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Rationalising development of classification systems describing livestock production systems for disease burden analysis within the Global Burden of Animal Diseases programme

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ABSTRACT

The heterogeneity that exists across the global spectrum of livestock production means that livestock productivity, efficiency, health expenditure and health outcomes vary across production systems. To ensure that burden of disease estimates are specific to the represented livestock population and people reliant upon them, livestock populations need to be systematically classified into different types of production system, reflective of the heterogeneity across production systems.

This paper explores the data currently available of livestock production system classifications and animal health through a scoping review as a foundation for the development of a framework that facilitates more specific estimates of livestock disease burdens. A top-down framework to classification is outlined based on a systematic review of existing classification methods and provides a basis for simple grouping of livestock at global scale.

The proposed top-down classification framework, which is dominated by commodity focus of production along with intensity of resource use, may have less relevance at the sub-national level in some jurisdictions and will need to be informed and adapted with information on how countries themselves categorize livestock and their production systems. The findings in this study provide a foundation for analysing animal health burdens across a broad level of production systems. The developed framework will fill a major gap in how livestock production and health are currently approached and analysed.

1. Introduction

Livestock provide a range of economic, social and cultural services, ranging from the provision of food and income to a source of manure, traction, stored wealth and social status (Yang et al., 2009; Nougairede et al., 2013). Healthy livestock populations have long been recognized as a necessity in low- and middle-income countries to support the livelihoods of livestock keepers and provide safe and affordable livestock products to consumers (Banda and Tanganyika, 2021). Combined with inadequate access to livestock health services, livestock diseases and other husbandry issues hinder livestock development (Perry and Rich, 2007; Herrero et al., 2010). In societies that are reliant on livestock, poor animal health thereby contributes to socio-economic insecurity, hunger and malnutrition (Perry and Rich, 2007; Rich and Perry,

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2011). Furthermore, livestock pathogens may directly threaten human health through the transmission of zoonoses and foodborne diseases (Newell et al., 2010; Li et al., 2020), with the largest burden of this felt by those living in the most marginalized and rural communities (Halliday et al., 2015). Inefficiencies in livestock production can also exacerbate environmental issues such as greenhouse gas emissions and soil erosion (e.g., Herrero et al., 2010; Herrero et al., 2013).

A systematic approach to evaluate the societal burden of livestock disease and identify where to target disease control efforts for maximum societal returns is lacking. The Global Burden of Animal Disease programme (GBADs) is working towards addressing this issue (Rushton et al., 2021). GBADs is building a standardized data-sharing platform to systematically collect epidemiological and economic data to assess the societal cost of livestock diseases globally. This platform can be used to inform investments in animal health.

The GBADs program includes themes that describe different aspects of an analytical framework and the development of analytical procedures to characterize livestock populations, biomass, economic value and disease burden (Huntington et al., 2021; Rushton et al., 2021). For GBADs, a livestock system classification process is being developed to enable stratification of livestock populations, economic value, animal health expenditure and losses and impacts of these losses by production systems. Attribution of the disease burden by cause and by impact on stakeholder groups as well as impacts on the wider economy, can then be estimated more specifically for each production system (Rushton et al., 2021). For example, the owners of cattle in a crop-livestock mixed system and a specialized dairy system are different, and they have different social-economic status in the country (Food and Agriculture Organization of the United Nations, 2018). Livestock herds and flocks within production systems will be similar in their age and breed structures, and input-output relationships (Herrero et al., 2010; Mayberry et al., 2017).

The economic consequences of livestock disease vary for different production systems due to the scale, speed and intensity of production and expenditure on animal health (Jemberu et al., 2014). The ability to create global estimates of the burden of animal disease is contingent on being able to classify and describe livestock production systems in low-income countries, low- and medium-income countries and high-income countries. Thus, disease burdens can be estimated at a global level and can also be compared between the developing and developed countries. The boundaries between different livestock production systems are, however, difficult to define, as differing geospatial, agro-ecological and socio-economic scales must be considered. Previous projects have proposed a variety of classifications, but there is currently no single system that is generally accepted as the standard for livestock disease burden estimation (Franceschini et al., 2009; Robinson et al., 2014; Brock et al., 2021). Additionally, development of a transparent sub-national livestock classification system is dependent on the availability and use of fine-scale quality data to ensure that results can be communicated using locally relevant, well-defined terms. A few issues need to be addressed for defining a livestock production system. Firstly, what variables to use for classification? Secondly, what data can be used for population, values and losses estimation? Thirdly, how the existing classification can benefit a classification system for GBADs purpose?

This manuscript establishes some top-down, broad livestock production system classification frameworks which can be used as platforms from which livestock population, production, value and disease burdens can be quantified at national, regional and global levels. The authors systematically reviewed pre-existing classification systems in order to understand existing classification frameworks and to develop frameworks that are sensitive to national, regional and global complexities of livestock keeping.

The broad level classification framework was tested using existing data from international databases and the Ethiopian Central Statistics Agency (CSA) to see if there are data to support values and burden analysis using the proposed classification framework. Ethiopia was chosen because it is a case study country for GBADs, and the livestock sector is economically and socially important in the country (Food and Agriculture Organization of the United Nations, 2018). GBADs aims to estimate the values and disease burdens in local livestock production systems. The test presented in this work showed how frameworks and ontologies driven by finer-scale data are needed for livestock production system classification at sub-national levels to appropriately quantify populations, economic value and disease burden estimates and provide data on where improved animal health access is needed.

2. Methods

2.1. Scoping literature review of existing livestock production system classification methods

A structured scoping literature review was conducted to understand datasets and methods used to develop existing livestock classification systems. The review was designed using elements of the population and their problems (P), exposure (E) and outcomes or themes (O) framework (Booth et al., 2019), where the target population is the main terrestrial livestock species (cattle, sheep, goats, pigs, poultry). Exposure refers to reasons why a livestock classification would be developed (e.g., to understand the disease, assess production values or productivity indicators) and the outcome includes classifying variables describing livestock classification systems.

