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Attributing Ethiopian animal health losses to high-level causes using expert elicitation

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ABSTRACT

The Global Burden of Animal Diseases programme is currently working to estimate the burden of animal health loss in Ethiopia. As part of this work, structured expert elicitation has been trialled to attribute the proportion of animal health losses due to three independent and exhaustive high-level causes (infectious, non-infectious, and external). Separate in-person workshops were conducted with eight cattle, nine small ruminant, and eight chicken experts. Following the Investigate-Discuss-Estimate-Aggregate protocol for structured expert elicitation, estimates were obtained for the proportion of animal health loss due to high-level causes in different combinations of health loss, species, age-sex class, and production system. Three-point questions were used to inform beta-pert distributions and capture uncertainty in estimates. Individual expert estimates were aggregated by quantile mean to produce average distributions. Random samples from these average distributions estimated that infectious causes inflict the highest proportion of health loss in Ethiopia, with at least 40 % of health losses estimated to be due to infectious causes in all categories. This study provides a rapid, simple, and engaging method to attribute the burden of animal health loss at a high-level. Results are informative, however will become increasingly useful once they can be compared with results from more sophisticated, data-driven models.

1. Introduction

The Global Burden of Animal Diseases (GBADs) programme is an ambitious consortium of animal health experts aiming to develop a platform that provides burden of disease estimates to inform evidence-based decision making at the global, national, and sub-national levels; comparable to the long-standing and constantly evolving Global Burden of Disease resource in humans (Rushton et al., 2018; Huntington et al., 2021; Rushton et al., 2021; Murray, 2022). This scope of work requires many integrated data-driven models producing estimates that can be aggregated and disaggregated through the application of an ontology. Such modelling requires an enormous amount of data for parameterisation. These data range from population and production values, prices of animals and products to disease frequency, impact and relative occurrence for different species, ages, sexes, and production systems in multiple locations across time. Sourcing such rich data in the animal health domain can be extremely challenging, particularly if they are to be applied in a standardised way for internally and externally consistent modelling (VanderWaal et al., 2017; Vial and Tedder, 2017). Given the challenges of limited data and the need for a vast number of data-driven models, estimating the burden of animal disease is an ongoing and iterative process that will produce increasingly refined burden estimates. The objective of this short communication is to describe a rapid and flexible method which allows countries to begin attributing the burden of animal disease to high-level causes using expert elicitation.

The broader methods and narrative behind the GBADs programme are described elsewhere (Rushton et al., 2018; Huntington et al., 2021; Rushton et al., 2021) however, some key features must be described as they are currently unpublished. The programme currently uses an animal health loss envelope (AHLE) metric to summarise the burden of

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animal disease at the farm-level. This envelope is the difference in gross margin between current farms and farms in an ideal setting (i.e. no mortality or production losses and without expenditure on health). The current structure of the AHLE means that it can be separated into three parts: the burden due mortality, the burden due to production losses, and the burden due to health expenditure. Mortality losses are those incurred when animals die, whilst production losses are those due to morbidity. Using foot-and-mouth disease as an example, a clear production losses would be decreased milk yield. Whilst mortality losses are those incurred when or if an animal dies, and health expenditure are those costs incurred during treatment and prevention.

This paper describes how the morbidity and mortality sections of the AHLE can be further attributed to high-level causes using expert elicitation. High-level causes are the three broadest categories of the current GBADs attribution hierarchy, similar to the use of chapters in the structure of the International Classification of Diseases (World Health Organization, 2022). All diseases and causes of animal health loss are considered to fit into one of these categories (infectious, non-infectious, and external causes) (Table 1). The health expenditure section of the AHLE has not been attributed in this way because expenditure on prevention and control is often generic or horizontal. Expenditure associated with biosecurity and husbandry are not cause-specific and hence span across these high-level cause categories, whilst data on cause-specific expenditure such as vaccines are more readily available and other methods can be used for their attribution.

