economic impact instead of the common practice of only considering the economic (monetary) impact.

Keywords: *DALYs, PALYs, east coast fever, societal burden, cattle, Zambia*

Introduction

The socioeconomic burden of disease is defined as the impact a disease has on society measured by financial cost, mortality, morbidity, or other indicators (Torgerson *et al.,* 2018). The socioeconomic burden of animal diseases is mainly estimated using economic models based on monetary costs (Torgerson et al., 2018). These economic models miss out on the non-monetary burden of disease, which is very significant in sub-Saharan Africa, where the social value of keeping livestock sometimes outweighs the economic value, which may sometimes seem irrational (Mumba et al., 2018). Cattle provide both direct and indirect benefits to resource-poor communities. Such benefits include a direct source of food like milk and meat, their use in agriculture (both as a source of draught power and manure), as a reservoir of wealth, and as a valuable cultural benefit. Therefore, when cattle loss occurs due to disease, the impact cuts across all societal levels, and as such, its direct costs need to be estimated using market prices. The indirect costs associated with cattle loss are more difficult to estimate, although their impact may seem to be more important than the direct financial costs (Otte and Knips, 2005). These indirect costs need robust mathematical models based on the non-monetary burden of disease. In this paper, we estimate the non-monetary societal burden of animal disease using a case study of East Coast Fever in cattle of Namwala District of Zambia.

Livestock production is an important socioeconomic activity in Zambia and contributes about 1.9% to its gross domestic product (GDP) (Lubungu and Mofya, 2013). In Zambia, livestock production is broadly categorised into commercial and traditional sectors (Muma et al., 2009). Commercial cattle farmers own large herds of mostly exotic cattle breeds and contribute 16% of the total cattle population (Mumba et al., 2018). In contrast, the traditional sector maintains the largest cattle population at 84% and consists of smallholder farmers who mostly keep local cattle breeds integrated with crop farming (Mumba et al., 2017). The traditional sector is characterised by limited disease management, limited adoption of animal confinement, high levels of animal mortality, and low productivity (Lubungu and Mofya, 2013). The main purposes of keeping cattle among traditional cattle farmers in Zambia include draught power, prestige, dowry payment, transport, sales in times of financial need, milk production, source of employment, and rarely for meat production (Mumba et al., 2018), hence, the social benefits being more important than financial value.

In Zambia, the primary concern that has been renowned for its devastating impact on cattle productivity is ECF (Billiouw et al., 2002). East Coast Fever causes high morbidity and mortality, decreased meat and milk production, loss of draught power, and manure, thereby causing significant social and economic distress to the individual farmer. It also causes significantly more deaths than other tick-borne diseases combined (OLivares and Wood, 2004). Control measures have been employed by the Veterinary Department and traditional farmers, including dipping, immunisation, and treatment, which are costly (Mulumba et al., 2000). Despite the efforts, ECF is still the major disease problem and constraint on Zambia's livestock development (Mulumba et al., 2000). Previous studies have estimated the financial and economic impact of the cost of control due to ECF in monetary terms (Mukhebi et al., 1992; Minjauw et al., 1999; Penne et al., 1999). While the financial and economic impact of ECF control has been determined in monetary terms, there has been no attempt to estimate how losses of cattle and their associated products (milk, meat, draught power) impact rural communities in non-monetary terms. Three studies have attempted to estimate zoonotic disease burden using a modification of DALYs by converting the non-monetary disease burden to monetary through the use of zDALY based on time trade-off (Shaw et al., 2017; FAO, 2018; Torgerson et al., 2018). This, however, was based on the zoonotic disease on the pretext that zoonotic diseases affect both humans and animals; thus, a time trade-off could be applied. The studies did not apply zDALYs to non-zoonotic management diseases such as ECF, a tick-borne disease in the context of traditional cattle farming practices, especially in sub-Saharan Africa. Therefore, this study focused on estimating the societal disease burden of ECF among rural cattle keeping households by estimating both the quality of life reduced due to disability (morbidity in terms of productivity) and lifetime lost due to premature mortality using Productivity Adjusted Life Years (PALYs), a modification of human Disability Adjusted Life Years (DALYs). PALYs estimate productivity losses of an animal for both morbidity and mortality and quantify the analysis of a disease burden of which the results can be used to analyse cost-effective alternative interventions. The use of DALYs or its modification has abstractly been criticised by other authors due to among other reasons: how to compare within and across animal species, the fact that for livestock producers maximising their animals' life expectancy is not necessarily a goal and that the same physical disabilities have very different outcomes in different livestock productions systems (Shaw et al., 2017; FAO, 2018; Torgerson et al., 2018). However, no studies have been conducted on the practical use of PALYs to estimate the non-monetary burden of the disease to provide a platform for further refinement of the mathematical models in the field of animal health economics.

Materials and Methods

We obtained ethical approval from ERES Converge of Zambia with an ethical clearance number (2017 – Jul – 021). Individual verbal consent was obtained from each participant through verbal explanation of the study purpose using English and local (Tonga and Nyanja) languages.

Study Sites and Design

We used a cross-sectional study design employing quantitative data collection techniques to collect data from traditional cattle farmers in Namwala District of Zambia. Namwala District was chosen because it has the highest cattle population in Zambia, estimated at 145,704 (DVS, 2019), with an estimated human population of 82,810 (Central Statistical Office, 2003).

