COVID-19 pandemic lessons: recipe for uncertainty research on climate-sensitive diseases

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Key Points:

- Global response to climate-sensitive diseases has been slow and like the "COVID-19" pandemic, understanding future vulnerabilities is key.
- There is need for new forms of research questions to analyze the anthropocentric and geopolitical context of health concerns.
- Pluralist dynamics of health systems management beyond the "One health" approach will help capture the role of Earth systems.

Abstract

Lessons from the strong global response to the coronavirus disease 2019 (COVID-19) pandemic and a renewed call for "One health" approach to health systems management in "The Lancet" parallel climate change emergencies. The weakened health – climate change nexus, perceived largely within public health need to engage how the Earth system (i.e. relationships between air, land, life and water on earth) in shaping the etiologies, incidences and transmission dynamics of diseases. The question "What are the drivers of the drivers of diseases?" using the context of diarrheal diseases is posed. Subsequently, we need to understand how (i) climatic risks drive biological health hazards, (ii) shifts in disease control services of ecosystems regulate diseases, (iii) climate change within Earth systems modify disease pathogens and species hosts relationships. Hence, safeguarding Earth system-related disease dynamics would inform pluralistic approaches beyond "One health".

Plain Language Summary

Threats posed by climate change to human health have been described as the greatest in the 21st century. Yet research to understand the influences of climate change on specific processes occurring between air, land, life and water on earth that affect diseases and transmission is still emerging. This is because such modifications are resulting in new forms of diseases. The understanding of which will help design strategies that bring together other disciplines and sectors that affect health because the issues are interdependent, in a holistic approach to health systems management.

1. Introduction

1.1. Disease emergence and case management

There is a renewed call for "One Health" approach to global health management amidst the Coronavirus Disease 2019 (COVID-19) pandemic in "The Lancet", to prevent, detect, and control disease outbreaks especially emerging infectious diseases (Jacobsen, 2020). The Lancet comment, "Will COVID-19 generate global preparedness?", argued that health systems be understood and managed across different sectors, similar to the Ecohealth approach of Butler & Friel (2006) over a decade earlier). The comment, grounded in social-demography, population health, and epidemiology, however, marginalized the role played by the Earth system, yet relevant for the current analysis. The "Earth system" represents the interactions of the earth´s physical, chemical, and biological processes, including natural cycles and deep Earth processes which provide the conditions necessary for life (Steffen et al., 2004) (Figure 1). The reasoning that the bio-geophysical environment contributes immensely to disease origin, incidence and spread, beyond the "One health" approach, evokes relevance of the "Ecohealth and Planetary health" approaches which define interactions resulting from shifts in ecosystems and social-ecological linkages (Lerner & Berg, 2017; Roger et al., 2016), of which climate change constitutes a proximate global disease burden. Combining the three aforementioned approaches conciliates ecological, socioeconomic, and political space in health (Jacobsen, 2020; Lerner & Berg, 2017; Roger et al., 2016), from which the concept of this paper is derived. Ecosystems are part of the Earth system (Figure 1), defined in the Millennium Ecosystem Assessment report as "*a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit. Humans being an integral part of the ecosystems*" (Leemans et al., 2003). The use of COVID-19 as an antecedent of the paper emphasizes the role of global response to potential climate change related disease pandemics. The SARS group of emerging diseases linked to changes to biodiversity-pathogens interactions and climate change (Keesing et al., 2010), is immensely overlooked of which COVID-19 is part.

1.2. Earth system and drivers of emerging diseases

Globally, land use change has been found to contribute most and close to half of emerging diseases underlain by human production practices, climate and weather factors (Keesing et al., 2010). Thus, climate-change-induced shifts are changing ecosystems and altering ecosystem functioning, implied in future vulnerabilities that define uncertainties (Grimm et al., 2013; Schirpke et al., 2017; Wardekker et al., 2012). Therefore, in exploring the link between climate change and ecosystem modification, and links to disease occurrence and transmission, we ask the question "*what are the drivers of the drivers of diseases*?" Subsequently, the goal of this paper is to frame how climate change modifies ecosystem service and implications for disease etiology, incidence, and transmission. Ecosystem services are "*Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth*" (Leemans et al., 2003). Declines and extinctions in biodiversity, caused by changes to ecosystems dependent multiple stressors and climate change (Figure 1), affect the risk of infectious disease exposures (Côté et al., 2016, Keesing et al., 2010; Schirpke et al., 2017). The Lancet and University College of London Institute for Global Health Commission in 2009 concluded that "Climate change is the biggest global health threat of the 21st century", citing heatstroke, extreme weather events, and links to disease outbreaks globally (Costello et al., 2009). Ten years on, policy actions of over 100 countries globally to incorporate climate change into disease monitoring and surveillance has been slow and inconclusive (World Health Organization (WHO), 2019).