2. Material and methods

Expert estimates were obtained for the proportion of the AHLE that could be attributed to infectious, non-infectious, and external causes for mortality and production loss in small ruminants, cattle, and chickens in Ethiopia. To ensure consistency throughout the GBADs programme, the elicitation was completed in a predetermined set of species, production systems, and age-sex classes based on the current structure of the AHLE and GBADs work that is underway or has recently been completed (Jemberu et al., 2022) (Table 2). For each species, production system, and age-sex combination, the experts completed a three-step question to provide minimum, most likely, and maximum estimates of the proportion of the AHLE due to each high-level cause for mortality and production loss, respectively. The most likely values were completed first and must sum to 100 %, reflecting that all causes of health loss can be classified as infectious, non-infectious, or external causes in a mutually exclusive manner. Minimum and maximum values then reflect the expert's uncertainty around their most likely value.

Estimates were collected by adapting the Investigate-Discuss-Estimate-Aggregate (IDEA) protocol for expert elicitation (Hemming et al., 2018). The workshop process can be summarised in the following steps:

1. The three-step questionnaire is completed by each expert independently.
2. Estimates are collected, anonymised, and used to create individual beta-pert probability distributions. These distributions are presented with an average distribution that is calculated using the mean minimum, mean most likely, and mean maximum values from all experts (Fig. 1). These figures are the focus of a facilitated discussion that gives experts the opportunity to provide the rationale behind their estimates and clarify any inconsistencies or misunderstandings of the process.
3. During the discussion, the three-step questionnaire is repeated by each expert so that they may revise their estimates if they wish.

Table 2
Animal categories used for expert elicitation. Burden estimates using expert elicitation were made for each combination of production system and age-sex class in this table for small ruminants, cattle, and chickens.

Species	Production system	Age-sex class
Small ruminants	Pastoral	Juvenile
	Crop livestock mixed	Sub-adult
		Adult female
		Adult male
Cattle	Pastoral	Juvenile
	Crop livestock mixed	Sub-adult
	Dairy	Adult
		Oxen
Chickens	Village	Juvenile
	Small holder	Sub-adult
		Adult

In-person workshops using the data collection method described above were conducted in Addis Ababa during May-November 2022 for each respective species. 9 experts attended cattle and small ruminant workshop respectively, whilst 8 experts attended the chicken workshop. Experts were primarily veterinarians with post-graduate qualifications employed in government, research, or clinical fields and were selected by the study team based on experience and reputation. Human ethics approval for this research was received from the appropriate committees (Organisation names and approval numbers withheld for author anonymity, as requested by editor).

The aggregation step of the IDEA protocol was completed after the data collection workshops. The mean of all experts' final minimum, most likely, and maximum estimates were used respectively to create average beta-pert probability distributions for each component of the AHLE (mortality and production loss), species, production system, and age-sex class combination. Each combination's average distribution was summarised by the median, fifth, and ninety-fifth quantiles (95 % uncertainty interval) of one thousand random samples.

Given the attribution framework, the total proportion of the AHLE due to the three high-level causes must sum to one for each set of combinations. This constraint may not always be met when taking random samples from the average distributions, due to the uncertainty captured and the independence of the minimum and maximum estimates. For example, a single random sample from each cause distribution may estimate that the attributable proportion of the AHLE is 0.50 for infectious causes, 0.20 for non-infectious causes, and 0.20 for non-infectious causes. These example samples result in a total proportion of the AHLE of 0.90 (0.50 + 0.20 + 0.20) due to the three causes. This is an irrational result since all causes of health loss have been defined as belonging to only one of the three high-level causes. To account for this, each set of samples for infectious, non-infectious, and external causes are related and scaled relative to their total, so that each series of related samples sum to one. In our example above these three samples would be scaled to 0.56 (0.5/0.9) for infectious causes and 0.22 (0.2/0.9) for non-infectious and external causes, and their sum is now one. The scaled samples were summarised by their median and 95 % uncertainty interval to reflect the proportion of the AHLE due to each respective cause

Table 1
A description of high-level attributable causes.

High-level cause	Description	Examples
Infectious	Diseases caused by an infectious agent (virus, bacteria, fungus, parasite, prion).	Gastrointestinal parasites, foot-and-mouth disease, peste des petits ruminant
Non-infectious	Health losses primarily caused by endogenous factors.	Dystocia, metabolic or nutritional disease.
External	Health loss primarily caused by exogenous or environmental factors.	Poisoning, predation, or trauma.

