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SI (EMERGING ZOONOSES)

The multiple burdens of zoonotic disease and an ecohealth approach to their assessment

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Abstract Zoonoses occur at the interface of human and animal disease and partly because their impact and management fall across two sectors they are often neglected. The Global Burden of Disease captures the impact of zoonoses on human health in terms of disability-adjusted life years (DALYs). Based on this, we estimate that in low income countries, zoonoses and diseases which recently emerged from animals make up 26 % of the DALYs lost to infectious disease and 10 % of the total DALYs lost. In contrast, in high income countries, zoonoses and diseases recently which emerged from animals represent less than 1 % of DALYs lost to infectious disease and only 0.02 % of the total disease burden. We present a framework that captures the costs of zoonoses and emerging disease to human, animal and ecosystem health in terms of cost of treatment, cost of prevention, health burden and intangible and opportunity costs. We also discuss how ecohealth concepts of transdisciplinarity, participation and equity can help in assessing the importance of zoonoses in developing countries and illustrate these with an example of assessing milk-borne disease.

Keywords Ecohealth · Zoonoses · Disease burden · DALYs · Prioritisation

This paper is part of a special supplement on assessing and managing urban zoonoses and food-borne disease in two African cities (Nairobi, Kenya and Ibadan, Nigeria).

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Introduction

By definition, zoonoses occur at the interface of human and animal health and assessment is often challenging: zoonoses have wide-ranging impacts on human health and livelihoods as well as animal and ecosystem health, and there are often complex social and political issues around their assessment and management, and, especially in the case of novel diseases, impacts may be highly variable and uncertain. This paper argues that approaches which can deal with complexity, uncertainty, different stakeholders as well as issues with social, economic, political and environmental implications can assist in better understanding and prioritising zoonoses in poor countries. Ecohealth is one such approach: it has been defined as systemic, participatory approaches to understanding and promoting health and well-being in the context of social and ecological interactions (Waltner-Toews 2009).

We review methods for prioritisation of disease generally and their application (or lack thereof) to zoonoses. We then make a preliminary assessment of the burden of zoonoses in least and most developed countries in terms of disability-adjusted life years (DALYs). Finally, we propose an ecohealth framework for the prioritisation of zoonoses that incorporates stakeholder values and illustrate this with an example.

Current assessment of zoonoses: DALYs and dollars

Things that are measured become more manageable and DALYs have been hailed as a great leap forward in assessing human health burden (Murray et al. 2000). Introduced by the Global Burden of Disease study in the early 1990s, DALYs are the present value of future years lost due to premature death or being alive with poor health. No

equivalent global metrics exist for animal diseases. However, individual countries and the World Animal Health Organisation have lists of notifiable diseases, which are based on historical concerns and expert opinion; these have been recently reviewed by Perry and Grace (2009). While animal health economists have estimated the costs for many individual diseases in different contexts, lists which give the costs of multiple diseases are much rarer, with the analyses of Bennett et al. (1999) covering important animal diseases in the UK, being a notable exception.

The Global Burden of Disease (GBD) assessment is widely accepted and supports comparison of different diseases, rational allocation of resources and measurement of progress. Yet, it is essentially a human health centric measure that only captures some of the burdens imposed by zoonotic disease. Issues which limit the utility of GBD in assessing zoonoses include: the DALY burden from zoonoses is not fully measured; the full cost of zoonoses to people is not captured; and the cost to the livestock sector, ecosystems and the future is treated separately. We will examine these issues in turn.

There are two problems with measuring the burden of zoonoses. Firstly, zoonoses (especially in poor countries) are widely unreported, and under-reporting is relatively greater for zoonoses than for non-zoonotic disease of comparable prevalence (Schelling et al. 2007). As the GBD report is based on national information on levels of mortality and cause of illness, this under-reporting is reflected in the GBD. Moreover, several zoonoses with considerable burdens are not included in the GBD assessment. For example, rabies is estimated to cost 1.7 million DALYs a year in Africa and Asia alone but is not included in the GBD (Maudlin et al. 2009); neither is cystic echinococcosis, cysticercosis, leptospirosis or brucellosis. These so-called neglected zoonoses mainly affect poor people in developing countries, who live in close association with livestock or wildlife and who have little access to health services. Summarising many authors, Utzinger and de Savginy (2006) attribute this neglect of tropical diseases (including zoonoses) to the diseases' primary impact on the poorest of the poor in rural and deprived urban settings, the underestimation of their public health and economic significance and the lack of coordinated research and control effort. Zoonoses have the additional disadvantage of falling between two sectors (World Bank 2010). The attention the GBD naturally draws to named diseases with large burdens (malaria, tuberculosis and HIV) inevitably draws attention and resources away from the zoonotic diseases which are not assessed or included (Maudlin et al. 2009).

