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Minireview

MINIREVIEW – Environmental Microbiology

Climate change and One Health

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One sentence summary: A One Health approach is advantageous for the adaptation to climate change effects on the health of humans and animals concurrently.

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ABSTRACT

The journal *The Lancet* recently published a countdown on health and climate change. Attention was focused solely on humans. However, animals, including wildlife, livestock and pets, may also be impacted by climate change. Complementary to the high relevance of awareness rising for protecting humans against climate change, here we present a One Health approach, which aims at the simultaneous protection of humans, animals and the environment from climate change impacts (climate change adaptation). We postulate that integrated approaches save human and animal lives and reduce

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costs when compared to public and animal health sectors working separately. A One Health approach to climate change adaptation may significantly contribute to food security with emphasis on animal source foods, extensive livestock systems, particularly ruminant livestock, environmental sanitation, and steps towards regional and global integrated syndromic surveillance and response systems. The cost of outbreaks of emerging vector-borne zoonotic pathogens may be much lower if they are detected early in the vector or in livestock rather than later in humans. Therefore, integrated community-based surveillance of zoonoses is a promising avenue to reduce health effects of climate change.

Keywords: One Health; climate change; animals; livestock; surveillance and response; mitigation

INTRODUCTION

The journal *The Lancet* recently published a countdown on health and climate change to track the effects of mitigating climate change on public health (Watts *et al.* 2017). It provides an extensive plan on the reduction of greenhouse gas emissions and the reduction of climate change. However, the paper focuses on human public health effects of climate change alone, neglecting the important animal and environmental health. Addressing the effects of climate change and climate variability on health in concert illustrates the difficulty to disentangle them from numerous other phenomena of global change. Climate change is superposed by demographic, social and economic, environmental and landscape changes (Hwang *et al.* 2017) which often cannot clearly be separately delineated (de Anda 2017). Modifications in vector, reservoir and pathogen lifecycles as well as diseases of domestic and wild animals and plants are influenced by multiple complex processes (Semenza and Suk 2017). This also applies to the disruption of synchrony between interacting species, trophic cascades and alteration or destruction of habitats (Patz and Hahn 2013; Stevenson *et al.* 2015).

Consequently, we argue that the ecosystem approaches to health framework, which recognize the inextricable linkage of humans, animals and their environment and social context (Forget and Lebel 2001; Charron 2012; Martin-Diaz *et al.* 2017) or health in social-ecological systems (Zinsstag *et al.* 2011) would offer a more comprehensive and broader context to address the effect of climate change on health.

Apart from the above broader concept, we present a framework to complement *The Lancet* Countdown and extend the conceptual thinking to animal health, assessing the effects of climate change on what we call One Health, an integrated view of health of humans, animals and plants (Zinsstag *et al.* 2005, 2015; Blaha 2012; Patz and Hahn 2013). In this paper, we limit our analysis to One Health and do not address climate change mitigation, which is well outlined by (Watts *et al.* 2017). The aim of this review is to (i) demonstrate advantages of integrated One Health approaches compared to conventional separated public and animal health approaches and (ii) examine the potential of One Health to adaptation to effects of climate change.

ONE HEALTH

We define One Health as any added value in terms of human and animal lives saved, reduced cost and sustained social and environmental services that can be achieved by a closer cooperation of human and animal health and other disciplines which could not be achieved if the sectors worked separately (Zinsstag 2015) (Table 1). For example, joint human and animal vaccination services for mobile pastoralists provide access to health care for populations which would otherwise be excluded and saves financial resources while sharing the cold chain and transport costs between human and animal health services (Schelling *et al.* 2005). As an example for a One Health approach to zoonoses control, it could be demonstrated that the benefits of brucellosis control for public health in Mongolia alone would not justify the cost of mass vaccination of livestock to prevent human brucellosis. But if all benefits of livestock brucellosis vaccination in the health and agricultural sectors are summed up, the societal benefits of livestock mass vaccination are three times higher than the intervention cost (Roth *et al.* 2003). Likewise, the annual cost of human post-exposure prophylaxis (PEP) from dog rabies is less than the cost of dog mass vaccination. However, the cumulative cost of dog mass vaccination with PEP is equal to the cumulative cost of PEP alone after 10 years as long as rabies is not re-introduced (Fig. 1) (Zinsstag *et al.* 2009; Mindekem *et al.* 2017). Savings can also be achieved from shared infrastructure. The World Bank estimates a saving of 26% of the operations cost of the Canadian Science Centre in Winnipeg, hosting laboratories for human and animal highly contagious diseases under one roof (World-Bank 2012). The recent outbreak of Q-fever in the Netherlands with several thousand human cases could probably have been largely avoided if the veterinary and public health authorities had maintained continuous communication (Enserink 2010). Conversely, the integrated animal and human surveillance of West Nile Virus (WNV) in Emilia Romagna, Italy, shows savings of more than one million Euro, as compared to separate sectorial disease surveillance (Paternoster *et al.* 2017).