The review included journal articles, abstracts, books and grey literature reporting on the development or usage of livestock classification systems. The search focused on classification systems that considered livestock disease or production at any scale from global to sub-national regions. The papers/reports either published primary data or summarized existing livestock classifications. Studies were excluded if they: examined only equids, companion animals or non-livestock species; were not focused on disease risk, production values or productivity of production systems; or did not include information on the criteria used to develop classifications. Keywords and phrases defining the population, exposure and outcome, including the reasons for the development of classification systems and language describing these, were identified and developed into search strategies (see Supplementary Information, Search strategies). An initial strategy was developed for Medline accessed using the Ovid Interface, after which strategies were developed for CABI (Abstracts and Global Health), SCOPUS and Google Scholar. Search results were collated and deduplicated in Zotero, and the articles were then uploaded to the Sysrev Platform (sysrev.com, Insilica LLC) for literature screening and extraction of data from documents (Bozada Jr. et al., 2021). Sysrev uses an automated screening model which works using machine learning to prioritise human screening. It builds and then re-ranks articles for screening with every 25 articles which are manually reviewed.

Titles and abstracts were screened by reviewers. The inclusion criteria were: Targeting the species of cattle, goat, sheep, pig and chicken; Journal articles, conference abstracts and grey literature such as government reports; Disease, production value or productivity focused; Classification of global, regional or national livestock systems; Published in any language. Then, the selected papers were accessed by reading the full text with required inclusion criteria based on describing the (1) the criteria for classification, (2) focus of the classification and (3) development or use of a classification system. Articles were included in the data extraction phase if they met all three inclusion criteria.

Data extraction was undertaken in Sysrev with article details reviewed in further depth, including assessing and, where necessary, removing the recommendation for data extraction. Data extraction fields included: target species and life-stage of livestock, spatial location for classification and whether this could be used within further work, the principle used to classify the livestock, the data variables and levels included in the classification, and the statistics reported as a part of the classification, a link to the dataset. Reviewers judged if the classification criteria could be reused for classifying livestock production at subnational, national, regional or global levels.

The review summary followed the principle of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2015). Following deduplication, a total of 7434 articles were obtained from the search strategies or after manual inclusion in the review due to their known relevance to the topic (see Appendices, Search results). Of these, 1022 articles were screened for inclusion in the full text review phase (13.7% of all articles), of which 176 met the inclusion criteria. Of these, 65 articles were fully reviewed for data extraction (Fig. 1).

2.2. Proposing classification system for GBADs

Based on the results from the literature review, combined with the needs of the GBADs program, top-down, broad- level classification frameworks were proposed for ruminant and monogastric production systems by the authors. Species such as horses, camels were covered in the ruminant production classification framework given they are also herbivorous animal, and they are raised like ruminants. Similarly, pig and chicken are combined as monogastric production system as they are similar in feeding and husbandry patterns. Commonly used variables in the reviewed literature offered a pool of variables that could be used to develop the framework for classification of livestock production systems. The teams from GBADs Themes (Rushton et al., 2021) suggested variables that are relevant to these aspects of disease burden analysis: biomass, output values, disease risks, animal health ontology and wider impacts of animal health loss.

Classification of livestock production systems should be detailed enough that farms under each category of the classification are similar in their key population structure, production and performance characteristics. However, if classification of livestock production systems is too detailed, it becomes difficult to identify data to support the analysis of disease burden within the defined systems. Thus, a hierarchical structure to the classification framework was proposed, so that the level of granularity could be tailored to the population of interest and data availability.

2.3. Testing the proposed classification system framework

It was vital to test if the proposed classification framework will work for classifying livestock production systems using data from existing international and national livestock databases. In this study, FAOSTAT, WAHIS, Eurostat, Gridded livestock of the World (FAO, 1997; Ben Jebara, 2007; Gilbert et al., 2018) and the Central Statistical Agency of Ethiopia's agriculture sampling survey (ASS-Ethiopia) (Central Statistical Agency of Ethiopia, 2020) were tested to see if they support splitting livestock populations using the classification framework. Ethiopia was chosen in this study because the GBADs Ethiopia case study was the most advanced and livestock data of the country were collected by the time the work was undertaken. CSA ASS–Ethiopia database collates data from