The second problem is one of attribution. The GBD is, as the name suggests, organised around diseases and not pathogens or transmission pathways. For example, diarrhoeal diseases, among the highest causes of morbidity and mortality in poor countries, comprise one category. Although the majority of important diarrhoeal pathogens are zoonotic (Schlundt et al. 2004), it is not currently possible to identify the zoonotic component from GBD figures. A promising initiative is underway to attribute food-borne disease to pathogen level (Kuchenmüller et al. 2009) which will assist in better understanding of the zoonotic burden. Other diseases named in the GBD which have both a zoonotic and non-zoonotic components include tuberculosis, schistosomiasis and lymphatic filariasis.

DALYs, by definition, only measure the disutility to the individual of being ill. They do not capture medical costs of illness to the individual or society. Individual costs of illness could include transport costs and purchase of medication. Societal costs could include the provision of health care infrastructure or running vaccination campaigns. Indirect costs include loss of production as the result of illness and costs of averting behaviour such as boiling milk or buying mosquito nets in order to reduce the risk of disease. In developing countries with limited resources, the costs of illness both direct and indirect are not ignorable and the focus on life years rather than the economic prosperity which would allow life years to be valued more highly has been questioned (Deaton et al. 2010).

Many zoonoses also have substantial impacts on the livestock system. A study in Mongolia incorporated both private and public costs of human illness and costs borne by the livestock sector (Roth et al. 2003). This found that only 10 % of the benefits of control accrued to the public sector. Unfortunately, this study remains almost unique in taking an integrated (One Health) approach to assessing the impacts of zoonoses.

While economic theory offers sophisticated tools that can capture most of the costs of zoonoses to the livestock sector, assessing the costs of damage to ecosystem is less advanced. Obviously, zoonoses can threaten diversity of species in an ecosystem as well as connectance (number of connections). This in turn undermines the stability of ecosystems (Rozdilsky and Stone 2001) and hence ability to deliver health services such as disease regulation. An example from West Africa illustrates ecosystem disruption leading to loss of disease regulation. The death of village pigs from African swine fever was followed by flare ups of human sleeping sickness (a zoonosis) as the tsetse vector left their usual resting sites and moved closer to the houses (Asonganyi et al. 1991).

Destabilised, invaded ecosystems are prone to disease emergence and zoonoses make up the majority (75 %) of emerging infectious disease (Jones et al. 2008). Disease emergence is a low probability, potentially high impact event, difficult to predict and assign a monetary cost to. For example, human immunodeficiency virus emerged from wildlife and has probably affected more people than any other disease at any other time. It ranks among the most important causes of mortality and morbidity in many of the

poorest countries. On the other hand, the current avian influenza pandemic looks unlikely to mutate to a human-to-human pandemic and the impacts to date on human mortality are negligible: 297 deaths from 2003 to July 2010.[1]

The DALY burden of zoonoses in low and high income countries

Even with these caveats, the GBD shows the severe negative impact of zoonoses in poor countries. The 59 low income countries (mainly in sub-Saharan Africa and South Asia) have a population of 2.4 billion and two thirds of the workforce is involved in agriculture. In these countries, infectious disease represents around 40 % of all disease burden. We estimated the burden of zoonoses according to two categories: food-borne zoonoses causing gastrointestinal disease and non food-borne zoonoses. We also estimated the burden of diseases which recently emerged from animals. Using a conservative estimate that only 50 % of the diarrhoeal burden is caused by zoonoses (Schlundt et al. 2004), then the burden of zoonotic diarrhoeal disease constitutes 9 % of the infectious disease burden and 4 % of the total burden. In estimating the disease burden of non food-borne zoonoses, we considered tetanus, Japanese encephalitis, Chagas disease, trypanosomiasis and leishmaniasis as predominantly zoonotic. For diseases with both zoonotic and anthroponotic components (tuberculosis, filiariasis and schistosomiasis), we used literature estimates for the proportion of disease which was zoonotic (Cataldi and Romano 2007; King and Freedman 2000). We estimated zoonotic disease other than diarrhoea represents 3.6 % of infectious disease and 1.4 % of the total burden. Disease recently emerged from animals (HIV) represents 13 % of infectious disease and 5 % of the total. Overall, zoonoses or diseases which recently emerged from animals make up 26 % of the infectious disease burden and 10 % of the total burden in low income countries. Among high income countries, zoonoses are responsible for just 0.7 % of the infectious disease burden and 0.02 % of the total burden (in terms of lost DALYs).