Similar savings have not yet been assessed but can be expected from food-borne zoonoses like salmonellosis and campylobacteriosis. Campylobacteriosis is one of the most important bacterial food-borne illnesses in humans caused, among others, through infection via handling and consumption of poultry meat. It is attributable to more than half of the Swiss winter peak of acute gastroenteritis (Bless *et al.* 2014) and for 40% of human campylobacteriosis cases in Belgium incurring over 10 million Euros annually of health care costs each in Belgium and Switzerland (Gellynck *et al.* 2008; Schmutz *et al.* 2017). Lowering *Campylobacter* spp. contamination of fresh poultry meat is feasible and cost-effective and has significantly reduced notifications of campylobacteriosis (by 52%) and hospitalizations for Guillain-Barré syndrome (by 13%) in New Zealand (Baker *et al.* 2012). In the following we examine the potential of such synergistic benefits of a closer cooperation of human and animal health to adapt to the effects of climate change.

CLIMATE CHANGE

Unequivocally, there is a warming of planet Earth since the 1950s, with increased temperatures of the atmosphere and the oceans. The amount of ice and snow has diminished; sea levels have risen; and an increased frequency of extreme weather

Table 1. Examples of added value of One Health compared to separated human and animal health approaches.

Domain	Added value	Reference
Health services	Joint human and animal vaccination services for mobile pastoralists provide access to health care for populations which would otherwise be excluded and save financial resources.	Schelling *et al.* (2005)
Zoonoses control	Mass vaccination of livestock against brucellosis does not only benefit public health, but is three times more profitable from a societal perspective.	Roth *et al.* (2003)
	Dog mass vaccination and human post-exposure prophylaxis is less costly than human post-exposure prophylaxis after 10 years	Zinsstag *et al.* (2009); Mindekem *et al.* (2017)
Surveillance and response	Integrated surveillance and response of West Nile Virus saves more than one million Euro compared to separate human and animal surveillance.	Paternoster *et al.* (2017)
Infrastructure	The Canadian Science Centre in Winnipeg, hosting laboratories under one roof for highly contagious diseases affecting humans and animals alike saves 26% of the operations cost, compared to two separate human and animal health laboratories.	World-Bank (2012)
Communication	The recent outbreak of Q-fever in the Netherlands with several thousand human cases could probably have been largely avoided if the veterinary and public health authorities had maintained continuous communication.	Enserink (2010)

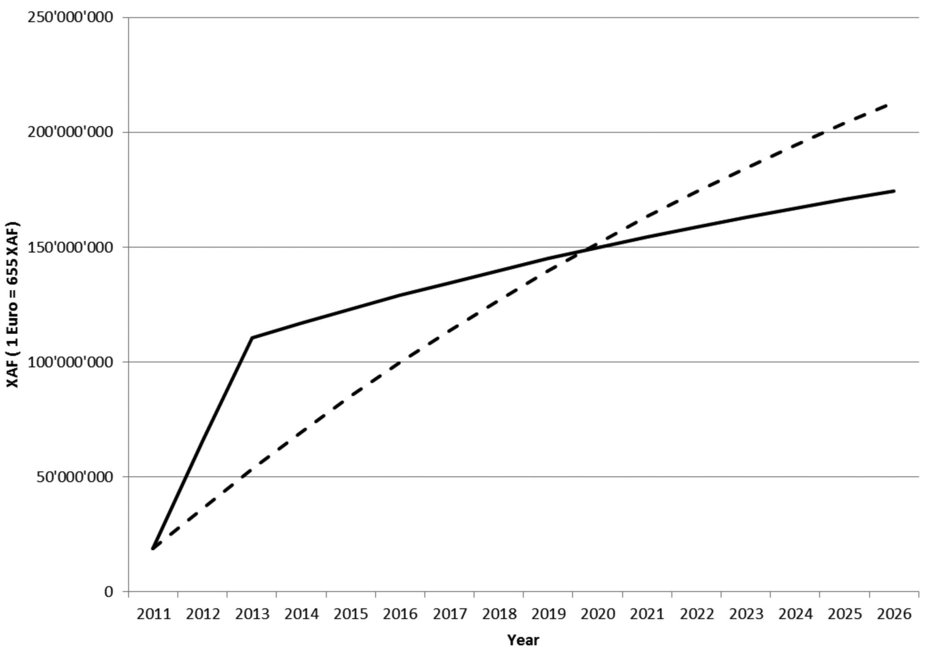

Figure 1. Cumulative cost in XAF (1 Euro = 655 XAF) of human post-exposure prophylaxis (PEP) against dog rabies (dashed line) and dog mass vaccination and PEP (black line) in N'Djaména, Chad (adapted from Mindekem *et al.* 2017).

events, heat waves, drought, floods, storms are observed in parallel to an increase of the concentration of greenhouse gases (IPCC 2014). Climate change affects a large number of sectors. This means that integrated approaches and intersectoral collaboration are essential to face such challenges. The authors restrict this analysis to the added value of One Health approaches to adapt to health effects of climate change.

REVIEW METHOD

The purpose of this minireview is to propose novel conceptual thinking on integrated approaches for health of humans, animals and plants in relation to climate change. For this review, we initially tested the search strategy by considering the public databases of peer-reviewed literature included by Web of

Science and PubMed from 2007 to date using keyword algorithms because One Health was not a recognized MESH term. Using a topic search, in Web of Science 1452 hits were returned while in PubMed 1070 hits were returned. Restricting the search field to title/abstract was possible in the PubMed database but not in Web of Science. Within the scope of our minireview, we deemed that sufficiently relevant publications should at least mention the keywords in the abstracts. Thus, we used the terms 'climate change' AND 'One Health' in the PubMed database with the search restricted to title/abstract in the timeframe from 2012 until 3 November 2017. We selected the time frame assuming that climate change and One Health as related topics were likely addressed only in the last decade. A test search expanding the time frame to the last 15 years returned exactly the same results. From 38 results, 35 were included following abstract review. One was excluded because no abstract was available, one was excluded as irrelevant because it investigated an extreme bush fire event and there was one duplicate. Twenty-nine full texts were freely available and included (see onlineAppendix).

