Animal (2018), **12:8**, pp 1699–1708 © The Animal Consortium 2018
doi:10.1017/S1751731118000630

animal

Review: Animal health and sustainable global livestock systems

B. D. Perry[1†], T. P. Robinson[2,3] and D. C. Grace[2]

[1]*Nuffield Department of Clinical Medicine, Jenner Institute, University of Oxford, P.O. Box 437, Gilgil 20116, Kenya;* [2]*International Livestock Research Institute (ILRI), P.O. Box 30709, Nairobi 00100, Kenya;* [3]*Food and Agriculture Organisation of the United Nations, Viale delle Terme di Caracalla, 00153 Roma, Italy*

(Received 4 March 2017; Accepted 27 February 2018; First published online 10 April 2018)

This paper discusses the sustainability of livestock systems, emphasising bidirectional relations with animal health. We review conventional and contrarian thinking on sustainability and argue that in the most common approaches to understanding sustainability, health aspects have been under-examined. Literature review reveals deep concerns over the sustainability of livestock systems; we recognise that interventions are required to shift to more sustainable trajectories, and explore approaches to prioritising in different systems, focusing on interventions that lead to better health. A previously proposed three-tiered categorisation of 'hot spots', 'cold spots' and 'worried well' animal health trajectories provides a mental model that, by taking into consideration the different animal health status, animal health risks, service response needs and key drivers in each system, can help identify and implement interventions. Combining sustainability concepts with animal health trajectories allows for a richer analysis, and we apply this to three case studies drawn from North Africa and the Middle East; Bangladesh; and the Eastern Cape of South Africa. We conclude that the quest for sustainability of livestock production systems from the perspective of human and animal health is elusive and difficult to reconcile with the massive anticipated growth in demand for livestock products, mainly in low- and middle-income countries, as well as the aspirations of poor livestock keepers for better lives. Nevertheless, improving the health of livestock can contribute to health sustainability both through reducing negative health impacts of livestock and increasing efficiency of production. However, the choice of the most appropriate options must be under-pinned by an understanding of agro-ecology, economy and values. We argue that a new pillar of One Health should be added to the three traditional sustainability pillars of economics, society and environment when addressing livestock systems.

Keywords: livestock, One Health, sustainability, development, complexity

Implications

Considerations of sustainability are central to development discourse. Within the context of sustainable agriculture, the subsector of livestock presents particular challenges and opportunities, with contrasting systems in industrialised and low- and middle-income countries (LMICs), and substantially different needs even within any one country. The paper summarises orthodox and heterodox thinking on the sustainability of livestock systems, and identifies health sustainability as an under-examined aspect. It illustrates the diversity of production systems and their animal health requirements with three case studies taken from different regions of the world. The paper concludes that the quest for sustainability of livestock production systems from the perspective of human and animal health is elusive but interventions to improve livestock health can have at least short-term benefits.

† E-mail: prof.brianperry@gmail.com

Introduction

This paper explores sustainability with reference to livestock systems, reviews the threats to, and opportunities for, sustainability, and introduces the concept of including One Health as a supplement to the traditional three sustainability pillars of economics, society and environment when addressing livestock. Three case studies, drawn from recent experiences of the authors, provide concrete illustrations of concepts discussed using a novel analytical framework that includes sustainability and health trajectory thinking.

Sustainability is complex. Brought into widespread use as 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' by the Brundtland Commission (World Commission on Environment and Development, 1987), understanding of sustainability has continued to evolve and be applied to different domains. In agriculture, sustainability frameworks usually have three components, or pillars, namely enhance environmental quality, sustain the economic

viability of agriculture and enhance the quality of life for society. These are also adumbrated in the most recent expression of sustainability, manifest in the 2030 Agenda for Sustainable Development launched in January 2016, which aims to end poverty, protect the planet and ensure peace and prosperity for all (UN, 2016).

Motivation for this paper

- The issue to be addressed: the inadequacies of the three pillars of sustainability when considering livestock systems
- The response proposed: the inclusion of One Health as a pillar of the sustainability concept when dealing with global livestock systems

Landmark studies of sustainability in livestock systems

Livestock systems have been a major concern for sustainability science, and for good reason. They occupy 30% of the land's ice-free surface and contribute to the livelihoods of billions of people (Herrero *et al*., 2014). At the same time, livestock are responsible for around 14% of global anthropogenic greenhouse gases, consume land and water resources otherwise available to people and are a major source of land, air and water pollution. Concerns over environmental impacts were an important driver of significant reviews of sustainability of the livestock sector.

Perhaps the most comprehensive of these was 'Livestock in the Balance' (FAO, 2009). The study covers livestock with respect to climate change, water use, land degradation, pollution and biodiversity, focusing on negative impacts. It concluded that the sector is expanding rapidly, driven by population growth, rising affluence and urbanisation, and decisive action is required if this increasing demand is to be met in ways that are environmentally sustainable.

Another key synthesis of the global challenges facing livestock systems is the White Paper commissioned by the International Science and Partnership Council on the drivers of global livestock research (Perry *et al*., 2014), and the responses to this from the Consultative Group for International Agricultural Research. As well as the issues raised in 'Livestock in the Balance', this document cited poor feed efficiency in livestock systems, the need for greater attention to natural resource management (including the water footprint of livestock), effluent pollution, the vulnerability of pastoral and dryland systems, the weakness of gender awareness and socially inclusive approaches, the inadequacies of animal health service delivery, and the weakness in translating research outputs to development outcomes.

Regarding the sustainability of livestock systems in Africa, Herrero *et al*. (2014) painted a very bleak picture of the enormous gaps between current livestock productivity in countries of the continent, and the future demands in animal source food consumption to 2050. The study predicted a huge deficit between demand and supply of animal source foods, and a dramatic shift to species (particularly poultry and pigs) in which the continent has not previously held a comparative advantage.

A recent United Nations High Level Panel of Experts report considered the role of livestock in sustainable agricultural development (HLPE, 2016). This report acknowledged the diversity of livestock systems and the need for context specific pathways. It took as inevitable the rapidly increasing demand for livestock products in LMICs and increases in global and regional livestock trade. Reducing greenhouse gases, improving employment conditions, better understanding of the role of women, and aligning consumption with nutritional needs were seen as key challenges and sustainability was construed as absolutely requiring attention to social, economic and health aspects. Notably, animal welfare featured prominently as a challenge to all aspects of sustainability.

