NOVEMBER 2020

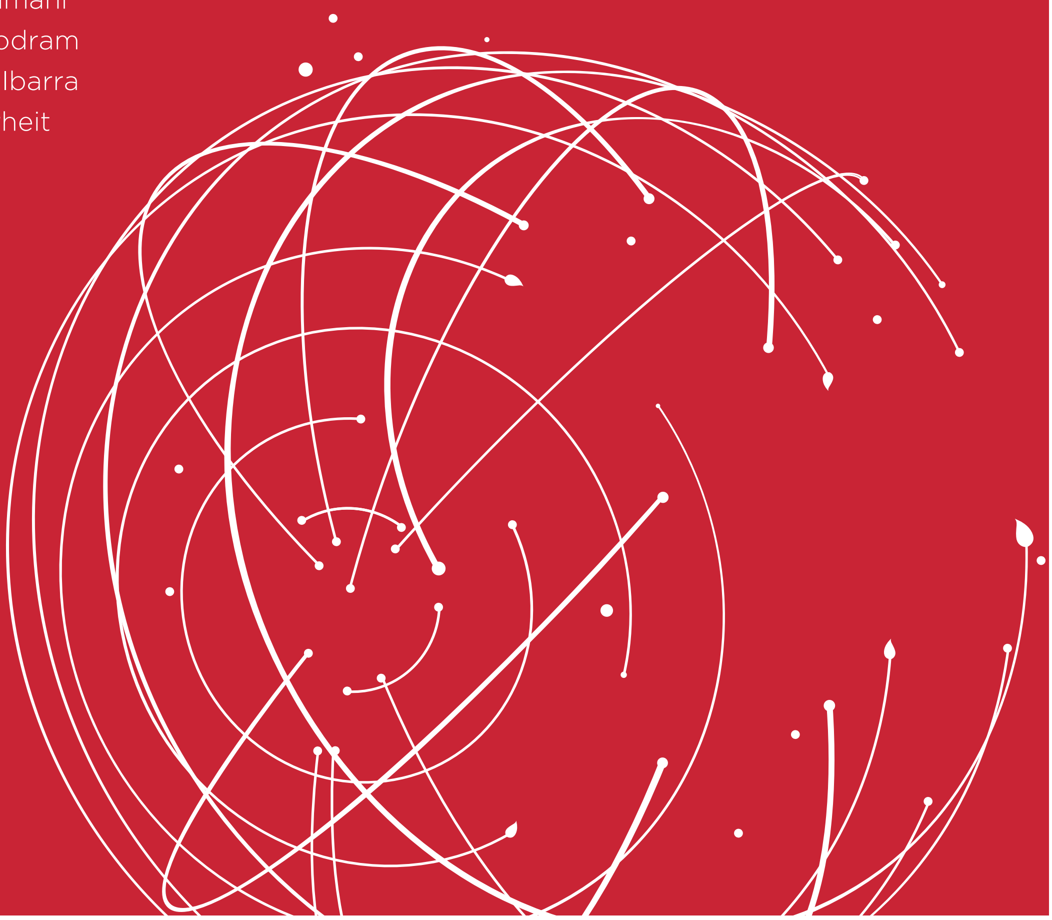
Qatar Foundation

World Innovation Summit for Health

UNHEEDED WARNINGS

MITIGATING THE IMPACT OF CLIMATE CHANGE ON COMMUNICABLE DISEASES

Jeremy Hess
Rachel Lowe
Muna Al Maslamani
Laura-Lee Boodram
Anna Stewart Ibarra
Judith Wasserheit



ONE **WORLD**
OUR **HEALTH**

Suggested reference for this report: Hess J, Lowe R. Unheeded warnings: Mitigating the impact of climate change on communicable diseases. WISH and BMJ (2020).

ISBN: 978-1-913991-07-4

UNHEEDED WARNINGS
MITIGATING THE IMPACT OF CLIMATE CHANGE ON COMMUNICABLE DISEASES

WISH 2020 Forum on Climate Change and Communicable Diseases

This report was commissioned by The BMJ for the World Innovation Summit for Health (WISH), which is an initiative of the Qatar Foundation. The BMJ peer reviewed, edited, and made the decision to publish the articles that are included in the report. The report was funded by WISH.

JOIN THE WISH RESEARCH COMMUNITY ON CLIMATE CHANGE

Climate change is one of the primary themes of the WISH 2020 research agenda. International co-operation will be key to helping health leaders better model the changes they wish to see, as well as drive improvements elsewhere.

As part of WISH's flagship report to equip health leaders with an understanding of the threats and opportunities that climate change creates for health, we invite health systems to join an ongoing WISH sub-community where they will be able to share lessons and ideas, and report back on their successes and challenges at the next conference in two years. Interested community members should express their support to wishclimateaction@qf.org.qa.

CONTENTS

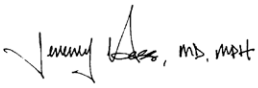
FOREWORD

We have made significant progress in reducing the global burden of infectious diseases over the past few decades. Improved sanitation, better hygiene practices, and comprehensive prevention and control efforts have averted countless deaths and saved millions of people from unnecessary pain and suffering.