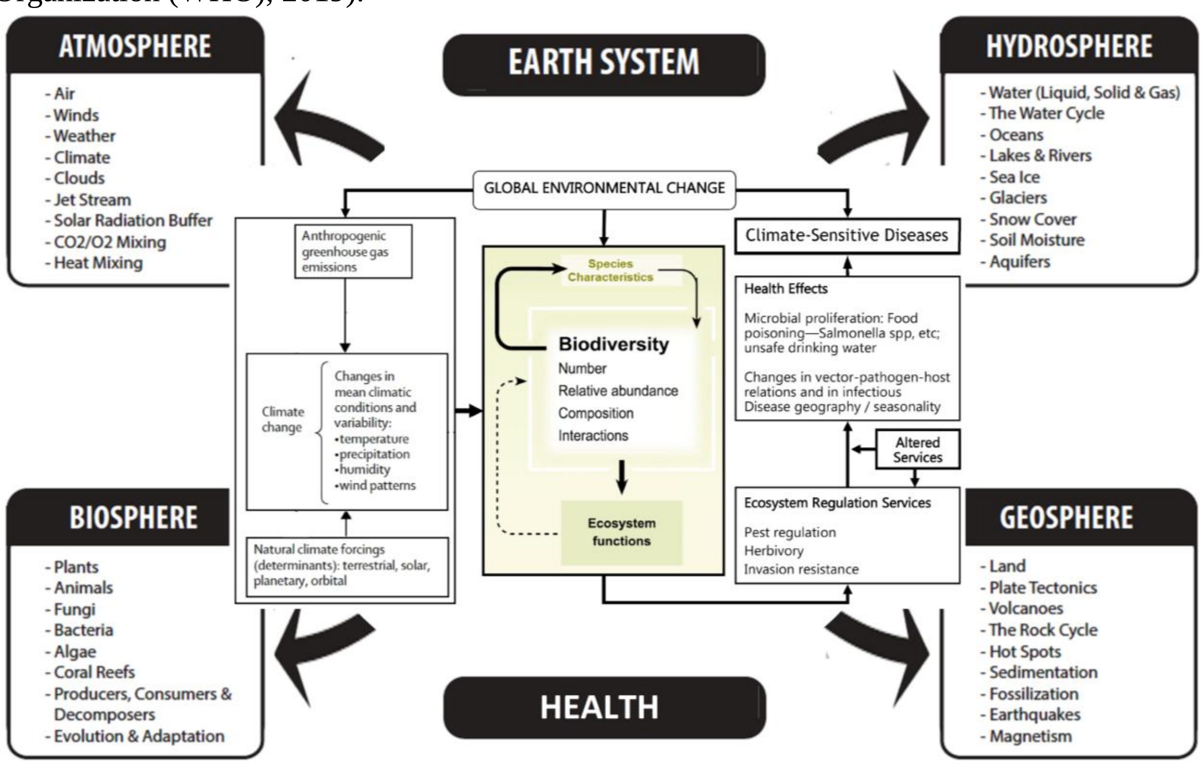

Figure 1. Schematic representation of the nexus between health, climate change and Earth systems processes and interactions (Source: adopted and modified from Leemans et al. (2003) and McMichael et al. (2006).