The complexity of applying sustainable intensification to livestock systems

As humans gave up hunter-gathering, agricultural systems have almost never been sustainable, in the sense that the practices have often outstripped the resource base and current prosperity came at the cost of future collapse (Diamond, 2005). Yet humans have, on the whole, become more populous, richer, healthier, better educated and attained more rights and achieved greater equity. From this perspective, current emphasis on sustainability may be unwarranted; technology will 'see us through' as it has done since the industrial revolution (Ridley, 2011). Under this paradigm, the attention of innovators might better be engaged in game-changing food system innovations, be it *in vitro* meat or insect farms than in seeking to attain sustainability (Bhat *et al*., 2017).

A contrasted minority opinion holds that instead of going too far, discourse on agricultural sustainability does not go far enough. The landmark reviews cited above all assume that demand for livestock products will continue to grow and systems must continue to intensify to meet demand. This combination of inevitable production growth along with required reduction in environmental impacts is seen as attainable through 'sustainable intensification', pioneered by (Pretty, 2008; Pretty *et al*., 2011) and consolidated by the (Montpellier Panel, 2013). However, some argue that these attempts to square the circle are unachievable and that sustainable intensification in the livestock sector is a contradiction in terms (Garnett *et al*., 2013); genuine sustainability can best be achieved through drastic reduction in livestock product consumption, and major shifts in the type of livestock products consumed (less muscle, more offal), along with limiting livestock production to pasture and by-products: in effect, sustainable de-intensification (Röös *et al*., 2016; Swain, 2016).

Health sustainability: an under-examined aspect of livestock sustainability

While the environmental impacts of livestock are prominent in the cited frameworks, the negative health externalities, with impacts comparable in magnitude have been

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

under-examined. Many sustainability scientists might be surprised to hear the likely future impact of pandemics on the global economy, combining both the mortality cost and the losses in income was in the same range as that of climate change – although at the lower end of the possible scale (Fan *et al*., 2016). In the landmark studies reviewed health sustainability does not appear as a category, and health implications are either not covered in detail (FAO, 2009; Herrero *et al*., 2014) or subsumed under social or economic pillars (HLPE, 2016). Negative implications, or threats to health sustainability, encompass the emerging, neglected and non-communicable diseases. While most novel human diseases emerge from wildlife, the majority of high impact novel diseases involve livestock, and the economic losses from six major outbreaks of highly fatal zoonoses between 1997 and 2009 amounted to at least US$ 80 billion (World Bank, 2012). However, the health burden of the neglected endemic zoonoses is likely to be orders of magnitude greater than that of novel diseases, and many of these neglected zoonoses are also associated with livestock (Grace *et al*., 2017). Livestock products are the food category most implicated as a cause of foodborne disease (Grace, 2015) and the health burden of foodborne disease has been recently shown to be comparable with that of the so-called 'big three' diseases that dominate development health spending (malaria, HIV-AIDs and tuberculosis) (Havelaar *et al*., 2015). But again, this burden is likely to be dwarfed by the rising tide of non-communicable illnesses including cardiovascular disease, diabetes and cancer, which are also associated with livestock consumption. The intensive livestock sector is a major consumer of antimicrobials and likely a significant contributor to antimicrobial resistance in people (Robinson *et al*., 2016). One report suggests that by 2050 antimicrobial resistance will be killing more people than cancer (O'Neill, 2014) if we carry on as we are.

While livestock associated disease is a clear threat to sustainability, improving animal health also represents a pathway towards more sustainable livestock systems. The overall burden of animal disease is not accurately quantified, but there is little doubt that it is both enormous and largely borne by LMICs. In Africa, diseases along with predation and drought cause the preventable deaths of one in four young ruminants and one in 10 adult ruminants each year (Grace *et al*., 2012). Even higher losses are seen in poultry. The global cost of livestock disease has been estimated in billions of dollars (Grace, 2014). As such, interventions that improve animal health would have two key contributions to health sustainability: first, they would decrease major negative externalities especially zoonotic diseases, antimicrobial resistance and emerging diseases; second, they would greatly improve the efficiency of production and hence reduce the negative environmental impacts.

Livestock are living entities, considered by many to have moral valence. Livestock disease not only has huge impacts on human health and economies but also is a major cause of poor animal welfare, and improving animal welfare would also generate substantial benefits to social sustainability.

Animal health in sustainable livestock development: a diversity of understandings

As the understanding of the burden of animal disease in LMICs grows, so does the diversity of opinions and approaches among different actors and disciplines as to where the priorities lie, and how these are best tackled. There has always been a historic divide between the priorities assigned by the technical and the social sciences, and the challenge has been to try and combine the technically feasible with the economically important and societally acceptable. Inevitably many institutions, governments and development organisations have to be selective in addressing animal health constraints to sustainable livestock development, depending on evidence, resource availability and institutional mandate. Examples of differing focuses include the following:

- Control of specific diseases: Classic examples are the campaigns and global and regional initiatives on rinderpest, foot-and-mouth disease (FMD), peste des petits ruminants (PPR) and rabies.
- Enhancing productivity by addressing the key performance detractors, which may be the endemic diseases such as parasitism.
- Poverty-focused, which inevitably means controlling those diseases affecting the rural and urban extremely poor and the livestock they keep.
- Gender-sensitive, recognising the role of women in livestock systems, and especially in caring for young and sick animals, and a values-based commitment to greater equity, which has led to a gender mainstreaming in many development and research for development initiatives. These approaches may prioritise diseases of poultry and pigs, often kept by women.
- Systems based, for example, coping with the multiple health challenges encountered in pastoral systems and rangelands, and the weak and inadequate diagnostic and response services.
- Climate-sensitive, for example reducing the contribution of livestock to greenhouse gas emissions or addressing climate-sensitive diseases such as blue tongue and Rift Valley fever.
- One health, which emphasises the links between animal health and the health of people and the environment, and the threat of emerging pandemic threats in different countries and regions considered to be at high risk.