Sample Size Calculation

We used Epitools (http://epitools.ausvet.com.au/) to calculate the sample size. Given a total population of 82,810 cattle farmers (Central Statistical Office, 2003), a confidence level of 95%, an estimated proportion of 50%, and desired precision of 5%, the necessary sample size was calculated at 385 respondents. We sampled and interviewed cattle farmers from Chitongo, Kabulamwanda, Maala, and Namwala Central veterinary camps.

Sampling Techniques

We approached the District Veterinary Officer (DVO) to provide a list of veterinary camps accessible by road and had a large number of cattle. Therefore, Chitongo, Kabulamwanda, Maala, and Namwala Central veterinary camps were selected. Veterinary camps are the smallest administrative offices in the district and are manned by veterinary assistants who report to the District Veterinary Officer (Sitali et al., 2017). These veterinary camps formed a sampling unit for the study. We used a simple random sampling technique to get the required sample size from a larger population in each veterinary camp. Veterinary camps with a larger number of cattle farmers had a higher proportion.

Data Collection Techniques

We developed a structured questionnaire to capture data on a wide range of variables related to the number of cattle owned per farmer, reasons for cattle keeping, health condition, cattle productivity, cattle morbidity and mortality, and cost structures on control of ECF. The field data collection was done in two seasons, in the cold-dry season and the hot-dry season, to factor in other seasonal conditions. However, this did not affect the results that were obtained. The questionnaire was pretested at the Namwala Central veterinary camp to assess clarity, practicality, feasibility, validity, and ambiguity. This was done to ensure high-quality data collection. The questionnaire was then revised after the pilot testing to improve clarity. The interviews were carried out in English, and for those farmers who could not communicate in English, were translated the questions to their respective dialects, including Citonga, Chinyanja, and Icibemba. A structured questionnaire was administered in a face-to-face interview. Farmers were interviewed at abattoirs, district veterinary offices, local markets, and households. This was so because farmers left their households in the early hours of the day and headed to these places to sell cattle for a return, thus, improving their livelihoods. This was also done because households are far from each other, making it practically impossible to visit the farmers at their homes.

Data Management and Statistical Analysis

We coded and entered data from questionnaires directly into the Statistical Package of Social Sciences (IBM SPSS Version 20). We performed descriptive statistics of scale variables and frequencies for string variables using SPSS. We then used mathematical calculus software called integral calculator (https://www.integral-calculator.com) by inserting the values of each parameter in the formulas for PALYs functions to estimate the non-monetary societal disease burden of ECF.

Model Assumptions

Why East Cost Fever?

East Coast Fever is the number one cause of cattle mortalities in Zambia (Billiouw et al., 2002; OLivares and Wood, 2004; Mulumba et al., 2000). This problem has been validated through literature reviews (Billiouw et al., 2002; OLivares and Wood, 2004; Mulumba et al., 2000), previous studies by the authors (Mumba et al., 2017, Mumba et al., 2018) and a questionnaire survey were farmers identified ECF as the number one cause of disease based on disease symptoms. The effects of ECF on productivity as highlighted in literature informed the basis for disability weight as highlighted in Table 1.

Why Bulls, Oxen, and Cows?

We estimated PALYs for cows, bulls, and oxen because of their productivity use for the benefit of farmers. Results from a questionnaire revealed that cattle become useful at 4 years and the main parameters for productivity were milk production, breeding, draught power, and social values. Calves are not considered productive hence, could not be used in the model. Similarly, steers were not considered productive because traditional cattle farmers do not rear cattle for fattening and slaughter as commercial beef farmers do. Price is not an incentive for traditional cattle farmers to sell cattle (Mumba et al., 2018); hence, only sell old animals that have lost their usefulness, as shown in Figure 1 under age weighting.

Productivity Adjusted Life Years

Productivity Adjusted Life Years are a modification of Disability Adjusted Life Years (DALYs). Productivity Adjusted Life Years for a disease or health condition are calculated as the sum of the years of life lost due to premature mortality (YLL) in the cattle population and the equivalent healthy years lost due to disability (YLD) for incident cases of the health condition (Salih, 2015). Productivity Adjusted Life Years calculations were done in three categories; without discounting and age weighting, with discounting but no age weighting, and with both discounting and age weighting. This was to factor in problems of validity and justice. We have derived the basic formulae for PALYs as shown in equation 1:

$$PALYs = YLD + LLY$$

(1)

Where

$$YLD = number\ of\ healthy\ life\ years \times the\ disability\ weight\ of\ full\ health\ (0) + life\ years\ lived\ with\ disability \times disability\ weight\ for\ ECF\ (0 < D_W \leq 1)$$

(2)

Since full health is weighted zero (0), the YLD equation reads as:

$$YLD = Life\ years\ lived\ with\ disability \times disability\ weight\ for\ ECF$$

and

(3)

$$YLL = Life\ years\ lost\ due\ to\ deaths \times the\ weighting\ of\ death\ (1)$$

The YLD and YLL can be calculated using three methods. These include without age weighting and discounting, discounting only, and both discounting and age weighting.