In addition, malnutrition makes up 3 % of the total burden of lost DALYs in low income countries. Malnutrition is inextricably linked to zoonoses: diseases such as cryptosporidiosis strongly predispose to malnutrition and vice versa. As well as potentially transmitting diseases, animal source foods are a vital source of micronutrients and high biological value protein, so, while avoiding animal source foods may reduce exposure to zoonotic pathogens, it may lead to malnutrition which in turn increases susceptibility to pathogens. Our analysis shows that the great burden of zoonoses is born by the poor.

Other approaches to assessing zoonoses

One of the first systematic attempts to rank zoonoses was a global study by the International Livestock Research Institute (Perry et al. 2002). This consisted of an evidence-based expert ranking which took into account socioeconomic, national and zoonotic impacts. Other rankings of livestock diseases reviewed by Perry and Grace (2009) include: the list of notifiable diseases by the World Animal Health Organisation (OIE); a listing by the Global Alliance for Livestock Veterinary Medicines of 13 poverty relevant livestock; and a listing of diseases important to the poor developed by participatory ranking. All include zoonoses, but because these lists are based on expert opinion, use differing criteria for gauging importance and, often, lack clear specifications on how the criteria are weighted or combined, there is wide divergence between the different lists in terms of which zoonoses appear on them and their relative ranking.

Lack of structured and transparent frameworks for prioritisation of zoonotic diseases can lead to decision-making of dubious rationality. In one African country, experts from the livestock and human health both included foot and mouth disease and New Castle disease (sic.) in their list of key zoonoses but neither list included campylobacteriosis or cryptosporidiosis (Anon 2010); the disease burden of which is undoubtedly several orders of magnitude higher than the two mentioned zoonoses. Another survey of key decision-makers in the field of emerging infectious disease in Southeast Asia found that avian influenza was considered the most important zoonosis, a ranking that seemed to reflect donor priorities rather than impact on poor people (Grace et al. 2010).

An ecohealth framework for better assessing zoonotic diseases

We argue that while GBD metrics capture important aspects of the significance of zoonoses, a more comprehensive understanding that takes into account the broader impacts of zoonotic diseases would be useful for developing countries. Ecohealth is one such holistic framework for understanding human, animal and environmental health. Ecohealth emerged from the 1990s linking environmental hazards, human well-being, natural resource management and human health (Cole et al. 2006). Early projects were mostly concerned with environmental hazards, while later work has extended to zoonoses, food safety, agriculture-associated disease and emerging infectious disease. Recent

[1] Cumulative number of confirmed human cases of avian influenza A/(H5N1) up to 22 July 2010 reported to WHO.

years have seen increasing alignment between ecohealth and other multi-disciplinary, holistic frameworks such as One Health (Zinsstag et al. 2011). While problem-oriented medicine underlies clinical medicine, ecohealth is at its core a solution-oriented methodology (Lebel 2003). It shifts the focus of research from assessment and diagnosis to management and communication, and a key principle is engagement of both decision-makers and local communities. An ecohealth perspective, that recognises the interdependence of human, animal and ecosystem health and the important influence of social, political and economic subsystems on health outcomes, could make costs of zoonoses more visible and a framework for this is proposed in Table 1.

Rational prioritisation takes into account not only the magnitude of the problem but also the attractiveness of the potential solutions. Questions of technical effectiveness of possible options and costs of implementation have long been part of the assessment of health interventions. Lately, realisation has grown that these are not enough to ensure uptake and sustainability of health interventions. Fortunately, socioeconomics, policy, psychology, innovation systems and other fields of research are helping to bridge the gap from knowledge to use (Kristjanson et al. 2009); ecohealth approaches incorporate much of this thinking.

