Submission from the International Center for Tropical Agriculture (CIAT) on behalf of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), to UNFCCC SBSTA 42 on issues related to agriculture in response to SBSTA decision FCC/SBSTA/2014/L.14.

These are views on the assessment of risk and vulnerability of agricultural systems to different climate change scenarios at regional, national and local levels, including but not limited to pests and diseases FCC/SBSTA/2014/L.14 paragraph 3 (b).

Climate and Livestock Disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios

Summary for policy makers

Livestock as a sector is extremely important to the global economy and to rural livelihoods. As of 2013, there was an estimated 38 billion livestock in the world, or five animals for every person. Most (81%) were in developing countries. Around one billion poor farmers keep livestock, many of them women. The burden of animal disease in developing countries is high: livestock disease probably kills 20% of ruminants and more than 50% of poultry each year causing a loss of approximately USD 300 billion per year. Climate change can exacerbate disease in livestock, and some diseases are especially sensitive to climate change. Among 65 animal diseases identified as most important to poor people, 58% are climate sensitive. Climate change may also have indirect effects on animal disease, and these may be greater than the direct effects.

In order to address climate impacts on this sector, we make the following recommendations:

- **Invest in 'no regret' adaptation responses**. Many adaptation responses based on improving the control of climate sensitive livestock diseases are 'no-regret' options, which, by reducing the burden of livestock disease disease, will enhance community resilience, alleviate poverty and address global inequity irrespective of climate change.

- **Improve disease surveillance and response** in order to detect changes in disease in a timely way, thus dramatically reducing the costs of response. This requires investment and innovation in disease reporting systems as well as laboratories capable of confirming diseases. Risk-based and participatory surveillance are promising options for improving disease reporting.

- **Increase the capacity to forecast** near term occurrence of climate sensitive diseases, and to predict longer-term distribution of diseases through better epidemiological information and ground-truthed models.

- **Improve animal health service delivery** by investing in the public sector and supporting innovations in the private sector such as community animal health workers linked to private veterinarians. Promote "One Health" and Ecohealth approaches to disease control, especially in vulnerable communities with high reliance on livestock (e.g. pastoralists in east Africa).

- **Support eradication of priority diseases** where this is economically justified. Develop diagnostics and vaccines, and promote adoption of good practices and strengthened biosecurity to improve disease control.

- **Increase the resilience of livestock systems** by supporting diversification of livestock and livelihoods, and integrating livestock farming with agriculture. Consider promotion of species and breeds that are more resistant to disease and climate change.

- **Adopt breeding strategies** focused on identifying and improving breeds that are better adapted to climate change impacts and disease.

- **Understand the potential land use changes** in response to climate change and monitor their impacts on animal disease to allow preventive or remedial actions.

Challenges and knowledge gaps

Some of the key challenges and knowledge gaps are:

- **Paucity of information**

The extremely poor availability of epidemiological (and ecological) observations on animal disease in poorest countries is a key constraint to developing our understanding of climate sensitive disease. Current surveillance systems only detect a small proportion of disease and livestock diseases surveillance is not well linked to human or wildlife disease surveillance.

- **Complexity of disease dynamics**

There are numerous pathways, direct and indirect, through which climate can influence disease. These drivers are not all equal, and impacts mediated through changes in human population and behaviour may induce effects orders of magnitude greater than those mediated through biological.

- **Multi-host disease systems**

A majority of climate-sensitive diseases affect many host species including livestock, wildlife and sometimes people. This makes their transmission dynamics quite stable and so their prevention and control measures will have to be very effective to achieve intended outcomes.

- **Joint occurrence of climate sensitive diseases in common landscapes**

A review of the risk maps reveals that a number of climate sensitive livestock diseases occur in some common areas given that their emergence and transmission are controlled by similar ecological factors.

- **Lack of laboratory and epidemiology capacity**

The lack of laboratory and epidemiology capacity is a long-standing problem in developing countries. Much effort and expense has been spent on improving capacity, and best approaches exist, but require investments.

Introduction

Since the widespread domestication of animals in the last 10,000 years, human livelihoods and well-being have been inextricably linked to the livestock they keep. As of 2013, there was an estimated 38 billion livestock globally, or five animals for every person (http://faostat.fao.org). The majority of livestock are kept in developing countries, by an estimated one billion poor livestock keepers, many of them women (Herrero et al., 2012). Livestock bring many benefits including income, nutrition, security and psychosocial benefits. But livestock also contribute to environmental degradation, pollution, foodborne and occupational diseases, and climate change. This paper looks at the interface between livestock, disease and climate change. As such, it contributes to understanding the risk and vulnerability of agricultural systems to different climate changes scenarios.

This paper starts with an overview of animal diseases, discussing which are likely to be climate sensitive and why. We next identify those climate sensitive livestock diseases that are most important to poor livestock keepers and the distribution of these diseases across regions, farming systems and livestock species. We then present three case studies on climate sensitive livestock diseases, for which there is some evidence of likely distribution under different climate scenarios. Next we present foresight results on future disease distribution and their drivers, as estimated by state veterinary services in Africa. Finally we draw attention to knowledge gaps, investment opportunities and finally make recommendations and draw conclusions. Factual information is summarised in Annex 1.