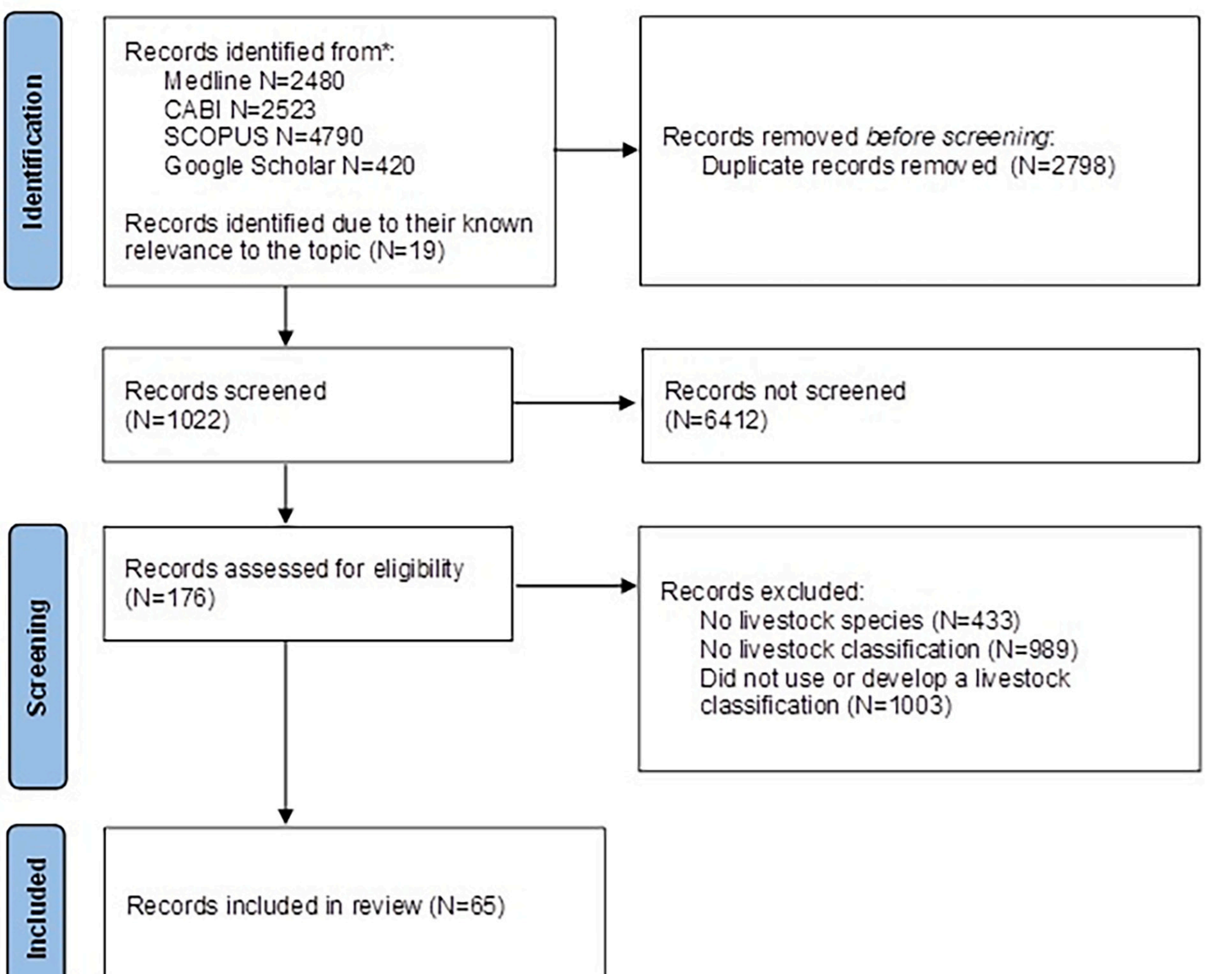

Fig. 1. PRISMA 2020 flow diagram for structure scoping review of livestock classification systems.
Note: *: duplicate records were produced when searching papers from databases using the same keywords; N is the number of papers identified.

the most comprehensive agriculture survey in the country and is believed to be the most reliable source of official livestock statistics at the national level. Cattle and chicken were used as test species for the classification frameworks for ruminants and monogastric animals. Data availability for live bodyweight, productivity, inputs, prices of live animal and their products and disease occurrence were accessed to see if they would support disease burden analysis using the proposed classification framework. These data were checked to see if they are available for system-specific analysis. For example, if burden analysis will be conducted for dairy and beef cattle production systems (by production purpose), there should be dairy-specific and beef-specific data on live weight, productivity, disease incidence etc. The two species were chosen as they are the most common ruminant and monogastric animals and there is abundant data available describing them from different sources. The data of live bodyweight, productivity, inputs, prices of live animal and their products and disease occurrence were checked because these are needed for estimating livestock biomass, values and losses.

3. Results

3.1. Scoping review

Sixty-five articles were included in data extraction. Most were journal articles (85%), with the remainder being book chapters, grey literature and conference abstracts (Appendix 1, Table 1). Twenty-one (32%) articles developed a classification for livestock production, whilst the remainder reported using previously published livestock classification systems within their work.

Ruminants were the focus of most articles describing classification systems with cattle described most commonly (32 papers), followed by sheep (18 papers) chickens (17 papers) and an additional 23 papers that targeted multiple species.

>80% of the articles introduced a classification system for national or sub-national analysis; global systems were less commonly described ($n = 3$, 5%) (Appendix 1, Table 2). Approximately 80% of the proposed national and sub-national pre-existing classification systems could potentially be reused for classifying livestock production systems at the same level, and a third (32%) of the global systems could be reused for classifying livestock production at a global level (Appendix 1, Table 3).

3.2. Characteristics of classification systems

Nine out of 65 papers used statistical analysis exclusively on farm-level data to classify livestock farms into different production groups. Statistical methods included: K-mean cluster analysis, multinomial logistic regression analysis, multivariate analysis, principal component analysis, multiple correspondence analysis, hierarchical ascending classification and hierarchical cluster analysis. Farm data used for analysis include ownership, livestock species, herd size, husbandry practices etc. Four of 65 papers used expert judgement to split farms into different categories. Farm characteristics that were used to classify livestock production included: production purpose, housing infrastructure, herd size, and management practices (Table 1). Three papers used more than one method to classify livestock production systems.

For ruminant and monogastric species, different variables were used to define categories within production systems. For monogastric animals, these included production purpose, herd size, disease risk and housing type (Table 2). For ruminant production (cattle, sheep and goat), the most used variables were production purpose, husbandry practices, agro-ecological condition, herd size, breed, and productivity (Table 3).

In 37 out of 62 articles (60%), livestock holdings were split into groups described in pre-existing livestock classification systems based on an overarching characteristic, such as production purpose, herd size, or breed. These characteristics often are proxies for a range of other data, for example "breed" indicates a range of production performance characteristics. Twenty-five articles used multiple variables to define production system classifications using a "decision-tree" structure. In 19 articles a hierarchy of two levels was used and 6 articles used 3 or 4 levels within their decision-tree structure.

3.3. The datasets and spatial resolutions of pre-existing classification systems

Datasets from multiple different sources were used to classify livestock production systems. Sources include estimates provided by international organisations, national government databases, published literature, geospatial layers, household surveys and livestock censuses. For global and regional livestock classifications, data provided by international organisations and the published literature were the mostly frequently used source (Table 4). For national and sub-national classifications, data from surveys and national databases were the frequently used source (Table 5).