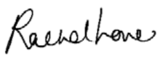
However, as exemplified by the COVID-19 pandemic, infectious diseases remain a pressing threat to global health, particularly as climate change is poised to exacerbate this issue in myriad ways. Increasing global temperatures have already expanded the areas where climate-sensitive infectious diseases thrive, putting millions more at risk of diseases such as malaria and dengue. Climate change will continue to increase the frequency of extreme weather events, including floods and drought, both of which can increase infectious disease risk; as seen with COVID-19, lack of access to clean water inhibits effective hand hygiene and contributes to disease spread. Urbanization and migration related to climate change, already underway and expected to grow rapidly in coming decades, will also complicate the prevention and control of many communicable diseases.

Policymakers and practitioners in all sectors have a responsibility to address climate change and mitigate its effects on human health, and this important topic is one of the primary themes of the WISH 2020 research agenda. In addition to our flagship Forum report, Health in the Climate Crisis: A Guide for Health Leaders, WISH partnered with *The BMJ* to commission two collections of peer-reviewed articles, on the effects of climate change on infectious diseases (this collection, *Unheeded warnings: Mitigating the impact of climate change on communicable diseases*) and the growing challenges of dry cities – Healthy Dry Cities.

This report (and a further collection of articles available online) explores the key infectious disease challenges related to climate change. It concludes with a number of recommendations to address these issues and reduce their associated health risks. We hope that policymakers will use this guidance as part of a wider effort to tackle the threat of climate change and ensure the wellbeing of future generations.



Professor Jeremy Hess
Professor in Emergency Medicine, Environmental and Occupational Health Sciences, and Global Health; and Adjunct Professor, Atmospheric Sciences; and Director, Center for Health and the Global Environment (CHanGE), University of Washington



Professor Rachel Lowe
Associate Professor and Royal Society Dorothy Hodgkin Fellow
Centre on Climate Change and Planetary Health and Centre for Mathematical Modelling of Infectious Diseases, London School of Hygiene & Tropical Medicine

SECTION 1. STRENGTHENING THE GLOBAL RESPONSE TO CLIMATE CHANGE AND INFECTIOUS DISEASE THREATS

Jeremy Hess, Laura-Lee Boodram, Shlomit Paz, Anna M Stewart Ibarra, Judith N Wasserheit, Rachel Lowe

Global health leaders have identified climate change as the greatest health challenge of the 21st century.[1] Impacts on infectious disease are a particular concern: there is growing evidence that some of the greatest health impacts of climate change are, and will continue to be, on the emergence, re-emergence, and spread of infectious diseases.[2] For at least two decades, global assessments have highlighted the need to reduce greenhouse gas emissions[3,4] and to invest more substantially in climate and health, including surveillance, preparedness, and response.[5,6,7]

The global health response has largely been characterized by skepticism and watchful inaction. The world's largest global health funders, including the US National Institutes of Health (NIH)[8] and the Bill & Melinda Gates Foundation (BMGF), still lack specific climate and health programming, let alone programming focused on climate change and infectious diseases. Climate change remains a vanishingly small element of the portfolio of funders like the European Commission and the Wellcome Trust that have stepped into the breach. Funding for training, research, and practice related to climate change and infectious disease has been limited accordingly.

This is partly because the evidence is difficult to parse.[9] The rationale for an association between climate change and infectious disease is clear, and mosquito-borne pathogens, particularly malaria and dengue, are of particular concern[10,11] given established climate sensitivities of vector populations.[12,13] But evidence of major impacts of climate change on communicable diseases has been somewhat limited. The relative importance of climate variability and change has been difficult to evaluate among drivers of disease incidence such as globalization, urbanization, migration, land use changes, poverty, vector-pathogen characteristics, and control measures.[14] In recent years, the world has seen substantial declines in many prevalent infectious diseases, including malaria, yellow fever, lymphatic filariasis, schistosomiasis, onchocerciasis, Chagas disease, and African trypanosomiasis,[15] indicating that other drivers have obscured any climate change contribution to disease incidence.

Gaps in the evidence base

Ruling out climate change as a key driver of infectious disease risk is premature, however, for several reasons (as described in Table 1). A precautionary approach would argue for more research to settle any remaining doubts.

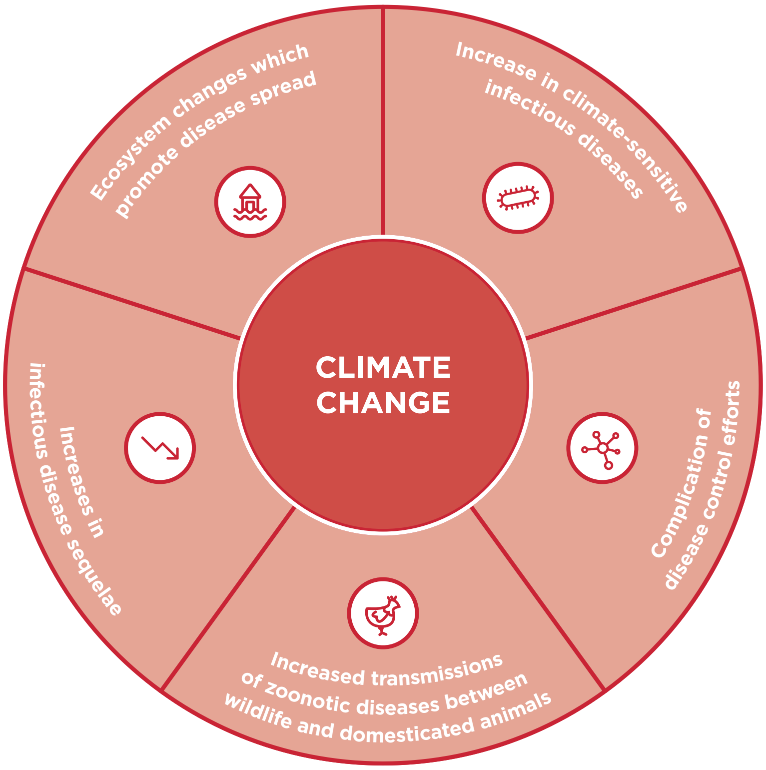
Table 1. Gaps in the evidence base[16,17,18]