The gathered information from the relevant papers was scrutinized for topics and issues related to climate change that do or would benefit from integrated approaches to health and from which an added value of a closer cooperation of human and animal health could be expected, based on our previous experience as outlined above. In the selected papers, the topics of food security and safety and extensive livestock systems and pastoralism were found prominently cited in relation to climate change, environmental sanitation appeared as a further topic of the interaction of climate change and One Health followed by the potential of integrated surveillance and response systems in relation to climate change-related emerging diseases. These themes are clearly not exhaustive, and further potential of One Health to mitigate the effects of the changing climate can be expected in the near future.

THE ADDED VALUE OF ONE HEALTH TO CLIMATE CHANGE ADAPTATION

Complementary to *The Lancet* Countdown on climate change (Watts *et al.* 2017), a One Health approach to climate change, without being exhaustive, may significantly contribute to the following contexts and issues: food security with particular emphasis on animal source foods, extensive livestock systems, especially the role of ruminant livestock, antimicrobial resistance control, environmental sanitation, and steps towards regional and global integrated syndromic surveillance and response systems. Arctic regions appeared as highly vulnerable to zoonotic disease (Dudley *et al.* 2015; Ruscio *et al.* 2015), although other geographic regions like drylands and mountains are also hotspots of climate change.

FOOD SECURITY AND FOOD SAFETY

Food security is addressed by *The Lancet* Countdown from a public health perspective but does not address ecological sustainability of food security (Batsukh *et al.* 2013). In semi-arid and highland areas, people require livestock for livelihoods and food security, using both fresh and transformed animal source foods (Jans, Mulwa Kaindi and Meile 2016). Black and Butler (2014) refer to the complex nature of climate change and food security and integrated approaches to health which could lead to a new theory of health as an outcome of social-ecological systems (Zinsstag *et al.* 2011). In our experience in North Mali, Chad and the Ethiopian Somali Regional State droughts affect not only humans but often kill significantly more livestock than humans with catastrophic consequences not only in milk-based dietary systems (Bechir *et al.* 2010). In many communities, minor disturbances in livestock strongly affect accessibility and availability of animal source foods, thereby decreasing opportunities for a diversified and nutritious diet and hence increasing the risk of malnutrition (FAO 2011). Observations of cereal and livestock prices are crucial for early detection of hunger crises (Bechir 2010). Heat stress affects many animals and food crops, reducing performance, growth and yield and likely also leading to increased animal mortality (Daramola, Abioja and Onagbesan 2012; Fahad *et al.* 2017). Conversely, climate change in temperate zones increases the vegetation period. However, to effectively translate prolonged vegetative periods into production growth, significant changes in agricultural systems and practices are required (FAO 2016).

EXTENSIVE LIVESTOCK SYSTEMS

The effect of methane production from rumination on climate change is known (Watts *et al.* 2017). A broader examination of this issue reveals that the ongoing increase of livestock production in the developing world elevates millions of small scale farmers out of the poverty trap (FAO 2011). At the same time, enormous increases in meat consumption in emerging middle classes in low and middle income countries contribute, albeit not exclusively, to an epidemiological transition and double burden of communicable and non-communicable diseases (Boutayeb 2006). As mentioned above, large areas of the world, for instance, semi-arid high and lowlands, could not sustain human life without use of livestock (Zinsstag *et al.* 2016). Climate change with increased droughts requires a high flexibility of mobile pastoralists and may lead to increased social conflicts when they must move into areas used by others (Herrero *et al.* 2016). An integrated societal view on global livestock production argues that ruminant livestock rearing should, within the limits of capacity of such social-ecological systems, be concentrated in semi-arid areas which cannot be used otherwise. In parallel, ruminant feedlot production would be stabilized or even decreased to reduce the climate impact of ruminant livestock and reserve substantial cereal food resources for human consumption. Altogether, a stabilization or reduction of global ruminant meat consumption seems inevitable and may have additional positive health effects.

INTEGRATED APPROACHES TO SAFE WATER, ENVIRONMENTAL SANITATION AND HYGIENE

Water, sanitation and hygiene (WASH) is an essential component of public health and of the One Health approach. Inappropriate animal and human excreta management can both contribute to the pollution of the environment (e.g. water and soils) and the spread of antimicrobial resistance and hence need to be managed jointly. Climate change leads to more frequent periods of high precipitation causing an excess in runoff and associated wash-off of human and animal feces containing zoonotic pathogens from manure-fertilized fields or open defecation to surface and drinking water sources will potentially increase the risk of disease outbreaks (Sterk *et al.* 2013, 2016). Increased extreme events such as hurricanes and flooding, for example, have been associated with the emergence of leptospirosis that necessitates close study of the animal reservoirs (Mwachui *et al.*