Household survey data were predominantly used for classification of livestock production at national and sub-national level. Databases used to establish livestock classification systems include FAOSTAT, the FAO's Gridded Livestock of the World, The Livestock Marketing Information Centre, the Australian Bureau of Agricultural and Resource Economics and Sciences, the Australian Bureau of Statistics (2020), and the Agriculture and Australian Lot Feeders Association (Vigre et al., 2016; Shapiro et al., 2017; Food and Agriculture Organization of the United Nations, 2018; van Hal et al., 2019; Thompson et al., 2020; Fordyce et al., 2021) (Appendix 1, Table 4).

3.4. Proposed classification system for GBADs

Classification frameworks were proposed for ruminant (Table 6) and monogastric (Table 7) production systems. The classification framework for ruminants and monogastric are overlapped in the three levels of 1) species 2) production purpose 3) herd size, with the further classification levels used to address the different issues of interest such as level of confinement, level of intensification and ecological land-use.

Table 1
Classification principles used and the percentage of each within reviewed livestock classification studies.

Principle used	Count	Percentage (%)*
Statistical analysis using farm characteristics data	9	35
Expert judgement	4	15
Production purpose	3	12
Housing infrastructure	3	12
Agro-ecological conditions	2	8
Herd size	2	8
Species	1	4
Management	1	4
Productivity	1	4

* Some papers used more than one data source, so the total exceeds 100%.

Table 2
Variables used in chicken and pig classifications, including the percentage of each within reviewed livestock classification studies.

Variable	Count	Percentage (%)*
Production purpose	4	27
Herd size	4	27
Disease risk	3	20
Housing	3	20
Husbandry practices	2	13
Agro-ecological condition	1	7
Confinement	1	7
Integration	1	7
Intensiveness	1	7

* Some papers used more than one data source so the total exceeds 100%.

Table 3
Variables used in ruminant classifications, including the percentage of each within reviewed livestock classification studies.

Variable	Count	Percentage (%)*
Production purpose	9	36
Husbandry practices	7	28
Agro-ecological condition	6	24
Breed	4	16
Herd size	4	16
Productivity	4	16
Economic character	2	8
Interaction between livestock and crops	1	4
Geographic location	1	4
Intensiveness	1	4
Ownership	1	4

* Some papers used more than one data source so the total exceeds 100%.

Table 4
Data sources used to develop global and regional livestock classification systems. Note, some papers used more than one data source so the total exceeds 100%.

Data source	Count	Percentage (%)*
Data from international organization	5	71
Published literature	5	71
Government database	2	29
Census	1	14
Geospatial layers	1	14

* Some papers used more than one data source so the total exceeds 100%.

Table 5
Data sources used to develop national and sub-national livestock classification systems.

Data source	Count	Percentage (%)*
Survey	18	69
National database	4	15
Published literature	3	12
Expert opinion	2	8
Data from international organization	1	4
Modelling data	1	4
Experimental study	1	4
Census	1	4

* Some papers used more than one data source so the total exceeds 100%.

3.4.1. *Classification system for ruminants and others (cattle, sheep, goats, horses, camels)*

The proposed variables for ruminant and other herbivorous animals include species, production purpose, herd size, breed and land-use, and ecological zones (see Table 6).

3.4.2. *Classification system for monogastric livestock (pigs and chickens)*

The proposed variables for monogastric animals include species, production purpose, level of integration, enterprise and level of confinement (see Table 7).

3.5. *Using existing data sources from international databases and Ethiopian central statistics agency to test the proposed livestock system classification framework*

All data sources explored supported population classification by species and some data sources could be used to support population classification to increasing levels of granularity. Ethiopian livestock central statistics agency (CSA) data included some information on livestock biomass, productivity, inputs and prices of livestock and their outputs whereas the international databases accessed had limited data on these variables (see Tables 8 and 9).

4. Discussion and conclusion

The aim of the GBADs programme is to offer evidence-based methods to estimate the impacts of livestock disease burden and the wider socio-economic impacts of the burden to different stakeholders in society. To support the methodology, a classification of livestock production systems is required so socio-economic burdens can be analysed by production system, including the livestock within the system and the people who are reliant on these livestock for their livelihoods. The classification framework should offer enough granularity so farms within one category have high similarity in the productivity but should also be simple enough, so it is not too challenging to get population, productivity, mortality and price values for each proposed category. The classification framework should also be adoptable by government and industry stakeholders, who would be the principal users of GBADs. The variables used to classify livestock production systems should therefore be in line with the variables being used by government and industry stakeholders to characterize livestock farms.

While the systematic review revealed a diversity of different livestock classification systems, none were considered suitable for application in the GBADs programme. Pre-existing livestock production system classifications used various classification principals because they had different objectives and needs. For example, target topics of the pre-existing classifications included: livelihood, disease control, greenhouse gas emissions, food security, environmental impacts and poverty (Kuit et al., 1986; Thornton et al., 2002; Moges et al., 2010; Robinson et al., 2011; Shaw et al., 2014; Vergne et al., 2016; Ibidhi and Ben Salem, 2019; Toro-Mujica et al., 2019; Yan et al., 2019). The differences between the aims of GBADs and pre-existing projects was considered when choosing variables from pre-existing classification systems to establish the top-down classification framework and irrelevant variables were not included.

Many pre-existing classification methods used statistical analysis (see Section 3.2) methods on farm-level survey data to classify production systems. Although these classifications were more detailed, locally relevant and useful for making finer level sub-national estimates, these were not suitable for analysis at global or national level as the data required to inform this classification process is not currently available in large scale global data sets. To support establishing animal health policies, systematic and continual collection of data on livestock population, productivity, values of inputs and outputs, and health status is needed to estimate and attribute livestock health losses.

A lack of clear definitions or inconsistent definitions of variables between studies was also observed. For example, the definitions of the backyard and small-scale farms were not specified in a study that used pig farm categories in Russia (Vergne et al., 2016) and another study on village-chicken production documented that it was challenging to define a farm that belongs to the system (Tabbaa and Hassanin, 2017). More detailed ontologies are required to ensure less confusion in future development of more detailed classification frameworks.