KNOWLEDGE GAPS	
	1. Location Some areas that have experienced significant shifts in cilmate, including parts of Africa and the Middle East, are underrepresented in the evidence base, which limits conclusions about climatic influences in certain regions.
	2. Annual trends There is limited research on the role of interannual climate variability, which is important for many infectious diseases with a marked seasonal component.
	3. Extreme events Insufficient attention has been paid to impacts of increasingly frequent and severe extreme weather events, which can influence the timing and intensity of disease outbreaks, and hinder response efforts.

In addition, interactions between climate change and other infectious disease drivers seem to be accelerating. Over two-thirds of human infectious diseases are zoonotic, causing widespread morbidity and mortality.[19] Zoonotic disease spillover is determined by interactions between humans and natural systems.[20] Increasingly widespread disruption of landscapes, and biodiversity through deforestation and agricultural development, changes socioecological systems, and forces humans, vectors, livestock, and pathogens into increasingly closer contact.[21] For example, land use and land cover changes, in parallel with temperature increase, may contribute to the spread of leishmaniasis by moderating vector activity.[22,23] This, combined with unplanned and precarious urbanization, increasing global connectivity via international travel and trade, and climate variability, can allow invasive vectors and novel pathogens to spread widely, with the potential for transcontinental pandemics with devastating public health, social, and economic consequences.[24]

Tipping towards action

Figure 1. Impact of climate change on infectious diseases



The detection and attribution of climate change effects on infectious diseases is challenging,[25] but substantial progress has been made. Climate change is emerging as an important driver in several cases. Dengue incidence, for example, has risen sharply over recent decades, and prior consensus has held that climate change is just one of many contributing factors.[26] But recent analyses indicate that climate change has had a more decisive role[27] and that climate change could have similar effects on other mosquito-borne diseases in some regions.[28] Other analyses have implicated climate change in the increasing incidence of diseases like Lyme and tick-borne encephalitis.[29,30] Notably, this evidence has arisen from groups based in regions with more access to climate change and health research funds.

Other signs of increasing effects of climate change on infectious diseases are emerging. For example, malaria incidence is increasing in the highlands of Colombia and Ethiopia,[31] Lyme disease is expanding its range northward as the climate warms,[32,33] and arboviral diseases are extending from the tropics into temperate regions globally.[34] In Europe, climate change has facilitated the spread and establishment of West Nile virus in new regions.[35] There are also signs that the autochthonous spread of some infectious diseases may be facilitated by climatic changes increasing ecological suitability (the availability of niches suitable for vectors and pathogens)[36] and vectorial capacity (the ability of the vector to transmit the disease) in multiple settings.[37,38] Emerging evidence reinforces concern for the future due to projected warming, urbanization, and global connectivity,[39] including large parts of Europe and Eurasia.[40]

The steady acceleration of climate change emphasizes the need for a more active posture to take advantage of response options while they are still available. Climate change is accelerating and ecosystems are nearing dangerous tipping points,[41,42,43] promoting infectious disease transmission through multiple pathways. One common pathway is increased transmission of zoonotic diseases between wildlife and domesticated animals.[44] Other pathways involve ecosystem changes. In wetland ecosystems, for example, heat and drought conditions may lead to water bodies shrinking and organic matter becoming more concentrated (eutrophication). Such conditions favor Culex pipiens, the main vector of West Nile virus.[45] The acceleration of these trends has the potential to constrain the range of response options we have at our disposal.[46]

Finally, climate change is likely to worsen infectious disease impacts by increasing sequelae and complicating control efforts. Climate change is expected to worsen food security and nutritional status,[47] limiting host ability to recover from infectious diseases and worsening sequelae. Migration, in response to increasingly scarce resources – such as water and arable land – and sea levels rising,[48] is also likely to create fertile conditions for infectious disease outbreaks that confound conventional control strategies.

Increasing resilience in global infectious disease practice

A ‘wait and see’ approach to climate change and health is short-sighted and invites unnecessary risk. Based on the weight of the evidence and established calls for specific actions, we recommend key ‘low regrets’ strategies to reduce health risks associated with climate change by improving the ability to anticipate and engage infectious disease risks effectively.