Disability Weight

Disability is defined as some form of inability to perform everyday tasks in a usual way for cattle. Disability weight is a weight function that reflects the severity of a cattle disease between 0 (perfect health) and 1 (equivalent to death). Each disability condition is assigned a number between 0 and 1, depending on the severity of the disease (Salih, 2015). Years lost due to Disability (YLD) are calculated by multiplying the incident cases by the duration and disability weight for the condition (Salih, 2015). We used the disability weights developed by Salih(2015), as shown in Table 1.

Discounting

Discounting means the value of a healthy life year today is set higher than the value of future healthy life years (Salih, 2015). It is an economic concept that individuals prefer benefits now more than in the future. Discounting future health affects both measurements of disease burden and estimates of the cost-effectiveness of an intervention (Salih, 2015). A total discounting function at any age *x* is given as indicated in Equation 4.

$$G(x) = e^{-rx}$$

(4)

Where r is the discount rate.

Age Weighting

Age weighting in DALYs means that the life years of children and older people are counted less than other ages (Salih, 2015). In cattle, age weighting determines the age at which cattle start and stop being useful in terms of milk, meat, draught power, manure, social status, dowry, and cultural ceremonies (Salih, 2015). Age weighting means that cattle's life years are counted differently because cattle are more productive at a particular age than others (Salih, 2015). Therefore, we valued life experiences during productive ages based on economic and social value in this study. The preference for productive ages is expressed mathematically, as indicated in Equation 5.

$$R(x) = \beta_1 x e^{-\beta_2 x^2} \quad (5)$$

Where x is the cattle's age, while β_1 and β_2 are parameters of the age-weighting function (Salih, 2015).

Figures 1 and 2 show the median age at which cattle are most and least productive for different activities, as revealed by our questionnaire survey results. As a particular member of a cattle population grows towards the productive age, its life becomes more valuable (the age weight increase) until it reaches its maximum at the expected age of maximum productivity. Then as it gets older, its life gradually loses value (Salih, 2015).

Basic Formulas for YLL and YLD under PALYs

The basic formula for YLD (without age weighting and discounting) is the product of the number of disability cases, the average duration of the disease, and the disability weight (Salih, 2015). Years lost due to disability for cattle is expressed as shown in Equation 6:

$$\textbf{YLD for cattle} = N_i \times D_w \times \mathrm{I} \quad (6)$$

Where N_i is the number of incident cases of ECF, D_w is the disability weight of ECF, and I is the average duration of the disability (ECF).

We used 0.5, 0.33, and 0.17 for cows, bulls, and oxen, respectively, based on each type of cattle's different productivity roles. The basic formula for YLL (without age weighting and discounting) is defined as the product of the number of deaths and the standard life expectancy at the age of mortality. years of life lost due to premature mortality is obtained, as shown in equation 7:

$$\textbf{YLL for cattle} = N_d \times L \quad (7)$$

Where N_d is the number of deaths, and L is the standard life expectancy at the age of death. Note that both formulae do not change whether we refer to humans or animals (Salih, 2015).

YLD and YLL with Discounting

The second method for calculating YLD and YLL considers the discounting function. We obtained the formula for YLD by multiplying the basic YLD formula with the discounting function, as: shown in equation 8.

$$\boldsymbol{YLD} = \frac{N_i D_w\left[1-e^{-rI}\right]}{r} \quad (8)$$

Where N_i is the number of incident cases of ECF, D_w is the disability weight of ECF, r is the discounting rate, and I is the duration of the disability.

Similarly, to find the formula for years of life lost due to premature mortality YLL, we modified Equation 7 by replacing the average duration I by the standard life expectancy at the age of death, as shown

$$\boldsymbol{YLL} = \frac{N_d\left[1-e^{-rL}\right]}{r} \quad (9)$$

Where N_d is the number of deaths, r is the discount rate, and L is the life expectancy (Salih, 2015).

YLD and YLL with both Discounting and Age-Weighting

To calculate the YLD that accounts for the duration of the life lost due to disability (ECF), duration from the age of onset, we integrated the disability weight times the age weight and discount function over the expected period of the disability. The YLD value of any disability weight (D_w) with discounting function, age weighting function, and number of disease cases (N_i), as given in equation 10;

$$YLD = N_i D_w \beta_1 e^{a_i r}\left[\sqrt{\pi} r e^{\frac{r^2}{4\beta_2}}\left(\frac{erf(2\beta_2(a_i+I)+r)+erf\left(\frac{2\beta_2 a_i+r}{2\sqrt{\beta_2}}\right)}{4\sqrt{\beta_2^3}}\right)+\left(\frac{-e^{-(a_i+I)(\beta_2(a_i+I)+r)}+e^{-a_i(\beta_2 a_i+r)}}{2\beta_2}\right)\right] \quad (10)$$

Where N is the number of incident cases of ECF, D_w is the disability weight, I is the duration of disability (ECF), r is the discount rate, a_i is the age of onset, and erf is error function, Typical values of β_1 and β_2 are 0.2332 and 0.01, respectively, as described by Salih (2015).