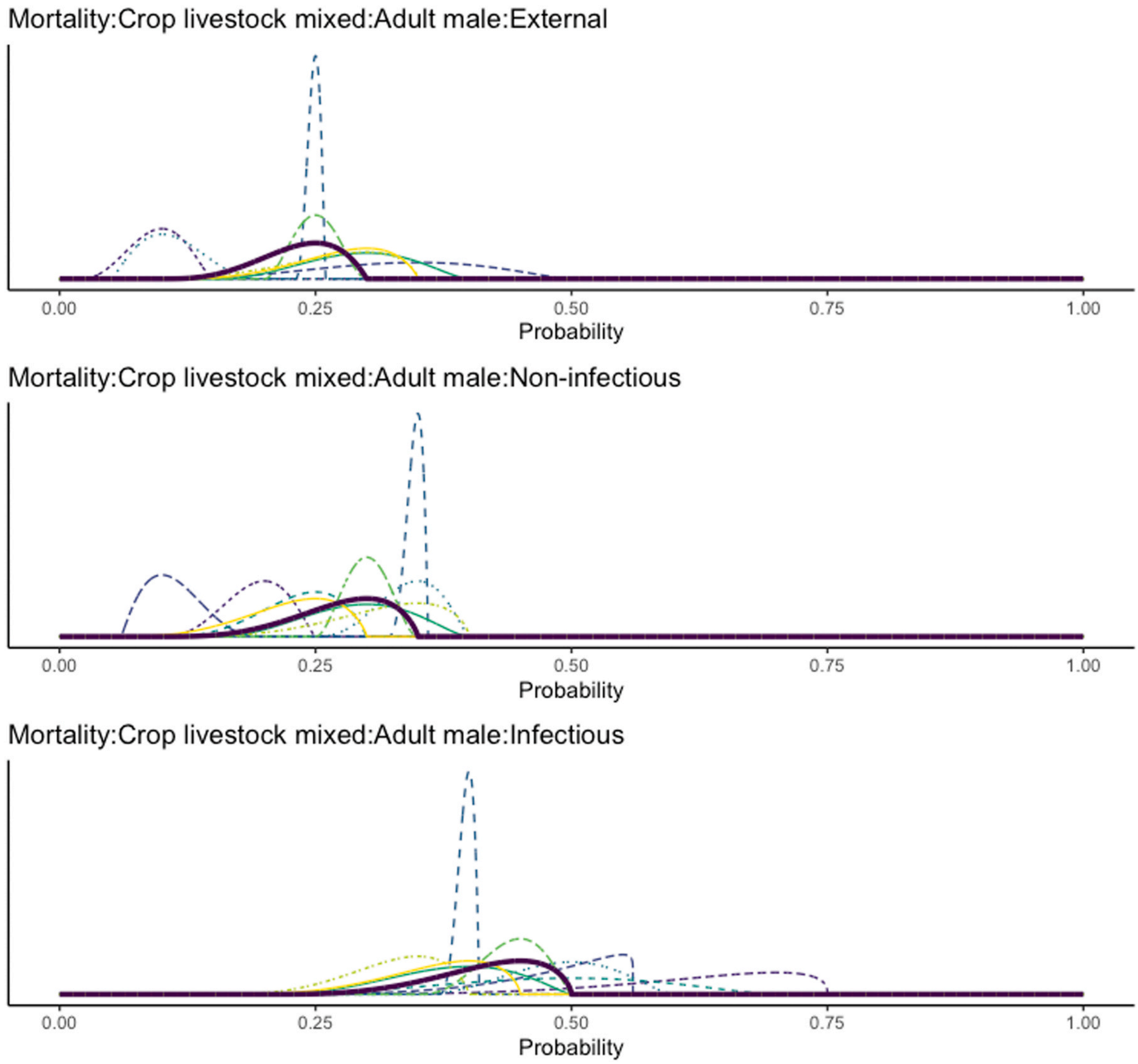

Fig. 1. Expert distributions for discussion. An example of round one estimates that are presented for discussion. The dashed lines represent individual experts, whilst the solid line represents the average distribution.

in the different category combinations.