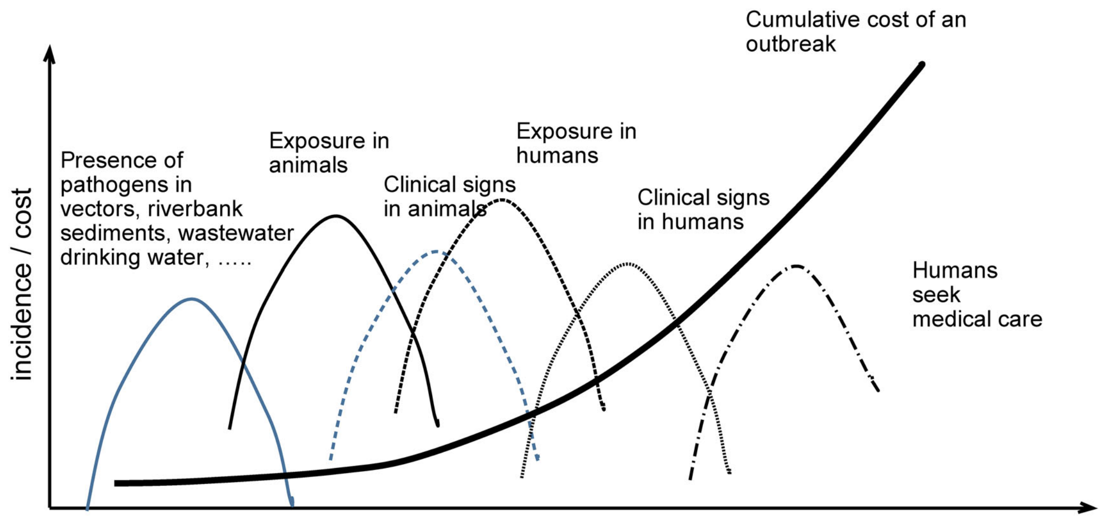

Figure 2. Schematic relationship of time to detection of an emerging pathogen and its cumulative cost of control. (Adapted and expanded from World-Bank 2012.)

2015). Similarly, for example, open defection of humans poses a risk for cysticercosis in cattle (Flutsch *et al.* 2008). This has also been shown for cryptosporidiosis and giardia in Africa (Squire and Ryan 2017). The link between climate change and diarrhea, a very sensitive disease to environmental sanitation conditions, has been highlighted in a number of recent studies (Thiam *et al.* 2017). Water and sanitation systems are very much sensitive to climate change extreme events, with particular challenges in urban contexts (Sherpa *et al.* 2014; Cissé *et al.* 2016). Climate warming also may lead to increased occurrence and relevance of non-cholera vibriosis in humans (Huehn *et al.* 2014). Pollution of riverbank sediments should be considered as an early warning sign for human and animal health, notably also in regard to coastal seafood production (Martin-Diaz *et al.* 2017). Safe procedures of integrated animal and human excrement recycling may reduce zoonotic disease risk and maintain valuable limited nutrient resources for food production (Nguyen-Viet *et al.* 2009; Dahal, Upadhyay and Ewald 2017). Such procedures include the composting of human and animal excreta (Zhang *et al.* 2014; Vu-Van *et al.* 2017). New double vault composting latrines reduce the number of viable *Ascaris suum* eggs and provide hygienically acceptable fertilizer (Jensen *et al.* 2009). Besides infectious diseases, further risk arises from high levels of mercury and persistent organic pollutants circulating within terrestrial and aquatic ecosystems which are a major concern for the reproductive health of humans (Dudley *et al.* 2015). Many sectors (particularly agriculture, water and health) are very much interconnected. Many African states cannot afford allocating to any of these sectors sufficient resources to achieve, for example, their related targets for Sustainable Development Goals. In that context, the challenges of climate change in environmental sanitation sector are huge, and integrated approaches, like the reduction of open defecation or low cost water cleaning beds while producing animal feed, can contribute a lot in facing these, particularly in Africa (Butler *et al.* 2014). Experts from the different sectors could work together in the elaboration of evidence-based sanitation safety plans (WHO 2015). The wider consideration of integrated approaches could bring the sectors working much closely together particularly in the domain of safety of water, integrated environmental sanitation and hygiene at different levels. The integrated management entails proper water protection, efficient waste treatment methods (at the household and community levels) including tailored safe recovery, recycling, and reuse of both human and animal excreta, designing appropriate technologies, setting relevant policies and promoting hygiene in the different contexts. More specifically, a number of interventions are recommended to reduce the exposure of humans to animal feces, e.g. proper disposing of both animal feces, creating safe child spaces in households, reducing cohabitation with animals, controlling animal movements, and promoting handwashing and domestic environment hygiene (Penakalapati *et al.* 2017). Transdisciplinary approaches, engaging scientists with communities and authorities, are proposed for sustainable problem solving (Ruscio *et al.* 2015), and such approaches are an integral part of One Health (Schelling *et al.* 2007; Zinsstag 2015).