Similarly, by replacing the duration of disease I with the standard life expectancy , the age of onset a_i with the age of death a_d, we obtain the YLL formula as given in equation 11;

$$YLL = N_d \beta_1 e^{a_d r}\left[\sqrt{\pi} r e^{\frac{r^2}{4\beta_2}}\left(\frac{erf(2\beta_2(a_d+L)+r)+erf\left(\frac{2\beta_2 a_d+r}{2\sqrt{\beta_2}}\right)}{4\sqrt{\beta_2^3}}\right)+\left(\frac{-e^{-(a_d+L)(\beta_2(a_d+L)+r)}+e^{-a_d(\beta_2 a_d+r)}}{2\beta_2}\right)\right]$$

(11)

Where N_d is the number of deaths, a_d is the age of death, and L is the standard life expectancy at the age of death.

Results

Estimating Societal Disease burden of ECF without Discounting and Age Weighting

The calculations of YLD, YLL, and PALYs without discounting and age weighting for different types of cattle are shown in Table 2. The YLD is 0.0096 years (approximately 1.8816 years for 196 cows), 0.0063 years (approximately 1.2617 years for 199 bulls), and 0.0033 years (approximately 0.6455 years for 198 oxen) per cow, bull, and ox, respectively. The YLL due to premature death is 14.98 years per cow (approximately 2936 years for 196 cows), 9.98 years per bull (approximately 1986 years for 199 bulls), and 14.98 years per ox (approximately 2966 years for 198 oxen). The number of PALYs lost is 14.9896 years (approximately 2937.8816 years for 196 cows), 9.9863 years(approximately 1987.2617 years for 199 bulls), and 14.9833 years (approximately 2966.6455 years for 198 oxen).

Estimating Societal Disease Burden of ECF with Discounting

The results revealed that cattle were most affected by ECF at the age of four years, and the duration of disease was seven days, after which an animal either responded to treatment or died of ECF. The YLD, YLL, and PALYs with discounting for cows, bulls, and oxen are shown in Table 3. The YLD is 0.0096 years (approximately 1.8816 years for 196 cows), 0.0063 years (approximately 1.2597 years for 199 bulls), and 0.0033 years (approximately 1.2597 years for 198 oxen) per cow bull and ox, respectively. The YLL are 6.5979 years (approximately 1293 years for 196 cows), 5.5959 years (approximately 1114 years for 199 bulls), and 6.5979 years (approximately 1306 years for 198 oxen) per cow, bull, and ox, respectively. The PALYs lost are 6.6075 years (approximately 1.294.8796 years for 196 cows), 5.6022 years (approximately

1115.7597 for 199 bulls), and 6.6012 years (approximately 1307.2597 years for 198 oxen) per cow, bull, and oxen, respectively.

Estimating Societal Disease Burden of ECF with Both Discounting and Age Weighting

The calculation for YLD, YLL, and PALYs with both discounting and age weighting are shown in Table 4. The YLD is 0.0105 years (approximately 1.9703 years for 196 cows), 0.0070 years per bull (approximately 1.3831 years for 199 bulls), and 0.0036 years per ox (approximately 0.7049 years for 198 oxen). The YLL are 5.1572 years (approximately 1011 years for 196 cows), 4.8741 years per bull (approximately 970 years for 199 bulls), and 5.1572 years per ox (approximately 1021 years for 198 oxen). The PALYs lost is 5.1677 (approximately 1012.9703 years for 196 cows), 4.8811 years (approximately 971.3831 years for 199 bulls), and 5.1608 years (approximately 1021.7049 years for 198 oxen) per cow, bull, and oxen, respectively.

PALYs Calculation on Namwala District Cattle Population *with Both Discounting and Age Weighting*

The total societal ECF disease burden (PALYs) for Namwala District is shown in Table 5. Namwala District has a total cattle population of 145,704 (DVS, 2019) that comprises every cattle type. We used the herd structure developed by (Lubungu et al., 2015), which states that an average of 36%, 5%, and 28% is the herd composition estimates for cows, bulls, and oxen. This translated into 52,453 cows, 7,285 bulls, and 40,797 oxen, giving us a total of 100,535 cattle population. The remaining value of 45,169 of Namwala district's cattle population consists of calves, heifers, and steers. Using the calculation category that comprises both discounting and age weighting, ECF causes a total of 517,165.40 PALYs in Namwala District.

Calculation of PALYS with Control of ECF

So far, we have calculated the PALYs lost without considering ECF control. We now calculate the number of PALYs that would have been averted when ECFs control is considered leading to a reduction in ECFs, that is, if the cows were medicated. In what follows, we assume that the cows received ECF control for their disease at the age of onset (a_i) or earlier, and as a result, did not die at the age of death (a_d) but lived r their expected life span at the age a_i (in the treated state). With these assumptions, the disability weight for the treated disease is 0.2 (in the case of a cow). Now we only need to calculate YLD with ECF control. This is achieved by changing the disability weight for the treated form of the disease from 0.5, 0.33, or 0.17 (without ECF control) to 0.2, 0.1, 0.01 (with ECF control) for a cow, ox, and bull, respectively. In this case, the cows (and the other animals in general) would have lived for their expected life at the age of onset. In the next section, we will start with estimating PALYs using basic formulas without discounting and Age-weighting, but with ECF control. Table 6 shows the calculation for YLD, YLL, and PALYs without both discounting and age weighting, with age weighting only, and with both age weighting and discounting with ECF control.