Livestock disease

In developed countries, farmed animal mortality is generally low, due to good control of diseases. But in developing countries, livestock have yet to see an epidemiological transition, and enormous numbers die annually, many from preventable disease. Meta-analyses suggest that around 20% of ruminants (25% of young and 10% of adult animals) and more than 50% of poultry die prematurely each year, and case studies indicate at least half is due to infectious disease (Otte & Chilonda, 2002).

Livestock diseases can be characterised as epidemic or endemic. Epidemics are defined as occurrence of a certain disease in a population above expected levels. These increases in disease can be termed outbreaks or plagues. Epidemics that occur over wide areas and affect many are called pandemics. The most serious epidemic diseases are caused by rapidly transmitting pathogens that produce acute and serious disease in large numbers of hosts. Many of these also pose a large threat to the wider economy and hence their control justifies public intervention. Most important livestock epidemics appear in the OIE single list (http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2015/). These include: foot and mouth disease, Newcastle disease, African swine fever, classical swine fever, and contagious bovine pleuropneumonia.

Endemic livestock diseases are those that are constantly present in a population. They often produce less dramatic signs than epidemic disease, because the host and pathogens have co-evolved in ways that reduce the virulence of the disease. Endemic diseases include parasitic infections (both internal and external), the enteric diseases common in very young animals, and many diseases of reproduction and production such as mastitis and abortion. Although endemic diseases is less dramatic, some believe that the overall impact of endemic disease is greater than epidemic. Even though a disease is endemic in an area, seasonal or sporadic outbreaks may occur.

Livestock diseases also have impacts on human health. Over 60% of human pathogens are zoonotic, or transmissible from animals (Taylor et al., 2001), but a smaller number of zoonoses are responsible for most illness. The most important are food-borne zoonoses, which cause billions of cases of illness each. Other important zoonoses acquired by direct contact or food includes bovine tuberculosis, brucellosis and leptospirosis.

Other zoonoses are emerging. For these diseases, human infection is currently rare, either because the pathogen is poorly adapted to humans (e.g. avian influenza) or occasions of transmission are infrequent. But as these pathogens evolve, they may become better adapted to humans, and this concerns underlies the efforts to control avian influenza in birds before it gets the chance to evolve into a Spanish Flu type strain capable of killing tens of millions of people as happened in 1918. A study by the World Bank found that, over the last couple of decades, zoonotic emerging diseases have had global costs of $6 billion (World Bank, 2012). Moreover, each year there is a one in a hundred chance of the world experiencing a $1 trillion dollar pandemic. In low-income countries, zoonoses and diseases, which recently emerged from animals make up 26 % of the infectious disease burden and 10 % of the total disease burden (Grace et al., 2012).

Climate sensitive livestock diseases

The distribution of infectious diseases, (human, animal and plant) and the timing and intensity of disease outbreaks is often closely linked to climate. Climate change may affect livestock disease through several pathways direct, and more indirect:

- Pathogens: higher temperatures and greater humidity generally increase the rate of development of parasites and pathogens that spend part of their life cycle outside the host. Changes to wind can affect spread of pathogens. Flooding that follows extreme climate events provides suitable conditions for many water-borne pathogens. Drought and desiccation are inimical to most pathogens.
- Vectors: vector-borne diseases are especially sensitive to climate change. Changes in rainfall and temperature regimes may affect both the distribution and the abundance of disease vectors, as can changes in the frequency of extreme events. Arthropod vectors tend to be more active at higher temperatures; they therefore feed more regularly to sustain the increase in their metabolic functions, enhancing chances of infections being transmitted between hosts. Small changes in vector characteristics can produce substantial changes in disease (Rogers, 1988).
- Hosts: some livestock will be exposed to new pathogens and vectors as their range increases and impacts can be severe. Climate stress (heat, inadequate food and water) can also lower immunity.
- Ecosystem services. Climate change can also influence disease transmission by altering ecosystem structure and function. IPCC (2007) estimates that 20-30% of the world's vertebrate species are likely to be at increasing high risk of extinction from climate change impacts within this century if global mean temperatures exceed 2-3° C. This would reduce the ability of ecosystems to dilute disease transmission through biodiversity.
- Humans: peoples' behaviour may change as the result of climate change and this may affect how they keep animals, which in turn may affect the exposure or vulnerability of animals to pathogens or vectors.

The direct effects of climate on animal disease are likely to be most pronounced for disease that are vector-borne, soil associated, water or flood associated, rodent associated, or air temperature/humidity associated are sensitive to climate. A relatively abundant literature had identified the different ways climate could have effects on these diseases, and these are summarised in annex 2.

These drivers are not all equal, and impacts mediated through changes in human behaviour (e.g. epidemics following wars or mass people movements) may induce effects orders of magnitude greater than those mediated through biological pathways (e.g. faster pathogen reproduction due to a warmer temperature). Moreover, while climate change could bring changes in disease distribution, changes in wealth and technology could outweigh these. From a centuries-long perspective, the overall trend is the world is becoming richer and disease control better (albeit with local and temporary setbacks).