Reduce carbon footprint

Globally, the health sector emits 4 percent of the world’s greenhouse gases – more than aviation or shipping,[49] sectors that have been scrutinized for their climate change contributions. To limit warming to 1.5°C without carbon removal from the atmosphere, emissions from all sectors need to decline to zero by 2050,[50] moving well beyond commitments made in the Paris Agreement. Health sector emissions are driven principally by domestic energy system intensity, the carbon intensity of the domestic economy, and demand for health services.[51] Major reductions in the health sector are feasible and consistent not only with maintaining but also advancing population health. The National Health Service (NHS) in the United Kingdom is working to reduce its greenhouse gas emissions by 80 percent from a 1990 baseline by 2050. Strong advocacy from the health sector to reduce carbon emissions is thus one of the more important levers for reducing its own carbon footprint, as is investment in energy efficiency in procurement and operations.[52,53] These investments are consistent with the sector's mission: mitigation activities have well-established benefits for health,[54,55] including reduced pollution exposure, and less obesity through healthier diets and more walking and cycling. Other efforts are needed as well. The health sector has been slow to divest from fossil fuels and should lead by example.[56,57,58] Climate change mitigation in healthcare systems must be adopted universally to achieve collectively endorsed mitigation targets. Help for poorer countries for greening their health sectors should be part of this commitment. A by-product of responses to the COVID-19 pandemic has been reduced emissions of greenhouse gases and other harmful co-pollutants.[59] While they hold the world's attention, health systems can work to leverage these temporary reductions, through the mechanisms mentioned above, and seize the opportunity to promote further greening during recovery efforts.[60]

Increase funding for climate and health

Nations should acknowledge and invest in strategies to further elucidate links and tackle climate-related health risks. The discipline of climate and health has been systematically deprived of funding for training, research, and other activities, including development and testing of interventions.[61] There is a conspicuous lack of investment in climate and health from major global health funders, including the BMGF and the NIH. Although funders such as the Wellcome Trust have tentatively engaged climate and health programming, their investments have been relatively timid in ambition and limited in scope. The Belmont Forum has recently prioritized climate and health, but direct funding from health agencies is limited, and funds cannot be spent in the countries most affected, despite their lack of contribution to the underlying problem and need for capacity.[62]

Recent years have seen some positive developments, including investments from the European Union and other international agencies in the Caribbean region for climate and health initiatives. This was spurred by regional advocacy and recognition of the high vulnerability of health systems in Caribbean small island developing states, particularly to climate-related disasters. Nevertheless, investment is directed principally toward infectious disease diagnostics and therapeutics to tackle negative health outcomes. Investigating and tackling climate change health effects and greening global health practices are afterthoughts, despite the potential for climate change to undermine the global health gains of recent years.

Frame the problem with a transdisciplinary lens

Framing is important to characterizing problems and identifying response options. Several interdisciplinary and intersectoral concepts have been proposed to offer a more proactive and holistic framework for tackling global health threats, such as EcoHealth, One Health, planetary health, planetary epidemiology, and planetary wellbeing.[63,64] These concepts share the notion that the health of humans, plants, animals, and the planet are inextricably linked. Other frameworks have identified the central importance of social determinants of health.[65,66] All of these frameworks reflect the fundamental importance of multiple sectors and disciplines coming together to improve health and wellbeing and the potential for working at cross-purposes when sectors do not work together.

These concepts have been embraced but not fully realized, as noted elsewhere in this collection. Transdisciplinary teams can learn to design more robust surveillance systems, develop innovative methodologies (such as quantifying and communicating model uncertainty and performing forecast verification) and effective communication strategies for target audiences on international, national, and city levels. Such teams could also bring in climate scientists and meteorologists to satisfy the long-standing suggestion for a merged community of practice.[67,68]

A broader frame could also lead to coupled action: efforts to reduce infectious disease effects, such as mosquito net distribution, could be linked with efforts to electrify villages, facilitating climate change mitigation and reducing population susceptibility to multiple hazards at the same time.

Incorporate environmental information into public health practice

The global response to climate change and its effects needs better information to support decision-making. The past decade has seen progress toward integrating climatic data into the surveillance of infectious diseases. The Global Framework for Climate Services provides guidance on how to bring climate information into mainstream health sector activities. Because this has not been broadly adopted in public health practice, however, many shortfalls still exist, including the lack of harmonization in the collection of climate and health data needed to inform climate adaptive responses. Integrating Earth observations (from satellites, weather stations, or drones, for example) and local environmental observations (such as from citizen science initiatives) into burden of disease estimates and disease surveillance activities could allow for the early detection of anomalies and facilitate preemptive actions.

Recognizing the utility of the Global Burden of Disease (GBD) study, and leveraging experience from that effort, the global health community could come together to pursue a major synthesis in environmental and health data – for example, an effort to link GBD data with data on ecosystem health and services. *The Lancet Countdown on Health and Climate Change* gestures towards such an analysis,[69] but there is potential for more substantial interdisciplinary collaborations, including interactions with policymakers. Leaders from the health community, including those from the GBD study, have emphasized the importance of such expanded efforts.[70]

These initiatives will need to: quantify and characterize exposure, vulnerability and risk for populations and health systems; identify and track key effects on population health over time; and attempt to identify the climate change components of infectious disease systems, among other health risks resulting from the changing climate, to help inform adaptation, mitigation, and surveillance strategies. These efforts will need to be well crafted, because effective transdisciplinary approaches rely on early, strong partnerships among diverse scientific experts and stakeholders (including policymakers, the private sector, and civil society) to ensure that the outcomes are relevant in guiding and informing actions. Relevant examples of successful efforts include several assessments of national vulnerability and adaptation, national adaptation plans for health, assessments of city climate risk, and projects using available adaptation funding. The Middle East Consortium on Infectious Disease Surveillance, for example, highlights the potential for regional collaborations.