For YLD, YLL, and PALYs without both discounting and age weighting but with ECF control, the number of years of life lived with disability (YLD) is 0.7518 years per cow. The years of life lost due to premature mortality (YLL) are zero years per cow. Years of life lost due to death is equal to zero on the assumption that ECF control will avert death hence, no premature mortality. Therefore, the number of PALYs lost per cow is 0.7518 (approximately 147.3528 years for 196 cows). For the bulls, the number of YLD is 0.3816 years per bull, while the number of YLL is zero years per bull, as explained earlier. The number of PALYs lost per bull is 0.3816 years (approximately 75.9384 years for 199 bulls). For the oxen, the number of YLD is 0.0380 years per bull. The number of YLL is zero years per ox. The number of PALYs lost per ox is 0.0380 years (approximately 7.524 years for 198 oxen).

For the calculation for YLD, YLL, and PALYs with age weighting (with ECF control), the number of YLD is 0.7508 years per cow. The YLL are zero years per cow, as we earlier explained. Therefore, the number of PALYs lost per cow is 0.7508 (approximately 147.1568 years for 196 cows). For the bulls, the number of YLD is 0.3812 years per bull. The number of YLL is zero years per bull. The number of PALYs lost per bull is 0.3812 years (approximately 75.8588 years for 199 bulls). For the oxen, the number of YLD is 0.0380 years per bull. The number of YLL is zero years per ox. The number of PALYs lost per ox is 0.0379years (approximately 7.5042 years for 198 oxen).

For the calculation for YLD, YLL, and PALYs with both Ages Weighing and Discounting (with ECF control), the number of YLD is 0.3552 years per cow. The YLL are zero years per cow, as we earlier explained. Therefore, the number of PALYs lost per cow is 0.3552 (approximately 69.6192 years for 196 cows). For the bulls, the number of YLD is 0.1804 years per bull. The number of YLL is zero years per bull. The number of PALYs lost per bull is 0.1804 years (approximately 35.8996 years for 199 bulls). For the oxen, the number of YLD is 0.0330 years per bull. The number of YLL is zero years per ox. The number of PALYs lost per ox is 0.0330 years (approximately 6.534 years for 198 oxen).

Calculation of PALYs Averted

Having calculated PALYs without and with ECF control, now we calculate PALYs averted per cow, bull, and ox by subtracting the value of PALYs with control from those without. Table 7 shows the PALYs averted due to ECF control using the basic formula, with discounting only and with both age weighting and discounting.

Discussion

This study aimed at estimating the disease burden of ECF among cattle-keeping households in Namwala District of Zambia using PALYs. The results revealed that ECF causes a total loss of 517,165.40 quality years lived of cattle due to morbidity and the loss of productivity due to premature mortality regardless of the administration of treatment. The products that are expected to be lost during these years are milk, meat, manure, use as dowry, and draught power. A significant value of years of a healthy life is lost in livestock when ECF control measures are not implemented. On the other hand, when control measures exist, the PALYs significantly reduce with possibilities of increased livestock productivity. This is true regardless of the type of livestock or the method used for calculating PALYs (categories). In the next section, we will only interpret the results of PALYs with discounting and age weighting. This is because results for other categories are interpreted in a similar way.

Calculation of PALYs with both discounting and age weighting revealed that the years of life lost due to disability (YLD) for a cow was 0.0105 years (approximately four days). This means that for a cow that develops ECF at the age of 4, the quality of life lived reduces by approximately four days regardless of treatment. The years of life lost due to premature mortality (YLL) for a cow that dies at the age of 4 was 5.1572 years, which means that the cow loses five years of productivity due to ECF.

The years of life lost due to disability (YLD) for a bull was 0.0070 years (approximately three days), meaning that for a bull that develops ECF at the age of 4 years regardless of treatment; the quality of life lived reduces by three days. The years of life lost due to premature mortality (YLL) for a bull were 4.8741 years. Therefore, per bull, approximately, five years of productivity are lost due to ECF.

The years of life lost due to disability (YLD) for oxen was 0.0036 years (approximately one day), meaning that for an ox that develops ECF at the age of 4 years regardless of treatment, the quality of life lived reduces by a day. The years of life lost due to premature mortality (YLL) for oxen were 5.1572 years. Therefore, per ox, approximately, five years of productivity are lost due to ECF.

We incorporated both age weighting and discounting to acquire more effective and accurate PALYs results that assessed both social values. The results without both discounting and age weighting yielded a total of 7,898 PALYs. The results with discounting but no age weighting resulted in a total of 3,718 PALYs. The results with both discounting and age weighting yielded a total of 3006 PALYs. Discounting is included to prevent giving excessive weight to deaths at younger ages, and the pattern of variation is mostly dictated by the shape of the age weighting function as PALYs decreased when the disease starts in the very early years of life or in the older ages of life with a short duration as stated by Salih (2015). Therefore, the most accurate PALYs results are those, which include both social values of discounting and age weighting. All the results for PALYs are reported to four decimal places because the years are also reported equivalent to days for easy understanding. For instance, one day is equal to 0.0027 years.