Understanding the health contributions to sustainability of livestock systems

One of the best examples of adopting an approach to priority setting among the many health constraints to livestock systems, which combines the technically feasible with the economically important, has been in the livestock and animal health strategy of the Bill and Melinda Gates Foundation. This has united the organisation's institutional ideals (productivity enhancement, smallholder focus and women's empowerment) with selected livestock health challenges for

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

which technologies are either available or feasible within a relatively short time frame (Julef, 2016), and address animal health issues deemed to be of priority to smallholder livestock producers.

What evidence has been gathered to define and quantify the impacts of diseases and the merits of improved animal health to the sustainability of different livestock systems? An approach to defining the impacts of animal disease and their control on different developmental processes involving poor livestock keepers and other actors in livestock commodity value chains in Africa and Asia was proposed by (Perry *et al.*, 2002). This initiative tried to differentiate between those diseases and syndromes constraining the fundamental assets of smallholders, those affecting market access, and those affecting the intensification process. Importantly the boundaries between the three categories are not always distinct; there is an inevitable degree of overlap. In estimating the geographical impacts of different diseases and disease syndromes, this classification was applied in broad terms to the livestock production system classification of (Thornton *et al.*, 2002) described earlier, and so in broad terms, disease impacts were categorised into their effects on three categories of livestock systems. These were pastoral (comprising livestock only systems in arid/semi-arid, humid/sub-humid and temperate/tropical highland rangelands), agro-pastoral (comprising mixed irrigated systems in arid/semi-arid, humid/sub-humid, temperate/tropical highland, and mixed rain-fed systems in arid/semi-arid, humid/sub-humid and temperate/tropical highland systems), and peri-urban (comprising landless) systems in sub-Saharan Africa, South Asia and South East Asia. However, defining the impacts of different diseases on these relatively crude livestock systems was not the main intention of this study, which focussed on the association with poverty, and with three process that were assumed to contribute to poverty reduction: strengthening livestock assets; intensification; and enhancing market access).

The role of dynamic livestock trajectories in providing context for health prioritisation

Extending this concept of clustering animal health impacts, dynamics and intervention options, (Perry *et al.*, 2013) proposed three global livestock disease and system trajectories, each of which face different risks to livestock health, each has different determinants of disease status and capacity to respond, and each requires different approaches to resolve them. The authors termed these trajectories the 'worried well', 'hot spots' and 'cold spots'. The 'worried well' described the increasingly industrialised livestock systems of the western world, the 'hot spots' describes the progressively intensifying and increasingly market-orientated (but high risk) systems in many LMICs, and the 'cold spots' describes the traditional livestock-dependent smallholder and pastoralist systems in many LMICs. While there are broad geographical separations, in reality all three systems now coexist in many LMICs and, as discussed below, provide extraordinary challenges in terms of meeting the demands for diverse disease control and animal health promoting policies and practices which serve a wide range of different stakeholders, and public, private and national interests. Table 1 illustrates the animal health status, animal health risks, service-response needs and key drivers for each of these three trajectories (Table 1).

Incorporating sustainability

These approaches did not explicitly include sustainability as a criterion for prioritisation or characterisation, which raises the question as to how including this might broaden perspectives on assessing and managing animal health risks in global systems. Some areas which might become more salient with a sustainability lens include the following:

- A broader understanding of the systems impacts of diseases on societies and ecosystems. Conventionally the focus has been on the direct costs and benefits of disease control, missing the indirect and downstream effects (e.g. the closing of markets for Rift Valley fever control, which ruined butchers' livelihoods (Rich and Wanyoike, 2010), and the culling of chickens for HPAI which increased stunting of children (Kavle *et al.*, 2015).
- Understanding relations between animal disease, resilience and poverty: health typically comprises a smaller cost in the farm enterprise/household than, for example, feed but is often the largest avoidable cost, and animal disease is a major cause of shocks to the farm household (both through loss of animals and zoonotic human illness). As such impacts are not just a linear decrease in farmer wellbeing but moving from a state of coping and improving to permanent entrapment in poverty (Narayan *et al.*, 2009; Bonds *et al.*, 2010; Grace *et al.*, 2017).
- The tension between diseases seen as obstacles to development and associated better environmental stewardship, and diseases seen as guardians of ecosystems. This debate is illustrated by the case of the tsetse fly, vector of the serious diseases of human and animal trypanosomosis, but as such a conserver of unique ecosystems: a role that is rapidly breaking down under the pressure of population growth and changes in land use (Anderson *et al.*, 2015).
- A similar but much newer narrative has grown around the role of biodiversity in disease regulation service. Initial research suggested that biodiversity downregulated disease through dilution effects and this was finding was much used to build a case for preserving biodiversity (Civitello *et al.*, 2015). As with the tsetse narrative, this attractive conclusion proved somewhat over simplistic: in other cases, biodiversity will be more likely to increase than to decrease infectious disease risk (Wood *et al.*, 2014).
- While grazing livestock have often been cast in the role of degraders of ecosystems, interest is growing in the role of livestock in creating and maintaining ecosystems. Summer grazing of cattle is the maintainer of Alpine mountain wooded pastures: a highly diverse and valued landscape

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

(Battaglini *et al.*, 2014). The Uruz project aims to breed back the aurochs, an extinct keystone species, to re-create, maintain and enhance the biodiversity and characteristics of natural ecosystems in Europe (Stokstad, 2015).

Animal health contributions to sustainable livestock systems: three recent ground-truthing case studies

The authors now draw on recent work in which they have been engaged to illustrate the different aspects of animal health and animal health interventions on livestock system sustainability with an added lens of animal health trajectories. Some provide very broad perspectives, others very narrow and finite aspects. They emphasise the sometimes starkly different roles animal health and disease play. The case studies cover the arid and semi-arid region of North Africa and the Middle East, the rich and fertile country of Bangladesh, and the remote and impoverished Eastern Cape of South Africa.

The case of the North Africa and the Middle East

We start with a 'hot spot' with severe threats to environmental sustainability, and moderate challenges to social and economic sustainability. It also encompasses systems representing all three health trajectories, and health ranks high among the priorities in each trajectory.