1.3. Interdependence of health system management

Lessons from the global resource mobilization response to the COVID-19 pandemic in the face of uncertainties, and recommendations of "One health" system approach provide a wakeup call to totally embrace the Paris climate agreement (PaCA). Because of COVID-19, uncertainties of climatic risks in disease patterns and mortality have come under sharp scrutiny (Liu et al., 2020; Mohammad et al., 2020), as United Nations Secretary-General recently linked climate change's unknown tipping point to COVID-19 (https://www.un.org/press/en/2020/sgsm20051.doc.htm). We focus on diarrheal diseases in this paper which has high temperatures, flooding and windstorms as prevailing drivers of the Earth system that make it climate-sensitive. The unpredictable effects of climate change on the interactions of species and their related functions represent one of the largest forecasting uncertainties (Pecl et al., 2017; Winder & Schindler, 2004). Unfortunately, many years of research in biodiversity and ecosystem functioning, and multispecies predator–prey interactions that rarely intersected (Ives et al., 2005), has hardly gone beyond conservative Earth systems research to impact health and diseases. Hence, using past, current, and accurate and reliable Earth systems data which capture meteorological and climatic information on ecosystem change provide evidence for viewing health responses to climate change challenges across multiple disciplines and uncertainty (Dovie et al., 2017; Jacobsen, 2020; Lerner & Berg, 2017; Yokohata et al., 2019). Subsequently, positioning ecosystem and health-related concepts in disease case prediction and response is relevant to the complex health – climate change - ecosystems nexus (Charron, 2012; Lerner & Berg, 2017; Leung et al., 2012; Rapport & Singh, 2006). Recent evidence shows that ecosystems do shift to new states, thereby imposing change on species interactions (Deyle et al., 2016; Kandziora et al., 2013; Pecl et al., 2017), which tend to drive emerging disease events in the presence of climatic elements, and speculate for COVID-19 (e.g. Ma et al., 2020; Şahin, 2020; Sajadi et al., 2020). However, it is the cascading impacts of climate change on the earth's energy on ecosystem functions and services rather than the first level (proximate) impacts and links to diseases which is yet to receive attention. In this paper, we use diarrheal diseases to recommend the combined "One Health, Ecohealth, and Planetary health" approach for health system management.

2. The health - climate change – ecosystem service nexus

The millennium ecosystem assessment (MEA) concludes that ecosystems play an important role in regulating the transmission of many infectious diseases (Patz et al., 2005). The report asserts that altered habitat, and resultant changes in vector breeding characteristics including sites or reservoir host distribution; niche invasions or interspecies host transfers; and changes in biodiversity (including loss of predator species and changes in host population density); constitute main biological mechanisms that have altered the incidence of many infectious diseases (Table 1). Climate change is modulating the ability of ecosystems to perform their functions and services across ecosystems (Bangash et al., 2013; Grimm et al., 2013; Kardol et al., 2010; Montoya & Raffaelli, 2010; Pedrono et al., 2016; Scheffers et al., 2016; Schirpke et al., 2017). This is further driven by "tertiary" health effects of climate change which are major human dimension issues of migration, conflict and hunger (Bowles et al., 2014). Uncertainties in magnitude of biophysical, demographic, geomorphic functions, etc., constitute confounding factors of health that tend to complicate health governance systems (Ogashawara et al., 2019; Parkes et al., 2010)). Land use change with its resultant ecosystems degradation is resulting in increasing emotional and mental illness (Rapport and Singh, 2006; Sandifer et al., 2017). Therefore, a considerable link established between climate change and health would complicate disease case management (Smith et al., 2014). Using medical, social, or public health instruments to address health solely as a policy problem or concern will not achieve the desired outcomes unless it was viewed from an Earth system perspective. Thus, Parkes et al. (2010) and Sorensen et al. (2017), analyze how modifications and the interactions within the Earth system to balance upstream social and ecosystem change foster health, sustainability and social–ecological resilience.

Table 1. Mechanisms of Disease Emergence and Examples of Diseases across Ecosystems (Source: Patz et al., 2005).

Mechanisms	**Ecosystems**				
	Cultivated Systems	**Dryland Systems**	**Forest Systems**	**Urban Systems**	**Coastal Systems**
Habitat alteration	schistomiasis Japanese encephalitis malaria	hantavirus Rift Valley fever meningitis	malaria arboviruses (e.g., yellow fever) onchocerciasis	lymphatic filariasis Dengue fever malaria	cholera
Niche invasion or host transfer	Nipah virus BSE (mad cow) SARS influenza		HIV (initially)	leishmaniasis	
Biodiversity change	leishmaniasis	onchocerciasis	rabies onchocerciasis	lyme disease	
Human-driven genetic changes	antibiotic-resistant bacteria		chagas disease	chagas disease	
Environmental contamination of infections agents	cryptosporidiosis leptospriosis			leptospirosis	diarrheal diseases