From our analysis, considering age weighting and discounting, approximately, 35% of the productivity years of a cow of its life span are lost due to ECF. In the case of bulls, approximately, 49% of a bull's productivity years are lost due to ECF. For oxen, approximately 35% of productivity years of oxen are lost due to ECF disease. However, introducing effective ECF control measures such as immunisation and tick control on cows, bulls, and oxen will reduce the loss of productivity years to approximately 0.02% (less than 1%), 0.01% (less than 1%), and 0.001% (less than 1%), respectively. Therefore, providing necessary resources to encourage farmers to take tick control measures (strategic and effective dipping and spraying cattle with acaricides) and routine immunisation will improve cattle productivity and lessen the disease burden of ECF and other tick-borne diseases. However, the challenge faced by these farmers is the inadequate supply of acaricides within Namwala, which results in farmers incurring extra costs to travel long distances to Choma, the nearest district, to purchase acaricides.

With regard to the study's limitations, DALYs in humans have been criticised in estimating the global burden of disease for, among other reasons, life expectancy, validity, and justice (Arnesen and Nord, 1999). For instance, the life expectancy of 82.5 for women and 80 for men may not be a true reflection of life expectancy for Africa. Similarly, for livestock, the length of animals' lives is not just determined by a desire to maximise life, especially among commercial farmers, but by other considerations mostly linked to human behaviour and decision-making (Shaw et al., 2017). This, however, should not be used to totally do away with a modification of DALYs for livestock. DALYs for livestock species, for example, cattle, can still be estimated in the context of production systems in developing and developed countries and be used for decision-making in animal health policy without necessarily converting non-monetary burden to monetary using time trade-off.

Similarly, between DALYs have been criticised for discriminating the young and old, especially in the category of DALYs, without discounting and age weighting. However, issues of discounting and age weighting solve the problem of giving more social value to young and old animals (justice). Age weighting means that the life years of cattle are counted differently because cattle are more productive at a particular age than others. In this study, age-weighting was based on the questionnaire, which indicated a broad variation in cattle's economic and social values at different ages. The impact of lost years of a healthy life varies significantly with cattle ages; for instance, lost years of healthy life during the productivity ages have a more significant negative impact than lost years of healthy life during the very early age or late age. According to our data, we value years of healthy life lived during productive ages over early and late ages. This choice is very reasonable, and it is made based on economic and social values.

The herd structure for the cattle in Namwala District comprises 36% cows, 28% oxen, 5% bulls, 12% calves, 12% heifers, and 7% steers (Lubungu et al., 2015). We estimated PALYs for cows, bulls, and oxen because of their productivity use for the benefit of farmers. Results from a questionnaire revealed that cattle become useful at four years and the main parameters for productivity were milk production, breeding, draught power, and social values. Calves are not considered productive hence, could not be used in the model. Similarly, steers were not considered productive because traditional cattle farmers do not rear cattle for fattening and slaughter as commercial beef farmers do. Since this study did not include heifers, steers, and calves, the total district PALYs did not include them because it was difficult to give them a disability weight based on productivity. Future studies should refine disability weights for all groups of cattle for inclusion into PALY models.

Conclusion and Recommendations

The value of 517,165.40 PALYs represents the loss of healthy years of life and quality of life for cattle due to ECF. The larger the number, the more the loss in cattle productivity, in this case, cows, bulls, and oxen, which are used in the farmers' major socioeconomic activities. Consequently, high PALYs indicate potential economic losses to livestock farmers. East Coast Fever is classified as a management disease and not a disease of national economic importance. Assessing PALYs for all animal diseases will help reclassify animal diseases based on their societal burden and not only economic assessment. Productivity adjusted life years calculations are helpful in cost-effective analysis, in particular, comparing different health intervention programmes for the same disease. Productivity adjusted life years are a tool in health policy that translates epidemiological data into useful information for decision-making. Based on the study findings, there is a need for further research on estimating the societal burden of all animal diseases countrywide using PALYs to assess, which disease needs prioritisation to minimise the loss of cattle productivity through morbidity and mortality. The results would not make more sense for decision-making on disease classification of national economic importance without ranking all key animal diseases using PALYs. This study forms a basis for ranking all diseases and accurately measures non-monetary animal diseases' societal burden.

Acknowledgments

We would like to thank Mr Ladislav Moonga for assisting with data collection and all the respondents to the questionnaires for making this study possible.

Funding

The research work was supported by a grant from the National Institute of Allergy and Infectious Diseases of the National Institutes of Health 'Spatial eco-epidemiology of tick-borne rickettsial pathogens' under award number R01AI136035 [PI – Gaff H], through a sub-award to the University of Zambia [PI – Chitanga S]. The content is solely the responsibility of the authors and does not necessarily represent the views of the National Institutes of Health.

Competing Interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Author Contributions

CM: conceptualisation, investigation, methodology, analysis, visualisation, manuscript development, and supervision of the MSc student (NM).

NM: investigation, methodology, analysis, visualisation, and manuscript development.

OS: methodology, analysis, visualisation, writing, and reviewing.

KSC: investigation, writing, and reviewing

ES: supervision, validation, writing, and reviewing.

KC: supervision, validation, writing, and reviewing.

SC: funding acquisition, project administration, supervision, validation, writing, and reviewing.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author [CM], upon reasonable request.