Most diseases, animal and human, occur in areas that are hot, wet, and poor. But tropical areas that are not poor tend to have disease levels comparable to non-tropical rich countries (e.g. Singapore and Hong Kong). Improved living standards, health care, public awareness and infrastructure are also important for resilience in the face of diseases. These factors explain much of the elimination of many vector-borne diseases from the US (Gubler et al., 2001), whereas the elimination of malaria from Finland is believed to be dependent on socio-economic factors such as household size and living standards (Hulden & Hulden, 2009). Because of this, it is difficult to develop credible estimates of the impact of animal disease under different climate scenarios. Broadly speaking, scenarios that suggest greater wealth, peace and sharing of knowledge should have less disease, including climate sensitive disease.

The effects of climate change on livestock and non-vector-borne disease have, with some exceptions, received little attention, and there is little detailed information on the likely impact of these diseases under different climate scenarios. A first step is to identify those livestock diseases, which are likely to be climate sensitive

Climate sensitive livestock diseases likely to be important to vulnerable people

The climate sensitive diseases likely to be of greatest impact are the diseases, which are most important for poor livestock keepers. We developed a methodology based on previous research to identify the priority climate sensitive diseases for poor livestock keeping communities (annex 2). The top 15 climate sensitive diseases of importance to the poor are shown in table 1. Among the most important diseases, food-and-water borne zoonoses were prominent (8 out of 15). These also impose a high human health burden. An estimated 94 million cases of gastroenteritis due to Salmonella species occur globally each year, with 155,000 deaths. Of these, 81million cases are foodborne. Campylobacteriosis is also predominately foodborne (Majowicz et al., 2010). The human health burden associated with campylobacter infection is even higher than the burden caused by salmonella. Also notable in the list of climate sensitive diseases of priority to the poor were the parasitic endemic diseases that impose a high burden on productivity, water-transmitted leptospirosis and soil associated anthrax.

Table 1: Livestock diseases likely to be most important to poor and vulnerable livestock keepers

	Importance index	Zoonotic disease	Region				Farming system		
Disease/pathogen			WA	ECSA	SA	SEA	Pastoral	Agro pastoral	periurban
Salmonellosis	13	1	1	1	1	1	1	1	1
Campylobacteriosis	13	1	1	1	1	1	1	1	1
Cryptosporidiosis	12	1	1	1	1	1	1/-	1	1
Leptospirosis	12	1	1	1	1	1	1	1	1
Botulism	12	1	1	1	1	1	1	1	1
Endoparasitosis	11	1/-	1	1	1	1	1	1	1
Listeriosis	11	1	1	1	1	1	1	1	1
Toxoplasmosis	11	1	1	1	1	1	1	1	1
Escherichia coli infection	10	1	1	1	1	1	1	1	1
Anthrax	9	1	1	1/-	1	1	1/-	1	1
Liver fluke (fascioliasis)	9	1/-	1	1	1	1	1/-	1	1
Trypanosomosis (tsetse)	9	1	1	1	0	0	1	1	1
Ectoparasites	9	1/-	1	1	1/-	1	1	1	1
Under-nutrition	9	0	0	1	1	1	1	1	1
% of diseases present		39	66	63	63	63	50	68	71

1 =an important problem; 1/- = a minor problem
Regions: WA = West Africa; ECSA = Eastern, Central and Southern Africa; SA = South Asia, SEA = South-East Asia

Case studies on better-studied climate sensitive livestock diseases

Projecting the impact of global environmental change on patterns of infectious disease is not simply a matter of plotting a rise in predicted temperature change, imputing changes in temperature sensitive pathogen development, and predicting future abundance and distribution. Pathogens, vectors, hosts and their environment interact within complex ecosystems, where processes can be up- or down regulated or undergo phase transitions. New evidence also suggests disease vectors may evolve in under a decade to changes in temperature (Egizi et al., 2015). As such, linear extrapolations of future diseases patterns are likely to be highly misleading.

Mathematical models have been used to deal with some of the complexities in understanding disease dynamics, and have proven to be powerful tools for understanding, and, to a lesser extent, predicting epidemiology. The main types of models used to forecast future climatic influences on infectious diseases include statistical, process-based, and landscape-based models. We here present three important climate sensitive diseases for which there is unusually rich data, based mainly on models.

Case study 1 -Trypanosomosis: Trypanosomosis is caused by a blood-borne parasite that is transmitted by the tsetse fly. Cattle are especially affected: the disease causes annual losses of some US$ 5 billion and, over the long run, has had the effect of limiting Africa’s agricultural income to some US$ 4.5 billion a year below its potential level (Shaw et al., 2014).

Current distribution: Tsetse-transmitted trypanosomosis occurs only in Africa and its distribution depends on the distributions of the tsetse species and sub-species that transmit the disease. The distributions of tsetse have been modelled extensively through numerous studies and has been demonstrated, amongst other things, to be highly dependent on climate, land cover and demography – factors that are changing now and will continue to change in the foreseeable future.