Much of the Middle East and almost all of northern Africa, is arid or semi-arid. Located at the juncture of Africa and Eurasia, topography alternates between high rugged mountains and plateaus and dry lowland areas. The region is rich in oil but poor in other resources; livestock (cattle, buffaloes, camels, sheep, goats, pigs and chickens) play an important role in ensuring food security and nutrition in the North Africa and Middle East (NEMA) region, supporting rural livelihoods and employment, and ensuring access to animal source foods (ASFs). Between 1993 and 2013, while global livestock numbers increased by 16%, the livestock biomass of this region grew by an impressive 25%, from 77 million livestock units to 96 million. There are several diverse livestock production systems (such as pastoral, agro-pastoral, mixed extensive, intensive and landless), and all are evolving in different ways (FAO, 2016).

Per capita income is one of the major factors influencing shifting preferences to high-value foods, such as ASFs. In the countries of the Gulf Cooperation Council per capita income is high, ranging from US$ 20 000 to US$ 97 419. Meat and dairy consumption are in the range of 44 to 75 and 83 to 197 kg/capita per year, respectively, and are among the highest in the region. However, the most rapidly growing ASF consumption appears to be found in countries with per capita incomes ranging from USD 2 000 to USD 10 000, such as the Maghreb countries, along with many of the countries in the Mashreq, as well as Iran. Animal source food consumption appears to stabilise once per capita income exceeds US$ 10 000.

While the livestock systems of the region are still dominated by traditional livestock production in keeping with the

Table 1 *Animal health and service response needs (modified from Perry* et al.*, 2013)*

Trajectory	Animal health status and drivers summary	Animal health risks	Animal health service response needs	Key drivers
Intensive production and marketing systems The intensified, organised, highly commercial and well run systems, in particular poultry, dairy and pigs, but also cattle and sheep meat systems	■ Primary supplier of ASFs to supermarkets ■ Generally well-controlled endemic disease ■ Specialised and often stretched private health services to livestock enterprises ■ Heightened public awareness ■ Real/perceived threat from rest of world	■ Food safety highly important; breakdowns widely publicised ■ Threat of increased antimicrobial resistance ■ Vulnerable to expanded distribution of vector-borne and other pathogens from tropical environments ■ Multi-sector economic impacts of disease incursions or scares	■ Better surveillance, including for new diseases ■ Appropriate and acceptable disease control measures ■ Incentives to develop new animal health products	■ Concerns over quality, safety and animal welfare ■ Climate change
'Hot spots' The intensifying and increasingly market-orientated sectors of low- and middle-income countries	■ Increasing intensification and widening of trading partnerships in an environment of endemic disease risk ■ Presence of several major infectious diseases ■ Absence of effective veterinary infrastructure ■ Limited voice in national animal health programmes	■ Endemic disease outbreaks ■ Inability to prevent and contain disease in the broader country and regional environment ■ Unachievable standards imposed by international authorities or trading partners emergence of new disease ■ Erosion of genetic resources associated with disease resistance	■ Greater private sector response capacity through vertical integration and other models ■ Greater interface with public sector health authorities ■ Greater understanding of returns this sector can bring to national economies	■ Livestock revolution (demand-driven intensification) ■ Changing patterns of global trade ■ Urbanisation
'Cold spots' The smallholder, pastoral and agro-pastoral systems dependent on traditional livestock-derived livelihoods	■ Severely constrained economically ■ Limited livestock/feed/health resources ■ Multiple endemic diseases ■ Often in harsh environments ■ Inadequate or totally absent animal health services	■ Multiple endemic diseases ■ Limited or no movement controls ■ Provides source of infection to market-orientated trajectory ■ Highest vulnerability to zoonotic disease	■ Specific services targeted at smallholder and marginal producers ■ Well-coordinated national systems bringing in NGO, private and donor-supported services ■ Particular attention to preparedness and response to shocks	■ Population growth ■ Climate variability

ASF = animal source food; NGO = non-government organisation.

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

Table 2 *Generalised livestock production systems in the countries of North Africa and the Middle East, based on livestock species and animal disease risk and response trajectories*

	Livestock system trajectory		
Livestock species	Industrialised large-scale intensive systems	'Hot spots': small-scale intensifying systems	'Cold spots': extensive low-input traditional systems
Large ruminants	Large-scale commercial dairy	Small-scale cattle and buffalo dairy	Extensive pastoral and smallholder
Small ruminants		Small-scale feedlot Small-scale dairy	Sheep and goat mixed pastoral
Poultry	Large-scale commercial producers and breeders (FAO's sectors 1 and 2)	Small-scale commercial (FAO's sector 3)	Backyard (FAO's sector 4)
Camels	Racing camels	Commercial milk and meat	Extensive pastoral

FAO = Food and Agriculture Organisation of the United Nations.

arid and semi-arid environments in which they are kept, the countries of the region are responding to the increased demand for ASFs in various ways. There is a process of livestock production system growth and intensification underway, particularly in the poultry and large-scale dairy industries, in which a small number of industrialised systems are emerging. In addition, an intensification process is occurring with small-scale producers of meat and milk from different species, in particular cattle, buffalo, small ruminants, camels and poultry. The association of the three livestock disease and system trajectories described above with the different livestock species present in countries of the region is summarised in Table 2.

Importantly, the animal health status, the health risks and the required animal health service response needs are different in the three trajectories, requiring different approaches to understanding them, communicating with different categories of stakeholders, and requiring interventions at quite different scales.

By presenting the livestock production and marketing systems of the region from a trajectory standpoint, an economics and incentive perspective is introduced which provides a complementary systems dynamics element to the more traditional agro-ecological approach to systems classification.

It is important to note that while this process of intensification is going on in two of the trajectories, the region as a whole is increasingly having to import ASFs from a variety of different sources, accounting for an estimated 20% of global milk powder imports and 15% of meat deliveries in 2014. Animal source food imports currently constitute ~32% of total food imports and >40% of the value increase in total food imports by the region between 2010 and 2014.