Given the results from our literature review and search of global livestock databases, we propose a hierarchical classification framework that can be used at a broad level (national, regional, global) as it offers flexibility when estimating biomass, value and disease burdens of livestock production. We present the classification framework separately for ruminants and monogastric animals due to the use of different variables in pre-existing classifications, however, they share many variables, such as species, production purpose and herd size. These variables can be used as a basic level of classification, and different characteristics could be included when there is data to support the more detailed classification. In addition, it may not be possible to classify livestock production systems using all the classification levels due to data gaps. For example, there are no clear definitions of cattle herd size categories and native/exotic breeds in the official Ethiopian livestock statistics, so it is challenging to split the population further into more detailed subgroups using the broad framework. It is also difficult to analyse each of the

Table 6
Proposed classification system for ruminant-plus production systems.

Levels	Name of level	Categories*	Explanations	Would this level impact the following aspects of disease burden analysis						
				Biomass	Type of outputs	Productivity of an output	Price of livestock and their products	Animal health inputs	Disease risk	Who will be impacted in a society
1	Species	Cattle Sheep Goats Horses Camels Deer		Yes. In general, different species will have different live body weight (Herrero et al., 2013)	Yes. Different species will have different outputs	Yes	Yes	Yes	Yes	Yes
2	Primary production purpose	Milk Meat Dual purpose animals Draught Wool/fibre Replacement stock	Dual purpose animals: an animal breed that provide at least 2 kinds of resources, such as meat and milk (for cattle) or wool (for sheep) Draught: domesticated animal used to pull heavy loads Replacement stock: livestock breeders that offer young livestock to other farms	Yes. Individuals of a species with different production purposes would have different body conditions.	Yes	Yes	Yes	Yes	Yes. For example, dairy cattle are more likely to have different diseases comparing to beef cattle (Aleri et al., 2021).	Yes. Value chain of different commodities would be different.
3	Herd size	Small Medium Large	Definition of categories of herd size can vary in places.	Maybe	No	Maybe	Maybe	Yes. Small farms are often using less veterinary service (Richert et al., 2013).	Yes. Herd size are often associated with disease risks (Shuaib et al., 2010).	Yes. Small farms are often owned by farmers, while large commercial farms are often owned by companies.
4	Breed	*Bos Taurus, Bos indicus* etc. (See FAO database: Domestic Animal Diversity Information System - DAD-IS)		Yes. Livestock of different breeds would have different average live body weights (Duguma, 2020).	Yes	Yes. Farms with different breeds of a species will have different productivity (Duguma, 2020).	Maybe. Cattle s of different breeds would have different prices (Traore et al., 2017).	Maybe	Different breeds would resistance to different diseases and health problems such as tuberculosis and heat stress (Vordermeier et al., 2012; Bayssa et al., 2021)	Maybe
5	Land-use and ecological zone**	LS LMS LGA LGH LGT MRA MRH MRT	LS: Landless systems in high population density areas LMS: Landless metropolitan systems, high population density areas with significant urban infrastructure LGA: Livestock only, rangeland-based (grazing) arid/	Maybe	Yes. Ruminant farms of different land-use and ecological zones would have different outputs.	Yes. Ruminant farms of different land-use and ecological zones would have different productivity.	Maybe	Yes. Ruminant farms of different land-use and ecological zones would have different veterinary accessibility.	Yes. Ruminant farms of different ecological zones would have different disease risks.	Yes. The owners of the ruminant farms of different land-use and ecological zones are different (e.g. Pastoralist, crop farmers and feedlot owners).

(*continued on next page*)

Table 6 (*continued*)

Levels	Name of level	Categories*	Explanations	Would this level impact the following aspects of disease burden analysis						
				Biomass	Type of outputs	Productivity of an output	Price of livestock and their products	Animal health inputs	Disease risk	Who will be impacted in a society
			semi-arid LGH: Livestock only, rangeland-based (grazing) humid/sub-humid LGT: Livestock only, rangeland-based (grazing) temperate/highland MRA: Mixed rainfed arid/semi-arid MRH: Mixed rainfed humid/sub-humid MRT: Mixed rainfed temperate/highland							

* Order of categories is not fixed. The levels are not necessarily in a strict hierarchical order, given categories in some levels would be highly associated with each other. For example, dual purpose cattle in Ethiopia are always native breed.

** Land use and ecological zones described by Robinson et al. (2011) will be used for global analysis and can be aggregated to align with local classifications and available data.

defined production systems in detail due to a lack of data for some. For example, specialized farms contribute <2% of the cattle population in Ethiopia, and there were no official statistics on the cattle population and productivity of this system.

Different sources of livestock data may support animal health loss analysis by production system with different levels of granularity. For example, in the global livestock database FAOSTAT, livestock populations were recorded by species or groups of species so the size of populations for different production purposes, such as dairy and beef (cattle) or layer and broiler (chicken), were unknown. In contrast, Eurostat data split the livestock population into production purpose categories. Although broadly, the top-down classification framework can divide livestock populations into some level of production system granularity using global datasets, there are data gaps in live weights, productivity and values that will challenge animal health loss analysis at these levels. Thus, production system -specific parameters would need to be estimated using other data sources such as literature, national level censuses and statistical agency data, and expert elicitation. It worth noting that the availability of subnational data describing livestock bodyweights, inputs/outputs and health were not covered in the test. However, the availability of more detailed population and production data within sub-national databases would meet the need for locally relevant classification frameworks, and thus the need for data collection at sub-national levels to inform the future building of these frameworks and ontologies. It is also worth noting that the evolution of livestock statistics in databases through ongoing, streamlined national-level data collection processes by international organisations provides an opportunity to solve this data gap problem.

Further work is required to enhance the proposed top-down classification framework and develop a framework that is informed by real data that can be used to classify production systems at sub-national levels and provide meaningful, stratified estimates of within country disease burden. The definitions of terms and categories used in classification frameworks should be established more systematically through development of livestock system classification ontologies.