Likely distribution under climate scenarios: The discussion here follows from earlier studies that looked at the possible changes in distributions of the three groups of tsetse in relation to changing climate and population density and expected disease control activities (McDermott et al. 2001; Thornton et al. 2005). The key findings of those studies were that climate change is indeed likely to change the distributional potential of tsetse but that anthropogenic changes resulting directly from population expansion would be more important in determining actual changes in tsetse distributions. Overall, it was estimated that a reduction of the tsetse distribution by some 15% may occur by 2030.

Previous authors were frank about the limitations of the studies. In an exploratory follow-up study (Robinson et al. unpublished results) we concentrated on a handful of important tsetse species, with representatives from each of the species groups, and used multivariate logistic regression models to predict their current distributions. Future climate variables were estimated based on 12 combinations of 4 General Circulation Models. These models for individual species gave much better current predictions, which was not surprising, given, for example, that very different climatic optima have been observed between species in the same group, and even between closely related sub-species in the same country (Robinson et al. 1997). The climate-based forecasts of future tsetse distributions showed important variability in responses among species but remained constrained by our poor ability to predict land use change.

Fifteen years on, our understanding of how the distribution and incidence of trypanosomosis is likely to change in the future has not advanced much, but it is clear that population growth and urbanisation in Africa is advancing apace (Gerland et al. 2014); that economic development is moving fast (Pinkovskiy and Sala-i-Martin 2014) and that feeding this more affluent population will require more agricultural development, making many areas less suitable for tsetse to survive.

In 1999 Budd estimated that only 2% of the distribution had been cleared by tsetse control operations since 1970 (Budd, 1999). In spite of clearly demonstrable economic benefits to be gained from dealing with tsetse and trypanosomosis (Shaw et al. 2006; 2014) control operations have been slow in coming.

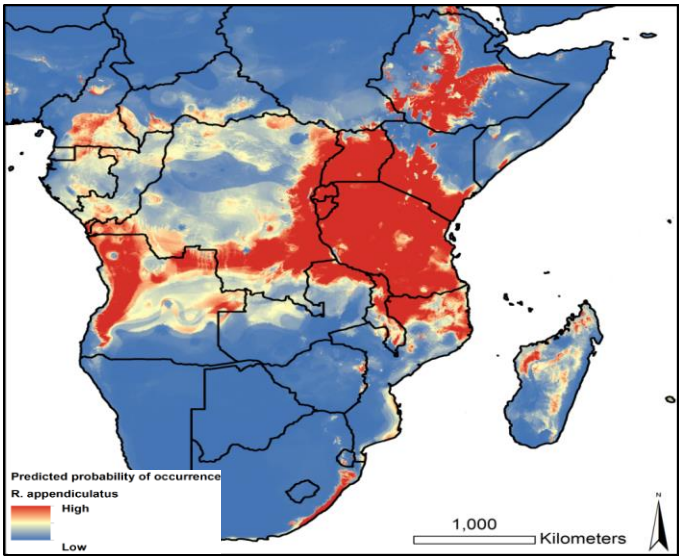
Whilst there may be a trend towards natural disappearance of tsetse-transmitted trypanosomosis in some areas this is not ubiquitous and will not happen soon. Diminished habitat and climate suitability may well enhance control operations in some areas but in other less developed areas tsetse may indeed spread into habitats that are becoming more suitable. Recent advances in our understanding of current tsetse and trypanosomosis distributions regional climate projections (http://www.ipcc.ch/index.htm); advances in multivariate modelling approaches (ref); improved population maps and projections; and agricultural land cover mapping all lend themselves to a more systematic analysis of changing distribution and incidence of trypanosomosis in Africa. Perhaps the time is ripe now for a renewed effort to include such foresight in helping tackle this important disease of poor livestock farmers in Africa.

Case Study 2 - Ticks and tick-borne diseases (TBDs): Ticks transmit many diseases among livestock including East Coast fever, cowdriosis, anaplasmosis, babesisosis, and ehrlichiosis. Ticks also transmit a number of zoonotic diseases; both viral like Crimean Congo hemorrhagic fever, and bacterial, such as coxiellosis (q-fever) and borreliosis (Lyme disease). East Coast fever is one of the most economically important diseases of cattle as it causes high mortality, morbidity and other production losses (Olwoch et al., 2008). It is transmitted by *Rhipicephalus appendiculatus* (brown ear tick). Other losses associated with the disease include lost potential of keeping indigenous, low producing livestock breeds which are more resistant, and high cost of chemical acaricides to manage the disease, not to mention the negative environmental impacts associated with this use (Perry, 2009).

Distribution: The brown ear tick is widely distributed throughout eastern, central and southern Africa, but absent from the Horn of Africa (Figure 1) (Leta et al., 2013). ECF generally follows the distributional ranges of the vector except where it has been eradicated (Norval et al., 1991). Environmental factors that influence the distribution of the tick species include precipitation and temperature; the tick is mainly found in areas that have high precipitation and moderate temperature Leta et al., 2013). Other factors that influence tick distribution include seasonal livestock movements and host density. Increasing the density of hosts increases host density (Cumming, 1998).