In the near future, the scaled samples for each category combination will be applied to the relevant dollar value provided by the AHLE to provide the monetary burden of animal health loss in each category combination. Variability between final expert estimates was assessed by the overall concordance correlation coefficient (CCC) (Barnhart et al., 2002) for minimum, most likely, and maximum values. All analysis described above was conducted in R and the code can be found on GitHub (specific link removed for author anonymity).

3. Results

Infectious causes were attributed to impose the highest proportion of animal health loss in Ethiopia. Infectious causes were attributed to causing a minimum of 40 % of the AHLE in all species. This ranged from 0.40 to 0.57 in cattle (Fig. 2, S2), 0.42–0.54 in small ruminants (Fig. 3, S2), and 0.40–0.58 in chickens (Fig. 4, S2), depending on the AHLE section, production system, and age-sex class examined. Although these ranges are similar, independent experts and workshops were used for each species and there are some differences both within and between species. For example, in chickens, infectious causes are responsible for a higher proportion of mortality loss compared with production loss. This change sees a lower proportion of mortality loss due to non-infectious causes (Fig. 4, S2). A similar pattern is seen in juvenile cattle (Fig. 2, S2) and neonatal small ruminants (Fig. 3, S2).

The uncertainty intervals surrounding the estimates suggest that the proportion of health loss due to infectious diseases is at least one-third and may be up to two-thirds in some categories (S2). The relatively large width of the uncertainty intervals is not unexpected given that causes of health loss are variable between animals, farms, regions, and time periods. Summarising all possible farms and animals in any given category is an inherently uncertain process. In addition, there may be limited data for the experts to base their opinions and these intervals also capture the uncertainty of the experts themselves. In this case any overlap of the distributions for the attributable proportion for each high-level cause is relatively small in most cases and primarily between non-infectious and external cause estimates. This variability is evident in the statistical agreement between experts. Whilst there was fair (CCC >0.4) to good (CCC>0.6) agreement between experts for most estimates, there was poor agreement in the minimum values for chickens, and the minimum and maximum values for small ruminants (Table 3).

4. Discussion

The approach and results from this study have provided stakeholders with rapid high-level attribution of animal health losses in key species.