Beyond the production systems dynamic and animal health risks and responses, the region appears to be at somewhat of a crossroads in terms of animal diseases; the list of those occurring in the region is long and growing. It includes lumpy skin disease (LSD), FMD, PPR, highly pathogenic avian influenza, Middle East respiratory syndrome coronavirus, brucellosis, sheep and goat pox and blue tongue, among many others. Some have spread north from continental Africa, some have emerged, and some have gathered in intensity, all threatening not only the economies of the region, but also those of Europe.

When the kaleidoscope of different disease risks and response needs is then placed in context, the region is characterised by the sheer number of infectious diseases, the significant number of infectious diseases with an expanding geographical distribution among them, the large number of zoonotic and foodborne disease and food safety hazards, and all in the face of weak veterinary services. As a result, determining priorities for animal health in the different livestock production systems and trajectories of the region is an enigma. In a regional context, the transboundary animal diseases such as FMD, PPR, sheep and goat pox, and HPAI all threaten the strong economies of the region, and also threaten neighbouring Europe and beyond. Failure to place these on the top of the priority list would surely be irresponsible. But in the context of food and nutritional security, priorities include the endemic diseases constraining the growing household production and small-scale system intensification, and the zoonotic and foodborne diseases of impact to smallholder farmers, vulnerable communities and the wider group of consumers in both formal and informal markets, and to overall food and feed safety. In other words, there are many competing priorities for animal health responses. Animal health services should be based on the diverse needs of the different production systems, the disease risks posed to different stakeholders – both domestic and regional, the disease impacts, and the types of responses required to reduce these impacts.

So what are the necessary classes of public and private animal health services required in the NEMA region? They include:

- Fundamental clinical animal health services for the different trajectory needs
- National emergency preparedness and response, official disease control campaigns (vaccination, etc.), early warning, disease prediction, contingency planning
- National zoonotic disease preparedness, management and response
- Food and feed safety and hygiene
- Vulnerability reduction and promotion of resilience in conflict and war situations
- Animal health and disease control leadership and capacity

However, if sustainability and appropriateness for ecosystem were to be a primary consideration for livestock

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

sector planning, other priorities might emerge. As discussed, this region is characterised by extreme water shortages, aridity, fragile ecosystems and is a crossroads for disease, with relatively well-off populations who have undergone massive population growth and urbanisation but are now stabilising. The answer would probably be that much of this region is not suited for more than the most rudimentary livestock: perhaps goats and camels kept under range management. The extensive, low-input systems do not have much room for intensification or expansion without putting undue stress on natural resources. Intensive systems are constrained by lack of water, need to import feed, high disease risk environment, and difficulty of waste disposal. Demand for livestock products, backed with capacity to pay for them, would warrant importation from areas with higher safety standards and lower environmental costs (e.g. New Zealand lamb and Irish beef). Animal health needs include surveillance against disease incursions and community based health for extensive ruminant systems. A small number of highly trained veterinarians can meet the luxury needs (racing camels, hunting birds, companion animals) while much of the veterinary healthcare would in effect be 'outsourced' as exporting countries, with conditions more propitious to livestock production, become the main suppliers. On the other hand, if greater reliance on local resources was considered desirable, this might imply dietary shifts away from ASFs.

Bangladesh

The second example is the animal health system in Bangladesh. Although environmental, economic and social threats to sustainability have been well documented, Bangladesh has demonstrated remarkable resiliency and recent decades have seen substantial improvements across a range of human development indicators (Nisbett *et al.*, 2017). In terms of our three animal health trajectories, two trajectories demand attention: the 'hot spots' of emerging intensive systems and the 'cold spots' of small scale and underserved mixed farmers.

Bangladesh is a low-lying, riverine country located in South Asia with a largely marshy jungle coastline situated within one of the four global risk areas for emergence of infectious diseases, and is still considered endemic for H5N1 HPAI. It is highly vulnerable to natural disasters: floods, cyclones, storm surge, river bank erosion, earthquake, drought, salinity intrusion, fire, tsunami and rising sea levels. Our case study explores the changing demands for animal health services to sustainable livestock systems is Bangladesh, and the veterinary educational needs to meet these. Population and economic growth in Bangladesh are both contributing to rapidly increase demand for ASFs, which is promoting a progressive intensification of livestock production systems in the country, particularly in the poultry and dairy sectors, but also in beef and small ruminants. The country has recently experienced numerous outbreaks of emerging and zoonotic diseases, including H5N1 HPAI, H1N1 pandemic influenza, Nipah, rabies, anthrax, bovine tuberculosis and brucellosis.

Bangladesh has seen substantial growth in the consumption of ASFs in response to the rapidly growing population, urbanisation and rising incomes (Rahman and Begum, 2014). This has fuelled an increase in livestock populations, and an increase in intensification of livestock systems. Animal health constraints, along with those of feeding and breeding, are paramount in this development and intensification process. How is the veterinary profession responding to this growing demand for their services?

There has been a traditional rite of passage from veterinary school to the government service (Department of Livestock Services (DLS)), but it appears that this no longer exists. According to statistics provided by the Bangladesh Veterinary Council, in 2014 there were just 68 new graduates entering government service (from what is presumed to be an annual total of 500 graduating veterinarians each year), and just 30 entering the DLS in 2015. This indicates DLS employment opportunities for just 13% and 5% of graduates over the last 2 years. The remainder of graduates appear to be joining the private and NGO sectors, and other arms of government service.

During the last 15 years or so, many new veterinary schools have emerged, driven by decisions made in central government to expand the capacity to train and graduate veterinarians in Bangladesh. The drivers behind these decisions are not totally clear; they do not appear to have been driven by specifically identified veterinary needs and demands from the regions, nor has the process been driven by demands from the veterinary community. The veterinary schools are all government funded, and the salaries of the staff in them supported by government. There are now nine veterinary schools in operation.

All schools offer a very full set of courses covering most of the traditional disciplines common in veterinary schools over the last 40 years or so. These are taught over 4 years, during which most of the teaching is conducted in classrooms in a didactic manner. There is then a fifth year in which the student is sent out for field experience for 6 to 12 months, depending on the university. Based on reviewing the published curricula, the courses do indeed appear to be full, and are described by students and teachers as overloaded.