Distribution under climate change: Olwoch et al. (2008) made an extensive analysis on the impact of climate change on the future distribution of ECF. They predict that the vector will decline in western arid regions of Africa due to an increase in temperature. The countries to be affected include Angola, Namibia and southern DRC. The study further shows that the suitability of northern and eastern Cape province of South Africa, Botswana, Zambia and eastern DRC to the vector, hence ECF will increase in the future due to enhanced rainfall and a reduction in temperature.

Fig. 1. Predicted habitat suitability for *R. appendiculatus* in Sub-Saharan Africa (source: Leta et al., 2013)



Case Study 3 - Rift Valley fever: Rift Valley fever (RVF) is an acute, mosquito-borne viral disease that mainly affects ruminants and humans. The virus was identified in 1930 in the shores of Lake Naivasha in Kenya. It can be transmitted by numerous genera and species of mosquitoes and infects a wide range of animals (Walter & Barr, 2011). This may explain why many lineages (at least 15) of the virus have been identified (Grobbelaar et al., 2011). RVF virus is classified as an emerging pathogen due to its increasing incidence in new hosts and geographical areas. Epidemics cause devastating socio-economic impacts arising from mortalities in the young stock, abortions, closure of markets and enforcement of export restrictions. The 2006-07 RVF epidemic in Kenya caused losses of over USD$32 million (Rich & Wanyoike, 2010).

The zoonotic potential of the virus was identified during an outbreak that occurred in Egypt in 1977 where it caused about 1 million cases in humans with 600 deaths (Soumare et al., 2012). The vast majority of human infections result from direct or indirect contact with the blood or organs of infected animals, handling of infected tissues during slaughtering, assisting animals during parturition, conducting veterinary procedures or from disposal of carcasses or foetuses (WHO, 2010). Therefore, certain occupation groups such as herders, farmers, slaughterhouse workers, and veterinarians have higher risk of infection than others. Human infections can also occur from the bites of infected mosquitoes (Anyamba et al., 2009). There is some evidence indicating that humans may acquire the disease by ingesting unpasteurized or uncooked milk from infected animals (WHO 2010).

RVF distribution: RVF occurs in sub-Saharan Africa and the Arabian Peninsula in endemic or epidemic proportions depending on the climate and vegetation types in the different regions. Improving water storage and utilization along river courses (e.g. development of dams and irrigation systems) enlarges areas that are suitable for mosquito development, increasing the risk of RVF endemicity. Some of these developments have been associated with RVF epidemics in Sudan, Mauritania/Senegal and Egypt. In general, the conversion of endemic to epidemic RVFV activity follows persistence of floods leading to the amplification of arthropod vector populations (Public & Aspects, 2005).

RVF epidemics usually occur in 5-15 year cycles following periods of excessive rainfall. Two key observations emerge from these patterns. First, RVF epidemics often occur in defined ecologies whenever “permissive” ecological and climatic conditions converge. In some of these places, RVFV is known to be endemic but little is known regarding the processes that permit persistence. It is possible therefore that many of such environments that currently maintain cryptic or endemic transmissions might get massive epidemics in the future as climate and land use changes deplete regulatory services of these ecosystems. The main driver for RVF epidemics in eastern and south Africa, and to some extent, west Africa and Saudi Arabia has been above-normal precipitation. Whereas epidemics in eastern Africa follow *El Nino* weather phenomenon, those in west Africa [mainly Senegal] are thought to occur after a “productive” rainfall where a primary rainfall event exceeding 10 mm is separated from a secondary but denser rainfall event by a dry period of about 6 days (Vignolles et al., 2009). This rainfall pattern is thought to favour breeding and hatching of the key mosquito vectors]. A few other epidemics have been associated with irrigation/dams, for instance, the 2000-2001 outbreak in Yemen (Abdo-Salem et al., 2006) and the 1977 outbreak in Egypt (Martin et al., 2008) and the 1987 epidemic in the Senegal River basin (Thonnon et al., 1999).

However, emergence is also linked to the gradual expansion of the geographical range of the virus via travel and livestock trade. Pastoralists, game and other animals are likely to respond to climate change by moving more frequently and widely, therefore aiding the dissemination of RVF virus and other infectious pathogens. Wind-aided dispersion of RVF virus-infected mosquito vectors could also play a role in introducing the virus to new environments; *Aedes* spp for example can travel 175 km or more in wind currents at altitudes of 1-2 km if temperatures are favourable (Public & Aspects, 2005).