TOWARDS REGIONAL AND GLOBAL INTEGRATED SURVEILLANCE–RESPONSE SYSTEMS

Integrated human and animal surveillance and response systems (iSRS) are one of the most important contributions of a One Health approach to mitigate effects of climate change. While public health surveillance is restricted to humans, understanding vector-borne diseases and climate change per se call for an integrated One Health approach (Semenza and Zeller 2014; Elbers, Koenraadt and Meiswinkel 2015). The above-mentioned example of integrated WNV surveillance in mosquitos, birds, horses and humans is a case in point (Paternoster *et al.* 2017). The World Bank makes a compelling case for integrated human and animal surveillance (Fig. 2), emphasizing that if emerging diseases can already be detected in vectors, livestock or wildlife, prior to detection in humans, very large costs could be averted (World-Bank 2012; Heymann and Dixon 2013). Savings of 344 to 360 billion USD over the next 100 years are expected from use of integrated surveillance of zoonoses with a pandemic potential (Pike *et al.* 2014). Savings from early detection of pathogens in vectors would not only apply to vector-borne zoonoses but also for vector-transmitted diseases like dengue fever (Li and Wu 2015).

Unfortunately, public and animal health surveillance systems often fail to communicate. For example, an outbreak of

Rift Valley fever (RVF) in Mauritania was mistaken for yellow fever and detected only after communication with the veterinary services who observed abortions due to RVF in livestock (Digoutte 1999). Febrile illness in Bamako, Mali, is most often associated with malaria, ignoring the importance of zoonotic diseases like brucellosis or Q-fever (Steinmann *et al*. 2005). Similarly, the Dutch public health authorities complained that more than 3000 cases of human Q-fever could have been prevented if the veterinary services had communicated a large outbreak in goats (Enserink 2010). It makes a lot of sense that the surveillance of vector-borne zoonoses is coupled between entomological, animal and human surveillance systems, e.g. for Japanese encephalitis virus in China (Baylis *et al*. 2016), borreliosis in Serbia (Savic *et al*. 2014) or West Nile Fever in Europe(Gossner *et al*. 2017). Such iSRS should also include terrestrial wildlife (Singh and Gajadhar 2014) and marine animals (Stephen 2014). The importance of including wildlife in iSRS is further demonstrated by the example of blood transcriptomes in lemurs that reveal novel parasitic zoonoses in Madacascar (Larsen *et al*. 2016). In South Korea, migration of wildlife, international human movement and illegal importation of wildlife were identified as the main risks for pathogen introduction into the country (Hwang *et al*. 2017). Individual countries like Mongolia are currently developing One Health iSRS systems (Batsukh *et al*. 2013), while others are proposed (Cheng, Mantovani and Frazzoli 2017).

In addition to integration of human and animal disease surveillance, modern communication technologies (Seid *et al*. 2016) used at the community level will provide the highest surveillance sensitivity and be instrumental in reducing time to detection and hastening etiological confirmation of pathogens responsible for outbreaks. Mobile technologies, in particular, can assist in the early detection of zoonoses and provide the opportunity to intervene before a few infections can turn into an epidemic. With mobile devices such as smartphones, relevant data can be collected and analyzed in near real time. These new opportunities have led to the emergence of infodemiology (Eysenbach 2011), a new discipline within public health informatics which includes applications such as the capturing of critical incidents regarding animal and human health to predict disease outbreaks, monitoring and tracking them for syndromic surveillance and sending alerts to the appropriate health authorities (Jean-Richard *et al*. 2014; Toda *et al*. 2017). Social media platforms also serve as novel sources of rich observational data for health research including infodemiology. However, the challenge often does not lie in the availability of relevant information, but in its aggregation and analysis. For this purpose, standards of reporting data sources and quality are needed so that data scientists and One Health experts can evaluate and compare methods and findings across studies and sectors (Schelling and Hattendorf 2015; Kim, Huang and Emery 2016).

Control and elimination of many zoonoses requires regional coordination to avoid re-introduction and to plan effective strategies for sustainable elimination. For example, bioregional approaches are proposed between Mexico and the USA (Pezzoli *et al*. 2014) and between the countries of the former Soviet Union (Bartholomew *et al*. 2015). Regional initiatives like the European Early Warning and Response System (EWRS, https://ewrs.ecdc.europa.eu/accessed 31 December 2017) would have the potential to be cross linked with animal disease surveillance. Global initiatives like the Global Outbreak Alert and Response Network (GOARN) http://www.who.int/ihr/alert_and_response/outbreak-network/en/ currently concentrate only on public health institutions, but the joint FAO-OIE-WHO Global early warning system for health threats and emerging risks at the human–animal–ecosystems interface (GLEWS www.glews.net) is a truly integrated global iSRS.

ONE HEALTH EDUCATION

One Health approaches show clear advantages over conventional public and animal health approaches not only for adaptation to and mitigation of climate change (Shomaker, Green and Yandow 2013), but also for surveillance of antimicrobial resistance and many non-communicable diseases. A main problem is lack of intersectoral collaboration, and particularly between the medical and veterinary communities, perhaps due to already full curricula with little time for adding integrated courses, despite evidence for the higher cost of over-specialization and lack of communication between sectors (Enserink 2010). There is an urgent need to include One Health meaningfully into medical and veterinary curricula (Rabinowitz *et al*. 2017), and the first massive open access online course already exists (www.futurelearn.com/courses/one-health accessed 31 December 2017). And (www.coursera.org/learn/global-health-human-animal-ecosystem accessed 31 December 2017). There is no need for new ministries or academic institutions if people are well trained and informed. Existing legal systems are adequate to regulate professional services in all sectors, but mechanisms to work better together and to communicate fully between the involved sectors of human health, animal health and environmental heath are of high priority (Videla and Urzua 2014).