Bangladesh is now at a juncture where it is necessary to carefully define the changing veterinary landscape in the country, in order to understand who will be the future employers, and what are the skills and qualities they will need over the next decade.

So, from a sustainability perspective, what type of livestock system and animal health support is best adapted to this densely populated, fertile, alluvial plain, with the highest percentage of cultivated land in south Asia? The current high population is the result and driver of a farming system dominated by smallholders (96% of holdings) with diversified on-farm and off-farm livelihood strategies: most keeping livestock, tending homestead gardens, and cultivating rice. Recent decades have seen marked intensification, and the high availability of water, the ability to use animal waste as soil fertilisers, and for animals to use

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

crop-residues offer scope for harnessing ecological cycles in food production. In this setting, livestock are a key part of most farms but it follows that curative healthcare of hundreds of millions of animals owned by tens of millions of smallholders cannot be met by the few dozen veterinarians employed by the government. One study found that nearly all livestock keepers had sick animals and sought care in the last 6 months. However, nearly all healthcare was provided by informal, unlicensed 'village doctors' and 'drug sellers' – most of whom provide treatments for both animals and people (Roess *et al*., 2013). As well as these locally evolved and officially unsanctioned systems, Bangladesh has been at the forefront of alternatives to supporting livestock including 'turnkey' poultry operations and community animal health. However, this had been in parallel with, rather than integrated into, veterinary training, which follows the conventional model described above.

So what is the way forward for animal health services in Bangladesh? There is strong a case for veterinarians in Bangladesh to be networked into the three functioning animal health systems: NGO services, large-scale business, and the unlicensed, informal system. Core competencies for veterinarians include disaster preparedness and response; surveillance for emerging diseases; co-ordinating population level preventive disease strategies; being the health providers of last resort and for serious cases; and avoiding negative externalities of animal healthcare when provided largely by animal health workers without 5-year veterinary training.

The Eastern Cape of South Africa

Our last example has seen continued and worsening environmental, economic and social challenges to sustainability. One animal health trajectory dominates: the 'cold spots' of underserved, smallholder systems.

The Eastern Cape of South Africa houses the former homelands of Transkei and Siskei. The province has 13.5% of South Africa's population but accounts for only 7.8% of gross domestic product. The unemployment rate for the prime working age groups of 25 to 54 has increased to 41.8%, an indicator of an area struggling for enterprise opportunities. Livestock keeping has been traditional among the Xhosa-speaking communities of the Eastern Cape for centuries (Ainslie, 2002) and the significant livestock numbers in the province have stimulated frequent calls for greater exploitation of this resource (see e.g. Coetzee *et al*., 2005). The Province is reported to hold over 3 million cattle, almost 8 million sheep, almost 3 million goats and about 150 000 pigs, more livestock that any other province in the country. Nevertheless, commercial exploitation of this resource by poor communities has been extremely limited, and small-scale intensification is a rarity. Central government interventions have in the past tended to focus on (a) the control of certain livestock diseases; (b) the introduction of stock reduction programmes as land rehabilitation initiatives; and (c) attempts to increase the off-take of cattle in these areas. There is very little evidence of demand-led value chain approach to development, seeking to open and expand market opportunities for livestock commodities emanating from the poorer sectors of society who are strongly dependent on livestock.

It is well recognised that livestock has a significant role to play in poverty reduction, development and food security in many LMICs (FAO, 2012; Smith *et al*., 2013), and the Eastern Cape is no exception (see e.g. Dzivakwi and Jacobs, 2010). Livestock play multiple roles, including safety nets, cash crops and providing psycho-social benefits.

However, the livestock systems of the province are generally characterised by low levels of commercialisation, poor productivity, remoteness from markets, weak market access management, poor public extension services and an inadequate infrastructure and funding base on which sustainable intensification initiatives could be built. Furthermore, the meat and livestock industry remains dominated by large-scale commercial producers, speculators, processors, hawkers and traders, and very few small-scale entrepreneurs have established themselves in the formal meat marketing chains. Small-scale intensive poultry systems for eggs and broilers is a significant development area in many African countries, but these are few in the Eastern Cape, where traditional backyard systems predominate (see Yusuf *et al*., 2014). Significantly, up to 80% of the population in poorest districts receive social grants; there is a culture of dependency and emigration.

So what recommendations does our analysis suggest for this system?

The roles of community animal health workers and veterinary para-professionals are well documented (Catley *et al*., 2004; Leyland *et al*., 2014). But the Eastern Cape Province appears to be the coldest of 'cold spots', for quite different reasons than the remote pastoral areas of North Africa and the Middle East. In this context, sustainability-driven livestock sector planning would more proactively control the optimal number and type of animals, given that these as well as the livelihoods of the people who keep them are largely dependent on support from the state. Here, livestock need to be included in urban and rural planning, and education and extension on appropriate management are important. Animal welfare is a more important consideration in South Africa than some other African countries and should also be incorporated (Trent *et al*., 2005). The longer term trends are that communities with less natural and social capital are likely to need more and better support: this should not come with negative environmental impacts and is likely to include the type of free or subsidised animal healthcare already provided in poorer areas by charities such as the Donkey Sanctuary and Brooke (Pearson and Krecek, 2006). In addition to the need for heavily subsidised support under such circumstances, there is potentially a role for the promotion of entrepreneurial livestock enterprises through publicly funded competitive grant schemes, so creating incentives for the progressive growth in commercial animal health service provision.

Conclusions and key messages

There is a need to embrace the diversity of production systems and the multiple roles that livestock play to different categories

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

of stakeholder in LMICs. The quest for sustainability of these systems, especially from the perspective of human and animal health, is apparently elusive and difficult to reconcile with the massive anticipated growth in demand for livestock products, mainly in LMICs, and as well as the aspirations of poor livestock keepers for better lives. Nonetheless, a relatively uncontroversial proposition is that improving the health of livestock can contribute to many environmental, economic, social and health aspects of sustainability. But in the context of diverse livestock systems, improving the health and wellbeing of livestock may take many different paths, including, perhaps, dramatic reductions in the numbers of animals kept and significant changes in the ways their health needs are addressed. Choice of the most appropriate options is challenged by the very different values of different animal health stakeholders, who we may broadly categorise as: the disease exterminators, the production enhancers, and the sustainable development advocates. Guidance in this area can come from: clear definitions of sustainability and sustainability objectives developed through consensus; more consideration and greater inclusion of the diversity of animal health service providers; and, targeting animal health provision for the often juxtaposed 'hot spots' and 'cold spots'.