Invest in decision-support modeling tools and communication

Established effective global health practices should be retained but need to be integrated with other strategies to support management decisions. Computational models can help disentangle and quantify the role of multiple infectious disease transmission risk factors, including climatic and environmental factors, human mobility, socioeconomic status, asymptomatic infections, and background immunity.

Predictive modeling has the potential to help decision-makers understand where infections will emerge or spread, or when future epidemics might occur. Outbreak predictions that use seasonal climate forecasts can prepare public health systems months in advance of a period of heightened risk of disease outbreaks, particularly in areas sensitive to large-scale climate phenomena, such as the El Niño–Southern Oscillation.[71, 72]

Combining novel data streams, including seasonal forecasts and local seroprevalence data, in early warning systems, could improve predictions of the timing and magnitude of outbreaks of multiple diseases.[73] Modeling approaches and processes for evaluating future climate change effects on infectious disease must be co-designed in partnerships involving public health climate practitioners and aligned with local priorities and capacities to identify the most appropriate spatial resolution, and tackle cross-scale problems.[74]

Supporting uptake of findings from these efforts is also important. A key component of effective model communication is the provision of user-friendly interfaces to openly share and visualize results and to provide access to modeling architecture to allow for scrutiny and reproducibility.[75] Educating policymakers and other stakeholders regarding modeling processes and interpretation of findings is also essential.[76, 77]

Challenges related to interpreting modeling results have been apparent in the COVID-19 response: software engineers, decision-makers, and the public calling for more transparent sharing of evidence used to inform vital decisions; and policymakers struggling to interpret seemingly disparate recommendations based on different model outputs. Looking forward, funders need to consider data science and software engineering as key components of any scientific tool kit and transdisciplinary epidemiological taskforce.

Build human capacity in data management, integrated surveillance, and leadership

Additional investment for incorporating climate considerations into global health practice, if and when it comes, should support training to maximize the effectiveness of programmatic investments. Although the discipline has continued to make halting progress, awareness remains low among the public health community of climate-related epidemiological and assessment tools.[78] We recommend updated and expanded health professional educational programming. Sustained funding is essential for:

- risk assessment, intervention development, program evaluation, and implementation.

- for training the next generation of climate and health leaders to facilitate the requisite interdisciplinary collaborations.
- for maintaining longer term projects for sustained impact and learning about implementation strategies.

In addition, funders should prioritize support for surveillance that incorporates environmental information and skills training for interdisciplinary practice.[79] For example, easy-to-implement, low-cost actions might include integrating weather data collection with malaria surveillance.[80] A recent study in the Caribbean[81] found that technical expertise in statistics, data science, and geographic information systems in the health sector needed to be strengthened to interpret basic climatic information, and integrate this information into a health early warning system. At the same time, climate practitioners need a better understanding about the decision priorities and needs of the health sector to be able to provide relevant bespoke and useful climate indicators. An early warning system requires an integrated approach that cuts across research, health and climate operations, data- and knowledge-sharing platforms, outreach and education, and in-country response activities. There are challenges to interdisciplinary design and work of this sort, including the need to develop shared language, perspective, and methods,[82] and future funding should recognize these concerns. Such climate-resilience actions should leverage and engage with other global health innovations that aim to reduce the burden of infectious diseases, such as the development of rapid, accurate, low-cost diagnostics; novel therapeutics and vaccines; innovative vector control and surveillance tools; and community education and social mobilization via social media.

A call to action in global health practice

Global health has been defined as

> an area for study, research, and practice that places a priority on improving health and achieving equity in health for all people worldwide … [that] emphasizes transnational health issues, determinants, and solutions; involves many disciplines within and beyond the health sciences and promotes interdisciplinary collaboration; and is a synthesis of population-based prevention with individual-level clinical care.[83]

The global health community has many actors that pursue this common agenda, including multilateral organizations; funders, including governments and foundations; non-governmental organizations (NGOs);

researchers; and practitioners. Action on climate and health – called out as an increasingly urgent priority by the World Health Organization (WHO), the Intergovernmental Panel on Climate Change (IPCC), and 197 signatories to the Paris Agreement – is squarely in the domain of global health, including its primary funders, organizations, and partners. Yet the calls of these multilateral organizations and governments have, in most cases, been met with a tepid response by global health funders and practitioners.

The COVID-19 pandemic has taught us the consequences of unheeded warnings, and similar effects, drawn out over a much longer timeframe, are increasingly likely as a result of years of inaction on climate and health. There is now increased attention on the importance of core public health systems and the global conditions that lead to disease emergence and pandemic spread. This is an opportunity for the global health community, particularly its funders, researchers, and practitioners, to better align with WHO and IPCC in their calls for action on climate and health, and usher in a new age in global health practice. The climate is changing rapidly, time is short, and options are increasingly limited: strong action must be taken now.

The global health community of governments, particularly the G20, and funders, particularly leaders including the NIH, the BMGF, and the Wellcome Trust, must seize the moment and take up the recommendations from WHO, the IPCC, and increasingly vocal members of the global health research and practice communities to prioritize equity, efficiency, and sustainability[84] including vigorous action on climate change and infectious disease. To protect hard-won gains, the global health community needs to recognize its shortcomings, broaden and expand its perspective, assume a proactive posture, and intensify its activity.