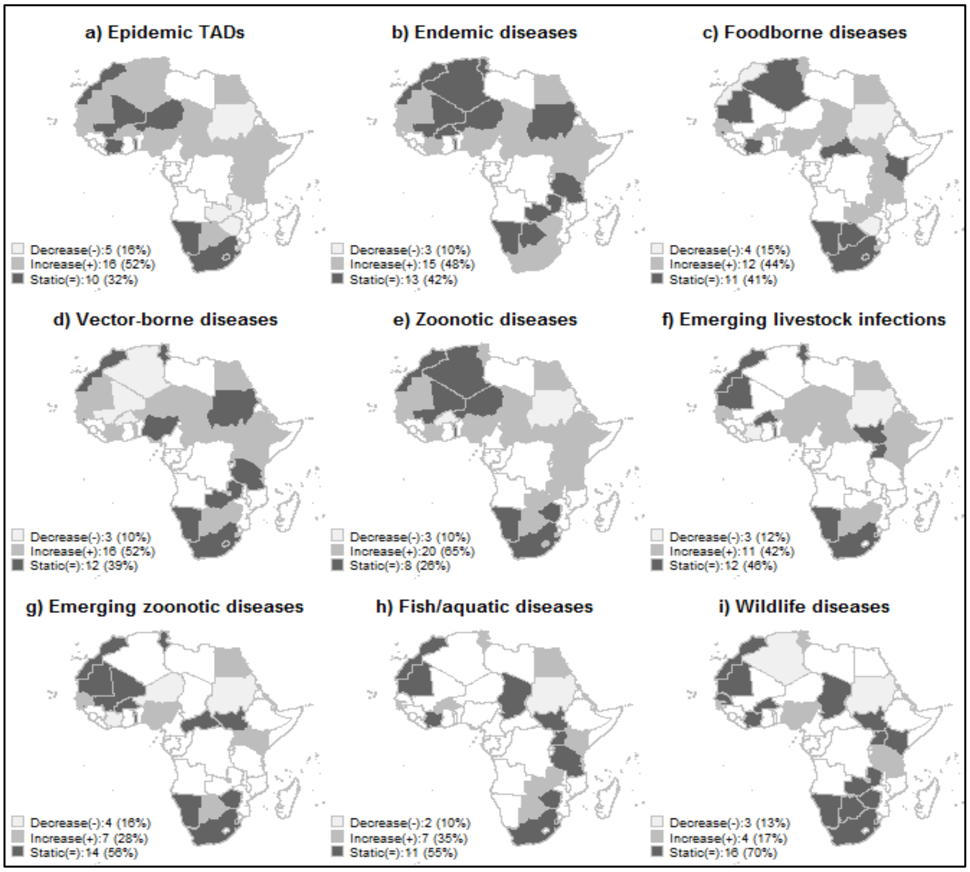
Distribution under climate change: Climate change will have important direct and indirect effects on RVF transmission. A rise in temperature increases the rate of transmission by increasing vectors’ feeding interval, development rate, and reduces the virus’s intrinsic incubation period. These effects only operate until a limit is attained where a further increase in temperature limits vectorial capacity (e.g. through increase in mortality rate, etc.). Rainfall distribution is important in determining the breeding sites for the vectors. Excessive rainfall decreases vector population densities through flushing of the breeding sites. The indirect effects of climate – which include changes in host distribution, ecology are thought to have more impacts on disease transmission than the direct effects mentioned earlier.

A model has been developed by University of Liverpool for predicting climate change effects on RVF distribution in East Africa (http://zgis186.geo.sbg.ac.at/hf_atlas/). The effects of temperature changes in the model are captured via varying the biting rate and the survival rates and the model simulations are driven using a combination temperature and rainfall data for the period 1980 – 2099 for two different emission scenarios after some of its parameters were calibrated using temperature and rainfall data over the period 1998-2010. The model uses entomological inoculation rate to evaluate changes in RVFV transmission risk over time. This analysis predicts a shift in the RVF enzootic areas, with a rise in temperature, from the low lying areas to areas that are currently cool – e.g. central and western Kenya and Rwanda. Temperature, in this case, appears to have an important effect but in the short-term, RVF virus activity is dependent on spatial distribution of rainfall.