Serving the diverse requirements of the different trajectories within LMICs means that there is a rapidly changing landscape of veterinary needs, which has substantial educational implications for the learning objectives appropriate for animal health providers. The veterinary education system in many LMICs, traditionally serving the government animal health systems, is often trapped in a time warp, unaware of – or unexposed to – the rapid growth and diversity of the systems it serves, and unable to update itself due to impoverishment, inadequate leadership or academic inertia. Veterinary education remains supply driven, and while the emphasis on mirroring education in high income countries facilitates global communication and linkages, it does not necessarily produce the veterinarians best suited to supplying the needs of the countries who pay for their training. At the same time, the education needs of the vast majority of those who provide most animal health services to smallholders and pastoralists are largely ignored, while their work is often illegal, poorly supported and prone to generate negative externalities (such as antimicrobial resistance). A sustainability perspective challenges us to develop a new vision for veterinarians and other health providers in LMICs. In the context of many millions of underserved livestock keepers, veterinarians must be problem solvers for animal health and welfare, able to work with a diversity of stakeholders and in diverse livestock systems. The international veterinary profession needs to embrace and support this broader vision of veterinary education and mission. In conclusion, sustainability science offers important insights to analyse and improve livestock systems, and adding a One Health lens or perspective is strongly recommended to address unique challenges and opportunities.

Acknowledgements

This paper is an invited contribution following the First Global Farm Platform conference (12 to15th January, 2016, Bristol, UK). The Global Farm Platform is an international initiative linking research farms around the globe to develop solutions for sustainable ruminant livestock production (www.globalfarmplatform.org). T.R. was supported in part by the Biotechnology and Biological Sciences Research Council (BB/L019019/1). The views expressed here are those of the authors.

Declaration of interest

None.

Ethics statement

All ethical standards have been met.

Software and data repository resources

None.

References

Ainslie A 2002. Cattle ownership and production in the communal areas of the Eastern Cape, South Africa. School of Government, University of the Western Cape, Cape Town.

Anderson NE, Mubanga J, Machila N, Atkinson PM, Dzingirai V and Welburn SC 2015. Sleeping sickness and its relationship with development and biodiversity conservation in the Luangwa Valley, Zambia. Parasites and Vectors 8, 1–14.

Battaglini L, Bovolenta S, Gusmeroli F, Salvador S and Sturaro E 2014. Environmental sustainability of Alpine livestock farms. Italian Journal of Animal Science 13, 431–443.

Bhat ZF, Kumar S and Bhat HF 2017. In vitro meat: a future animal-free harvest. Critical Reviews in Food Science and Nutrition 57, 782–789.

Bonds MH, Keenan DC, Rohani P and Sachs JD 2010. Poverty trap formed by the ecology of infectious diseases. Proceedings of the Royal Society B: Biological Sciences 277, 1185–1192.

Catley A, Leyland T, Mariner JC, Akabwai DMO, Admassu B, Asfaw W, Bekele G and Hassan HS 2004. Para-veterinary professionals and the development of quality, self-sustaining community-based services. Revue scientifique et technique (International Office of Epizootics) 23, 225–252.

Civitello DJ, Cohen J, Fatima H, Halstead NT, Liriano J, McMahon TA, Ortega CN, Sauer EL, Sehgal T, Young S and Rohr JR 2015. Biodiversity inhibits parasites: broad evidence for the dilution effect. In Proceedings of the National Academy of Sciences, pp. 8667–8671.

Coetzee L., Montshwe B.D. and Jooste A 2005. The Marketing of Livestock on communal lands in the Eastern Cape Province: constraints, challenges and implications for the extension services. South African Journal of Agricultural and Extension 34, 81–103.

Diamond J 2005. Collapse how societies choose to fail or succeed. Penguin Group (USA) Inc., Hudson Street, New York, NY.

Dzivakwi R and Jacobs P 2010. Support for pro-poor agricultural development and rural poverty reduction in Eastern Cape. In African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, 19 to 23 September, Cape Town, South Africa.

Fan VY, Jamison DT and Summers LH 2016. The inclusive cost of pandemic influenza risk. NBER Working Paper No. 22137. Retrieved on 11 September 2017 from http://www.nber.org/papers/w22137.

FAO 2009. The state of food and agriculture: livestock in balance. FAO, Rome.

FAO 2012. Livestock sector development for poverty reduction: an economic and policy perspective – Livestock's many virtues (ed. J Otte, A Costales, J Dijkman, U Pica-Ciamarra, T Robinson, V Ahuja, C Ly and D Roland-Holst). Rome, 161 pp.

FAO 2016. Livestock contribution to food security in the near East and North Africa. In FAO Regional Conference, 9–13 May 2016, Rome, Italy.

Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffmann I, Smith P, Thornton PK, Toulmin C, Vermeulen SJ and Godfray HCJ 2013. Sustainable intensifi cation in agriculture: premises and policies. Science Magazine 341, 33–34.

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press

Grace D 2014. The business case for One Health. Onderstepoort Journal of Veterinary Research 81, 1–6.

Grace D 2015. Food safety in low and middle income countries. International Journal of Environmental Research and Public Health 12, 10490–10507.

Grace D, Lindahl J, Wanyoike F, Bett B, Randolph T and Rich KM 2017. Poor livestock keepers: ecosystem-poverty-health interactions. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 372, 20160166.

Grace D, Mutua F, Ochungo P, Kruska R, Jones K, Brierley L, Lapar L, Said M, Herrero M, Phuc PM, Thao NB, Akuku I and Ogutu F 2012. Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. ILRI, Nairobi, Kenya.

Havelaar AH, Kirk MD, Torgerson PR, Gibb HJ, Hald T, Lake RJ, Praet N, Bellinger DC, de Silva NR, Gargouri N, Speybroeck N, Cawthorne A, Mathers C, Stein C, Angulo FJ and Devleesschauwer B 2015. World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. PLOS Medicine 12, e1001923.