Our vision is for a sustainable, proactive new age in global health, in which it expands its frame, leads by example, works with partners from other disciplines, invests in new skill development and interventions, and is resilient to extreme events, shocks, and large population movements.

A reorientation of global health practice requires input and engagement from all of its actors. Development and health agencies need to incorporate recommendations for changing priorities and practice. Funders – particularly the BMGF, which has a disproportionate effect on information flow and priority setting through its support of the GBD study – have an important role to play in framing the problem, promoting transdisciplinary approaches, and increasing transparency and accountability. Opportunities to expand current efforts to incorporate climate action abound. Assessments of action on the sustainable development goals (SDGs) and their health impacts,[85,86] for example, could easily expand to incorporate climate action. Both governments and funders have important roles in prioritizing decarbonization in global health programming, practice and research, including efforts to green global health supply chains and reduce health sector carbon intensity. Practitioners have a role to play as well, by demanding that investment in transdisciplinary training and data integration become routine, and creating pathways for career development in climate and health.

Health organizations, including ministries and large NGOs, should engage with scientists from various disciplines (such as climatology, ecology, social sciences, biology, and modeling) to design and prioritize policy-oriented research, including strengthening and evaluating adaptation of the health systems. This involves greening our own practice; investing in substantial, durable interdisciplinary activities and effective data sharing; breaking down informational and disciplinary silos; wrestling with complex issues beyond diagnostics and therapeutics; and supporting decisions that reduce health risks across multiple sectors. This will take substantial, sustained investment, development of new training pathways, support of new data streams, and commitment to working with stakeholders, including communities and policymakers.

Global health needs to think more holistically and act more comprehensively. We know what challenges climate change brings and how to respond. Now we need the will.

Key recommendations

- Prioritize decarbonization, including in the health sector and global health practice.
- Increase funding for climate and health research and practice.
- Encourage a transdisciplinary approach and support interdisciplinary activity.
- Incorporate environmental information into public health practice and assessments.
- Invest in decision-support modeling tools and communication.
- Build human capacity in data management, integrated surveillance, and leadership.

SECTION 2. TRACKING INFECTIOUS DISEASES IN A WARMING WORLD

Kris A Murray, Luis E Escobar, Rachel Lowe, Joacim Rocklöv,
Jan C Semenza, Nick Watts

In one of the first articles published by *The BMJ* on climate change in 1991, Haines wrote: "Eight of the hottest 10 years this century have occurred since 1980."[87] Noting the influence of temperature on the life cycles of several vectors, hosts, and pathogens, Haines went on to question the implications of predicted climate change for many infectious diseases. It is discomforting that today, three decades later, circumstances have hardly changed, and that early forecasts have begun to ring true.[88,89] Eight of the 10 hottest years on record have now occurred since 2010;[90] associations between climate change and the burden, transmission, or distribution of many infectious diseases (principally caused by protozoan, helminth, vector-borne, foodborne, soilborne, and waterborne pathogens) are increasingly being reported;[91] the European Centre for Disease Prevention and Control (ECDC) now ranks climate among the most frequently implicated 'drivers' of infectious disease threats;[92] and WHO now recognizes climate change as one of the major health challenges of the 21st century.[93]

In such a rapidly changing world, how can researchers, health professionals, and policymakers keep track of the risks and intervene accordingly? How can policy options be evaluated, particularly when aiming to achieve globally agreed sustainable development, environmental (including the Paris Agreement), and health management targets?[94,95]

One emerging strategy is the use of climate change 'indicators', which aim to keep track of historical and future predicted trends in key impact areas related to climate change. Such indicators have taken on a range of functions, including quantifying and characterizing exposure, vulnerability, and risk for both populations and health systems, identifying and tracking key impacts on population health, and evaluating changes in adaptive capacity and resilience.[96] Indicator initiatives explicitly aim to go beyond the fractured, and often inconsistent, evidence base presented in the primary scientific literature to bring together or generate relevant information in some generally consistent fashion. They also tend to focus more specifically on the analysis of trends through time, often with an emphasis on accessible yet powerful data sharing and visualizations to stimulate action across sectors and track progress towards some predefined targets. Here we illustrate how climate-sensitive infectious diseases (CSIDs) are being used as climate change indicators to help stimulate and inform public health responses to climate change.

Climate change and health indicators

An example of a benchmark for the quantification and comparison of varying health outcomes is the Global Burden of Disease (GBD) program.[97] This quantifies death and loss of health and wellbeing from hundreds of diseases and their risk factors, and is used to guide health surveillance and improve global health management policies. However, although the GBD program estimates the global burden of several CSIDs, it does not capture some important but difficult to define health impacts, including from health inequalities or climate change.[98]

Several climate change indicator initiatives, ranging in scale from local to global, seek to partially fill this gap. Indicator initiatives specifically targeting climate change and health are relatively recent but have been advocated for widely; examples of key efforts are summarized in Table 2.