Foresight exercise on livestock disease futures in Africa

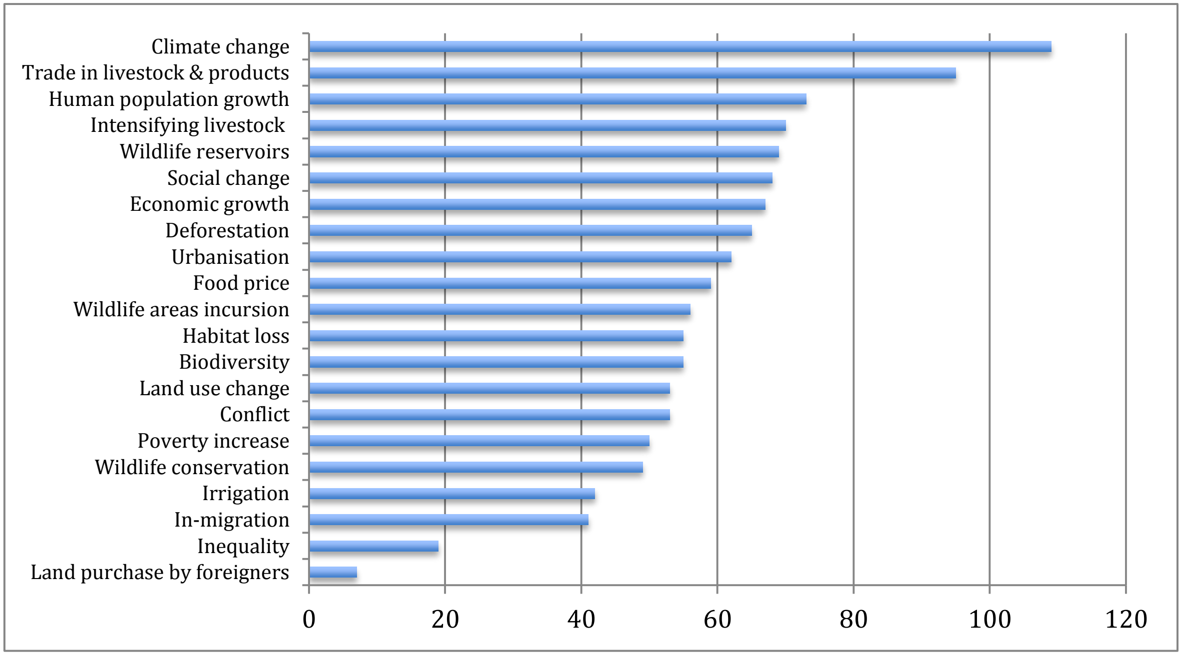
We conducted a survey of Veterinary Authorities of the 54 countries in Africa as part of a study commissioned by the OIE. Some of the questions focused on state veterinary services opinion on diseases trends and their drivers. Overall, livestock diseases in Africa were considered to be increasing or static: for 44% of the diseases assessed the trend was up, for 44% it was static and only for 12% was the trend downwards. Zoonotic, epidemic and vector borne diseases were estimated to be increasing most and wildlife diseases least (Figure 2). Vector-borne diseases are clearly climate sensitive as are many epidemic and zoonotic diseases.

Figure 2: Veterinary Services' perception of disease trends in Africa for different disease categories



Understanding the drivers of disease helps predict and manage diseases. The most important drivers of change in the patterns of disease were considered to be climate change and trade in livestock and products. A broad range of demographic, social, economic and environmental drivers were seen to have some importance, while inequality and land purchase by foreigners were not considered important (figure 3). Respondents added additional drivers of disease: globalisation, illegal trade and porous borders.

Figure 3: Drivers of change in disease dynamics



Challenges and knowledge gaps

This paper provides background information on important animal diseases that are likely to be climate sensitive and summarises three diseases for which there is relatively good information. However, for most of the diseases important to the well-being of poor peopled in climate change vulnerable systems we do not well understand the likely, or even possible, impacts of climate change. Some of the key challenges and knowledge gaps are:

- **Paucity of information**: The extremely poor availability of epidemiological (and ecological) observations on animal disease in poorest countries is a key constraint to developing our understanding of climate sensitive disease. Official disease reporting systems are plagued by massive under-reporting and the research studies that provide more accurate information are often small, un-representative and old (Grace et al., 2012b).

- Co**mplexity of disease dynamics**: There are numerous pathways, direct and indirect, through which climate can influence disease. These drivers are not all equal, and impacts mediated through changes in human population and behaviour may induce effects orders of magnitude greater than those mediated through biological). Moreover, while climate change undoubtedly could bring changes in disease distribution, changes in wealth and technology could outweigh these.

- **Multi-host disease systems**: A majority of climate-sensitive diseases affect multiple host species including livestock, wildlife and sometimes people (for example this is the case for RVF, tick borne diseases, and echinococcosis). This makes their transmission dynamics quite stable and so their prevention and control measures will have to be very effective to achieve intended outcomes. Even in developed countries, diseases with wildlife hosts are very difficult to control as witnessed by the challenges in controlling bovine tuberculosis in the UK and New Zealand and brucellosis in the Yellowstone National Park in the United States. Multi-host diseases also offer immense challenges in research since it is usually difficult to collect all the data that would be required to estimate transmission coefficients to inform control interventions.

- **Joint occurrence of climate sensitive diseases in common landscapes:** A review of the risk maps reveals that a number of climate sensitive livestock diseases occur in common areas; not suprising, given that their emergence and transmission are controlled by similar ecological factors. Whereas this suggests that it would be possible to develop risk maps that identify these locations (pathogenic landscapes), there are underlying challenges on how to manage each disease identified. In addition, these areas would also have climate sensitive diseases of public health importance such as malaria, dengue fever, etc. The occurrence of a high number of diseases can overwhelm both private and public health services providers.

- **Lack of laboratory and epidemiology capacity:** Common challenges include: lack of external quality assurance; lack of essential reagents, inadequate standard operating procedures, noncompliance with internationally recognized, insufficient capacity for data analysis and dissemination, inadequate training of staff performing and interpreting susceptibility tests, lack of national guidelines, and weakness of national programs.

Opportunities and options

We finish by suggesting some options for action in the face of the enormous current impact of animal diseases in developing countries and the prospect of climate sensitive diseases becoming even more problematic as climate changes.