COVID-19 lockdowns and face masks, were respectively likened to decarbonization (mitigation), and adaptation, for climate change, shedding light on how coordinated response promote healthy behaviors. There is little to report on how infectious diseases result from changing conditions of species when it is about the health sector, even in the developed world (Lesnikowski et al., 2011). Severe climate change and impacts on health is known to result typically from three basic pathways. These are (i) the direct impacts relating primarily to extreme weather including heat waves, droughts, and heavy rain, (ii) the effects mediated through natural systems, and (iii) systemically mediated by human systems including conflicts, economic instability and environmental decline (Kjellstrom & McMichael, 2013; McMichael, 2013; Smith et al., 2014). The effects of global change on the structure and function of terrestrial ecosystems are regulated from interactions across the Earth system (Bardgett & Wardle, 2010; Grimm et al., 2013; Kandziora et al., 2013). Thus, the changing state of ecosystems impact disease-causing organisms as spatiotemporal dynamics of microbial communities hugely affecting the behavior of those organisms, exhibit interspecies exchange of metabolites in ecosystems (Harcombe et al., 2014). Similarly, the role of aerosols of biological origin in the Earth system, are essential for the reproduction and spread of organisms across various ecosystems (Fröhlich-Nowoisky et al., 2016), and documenting such interactions and shifts would transform understanding of patterns in the occurrence of disease vectors and alteration in spatial and temporal transmission (Bezirtzoglou et al., 2011; Haines, 2012; Haines et al., 2006; IPCC, 2007, 2014; Jankowska et al 2012; Kovats, 2010; Maibach et al., 2008; McMichael et al., 2006; Patz et al., 2008).

3. The case of diarrheal diseases

3.1. Earth systems linkages

Climate change acts to exacerbate existing patterns of ill health by modifying underlying vulnerabilities of environment and socio-demographic origin (Smith et al., 2014). Studies suggest that women, children, young people, and the elderly are at greater risk of climate related illness, with adverse effects of malaria, diarrhea, and under-nutrition concentrated among children (Michon et al., 2007; Perera, 2008; Xu et al., 2013). Thus these vulnerable groups have higher exposures meaning they are disproportionally affected by climate change related health concerns including diarrheal diseases because of variable underlying pressures (e.g. poverty and gender inequality). Therefore, given differences in the impacts of climate change on different ecosystems already having species undergoing change, the expected incidence, distribution and transmission of diarrhea would potentially differ. This is because trophic interactions across ecosystem boundaries determine how ecosystems affect each other and the species and type of influence on the interaction (Grimm et al., 2013; Romero & Srivastava, 2010). Diarrheal diseases have since 1990 remained one of the top ten major causes of death globally and mostly ranked in the top four (Karuga, 2018). The incidence of diarrhea has been associated with high temperatures, flooding and windstorms that adversely affect health (Carlton et al., 2014; Jakubicka et al., 2010; Kolstad & Johansson 2011; Schnitzler et al., 2007). Mostly however, neither the specific causes of the diarrheal illness nor, the mechanism for the association with climatic factors are known although *Salmonella* and *Campylobacter* bacterial pathogens do show distinct seasonality in infection and higher disease rates at warmer temperatures (Lake, 2009). Alexander et al. (2013), predicts amplified diarrheal disease in the peak of the dry season, and decline in the incidence in the wet season. This means that the "behavior" of elements within the Earth system in "driving the drivers" of diseases amplify the concept of interconnectedness across sectors within different climatic risks (Yokohata et al., 2019). The case of diarrheal diseases attributed to climate change impacts globally is established (McMichael et al., 2004), and of the 3.6 million annual childhood deaths in Africa, 11% was due to diarrheal diseases (Liu et al., 2012). Kolstad and Johansson (2011), projected an increase of 8 to 11% in the risk of diarrhea in the tropics and subtropics by 2039, omitting key variables of socioeconomic change and shifts in ecosystems including the geographies. Altering ecosystem services in any form, shifts ecosystems significantly especially warming in excess of 2°C (IPCC, 2014). Consequentially, from the theoretical model (Figure 2), it will be expected that diarrheal incidence (DI) and subsequent transmission will be different for ecosystem type A (ECOTYPE A), type B (ECOTYPE B) and type C (ECOTYPE C) due to differential impacts of climate change. The impacts would then change intra-ecosystems interactions supporting the disease regulation and control services of the differently linked ecosystem types in character and species shift (Figure 2). Thus, "DI" in Figure 2 will be different for the ecotypes and that DI-A, DI-B and DI-C will be heterogeneous and representing differences in disease detection and case management including surveillance, early warning, and treatment. However, due to the effect of confounding factors within the Earth system (Figure 2), DI-A would potentially be similar to DI-B or DI-C or DI-B to DI-C (Figure 2).