CONCLUSION

Here we presented an account of the unmatched value of a One Health approach over the conventional public health approach. Its advantages go beyond human and animal health. One Health is well suited for community-based contextual problem solving through transdisciplinary processes. It is this aspect of One Health which suggests the groundbreaking directions in the pursuit of high networking of different disciplines and that garnered the attention of both scientific and non-scientific communities. In the case of climate change, integrated One Health approach offers societally meaningful collaborative efforts to reconcile scientific disciplines, policy making and local knowledge by engaging non-academic stakeholders and different academic disciplines to act together locally, nationally and globally to address and solve health problems related to climate change.

SUPPLEMENTARY DATA

Supplementary data are available at *FEMSLE* online.

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REFERENCES

Baker MG, Kvalsvig A, Zhang J *et al.* Declining Guillain-Barre syndrome after campylobacteriosis control, New Zealand, 1988–2010. *Emerg Infect Dis* 2012;**18**:226–33.

Bartholomew JC, Pearson AD, Stenseth NC *et al.* Building infectious disease research programs to promote security and enhance collaborations with countries of the former soviet union. *Front Public Health* 2015;**3**:271.

Batsukh Z, Tsolmon B, Otgonbaatar D *et al.* One Health in Mongolia. *Curr Top Microbiol Immunol* 2013;**366**:123–37.

Baylis M, Barker CM, Caminade C *et al.* Emergence or improved detection of Japanese encephalitis virus in the Himalayan highlands? *T Roy Soc Trop Med H* 2016;**110**: 209–11.

Bechir M. *Food quality, nutrition and food security in relation to milk production among nomadic pastoralists in Chad*. Thesis, University of Dakar. 2010.

Bechir M, Schelling E, Bonfoh B *et al.* Seasonal variations in the nutritional status of nomad and sedentary children less than 5 years of age living in the Sahel in Chad. *Med Trop* 2010;**70**:353–8.

Black PF, Butler CD. One Health in a world with climate change. *Rev Sci Tech* 2014;**33**:465–73.

Blaha T. One world–one health: the threat of emerging diseases. A European perspective. *Transboundary and emerging diseases* 2012;**59**(Suppl 1):3–8.

Bless PJ, Schmutz C, Suter K *et al.* A tradition and an epidemic: determinants of the campylobacteriosis winter peak in Switzerland. *Eur J Epidemiol* 2014;**29**:527–37.

Boutayeb A. The double burden of communicable and non-communicable diseases in developing countries. *T Roy Soc Trop Med H* 2006;**100**:191–9.

Butler CD, Mathieson A, Bowles DC *et al.* Climate change and health in Africa. In: Butler C (ed). *Climate Change and Global Health*. Oxfordshire: CAB International, 2014, 218–27.

Charron DF. Ecosystem approaches to health for a global sustainability agenda. *EcoHealth* 2012;**9**:256–66.

Cheng R, Mantovani A, Frazzoli C. Analysis of food safety and security challenges in emerging African food producing areas through a One Health Lens: the dairy chains in Mali. *J Food Protect* 2017;**80**:57–67.

Cissé G, Traoré D, Touray S *et al.* Vulnerabilities of water and sanitation at households and community levels in face of climate variability and change: trends from historical climate time series in a West African medium-sized town. *Int J Global Environ Issues* 2016;**15**:81–99.

Dahal R, Upadhyay A, Ewald B. One Health in South Asia and its challenges in implementation from stakeholder perspective. *Vet Rec* 2017;**181**:626.

Daramola JO, Abioja MO, Onagbesan OM. Heat stress impact on livestock production. In: Sejian V, Naqvi, SMK, Ezeji T *et al.* (eds.) *Environmental Stress and Amelioration in Livestock Production*. Berlin, Heidelberg: Springer, 2012.

de Anda JH. ISVEE 14 Yucatan 2015 14th symposium of the international society for veterinary epidemiology and economics. *Prev Vet Med* 2017;**137**:109–11.

Digoutte JP. Present status of an arbovirus infection: yellow fever, its natural history of hemorrhagic fever, Rift Valley fever. *Bull Soc Pathol Exot* 1999;**92**:343–8.

Dudley JP, Hoberg EP, Jenkins EJ *et al.* Climate change in the North American Arctic: A One Health perspective. *EcoHealth* 2015;**12**:713–25.

Elbers AR, Koenraadt CJ, Meiswinkel R. Mosquitoes and Culicoides biting midges: vector range and the influence of climate change. *Rev Sci Tech* 2015;**34**:123–37.

Enserink M. Infectious diseases. Questions abound in Q-fever explosion in the Netherlands. *Science* 2010;**327**:266–7.

Eysenbach G. Infodemiology and infoveillance. *Am J Prev Med* 2011;**40**:S154–8.

Fahad S, Bajwa AA, Nazir U *et al.* Crop production under drought and heat stress: plant responses and management options. *Front Plant Sci* 2017;**8**:1147.

FAO. *World Livestock 2011 - Livestock in food security*. Rome, Italy. 2011.

FAO. *Climate Change and Food Security: Risks and Responses*. Rome, Italy. 2016.

Flutsch F, Heinzmann D, Mathis A *et al.* Case-control study to identify risk factors for bovine cysticercosis on farms in Switzerland. *Parasitology* 2008;**135**:641–6.