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TABLES

Table 1: ***Definition of Disability Weight (*D_w*) for Cattle (Developed by Salih** 2015)*

Levels	Description	D_w
1	1. Beef production [(500 - 600kg for oxen), (300 - 516kg for bulls), (320 - 440 kg for cows)]. 2. Milk production [5 - 6 litres per day]. 3. Draught power [3 - 5hrs for cows, 5 - 6hrs for oxen]. 4. Social status [acceptable]. 5. Dowry payment [acceptable]. 6. Cultural ceremonies [acceptable].	0
2	1. Beef production [(400 - 499kg for oxen), (260 - 299kg for bulls), (280 - 319kg for cows)]. 2. Milk production [3:5 - 4:9 liters per day]. 3. Draught power [2 - 3hrs for cows, 3 - 4hrs for oxen]. 4. Social status [not very acceptable for the reason of loss of condition]. 5. Dowry payment [not very acceptable for the reason of loss of condition]. 6. Cultural ceremonies [not very acceptable for the reason of loss of condition].	0:01 - 0:33

3	1. Beef production [(300 - 399kg for oxen), (220- 259kg for bulls), (200 - 239kg for cows)]. 2. Milk production [2- 3:4 liters per day]. 3. Draught power [1 - 2hrs for cows, 2 - 3hrs for oxen]. 4. Social status [not acceptable for the reason of being diseased]. 5. Dowry payment [not acceptable for the reason of being diseased]. 6. Cultural ceremonies [not very acceptable for the reason of being diseased].	0:34 - 0:66
4	1. Beef production [(300 - 399kg for oxen), (220 - 259kg for bulls), (200- 239kg for cows)]. 2. Milk production [2 - 3:4 liters per day]. 3. Draught power [1 - 2hrs for cows, 2- 3hrs for oxen]. 4. Social status [not acceptable for the reason of being diseased]. 5. Dowry payment [not acceptable for the reason of being diseased]. 6. Cultural ceremonies [not very acceptable for the reason of being diseased].	0:67 -0:99

Table 2: ***Calculation for PALYs Without Discounting and Age Weighting***

Animal	N_i	a_i (yrs)	I (days)	D_w	**YLD (yrs)**	N_d (yrs)	L (yrs)	**YLL (yrs.)**	**PALYs (yrs)**
Cow	196	4	7	0.5	1.8816	196	15	2936	2937.8816
Bull	199	4	7	0.33	1.2617	199	10	1986	1987.2617
Oxen	198	4	7	0.17	0.6455	198	15	2966	2966.6455

Table 3: ***Calculation for PALYs with Discounting***

Animal	N_i	a_i (yrs)	I (days)	D_w	**YLD (yrs)**	N_d (yrs)	L (yrs)	**YLL (yrs)**	**PALYs (yrs)**
Cow	196	4	7	0.5	1.8796	196	15	1293	1294.8796
Bull	199	4	7	0.33	1.2597	199	10	1114	1115.7597
Oxen	198	4	7	0.17	1.2597	198	15	1306	1307.2597

Table 4: ***Calculation for PALYS with Both Discounting and Age Weighting***

Animal	N_i	a_i *(yrs)*	I (Days)	D_w	YLD (yrs)	N_d (yrs)	L *(yrs)*	YLL (yrs)	PALYs (yrs)
Cow	196	4	7	0.5	1.9703	4.0192	15	1011	1012.9703
Bull	199	4	7	0.33	1.3831	4.0192	10	970	971.3831
Oxen	198	4	7	0.17	0.7049	4.0192	15	1021	1021.7049

Table 5: ***PALYs Calculation on Namwala District Population with Both Discounting and Age Weighting***

Cattle	Population	YLD (yrs)	YLL (yrs)	PALYs (yrs)
Cows	52,453	550.8	270,510.6	271,061.4
Bulls	7,285	51	35,507.9	35,558.8
Oxen	40,797	146.9	210,398.3	210,545.2
TOTAL	**100,535**	**748.7**	**516,165.40**	**517,165.40**

Table 6: ***PALYs Calculations with ECF Control***

PALYs Calculation Using Basic Formula (with ECF control)							
Cattle	N_d	a_i	I **(days)**	D_w	**YIELD**	**ALL**	**PALYs**
Cow	196	4	7	0.2	Total (yrs) = 0.7518 yrs(≈0.003836 years per Cow) Total (days) = 275 days (≈ 1.4 days per Cow)	0	0.7518 yrs 275 days
Bull	199	4	7	0.1	Total (yrs) = 0.3816 yrs (≈ 0.001918 years per Bull) Total (days) = 139 days (≈ 0.7000 days per Bull [Less than one day])	0	0.3816 yrs 139 days
Oxen	198	4	7	0.01	Total (yrs) = 0.0380 yrs (≈ 0.000192 years per Bull) Total (days) = 13.8600 days (≈0.0700 days per Bull [less than one day])	0	0.0380 yrs 13.8600 days
PALYs Calculation With Age Discounting (with ECF control)							
Cow	196	0.13	7	0.2	Total (yrs) = 0.7508 yrs (≈0.003831 yrs per Cow) Total (days) = 180 days (≈0.9192 days per Cow)	0	0.7508 yrs 180 days