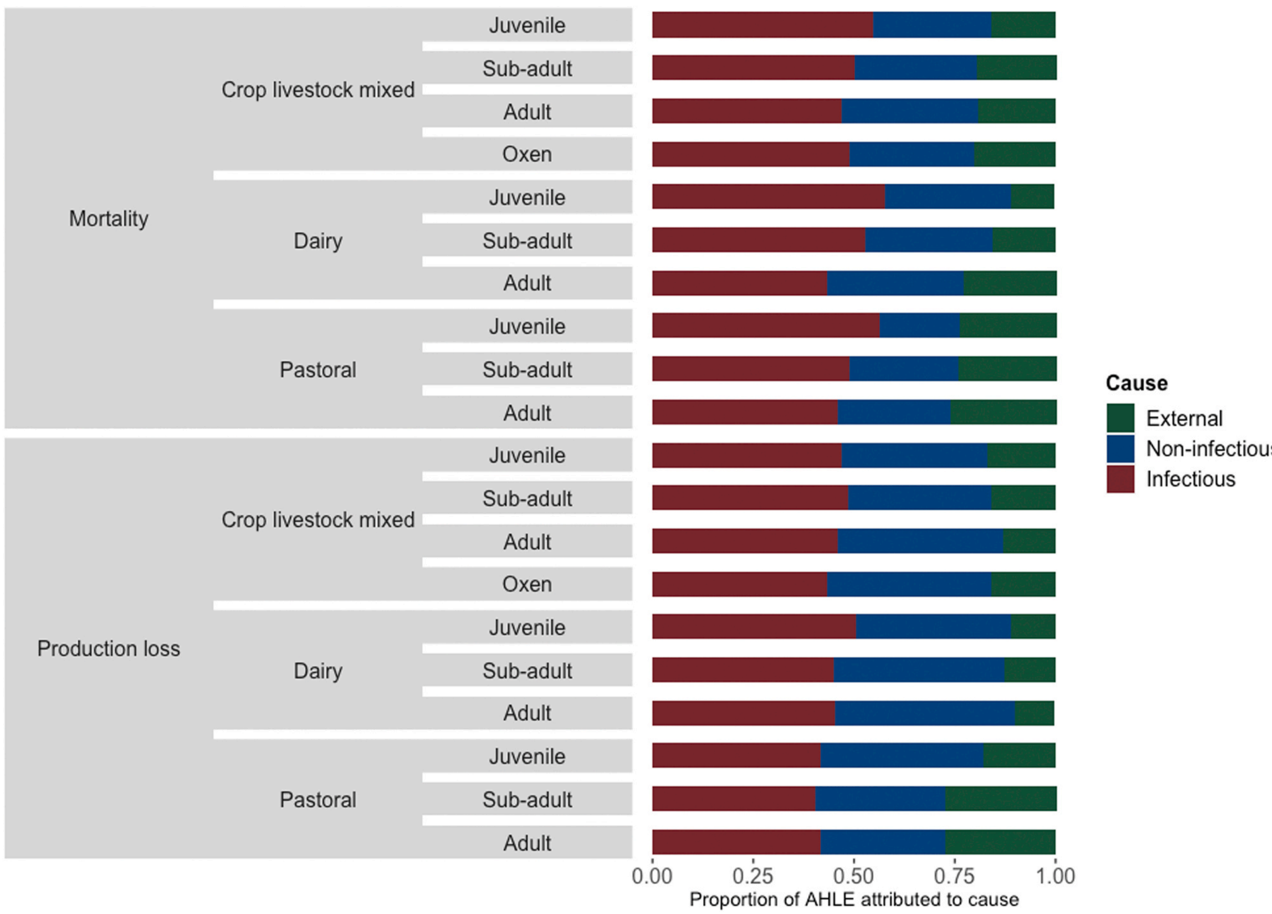

Fig. 2. Median proportion of the animal health loss envelope attributed to external, non-infectious, and infectious causes in cattle.

Importantly, it has encouraged local stakeholder engagement in burden of animal diseases estimates. The approach provides a transparent framework and results that allow the prioritisation of resources in a quantitative manner based on expert judgement. Often this process already occurs however, it is often within small groups and behind closed doors. The next step in the GBADs Ethiopian case study is to combine the attributable proportions, presented above, with AHLE estimates produced by dynamic population and production models (Jemberu et al., 2022). These results will be disseminated through the GBADs knowledge engine with online and interactive dashboards. The dashboards will allow users to examine different aspects and scales of the AHLE depending on their needs. For example, users interested only in the pastoral system will be able to view these results in detail, broken down by age-sex class.

The results of this study cannot be validated due to the lack of available. The very reason why an expert elicitation approach was necessary. More sophisticated data-driven models are in development that will allow for detailed attribution of the AHLE through disease-specific estimates. The expert elicitation results presented in this study can then be compared to data-driven results. However, such data-driven models require significant investment in data collation and analysis. A large number of models are required before relative burdens can be understood however, by using expert attribution at the start of a burden of disease framework, models can be designed in a participatory manner with stakeholder knowledge in mind. Ideally, burden of disease frameworks should be driven by readily available quantitative data. The most representative source of animal health data in the veterinary sectors usually comes from academic peer-reviewed literature. Unfortunately, these data suffer from publication bias and some causes of health loss are overstudied, whilst others are missed. These data are also expensive and complicated to collect. This means they are rarely collected, and some aspects of the burden of disease must rely on expert elicitation. As a result, estimating the burden of disease for understudied causes becomes extremely uncertain. Initial expert attribution at a high level will allow for the results of data-driven GBADs modelling to be ground-truthed against expert opinion and can be completed rapidly whilst more specific models are being designed and their relevant data collated. Another possibility would be to incorporate the resulting distributions into the aggregation of data-driven burden of disease estimates by implementing them as priors in a Bayesian framework.