Forget G, Lebel J An ecosystem approach to human health. *Int J Occup Environ Health* 2001;**7**:S3–38.

Gellynck X, Messens W, Halet D *et al.* Economics of reducing Campylobacter at different levels within the Belgian poultry meat chain. *J Food Prot* 2008;**71**:479–85.

Gossner CM, Marrama L, Carson M *et al.* West Nile virus surveillance in Europe: moving towards an integrated animal-human-vector approach. *Euro Surveill* 2017;**22**:30526

Herrero M, Addison J, Bedelian C *et al.* Climate change and pastoralism: impacts, consequences and adaptation. *Rev Sci Tech* 2016;**35**:417–33.

Heymann DL, Dixon M. The value of the One Health approach: shifting from emergency response to prevention of zoonotic disease threats at their source. *Microbiol Spectr* 2013;**1**.

Huehn S, Eichhorn C, Urmersbach S *et al.* Pathogenic vibrios in environmental, seafood and clinical sources in Germany. *Int J Med Microbiol* 2014;**304**:843–50.

Hwang J, Lee K, Walsh D *et al.* Semi-quantitative assessment of disease risks at the human, livestock, wildlife interface for the Republic of Korea using a nationwide survey of experts: A model for other countries. *Transbound Emerg Dis* 2018;**65**:e155–64.

IPCC. Climate Change 2014: Synthesis Report. In: Core Writing Team Pachauri, RK, Meyer, MA (eds). *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland 2014, 151.

Jans C, Mulwa Kaindi DW, Meile L. Innovations in food preservation in pastoral zones. *Rev Sci Tech* 2016;**35**:597–610.

Jean-Richard V, Crump L, Moto Daugla D *et al.* The use of mobile phones for demographic surveillance of mobile pastoralists and their animals in Chad: proof of principle. *Global Health Action* 2014;**7**:23209.

Jensen PK, Phuc PD, Konradsen F *et al.* Survival of Ascaris eggs and hygienic quality of human excreta in Vietnamese composting latrines. *Environ Health* 2009;**8**:57.

Kim Y, Huang J, Emery S. Garbage in, garbage out: data collection, quality assessment and reporting standards for social