Bull	199	0.13	7	0.1	Total (yrs) = 0.3812 yrs (≈ 0.001915 yrs per Bull) Total (days) = 91 days (≈0.4596 day per bull [less than one day])	0	0.3812 yrs 91 days
Oxen	198	0.13	7	0.01	Total (yrs) = 0.0379 yrs (≈ 0.000192 yrs per Ox) Total (days) = 9 days (≈ 0.0460 day per ox [less than one day])	0	0.0379 yrs 9 days
PALYs Calculation With both Ages Weighing and Discounting (with ECF control)							
Cow	196	4	7	0.5	Total (yrs) = 0.3552 yrs (≈0.001813 yrs per Cow) Total (days) = 130 days (≈0.6616 day per cow [less than one day])	0	0.3552 yrs 130 days
Bull	199	4	7	0.33	Total (yrs) = 0.1804 yrs (≈0.000906 yrs per bull) Total (days) = 66 days (≈0.3308 day per bull [less than one day)	0	0.1804 yrs 66 days
Oxen	198	4	7	0.17	Total (yrs) = 0.0179 yrs (≈0.000091 yrs per Oxen) Total (days) = 6.5 days (≈0.0330 day per oxen [less than one days)	0	0.0179 yrs 6.5 days

Table 7: ***PALYs Averted Per Cow, Bull, and Ox***

Calculation of PALYs averted per cow, bull, ox (Basic formula)			
Cattle	**PALYs (without ECF control)**	**PALYs (with ECF control)**	**PALYs averted**
Cow	14.9892 yrs	0.003836 yrs (≈ 34 hrs)	14.9854 yrs
Bull	9.9862 yrs	0.001918 yrs (≈ 17 hrs)	9.9843 yrs
Oxen	14.9831 yrs	0.000192 yrs (≈ 2 hrs)	14.9829 yrs
Calculation of PALYs averted per cow, bull, ox (with discounting)			
Cow	6.6065 yrs	0.003831 yrs (≈ 33 hrs)	6.6027 yrs
Bull	5.6068 yrs	0.001915 yrs (≈ 16 hrs)	5.6049 yrs
Oxen	6.6023 yrs	0.000192 yrs (≈ 1 hrs)	6.6021 yrs

Calculation of PALYs averted per cow, bull, ox (Ages weighting and discounting)			
Cow	5.1682 yrs	0.001813 yrs (≈16 hrs)	5.1664 yrs
Bull	4.8813 yrs	0.000906 yrs (≈ 8 hrs)	4.8804 yrs
Oxen	5.1601 yrs	0.000091 yrs (≈ 1 hrs)	5.1600 yrs

Figure Legends

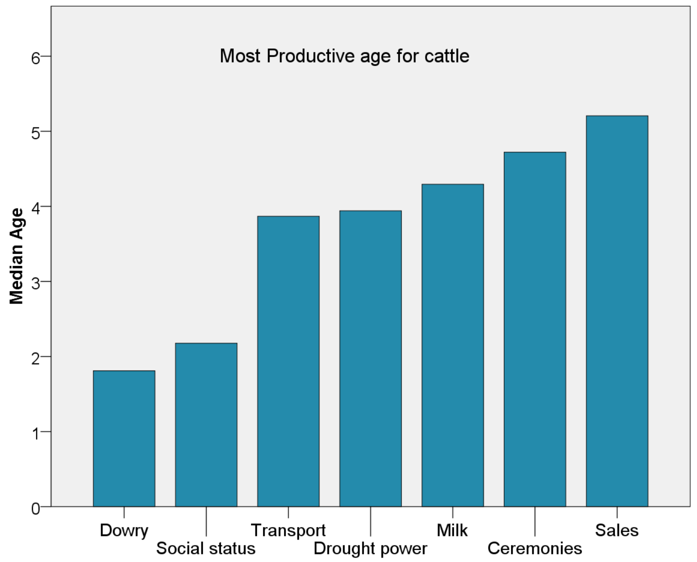

Figure 1: Most Productive Age for Cattle for Different Activities Based on Questionnaires

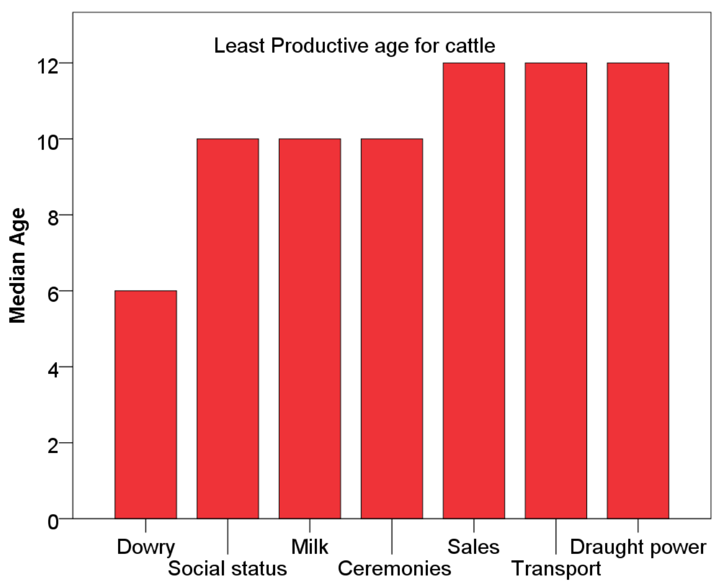

Figure 2: Least Productive Age for Cattle for Different Activities