There are many different methods for conducting structed expert elicitation. The most robust in quantitative terms, is the Classical method (Cooke, 1991). The World Health Organization's Foodborne Disease Burden Epidemiology Reference Group used this method to estimate the proportion of foodborne illness to different sources and exposure pathways (Devleesschauwer et al., 2015; Havelaar et al., 2015; Aspinall et al., 2016; Hald et al., 2016). When attributing specific agents, it is possible to ask experts to provide their knowledge on well documented measures of association and frequency (Aspinall et al., 2016; Hald et al., 2016). These studies still face many of the same limitations present in any expert elicitation and wide uncertainty intervals are still seen when attributing the burden of foodborne disease to different exposure pathways (Hald et al., 2016). In this case study, there is no work that can appropriately test the experts' knowledge of the relative proportion of health loss due to the three high-level causes. It may have been possible to use adjacent calibration questions, however the field of knowledge for the target variables is extremely broad. Calibrating experts to specific questions for such a broad judgement did not seem reasonable or practical given the study resources available. High quality calibration questions are required for credible estimates (Colson and

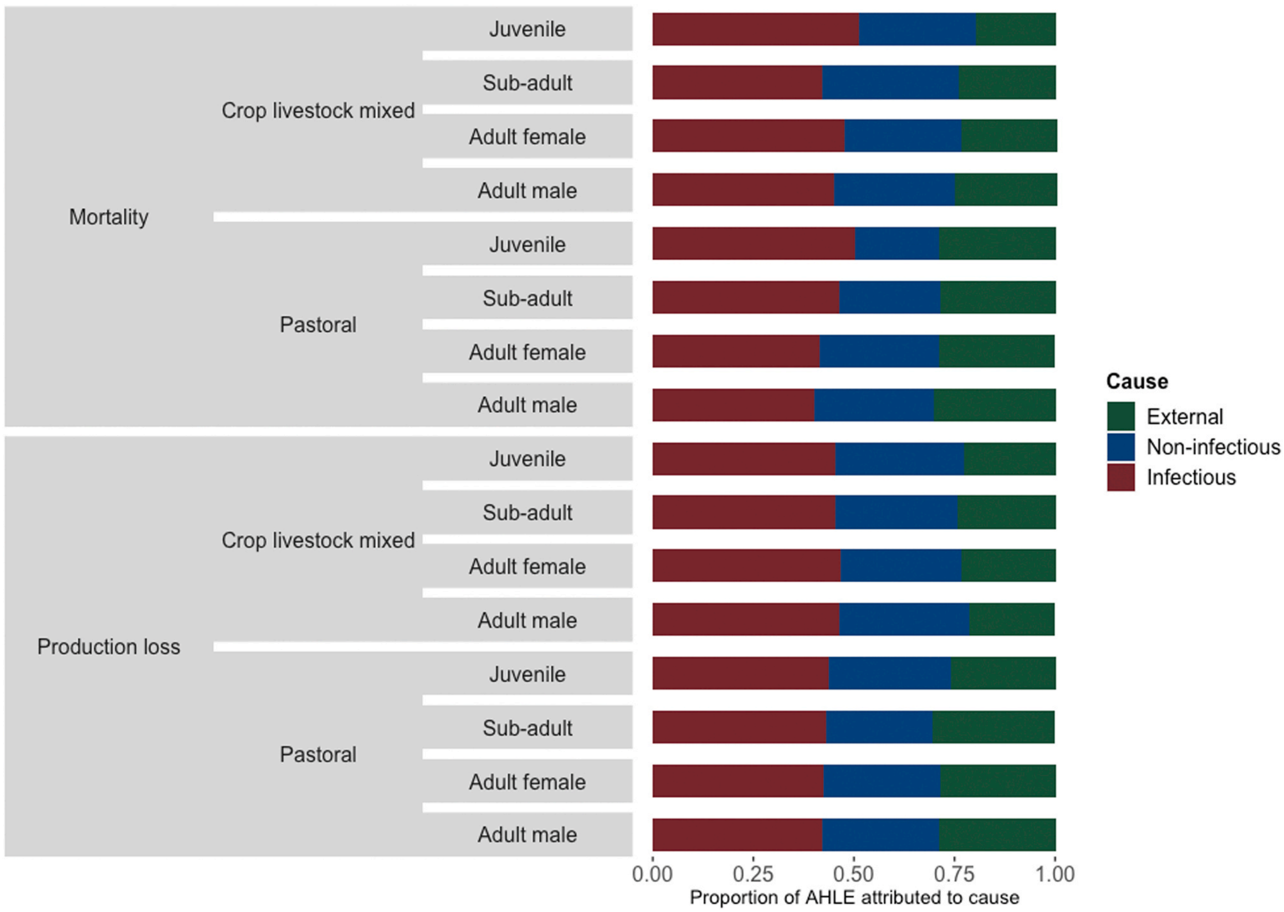

Fig. 3. Median proportion of the animal health loss envelope attributed to external, non-infectious, and infectious high-level causes in small ruminants.

Cooke, 2018) and the choice not to use performance-based weighting of experts is a viable alternative when there are no representative calibration questions (Hemming et al., 2022). Calibration and weighting of experts will be considered in future efforts and has been applied to other expert elicitation activities within GBADs.

This study has several limitations. Many of these surround the use of expert elicitation. Simply put, this study relies heavily on the experts available, their level of knowledge, personal experience, and their interest in the process. This makes the estimates potentially susceptible to bias and heuristics. The purposive selection of experts may lead to selection bias; however, the creation of a sampling frame of animal health experts in Ethiopia was beyond the scope of this study. A structured elicitation protocol has been used in an attempt to reduce the influence of any biases (Hemming et al., 2022). It is assumed that the experts have provided their best estimates for parameters which they understood and were able to provide a sound estimate. Final expert estimates were aggregated by their minimum, most likely, and