Herrero M, Havlík P, Amanda Palazzo and Valin H 2014. African livestock futures: realizing the potential of livestock for food security. Poverty Reduction and the Environment in Sub-Saharan Africa, Geneva, Switzerland.

HLPE 2016. Sustainable agricultural development for food security and nutrition: what roles for livestock? HLPE, Rome.

Julef N 2016. Livestock program of the Bill and Melinda Gates foundation. Retrieved on 23 March 2018 from https://www.slideshare.net/KisacoResearch/nick-juleff-senior-program-officer-bill-melinda-gates-foundation.

Kavle JA, El-Zanaty F, Landry M and Galloway R 2015. The rise in stunting in relation to avian influenza and food consumption patterns in lower Egypt in comparison to upper Egypt: results from 2005 and 2008 Demographic and Health Surveys. BMC Public Health 15, 1–18.

Leyland T, Lotira R, Abebe D, Bekele G and Catley A 2014. Community-based animal health workers in the Horn of Africa. An Evaluation for the Office of Foreign Disaster Assistance. Addis Ababa and Vetwork, Great Holland, UK.

Montpellier Panel 2013. Sustainable intensification: a new paradigm for African agriculture. Retrieved on 23 March 2018 from https://ag4impact.org/publications/montpellier-panel-report2013/.

Narayan D, Pritchett L and Kapoor S 2009. Moving out of poverty: success from the bottom up, volume 2. The World Bank and Palgrave Macmillan, Hampshire, UK

Nisbett N, Davis P, Yosef S and Akhtar N 2017. Bangladesh's story of change in nutrition: strong improvements in basic and underlying determinants with an unfinished agenda for direct community level support. Global Food Security 13, 21–29.

O'Neill J 2014. Review on antimicrobial resistance. Antimicrobial resistance: tackling a crisis for the health and wealth of nations. London, UK.

Pearson RA and Krecek RC 2006. Delivery of health and husbandry improvements to working animals in Africa. Tropical Animal Health and Production 38, 93–101.

Perry BD, Morton J and Stur W 2014. A strategic overview of livestock research undertaken by the Consultative Group for International Agricultural Research (CGIAR) Consortium, 64 pp. Retrieved on 23 March 2018 from http://www.sciencecouncil.cgiar.org/system/files_force/ISPC_WhitePaper_StrategicReviewLivestock.pdf?download=1.

Perry BD, Grace D and Sones K 2013. Current drivers and future directions of global livestock disease dynamics. Proceedings of the National Academy of Sciences 110, 20871–20877.

Perry BD, Randolph TF, McDermott JJ, Sones KR and Thornton PK 2002. Investing in animal health research to alleviate poverty. International Livestock Research Institute (ILRI), Nairobi, Kenya, 140 pp plus CD-ROM. Retrieved on 23 March 2018 from https://cgspace.cgiar.org/handle/10568/2308.

Pretty J 2008. Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B: Biological Sciences 363, 447–465.

Pretty J, Toulmin C and Williams S 2011. Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability 9, 5–24.

Rahman S and Begum IAAM 2014. Livestock in Bangladesh: distribution, growth, performance and potential. Livestock Research for Rural Development. Retrieved on 23 March 2018 from http://www.lrrd.org/lrrd26/10/rahm26173.html.

Rich KM and Wanyoike F 2010. An assessment of the regional and national socio-economic impacts of the 2007 Rift Valley fever outbreak in Kenya. American Journal of Tropical Medicine and Hygiene 83, 52–57.

Ridley M 2011. The rational optimist: how prosperity evolves. Harper Perennial, New York.

Robinson TP, Wertheim HFL, Kakkar M, Kariuki S, Bu D and Price LB 2016. Animal production and antimicrobial resistance in the clinic. The Lancet 387, e1–e3.

Roess AA, Winch PJ, Ali NA, Akhter A, Afroz D, El Arifeen S, Darmstadt GL and Baqui AH 2013. Animal husbandry practices in rural Bangladesh: potential risk factors for antimicrobial drug resistance and emerging diseases. American Journal of Tropical Medicine and Hygiene 89, 965–970.

Röös E, Patel M, Spångberg J, Carlsson G and Rydhmer L 2016. Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 58, 1–13.

Smith J, Sones K, Grace D, MacMillan S, Tarawali S and Herrero M 2013. Beyond milk, meat, and eggs: role of livestock in food and nutrition security. Animal Frontiers 3, 6–13.

Stokstad E 2015. Bringing back the aurochs. News 350, 32.

Swain M 2016. The future of meat. The Breakthrough. Retrieved on 11 September 2017 from https://thebreakthrough.org/index.php/issues/the-future-of-food/the-future-of-meat.

Thornton PK, Kruska RL, Henninger N, Kristjanson PM, Reid RS, Atieno F, Odero AN and Ndegwa T 2002. Mapping poverty and livestock in the developing world, International Livestock Research Institute (ILRI), Nairobi.

Trent N, Edwards S, Felt J and Meara KO 2005. International Animal Law, with a concentration on Latin America, Asia, and Africa. Humane Society Press, Washington, DC.

UN 2016. The sustainable development goals report. UN, New York.

Wood CL, Lafferty KD, DeLeo G, Young HS, Hudson PJ and Kuris AM 2014. Does biodiversity protect against infectious disease? Ecology 95, 817–832.

World Bank 2012. People, pathogens and our planet – The Economics of One Health, volume 2, World Bank. Washington, DC. Retrieved on 23 March 2018 from http://documents.worldbank.org/curated/en/612341468147856529/People-pathogens-and-our-planet-the-economics-of-one-health.

World Commission on Environment and and Development 1987. Our Common Future: Report of the World Commission on Environment and Development. Oslo.

Yusuf SFG, Lategan FS and Masika PJ 2014. Characterization of indigenous poultry production systems in the Nkonkobe Municipality, Eastern Cape Province South Africa. Journal of Agricultural Sciences 5, 31–44.

https://doi.org/10.1017/S1751731118000630 Published online by Cambridge University Press