Table 2. Indicator initiatives targeting climate change and health

Type of initiative	Key examples
Learned societies	The State Environmental Health Indicators Collaborative (SEHIC)[99]
Health authorities	The US Centers for Disease Control and Prevention (CDC)[100]
Government agencies	The US Environmental Protection Agency,[101] the European Environment Agency, and the forthcoming proposal for an EU observatory for climate change and health, and the EU Adaptation Strategy planned for 2021[102]
Funders	The Wellcome Trust[103]
Academic consortiums	The Inter-Sectoral Impact Model Intercomparison Project[104] and the Lancet Countdown on Health and Climate Change[105]

Where numerous indicator initiatives have tackled some of the more direct impacts of climate change on health, or those for which greater volume and quality of data exist (for example, heat-related mortality), few indicators exist for more complex, indirect impact areas such as infectious diseases. For example, the CDC's Environmental Public Health Tracking Network currently reports on flood and heat vulnerability trends, but not infectious diseases.[106]

Global trends in climate-sensitive infectious diseases (CSIDs)

Current CSID indicators focus primarily on the climatic suitability or population vulnerability components of disease transmission risk, as opposed to case or burden data.

To illustrate, we briefly highlight some of our work as part of the Lancet Countdown on Health and Climate Change,[107] for which we have developed indicators to:

1. assess spatial and temporal trends in the environmental suitability for CSID transmission (for dengue, malaria, and pathogenic *Vibrio* bacteria).
2. evaluate the changing basis of population vulnerability to arboviruses (that is, factoring in national characteristics that define their propensity to be adversely affected by infectious disease threats, such as public health measures).

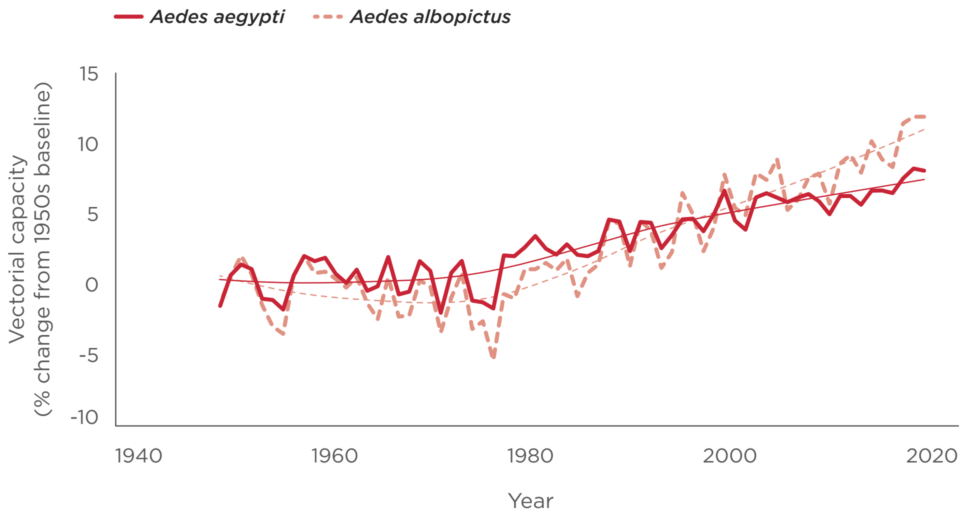
Briefly, indicator analyses for dengue, malaria, and pathogenic *Vibrio* bacteria show increases in the environmental suitability for disease transmission over past decades. For example, 2017 was the second most suitable year on record for the transmission of dengue virus, with average increases of 7.2 percent and 9.8 percent in vectorial capacity observed in the past five years compared with a 1950s baseline for the key vectors *Aedes aegypti* and *A. albopictus*, respectively (see Figure 2).

Despite these increases, country-level vulnerability to dengue outbreaks (that is, exposure to mosquitoes after controlling for the presence of disease-relevant public health measures) has decreased globally by 31 percent since 2010, although some regions remain more vulnerable than others and progress has reversed in these regions in recent years (see Figure 3). The number of suitable months per year for the transmission of malaria (*Plasmodium falciparum*) in the African highlands has increased by 29.9 percent in the past five years compared to a 1950s baseline.

By contrast, other regions do not show an increasing trend for malaria, potentially due to some areas (for example, lowlands) becoming too warm or experiencing shifts away from the combinations of temperature, rainfall, and humidity that enhance transmission (see Figure 4). For waterborne diseases caused by pathogenic *Vibrio* bacteria, similarly strong increases in the percentage of coastal area suitable for transmission are observed at northern latitudes (40–70° N) (see Figure 5 top), in the Baltic Sea (Figure 5 middle) and along the north east coast of the