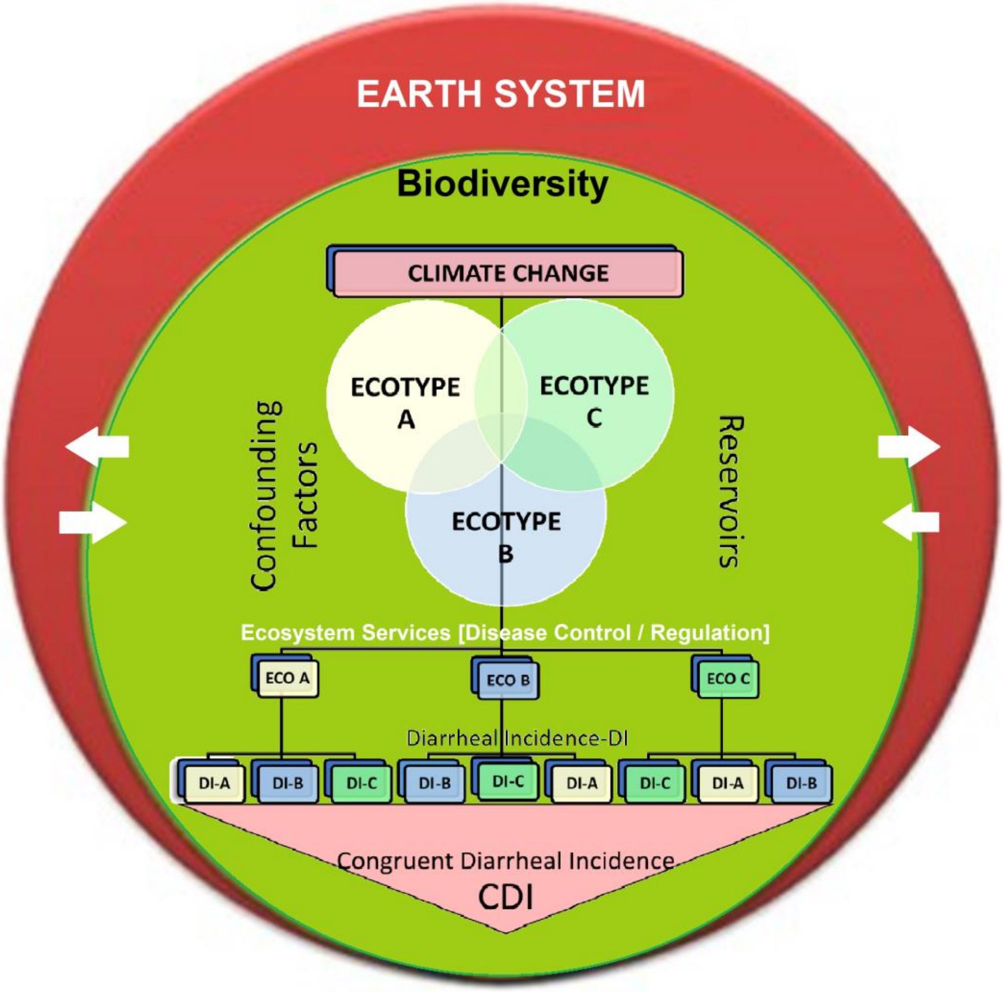

Figure 2. A framework establishing the linkages between diarrheal disease incidence (DI) and different ecosystem types (Ecotype). Where: Ecotype A – ecosystem type A; Ecotype B- ecosystem type B; Ecotype C- ecosystem type C; (DI-A) -diarrheal incidence on ecosystem type A; (DI-B)- diarrheal incidence on ecosystem type B: (DI-C)- diarrheal incidence on ecosystem type C.

3.2. Emerging questions

Given the multiple Earth system dynamics, climate change and the combined health system approach, three questions emerge:

(a) Question 1: What thresholds of the impacts of climate change will cause the disease regulation and control services of ecosystems to behave in a manner that affect the total expression of diarrheal diseases?