media data use in health research, infodemiology and digital disease detection. *J Med Internet Res* 2016;**18**:e41.
Larsen PA, Hayes CE, Williams CV *et al.* Blood transcriptomes reveal novel parasitic zoonoses circulating in Madagascar's lemurs. *Biol Lett* 2016;**12**:20150829.
Li Y, Wu S. Dengue: what it is and why there is more. *Sci Bull* 2015;**60**:661–4.
Martin-Diaz J, Garcia-Aljaro C, Pascual-Benito M *et al.* Microcosms for evaluating microbial indicator persistence and mobilization in fluvial sediments during rainfall events. *Water Res* 2017;**123**:623–31.
Mindekem R, Lechenne MS, Naissengar KS *et al.* Cost description and comparative cost efficiency of post-exposure prophylaxis and canine mass vaccination against rabies in N'Djamena, Chad. *Front Vet Sci* 2017;**4**:38.
Mwachui MA, Crump L, Hartskeerl R *et al.* Environmental and behavioural determinants of leptospirosis transmission: a systematic review. *PLoS Neglect Trop D* 2015;**9**:e0003843.
Nguyen-Viet H, Zinsstag J, Schertenleib R *et al.* Improving environmental sanitation, health, and well-being: a conceptual framework for integral interventions. *EcoHealth* 2009;**6**:180–91.
Paternoster G, Babo Martins S, Mattivi A *et al.* Economics of One Health: costs and benefits of integrated West Nile virus surveillance in Emilia-Romagna. *PLoS ONE* 2017;**12**:e0188156.
Patz JA, Hahn MB. Climate change and human health: a One Health approach. *Curr Top Microbiol Immunol* 2013;**366**:141–71.
Penakalapati G, Swarthout J, Delahoy MJ *et al.* Exposure to animal feces and human health: a systematic review and proposed research priorities. *Environ Sci Technol* 2017;**51**:11537–52.
Pezzoli K, Kozo J, Ferran K *et al.* One Bioregion/One Health: an integrative narrative for transboundary planning along the US-Mexico border. *Global Society* 2014;**28**:419–40.
Pike J, Bogich T, Elwood S *et al.* Economic optimization of a global strategy to address the pandemic threat. *P Natl Acad Sci USA* 2014;**111**:18519–23.
Rabinowitz PM, Natterson-Horowitz BJ, Kahn LH *et al.* Incorporating One Health into medical education. *BMC Med Educ* 2017;**17**:45.
Roth F, Zinsstag J, Orkhon D *et al.* Human health benefits from livestock vaccination for brucellosis: case study. *Bull World Health Organ* 2003;**81**:867–76.
Ruscio BA, Brubaker M, Glasser J *et al.* One Health—a strategy for resilience in a changing arctic. *Int J Circumpol Heal* 2015;**74**:27913.
Savic S, Vidic B, Grgic Z *et al.* Emerging vector-borne diseases—incidence through vectors. *Front Public Health* 2014;**2**:267.
Schelling E,, Hattendorf, J. One Health study designs. In: Zinsstag J, Schelling E, Waltner-Toews D *et al.* (eds.) *One Health: The Theory and Practice of Integrated Health Approaches*. Oxfordshire, London:CABI, 2015, 107–21.
Schelling E, Wyss K, Béchir M *et al.* Synergy between public health and veterinary services to deliver human and animal health interventions in rural low income settings. *BMJ* 2005;**331**:1264–7.
Schelling E, Wyss K, Diguimbaye C *et al.* Toward integrated and adapted health services for nomadic pastoralists and their animals: A North-South partnership. In: Hirsch Hadorn G, Hoffmann-Reim H, Biber-Klemm S *et al.* (eds.) *Handbook of Transdisciplinary Research A Proposition by the Swiss Academies of Arts and Sciences*. Heidelberg:Springer, 2007, 277–91.
Schmutz C, Mausezahl D, Bless PJ *et al.* Estimating healthcare costs of acute gastroenteritis and human campylobacteriosis in Switzerland. *Epidemiol Infect* 2017;**145**:627–41.
Seid MA, Yoseph LW, Befekadu UW *et al.* Communication for the development of pastoralism. *Rev Sci Tech* 2016;**35**:639–48.
Semenza JC, Suk JE. Vector-borne diseases and climate change: a European perspective. *FEMS Microbiol Lett* 2017;**365**.
Semenza JC, Zeller H. Integrated surveillance for prevention and control of emerging vector-borne diseases in Europe. *Euro Surveill* 2014;**19**:20757
Sherpa AM, Koottatep T, Zurbrügg C *et al.* Vulnerability and adaptability of sanitation systems to climate change. *J Water Clim Change* 2014;**5**:487–95.
Shomaker TS, Green EM, Yandow SM. Perspective: One Health: a compelling convergence. *Acad Med* 2013;**88**:49–55.
Singh BB, Gajadhar AA. Role of India's wildlife in the emergence and re-emergence of zoonotic pathogens, risk factors and public health implications. *Acta Trop* 2014;**138**:67–77.
Squire SA, Ryan U. Cryptosporidium and Giardia in Africa: current and future challenges. *Parasite Vector* 2017;**10**:195.
Steinmann P, Bonfoh B, Farah Z *et al.* Seroprevalence of Q-fever in febrile individuals in Mali. *Trop Med Int Health*2005;**10**:612–7.
Stephen C. Toward a modernized definition of wildlife health. *J Wildlife Dis* 2014;**50**:427–30.
Sterk A, Schijven J, de Nijs T *et al.* Direct and indirect effects of climate change on the risk of infection by water-transmitted pathogens. *Environ Sci Technol* 2013;**47**:12648–60.
Sterk A, Schijven J, de Roda Husman AM *et al.* Effect of climate change on runoff of *Campylobacter* and *Cryptosporidium* from land to surface water. *Water Res* 2016;**95**:90–102.
Stevenson TJ, Visser ME, Arnold W *et al.* Disrupted seasonal biology impacts health, food security and ecosystems. *Proc Biol Sci* 2015;**282**:20151453.
Thiam S, Diene AN, Sy I *et al.* Association between childhood diarrhoeal incidence and climatic factors in urban and rural settings in the Health District of Mbour, Senegal. *Int J Env Res Pub He* 2017;**14**.
Toda M, Njeru I, Zurovac D *et al.* Understanding mSOS: a qualitative study examining the implementation of a text-messaging outbreak alert system in rural Kenya. *PLoS One* 2017;**12**:e0179408.
Videla OE, Urzua JO. The benefits of incorporating the One Health concept into the organisation of veterinary services. *Rev Sci Tech* 2014;**33**:401–6, 393–409.
Vu-Van T, Pham-Duc P, Winkler MS *et al.* Ascaris lumbricoides egg die-off in an experimental excreta storage system and public health implication in Vietnam. *Int J Public Health* 2017;**62**:103–11.
Watts N, Adger WN, Ayeb-Karlsson S *et al.* The Lancet Countdown: tracking progress on health and climate change. *Lancet* 2017;**389**:1151–64.
WHO. *Sanitation Safety Planning: Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta*. 2015 Geneva, Switzerland.
World-Bank. *People, Pathogens and Our Planet: Volume 2: The Economics of One Health*. Report No. 69145-GLB: 50. 2012 Washington, D.C.
Zhang H, Shi J, Liu X *et al.* Occurrence of free estrogens, conjugated estrogens, and bisphenol a in fresh livestock excreta and their removal by composting in North China. *Environ Sci Pollut Res* 2014;**21**:9939–47.

Zinsstag J, Schelling E, Wyss K, Mahamat MB Potential of cooperation between human and animal health to strengthen health systems. *Lancet* 2005;**366**:2142–45.

Zinsstag J, Durr S, Penny MA *et al.* Transmission dynamics and economics of rabies control in dogs and humans in an African city. *P Natl Acad Sci USA* 2009;**106**:14996–5001.

Zinsstag J, Schelling E, Bonfoh B *et al.* The future of pastoralism: an introduction. *Rev Sci Tech* 2016;**35**:335–55.

Zinsstag J, Schelling E, Waltner-Toews D *et al.* From 'one medicine' to 'one health' and systemic approaches to health and well-being. *Prev Vet Med* 2011;**101**:148–56.

Zinsstag J, Schelling E, Waltner-Toews D *et al.* *One Health: The Theory and Practice of Integrated Health Approaches*. CABI, Wallingford, England, 2015.