The frameworks developed in this study need to be tested for other species and countries and the occurrence of health hazards in the classified production systems need to be assessed using available data. We would like to work with animal health database holders (WAHIS, EMPRES-i and Animal Disease Information System of EU) to see if existing animal health datasets will support disease burden analysis by proposed broad-level production system classes. Currently these animal health databases only provide disease data by species, but this could be further disaggregated in future if GBADs programme methods and outputs are to be used internationally. Additionally, only data for infectious diseases are available in these international databases and GBADs plans to incorporate losses from non-infectious diseases and external causes, thus we continue to advocate for collection of all livestock health data, not only infectious disease data. Finally, the evolution of livestock production systems implies that new categories in the classification framework may need to be considered in the future.

Ethics statement

The study was reviewed and approved by CSIRO.

Author contributions

DM, MA, BH and JR contributed to the conceptualization and supervision. YL contributed to the conceptualization and Methodology, formal analysis and writing of the original draft of the manuscript. KM contributed to the methodolgy and writing of the original draft of the manuscript. YL, KM, PR, WG, GC, KR, WJ, AL, GP, SK, AK, MJ, DS contributed data curation, investigation, validation and visualization. DM, WG, EMK, MB, TJ and PS contributed to writing-review & editing. All authors have read and approved the submitted version of the

Table 7
Proposed classification system for classification system for monogastric livestock.

Levels	Name of level	Categories*	Explanations	Would this level impact the following aspects of disease burden analysis						
				Biomass	Type of outputs	Productivity of an output	Price of livestock and their products	Animal health inputs	Disease risk	Who will be impacted in a society
1	Species	Chicken Pig		Yes. Different species will have different live body weight (Herrero et al., 2013)	Yes. Different species will have different outputs	Yes	Yes	Yes	Yes	Yes
2	Breed and production purpose	Eggs Meat Dual-purpose Replacement animals	Replacement animals: breeding farms where the main purpose is to produce fertilised eggs or day-old chicks for distribution to other producers It is assumed that breeds align with specific production purposes, e.g., commercially-orientated meat and egg birds will be specific pure lines or intentional crosses.	Yes. Individuals of a species with different production purposes would have different body conditions (Mueller et al., 2018; Martins et al., 2020).	Yes	Yes	Yes	Yes	Yes. For example, chicken or pig of different breeds have different susceptibility to diseases and climate conditions (Kalantan et al., 1991; Le Dividich et al., 1991).	Yes. Value chain of different commodities would be different.
3	Level of integration	Integrated Non-integrated	Integration is considered as the breeding, growing, processing and provision of inputs (e.g., feed milling) all are coordinated by the same business. In some cases, it can be used to describe “coordination” or contractual agreement to supply	Maybe	No	Maybe	Maybe	Yes. Integrated farms may have a higher input on biosecurity (Komaladara et al., 2018; Indrawan et al., 2020).	Yes. Integrated farms may have different disease risks than the non-integrated farms.	Yes. The supply chain of the contracted farms would be different from the non-contracted farms (Setiadi et al., 2022).
4	Enterprise	Informal market Small commercial Large commercial	This level incorporates comments around infrastructure, flock size, and also markets. Informal market: poultry raised in systems where the main purpose is home or local consumption, or where stocks are kept for social/cultural purposes. This could include backyard poultry in high-income countries where poultry are often pets that sometimes lay eggs. Small	Maybe	No	Maybe	Yes	Maybe	Maybe	Yes. The value Chains of the animal products are different.

(continued on next page)

Table 7 (*continued*)

Levels	Name of level	Categories*	Explanations	Would this level impact the following aspects of disease burden analysis						
				Biomass	Type of outputs	Productivity of an output	Price of livestock and their products	Animal health inputs	Disease risk	Who will be impacted in a society
			commercial: commercial farm with a small flock of chicken. More likely to be owner-operated and more basic technology. Large commercial: commercial farm with a large flock of chicken, more likely to be employee-operated and latest technology.							
5	Level of confinement	Small cages/pens Colony (large) cages/pens Barn reared Free range (housed with free access to range) Not housed	Small cages/pens: farms with small cages/pens for poultry/pigs without environment control Colony cages/pens are pens or stacked cages in rows inside environmentally controlled, windowless sheds Barn reared: pigs/poultry are housed indoors but not in caged/pen systems, and they can't access a range Free range: pigs/poultry are housed with free access to range Non-house: backyard scavenging poultry/pigs	Maybe	Maybe	Yes. For example, free range layers would have different laying rate than caged layers (Wang et al., 2009).	Yes. For example, free range eggs would have different price than eggs from caged chicken.	Yes.	Yes. Caged chicken would have different disease risks comparing to free range chicken (Denagamage et al., 2015).	Yes. The owners of the farms of different level of confinement are different (e.g. farmers and professional pig/chicken farm owners).

Table 8
Availability of data from different data sources for classifying cattle production systems.

Data sources	Population data for the proposed classification framework	Levels by which the population can be split*	Live body weight data	Data on productivity	Inputs such as feed, housing and vet cost	Data on livestock & products prices	Disease surveillance data
FAOSTAT	Yes	1	Not available but can be extrapolated**	Not available but can be extrapolated	Not available	Available	Not available
WAHIS	Yes	1,2	Not available	Not available	Not available	Not available	Available
Eurostat	Yes	1,2,3	Not available	Available	Not available	Partly available	Not available
Gridded livestock density layer	Yes	1, 5	Not available	Not available	Not available	Not available	Not available
ASS-Ethiopia	Yes	1, 2, 3, 4	Not available	Partly available	Partly Available	Not available	Not available

* The numbers in this column refer to the levels in Table 6.
** The live bodyweight can be extrapolated using the total meat output and number of production animal in a country. More details can be found in the literature (Gochez et al., 2019).

Table 9
Data from different data sources for classifying chicken production systems.