A main pillar of ecohealth is participation: that is the involvement of communities, decision-makers and researchers as partners in developing health solutions. Participatory approaches are a family of methods with the core assumption that people must participate fully in the processes of learning about their needs and opportunities and in the action required to address them. Participatory approaches have been shown to be more effective, more sustainable, less costly and more ethical in their inclusion of the poor in the planning and decisions that affect them than top-down, outsider-led initiatives (Duraiappah et al. 2005). Participation brings ethics and values to the debate on health care decision-making. For example, most people are concerned with fairness in health care; where women are systematically disadvantaged and disempowered then stakeholders may wish to prioritise DALYs lost by women and children. Ecohealth approaches often explicitly acknowledge gender and social equity as another fundamental principle. Participatory processes incorporate the preferences of stakeholders. As such, they recognise that disease is only one problem which communities face, and that controlling disease may be desirable from a public health perspective but undesirable from a community perspective (if, for example, strict food safety regulations mean poor farmers are pushed out of markets).

Complex, interconnected and multifaceted problems tend to elude simple, one-shot solutions. There are many definitions of transdisciplinarity: some emphasise the transcending of disciplines to develop solutions that are the result of synergistic collaboration and so greater than the sum of disciplinary inputs (Rosenfield 1992). Other definitions emphasise the inclusion of decision-makers and communities in research for health (Lebel 2003). In either case, solving non-straightforward problems often requires a combination of disciplines and actors that by working together achieve more than the sum of their individual contributions. An ecohealth approach to zoonosis prioritisation would involve the insights from multiple disciplines to understand the multiple burdens of disease.

Ecohealth thinking also stresses looking beyond management of the symptoms to address the 'causes of causes' which underpin the more obvious drivers. For example, while

Table 1 The multiple burdens of zoonotic disease: human, animal and ecosystem health

	Actors	Cost of illness	Cost of prevention	Intangible and opportunity costs
Private	Individual and household	**Treatment costs (e.g. medication), loss of household production**	*Risk mitigation such as boiling water, buying filters*	***Disutility of ill health for individual (DALY)***
				Disutility of ill health for friends, family, etc.[a]
	Livestock sector	**Cost of treatment, herd slaughter, product recall, mortality, morbidity, lower production, loss of export**	*Costs of increased biosecurity, vaccination, practices and procedures to control disease along the value chain*	Cost of future emerging disease[a]
				Loss of animal genetic resources[a]
Public	Health (human and animal)	**Treatment costs (hospital provision, etc.), outbreak costs, movement restrictions, culling, vaccination**	*Risk mitigation such as water fluoridation, vaccination* *Disease surveillance, research*	Loss of opportunities occasioned by spending on disease prevention and cure[a]
	Ecosystem	*Spill-over into wildlife, loss of ecosystem services*	*Biosecurity, avoiding wildlife and vectors, disease surveillance, research*	

Market prices available and commonly included in economic assessments of disease—bold; market prices less available and commonly ignored in economic assessments of disease—italics; included in health metrics (DALYs)—bold italics

[a] Market prices not available but costs can be estimated through other methods

improving biosecurity may be a quick fix to the problem of avian influenza, systems-based thinking might look at reducing the intensity of poultry production and its proximity to wetlands.

What then would an ecohealth-informed prioritisation of zoonoses look like? We next present a hypothetical framework based on the authors' ongoing research work in Africa and Asia (Grace and Randolph 2009) and provide an example of ecohealth-informed decision-making for zoonosis prioritisation which takes into account stakeholders' values and opinions, local context and impacts and issues that cut across disciplines.

An example of participatory prioritisation of health risks using an ecohealth framework

The process starts when communities, decision-makers or researchers are concerned over a potential health problem. In this example, we explore the risks associated with raw milk. Next, stakeholders are identified: these include all those who are affected negatively or positively by the problem or who would be affected by potential solutions. In our example, this would certainly include milk producers, milk hawkers, milk processors, milk retailers, consumers, animal health service providers, human health service providers and regulators of the milk trade.

The next stage consists of better understanding the problem. This may include participatory analyses with different groups of stakeholders using tools like problem tree, ranking and rating and mapping to better understand the problem associated with raw milk (who consumes it, how much, what is the evidence for harm, who benefits from selling raw milk, how much, etc.). These analyses can be complemented with rapid epidemiological surveys to identify the hazards present in raw milk.