maximum points rather than their entire distributions. This choice of mean quantile aggregation results in outlying experts having an influence on the final average distribution. With the imperfect concordance of the expert estimates described above, this seems a reasonable compromise and a comparison of different aggregation approaches was beyond the scope of this study. In addition, this approach was somewhat necessitated by the number of different experts, and health loss, species, production system, and age-sex combinations. The large number of combinations limits the number of animal categories that can be included for analysis. The workshops conducted in this study were completed in a half day and as a result, only a certain number of estimates could be elicited before expert fatigue would become an issue. The similar estimates within species suggests that there may be limits to the level at which experts can make accurate and precise estimates of the attributable proportion due to high-level causes.

The approach described in this study should be appealing to many in the animal health sector due to its simplicity, speed, and way in which it engages stakeholders. The principles of conditional probability allow for flexibility in the method, and the choice of categories and classes can be changed depending on the context of the work. If such work is to be compared across countries and regions, an ontology or well-defined vocabulary and classification system is essential for a common understanding and documentation. Clear definitions of the hierarchical structure and groupings of populations and diseases are required so that estimates can be related and aggregated within and across different levels using conditional probability.

5. Conclusions

A lack of coordinated effort to support countries in estimating their burden of animal disease has led to a scenario where there is little guidance for how countries should conduct such work. The GBADs programme is developing methods to support countries in their efforts, with the results also being utilised by global models. It is hoped that robust and transparent estimates can help inform the equitable investment and allocation of resources in animal health systems (Huntington et al., 2021). This short communication describes how high-level expert elicitation can be applied to overcome some of the immediate data limitations that are present in the animal health sector and encourage stakeholder engagement in burden of animal disease estimates, particularly in low-resource settings. Whilst acknowledging the limitations of any expert elicitation, the method presented provides countries with the ability to begin investigating and documenting the burden of animal