- N**o-regret adaption options**: Many adaptation responses to improve the control of climate sensitive livestock diseases are ‘no-regret’ options, which enhance community resilience, alleviate poverty and address global inequity. These are sensible development and public health interventions. For example, trypanosomosis and ECF are two of the most serious and most climate sensitive animal pests. Moreover, there are proven disease control methods that are highly cost-effective but require investments by governments or development actors. Investing in community-based vector control for the trypanosomosis vector and roll out for the infection and treatment ‘vaccination’ for ECF will have benefits many times costs. The likely worsening of these diseases under climate change is an addition motivation for control, but even if this did not transpire, control would be fully justified.

- **Improve surveillance and response capacity**: Accurate information on its presence, level, and impacts and the costs for controlling disease is needed to plan disease control. Disease surveillance is an information-based activity that involves collection and analysis of information on disease occurrence. Well-functioning surveillance systems and timely responses may reduce the cost of outbreaks by 95% (Grace, 2014). Most developing countries currently lack capacity to detect disease. Promising surveillance and reporting opportunities for poor countries include:
    - Risk based (targeted) surveillance: the assumption in traditional surveillance, that the probability of disease is constant across all individuals in the reference population is not

    realistic. By concentrating surveillance on the diseases, sectors, sub-populations or areas most likely to be affected, costs can be saved and efficiency increased.
  - mSurveillance: mobile phones have reached widespread cover in developing countries. Pilot programs involving veterinarians, community animal health workers and farmers have been successful in several countries.
  - Participatory disease surveillance was originally used in Africa to include local communities in detection and reporting of rinderpest. It has subsequently been used for several diseases including avian influenza. It often reaches further and costs less than traditional surveillance. However, reports typically require confirmation

- **Forecasting and prediction of disease**: Satellite data are increasingly being used to aid disease prediction especially for those diseases that occur in epidemics such as RVF, malaria, etc. Disease prediction is also becoming an important tool since traditional knowledge is no longer reliable for designing coping mechanisms. Prediction however needs to be grounded on disease transmission patterns; therefore, a good understanding about the disease and its epidemiology is important. Satellite data have also been found to overestimate rainfall in dry areas and underestimate it in the highlands (Dinku et al., 2008). There is however a huge potential to calibrate these data based on the local Meteorology Station data in order to reliably use them in short-term disease prediction and longer term forecasting.

- **Improve animal health service delivery**: The last several decades have seen interest in better linking human, animal and environmental health, an approach called "One Health" and Ecohealth. These are based on cross-disciplinary collaborations at the interface of population biology, epidemiology, community ecology, etc. will be required. Community animal health programs have been successfully implemented in many countries but require an enabling national animal health policy, which is not always present.

- **Support eradication and control of priority diseases**: Rinderpest, a catastrophic disease of ruminants, was the second disease to be eradicated from the planet (after smallpox). FAO estimates that eradication led to some USD 920 million in annual economic benefits in Africa alone, bringing immense benefits to livestock keepers. Global eradication may not be feasible, but many diseases can be controlled by a combination of treatment, vaccination, culling, and reduction of transmission. Control is usually staged with initial measures used to reduce prevalence progressing to more rigorous and expensive methods to eliminate infection. Some control technologies with potential to improve control of climate sensitive disease include:
  - Multivalent vaccines that can confer immunity to multiple diseases
  - Thermo-tolerant vaccines that do not require a cold-chain
  - Breeding for disease livestock breeds since they withstand multiple diseases
  - Insecticides (e.g. pyrethroids) which are effective against several multiple vectors

- **Improve the resilience of livestock systems**: Livestock can play a greater role in adaptation to climate change and variability. In fact livestock husbandry is regarded as a form of adaptation compared to crop agriculture because livestock are mobile and so can be moved to areas with available feed and water. Livestock producers have always used their knowledge of the environment and experiences to adapt to climatic changes but these traditional systems are proving insufficient to meet current challenges. Changes that could be instituted to help livestock farmers adapt better include:
  - Diversification of livestock and livelihoods

    - Integrating livestock farming with agriculture
    - Identifying and improving breeds that are better adapted to the environment and disease
    - Adopting farming practices that limit green house gas emissions e.g. better management of manure, replacing fertilizers wit biological/nitrogen fixing legumes, soil conservation tillage, etc.

- **Consider the implications of climate change responses on disease**: Land use changes that implemented in response to climate change and variability can be sources of ecosystem disservices, which result in more animal (and human disease). For example, these changes may result in loss of biodiversity (and hence the risk more disease), nutrient runoff, sedimentation of waterways, greenhouse gas emissions, and pesticide poisoning of humans and other non-target species. Understanding potential changes and monitoring their occurrence will allow preventive or remedial actions.

Conclusions

Livestock have important roles in providing income, food, security and psychosocial benefits for over a billion poor households. Animal disease is the single greatest threat to livestock assets, a major risk to human health, and huge source of risk as new disease emerge every four months. Of the animal diseases of most relevance to vulnerable agricultural systems, the majority are climate sensitive. There is little information on the possible changes in distribution and impact under climate change scenarios, but for two of three well-studied diseases changes in disease dynamics will have serious additional impacts under climate change scenarios. Fortunately, there are a range of ‘no-regret’ adaption options that can reduce the burden of disease present and future.

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