Once information is gathered, stakeholders meet to decide what, if anything, needs to be done about the problem. If action is necessary, then participatory planning can be used to decide what to tackle first. Part of this could be prioritising specific zoonoses.

Table 2 is an example of a matrix which incorporates stakeholders' concerns and information about how relevant they are to the pathogens present in raw milk and which can help in decision-making. The matrix is populated as follows. First, zoonoses are selected from the universe of all possible zoonoses that may be a problem in this context. This can be done by a systematic literature review, expert opinion, participatory methods, rapid surveys or some combination of these. Next, stakeholders identify the criteria which are important to them in prioritising zoonoses and give these a weight according to how important they are (criteria weights). Stakeholders are encouraged to look at the roots of problems and to understand the interdependence of human, animal and ecosystem health.

In our example, stakeholders considered four important criteria and weighted them as follows (criteria weights):

The pathogen causes a severe illness in people = weight 3.
The pathogen also causes disease in cattle = weight 2.
The pathogen is easy to control = weight 1.
The pathogen is common (high prevalence) = weight 1.

Next, stakeholders with the help of researchers rank zoonoses in terms of how relevant the criterion is to the pathogen (relevance weights). This requires understanding of epidemiology; economics of disease losses and control costs; the social and gender determinants of risk and impact; and the policy implications of control. Then, criterion weights are multiplied by relevance weights and summed to obtain an overall score for each zoonosis considered. Finally, stakeholders 'interview" the matrix: that is discussed together and see how it helps achieve consensus on what problem to tackle first.

Utility of an ecohealth approach to disease prioritisation

What cannot be measured, cannot be managed, and in this paper, we argue that failure to take into account the multiple burdens associated with zoonoses may lead to decision-making that does not reflect the priorities of stakeholders. Comprehensively measuring the economic, social and environmental costs of zoonoses in developing countries could prove prohibitively expensive and we propose an alternative

Table 2 Matrix to help understand which zoonoses are important to stakeholders based on importance weight (IW) and relevance weight (RW)

Criteria and (IW)/condition (RW)	Severe illness (3)		Common (1)		Affects cattle (2)		Easy control (1)		Sum
	RW	RW × IW	RW	RW × IW	RW	RW × IW	RW	RW × IW	
Brucella abortus	3	9	2	2	3	6	1	1	18
Cryptosporidium parvum	2	6	3	3	1	2	2	2	13
Mycobacterium bovis	3	9	1	1	3	6	1	1	17
Diarrhoeagenic *Escherichia coli*	2	6	2	2	1	2	2	2	12
Antibiotic residues	1	3	2	2	1	2	2	2	9

based on rapid and participatory methods. By viewing the assessment of multiple disease burdens through the lens of community perceptions, the approach obviates the need for complex data collection and modelling and also speaks directly to the concerns of stakeholders.

This approach is not an alternative to disease burden or economic assessment, but rather a pragmatic approach to produce actionable priorities for specific communities: health and economic assessments, privilege objectivity and wide generalisation; this method is context-specific and subjective. As such, the method is aligned with participatory planning for communities.

Conclusions

DALYs have been an important innovation and are very useful at doing what they set out to do, that is, measuring the burden of human health in terms of death and disability. Our analysis shows that zoonoses and diseases which emerged from animals make up around one quarter of the infectious disease burden in low income countries. Given that infectious disease is responsible for 40 % of the total burden, zoonoses and diseases recently emerged from animals represent a major public health problem. In contrast, these diseases have much less impact in high income countries, and this may contribute to their global neglect. While DALYs are the best global measure of sickness and death due to infectious disease, as a human health centric measure, they only capture one of the multiple burdens of zoonoses. Other important impacts include cost of human illness, losses borne by the livestock sector and impairment of ecosystem ability to provide health-regulating services. Rational risk management should be driven not only by the multiple burdens of disease, but by the attractiveness of strategies available to deal with diseases. Ecohealth/One Health approaches to disease prioritisation offer a framework for a comprehensive assessment which incorporates stakeholder perspectives, can deal with complexity and trade-offs, meets the unique needs of communities and is relatively inexpensive and easy to apply.

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