Data sources	Population data for proposed classification framework	Levels by which the population can be split *	Live body weight data	Productivity data	Inputs such as feed, housing and vet cost	Data on livestock & products prices	Disease surveillance data
FAOSTAT	Yes	1	Not available but can be extrapolated	Not available but can be extrapolated	Not available	Available	Not available
WAHIS	Yes	1, 2	Not available	Not available	Not available	Not available	Available
Eurostat	Yes	1, 2	Available	Available	Not available	Partly available	Not available
Gridded livestock density layer	Yes	1	Not available	Not available	Not available	Not available	Not available
ASS-Ethiopia	Yes	1, 2	Not available	Partly available	Available	Not available	Not available

[*] The numbers in this column refer to the levels in Table 6.

manuscript.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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A full list of the members of the GBADs themes can be accessed here: www.animalhealthmetrics.org/acknowledgements.

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Appendix

List of contents

1. Literature review method
2. Additional analysis results of the literature review

1. Literature review method

Search strategies

MEDLINE(R) via Ovid interface. Searches were undertaken for literature published between January 01, 1946 and July 08, 2021.

1. livestock.tw. 27,822.
2. cattle.tw. or Cattle/ or zebu.tw. or bovine.tw. 438,210.
3. goats.mp. or Goats/ 37,784.
4. sheep.mp. or Sheep/ or Sheep, Domestic/ 146,715.
5. pig.mp. or Swine/ or swine.mp. 311,457.
6. Chickens/ or chicken*.mp. or poultry.mp. or Poultry/ 197,059.
7. Goats/ or Sheep/ or small ruminant*.mp. 142,844.
8. ruminant*.tw. or Ruminants/ 22,210.
9. *Livestock/ 2022.
10. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 1,056,200.
11. (agriculture or farm* or rearing or production or husbandry or industry).tw. 1,237,922.
12. 10 and 11 132,579.
13. zoonoses.mp. or Zoonoses/ 20,920.
14. Animal Husbandry/ or husbandry practice$.mp. 22,203.
15. 12 or 13 or 14 164,385.
16. diseases.tw. 1,082,517.
17. Disease Eradication/ or Disease Outbreaks/ or control strateg*.tw. 107,895.
18. Economics/ or economic.tw. or monetary.tw. or non-monetary.tw. 262,433.
19. benefit*.mp. or Cost-Benefit Analysis/ 828,625.

20. biomass.mp. or "land use".tw. or Policy Making/ or policy.tw. or Environmental Policy/ or Public Policy/ or Health Policy/ or Policy/ 381,401.
21. Environmental Monitoring/ or Risk Assessment/ or environmental risk*.tw. or Environment/ or "environmental impac*".mp. or geograph*.tw. or environment*.tw. 1,597,358.
22. "carrying capacity".tw. or "Conservation of Natural Resources"/ or population projection*.tw. or Population Growth/ or Population Dynamics/ 100,439.
23. ("off take" or offtake).mp. 136.
24. Animal Feed/ or "feed resource*".tw. or "land requirement*".tw. or "land use".tw. or landuse.tw. 68,651.
25. (production system* or production sector*).mp. 8577.
26. Crops, Agricultural/ or Agriculture/ or agricultural system$.mp. 57,890.
27. "land tenure".tw. 246.
28. Animal Distribution/ or distribution.mp. 1,167,914.
29. "crop-livestock".mp. 177.
30. 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 4,872,654.
31. 15 and 30 63,389.
32. (classification or classify* or typology or map or maps or mapping or information system* or dataset*).tw. 904,392.
33. ("agglomeration index" or grid*).mp. 30,244.
34. 32 or 33 930,130.
35. 31 and 34 2478.
36. ("Gridded Livestock of the World" or "Livestock Geo-Wiki" or "GLW dataset" or "Global Livestock Impact Mapping System").mp. 7.
37. 35 or 36 2480.

CABI (abstracts and global health). ((((agglomeration index OR grid*) OR (classification OR classify* OR typology OR map OR maps OR mapping OR information system* OR dataset*)) AND (((land requirement* OR land use OR landuse OR production system* OR production sector* OR agricultural system* OR land tenure OR distribution OR crop-livestock) OR (animal feed OR feed resource*) OR (off take OR offtake) OR (population projection* OR population growth OR population dynamics) OR (carrying capacity) OR (environmental monitoring OR risk Assessment OR environmental risk* OR environment OR environmental impac* OR geograph* OR environment*) OR (policy making OR policy) OR (biomass OR land use) OR ((economic* OR monetary OR non-monetary OR benefit* OR Cost-benefit Analysis)) OR (disease*) OR ((disease eradication OR disease outbreak* OR control strategy*))) AND (((animal husbandry) or (husbandry practice*)) OR (zoonos* or zoonoses) OR ((agriculture OR farm* OR rearing OR production OR husbandry OR industry) AND (subject:(livestock or cattle OR zebu OR bovine OR goat* OR sheep OR small ruminant* OR ruminant* OR pig* OR swine OR chicken* OR ruminant* OR *livestock)))))) OR (((Global Livestock Impact Mapping System) OR (GLW dataset) OR (Livestock Geo-Wiki) OR (Gridded Livestock of the World)))) AND (yr:[1946 TO 2021])