A number of studies have shown that outcomes of large-scale environmental changes which involve biodiversity loss and ecosystem degradation impinge on population and human health simultaneously and often interactively (Haines, 2012; Houghton et al., 2012; Rapport & Singh, 2006; Zell, 2004). The nature of interactions among species driven by climate change have unexpected consequences which impact the unique responses of species (Winder & Schindler, 2004). Therefore, energy levels in ecosystems, transfer of resources and interactions among species, similarly, observed for predator–prey interactions, and biodiversity and ecosystem functioning affect disease-causing organisms (Bardgett & Wardle, 2010; Ives et al., 2005; Kandziora et al., 2013). Thus, a diarrhea incidence expresses differently in different ecosystem types including severity (Figure 2). Climatic risks intersect with mechanics of multiple sectors and having linkages to the built environment, food systems, zoonotic disease transmission, migration, human security, ecosystem change (Charron, 2012; Bowles et al., 2014; Leung et al., 2012; Rapport & Singh, 2006; Yokohata et al., 2019). Sorensen et al. (2017) observed that a trigger in natural disasters under irregular climatic conditions force-multiplied the Zika Virus. The application of earth observation systems (EOS) approach to health surveillance (Houghton et al., 2012), the extension of which would give meaning to disease dynamics as health promotion has largely ignored many aspects of the disproportionate disruption of the earth's resources (Butler & Friel 2006; Wu et al., 2016).

(b) Question 2: What attributes of diarrheal diseases related to host – pathogen relationship would be driven potentially by the alteration in the disease control services of ecosystems, and how would this differ for incidence of diarrheal diseases for different ecosystem types?

Biodiversity loss frequently increased the rate of transmission for pathogens and found to be associated with over 300 emerging disease events in humans around the world between 1940 and 2004, with climate change as one of the drivers (Jones et al., 2008; Keesing et al., 2010). The severe acute respiratory syndrome or SARS, and the West Nile virus in the Americas were cited, and that outbreaks of infectious diseases, was changing with warming (WHO 2004), and now potentially implicating COVID-19. Arguably so, there are calls to improve understanding of how spatial–temporal processes of climate change and shifts in infectious diseases are predicted (Pecl et al., 2017; Wu et al., 2016).

(c) Question 3: What sector-interdependent determinants or classifications within the Earth system at scale (e.g. primary, secondary, tertiary, quaternary) link climate change, ecosystems and health in understanding the etiology, incidence and transmission of diarrheal diseases, surveillance, case management and health planning?

This question suggests the need to establish measurable indicators at the interface of climatic factors and their influences on ecosystems and links to temporal trends in the cumulative incidence of diarrheal diseases. The effects of confounding factors within the Earth system and common to all ecosystem types, which potentially outweigh climate change effects on different ecosystems will not alter diarrheal incidence – "congruent diarrheal incidence (CDI)" (Figure 2). The understanding and analysis of this becomes vital when key elements of the Earth system are accounted for (e.g. land-cover change and land use dynamics, effects of changing hydrology, impacts of geological process) and across social-ecological linkages in defining health outcomes.

The principle of sector interdependency in responding to impacts of climate change (Yokohata et al., 2019), similarly will intensify understanding of the health - climate change nexus beyond the current analysis undermining efforts at multi-sector integration (Bezirtzoglou et al., 2011; Keune et al., 2012; Lesnikowski et al., 2013; Stern et al., 2013).

4. Conclusion

Observations in this paper suggest that climate-sensitive diseases (including diarrhea) face shifts to host – pathogen relationships within changing ecosystems, requiring explanations of climate-dependent biological hazards which the health sector adopts for case detection and management such that no single sector offers total solution to human health issues. The nexus “One health-Ecohealth-Planetary health” is at crossroads of climate change challenges to health using Earth system perspective to also include health disaster risk reduction which brings relevance to the Sendai Disaster Risk Reduction Framework (SDRRF). The need for the health sector to do more to adopt indicators beyond the routine health determinants and disease case management has been recommended in earlier studies (Dovie et al., 2017; Lesnikowski et al., 2011). Earth systems research under different climate scenarios and links to disease host-pathogen relationships and exposure to infectious diseases require strong scientific response using new explanations (Wu et al., 2016), towards planning for future vulnerabilities associated with climate change (Wardekker et al., 2012, Lesnikowski et al., 2013). In conclusion, the understanding of the effects of ecosystem shifts in different anthropocentric and geopolitical contexts offer opportunities for enhanced pluralistic approach to health interventions research that coevolve new instruments to address medical, social, and public health concerns.

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