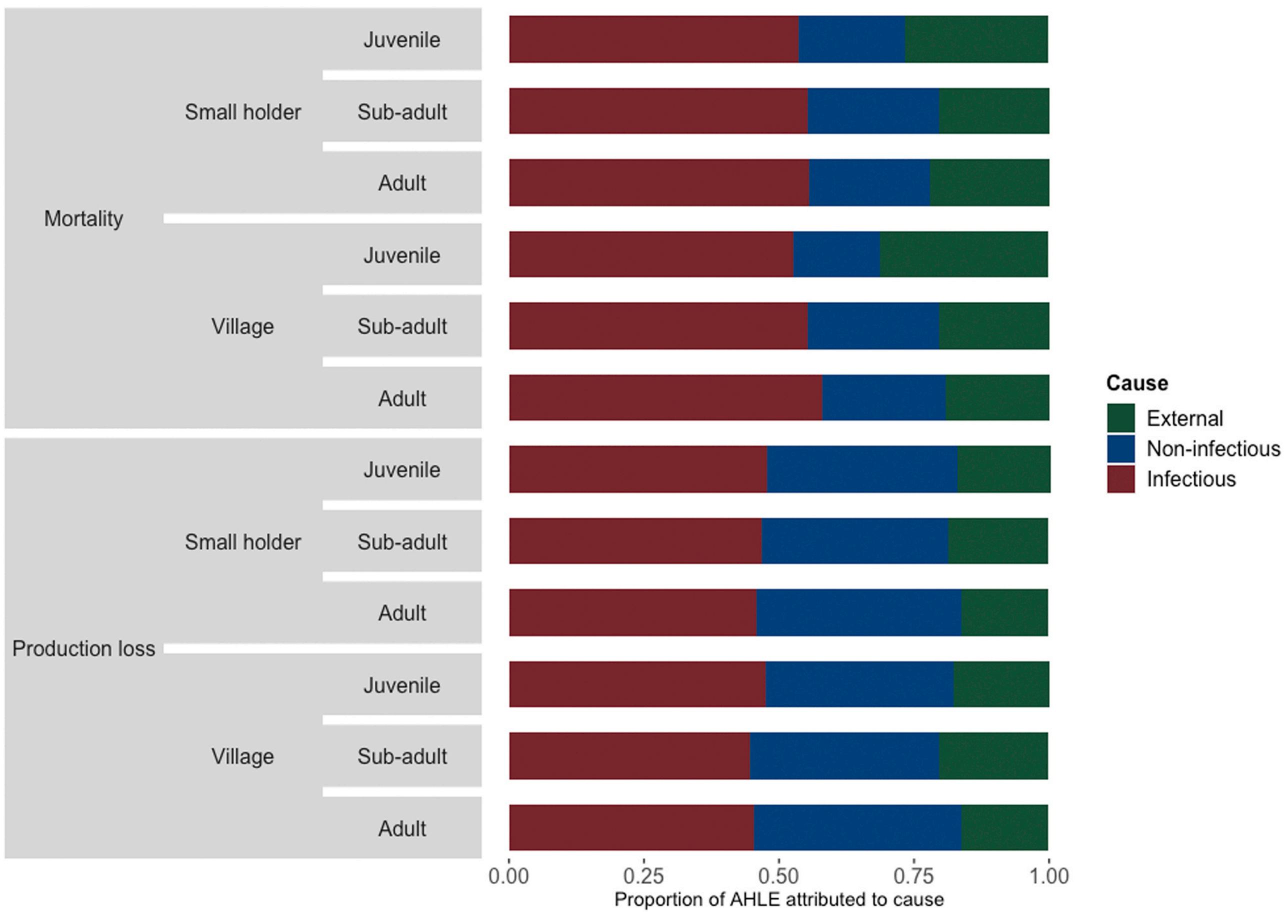

Fig. 4. Median proportion of the animal health loss envelope attributed to external, non-infectious, and infectious high-level causes in chickens.

Table 3
A summary of concordance of expert estimates.

Species	Overall concordance coefficient[a]		
	Minimum estimates	Most likely estimates	Maximum estimates
Cattle	0.45	0.65	0.55
Small ruminants	0.25	0.43	0.37
Chickens	0.35	0.51	0.45

[a] Interpretation: poor <0.40, fair 0.40–0.59, good 0.60–0.74, excellent 0.75–1.00 (Cicchetti, 1994)

health loss in their country by providing baseline expert estimates attributed to high-level causes of animal disease. Ultimately the data gaps filled by the expert elicitations need to be filled by more structured and robust methods of data collection for model parameterisation. The GBADs programme is working on generating business cases for such work in the future. The authors and wider GBADs programme welcome any constructive feedback and discussion via the GBADs website (https://animalhealthmetrics.org/).

Declaration of Competing Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.106077.

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