Scopus. (((((TITLE-ABS-KEY(livestock OR cattle OR zebu OR bovine OR goat* OR sheep OR small AND ruminant* OR ruminant* OR pig* OR swine OR chicken* OR ruminant* OR *livestock)) AND (TITLE-ABS-KEY(agriculture OR farm* OR rearing OR production OR husbandry OR industry))) OR (TITLE-ABS-KEY((zoonos* or zoonoses))) OR (TITLE-ABS-KEY((animal husbandry) or (husbandry practice*)))) AND ((TITLE-ABS-KEY(land requirement* OR land use OR landuse OR production system* OR production sector* OR agricultural system* OR land tenure OR distribution OR crop-livestock)) OR (TITLE-ABS-KEY(animal feed OR feed resource*)) OR (TITLE-ABS-KEY(off take OR offtake)) OR (TITLE-ABS-KEY(population projection* OR population growth OR population dynamics)) OR (TITLE-ABS-KEY(carrying capacity)) OR (TITLE-ABS-KEY(environmental monitoring OR risk Assessment OR environmental risk* OR environment OR environmental impac* OR geograph* OR environment*)) OR (TITLE-ABS-KEY(policy making OR policy)) OR (TITLE-ABS-KEY(biomass OR land use)) OR (TITLE-ABS-KEY(economic* OR monetary OR non-monetary OR benefit* OR Cost-benefit Analysis)) OR (TITLE-ABS-KEY(disease*)) OR (TITLE-ABS-KEY(disease eradication OR disease outbreak* OR control strategy*)))) AND ((TITLE-ABS-KEY(classification OR classify* OR typology OR map OR maps OR mapping OR information system* OR dataset*)) OR (TITLE-ABS-KEY (agglomeration index OR grid*)))) OR ((TITLE-ABS-KEY(Global Livestock Impact Mapping System)) OR (TITLE-ABS-KEY(GLW dataset)) OR (TITLE-ABS-KEY(Livestock Geo-Wiki)) OR (TITLE-ABS-KEY(Gridded Livestock of the World))) AND (LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"VETE") OR LIMIT-TO (SUBJAREA,"BIOC") OR LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"ECON") OR LIMIT-TO (SUBJAREA,"MULT") OR LIMIT-TO (SUBJAREA,"COMP") OR LIMIT-TO (SUBJAREA,"DECI") OR LIMIT-TO (SUBJAREA,"HEAL") OR LIMIT-TO (SUBJAREA,"Undefined") OR LIMIT-TO (SUBJAREA,"MATH")) AND (EXCLUDE (PUBYEAR,1931)) (and using date restrictions (AND PUBYEAR >2016), (AND PUBYEAR >2010 AND PUBYEAR <2017), (AND PUBYEAR <2011 AND (EXCLUDE (PUBYEAR,1931) to limit the results to under 2000 for downloading).

Google scholar. Searches were undertaken for literature published between 1946 and 2021. Three searches were undertaken (clearing search history and Cookies in-between) and sorted by relevance with the first 140 references obtained from each. Search results were imported into Endnote then exported to Mendeley:

1. In the google search bar: classification livestock typology OR map OR classify OR mapping OR economic OR biomass OR production OR system OR policy OR cattle OR zoonoses OR land OR use OR tenure OR distribution OR economic.
2. In the google search bar: livestock classification OR typology OR map OR classify OR mapping OR economic OR biomass OR production OR system OR policy OR cattle OR zoonoses OR land OR use OR tenure OR distribution OR economic.
3. In the google search bar: classify livestock typology OR map OR classify OR mapping OR economic OR biomass OR production OR system OR policy OR cattle OR zoonoses OR land OR use OR tenure OR distribution OR economic.

Search results

- OVID Medline $N = 2480$ – deduplicated $N = 2474$;

- CABI (Abstracts and Global Health) – $N = 2523$;
  - o Deduplicated OVID and CABI searches $N = 4816$;
- SCOPUS $N = 4790$;
  - o Deduplicated OVID, CABI and SCOPUS searches $N = 7152$;
- Google Scholar - Took first 140 references (sorted by relevance) from each, then deduplicated. Imported into Endnote then exported $N = 397$ (once deduplicated in Endnote) to Mendeley using an Endnote XML file;
  - o Deduplicated for all sources $N = 7434$.

Data extraction items

Data Extraction were conducted in 2 sifts. In the sift one, reviewers extracted the following basic information:

- What were the livestock species covered?
- classification focus: production value, productivity, disease or no livestock classification?
- Does the study use, develop or not use livestock classification?
- What types of publication it is: Journal article, conference abstracts, grey literature, book/book chapter?

Then the reviewers would decide if the paper should be further checked in sift two. The paper included in sift two were reviewed by reading the full text. The following additional information were extracted:

- What was the scale of the classification: sub-national, national, regional or global?
- What were the classification principles in the study?
- What were the classification variables used?
- What data sources were used to support the livestock production classification?

2. Additional analysis results of the LR

Table 1
Counts and proportions of articles included in data extraction to describe published livestock classification systems.

Type of article	Count of articles	Proportion of total included papers
Book/book chapter	4	6%
Conference abstracts	2	3%
Grey literature	4	6%
Journal article	55	85%

Table 2
Counts and proportions of articles that described classification systems at different scales.

	Count	Proportion
Global	3	5%
Regional	7	11%
National	15	23%
Sub-national	38	58%
No geographical foci	7	11%

Table 3
Counts and proportions of articles that could be used for classification systems at different scales.

	Count	Proportion
Global	21	32%
Regional	29	45%
National	53	82%
Sub-national	52	80%

Table 4
The open databases and links for establishing pre-existing livestock classification systems described in the literature review.

Databases and links	Article
Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (2020) Farm survey data for the beef, slaughter lambs and sheep industries; Australian Bureau of Statistics (ABS) (2020) Agriculture; Australian Lot Feeders Association (ALFA). Available at: https://www.agriculture.gov.au/abares/research-topics/surveys/farm-survey-data;https://www.abs.gov.au/statistics/industry/agriculture; Available at https://www.feedlots.com.au/figures	Fordyce et al. (2021)
Livestock Marketing Information Center. Available at: https://lmic.info/	Thompson et al. (2020)
LSMS database. Available at: https://datacatalog.worldbank.org/search?q = ethiopia%20socioeconomic%20survey%202,018%202,019;	Shapiro et al. (2017)
FAO Gridded Livestock of the World: https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1236449/	Food and Agriculture Organization of the United Nations (2018)
FAOSTAT. Consumption, Livestock and Fish Primary Equivalent (5). Available at: http://faostat.fao.org/site/610/	Vigre et al. (2016); van Hal et al. (2019)

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