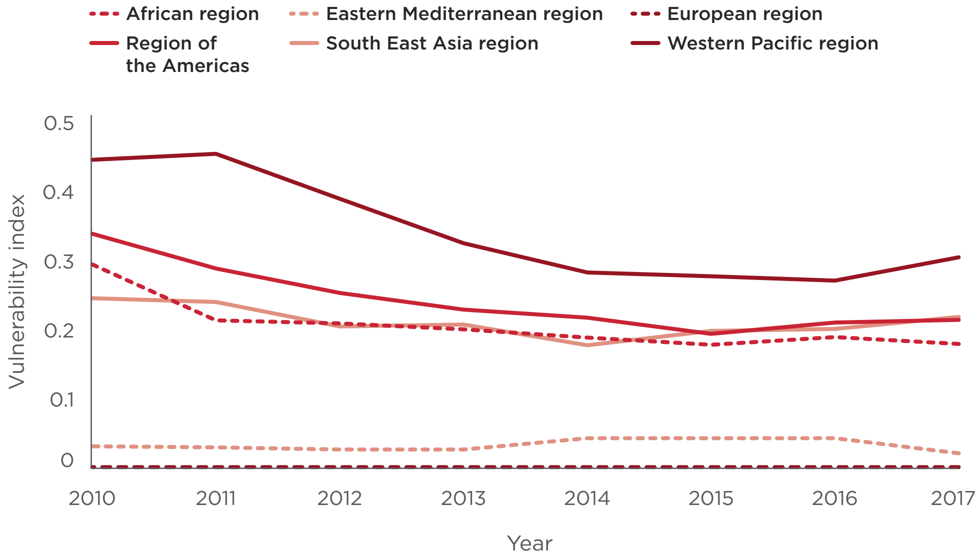
US (Figure 5 bottom). The number of days per year suitable for *Vibrio* in the Baltic reached 107 in 2018: double the early 1980s baseline (Figure 5 middle).

Figure 2. Dengue vectorial capacity over time



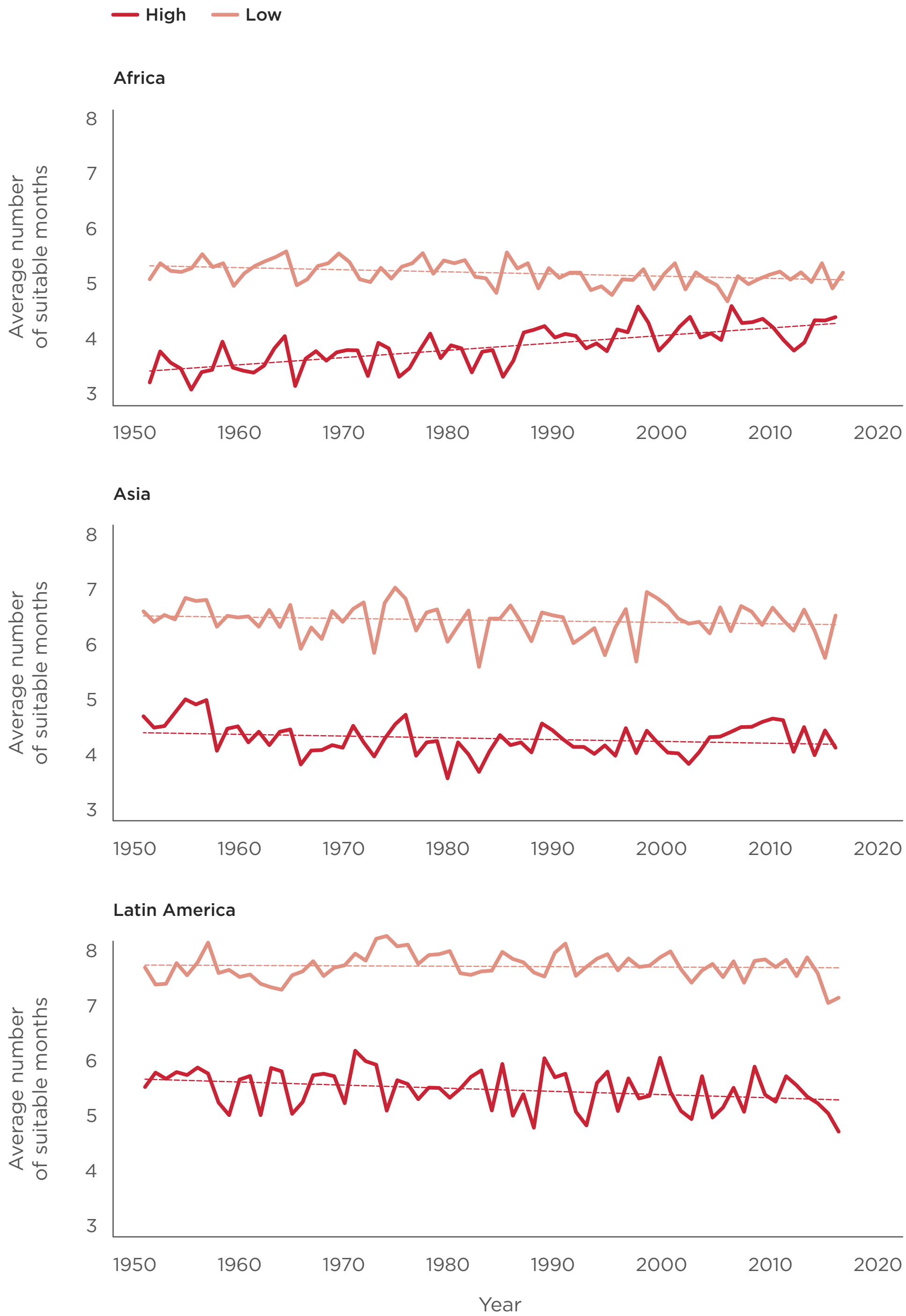
Note: Mathematical models of dengue vectorial capacity for *A aegypti* and *A albopictus* mosquitoes reveal temporal changes in the potential for dengue transmission due to a warming climate since 1950. For details on methodology and expanded interpretations, see the Lancet Countdown on Health and Climate Change.[108]

Figure 3. Improved public health measures against dengue, by region, over time



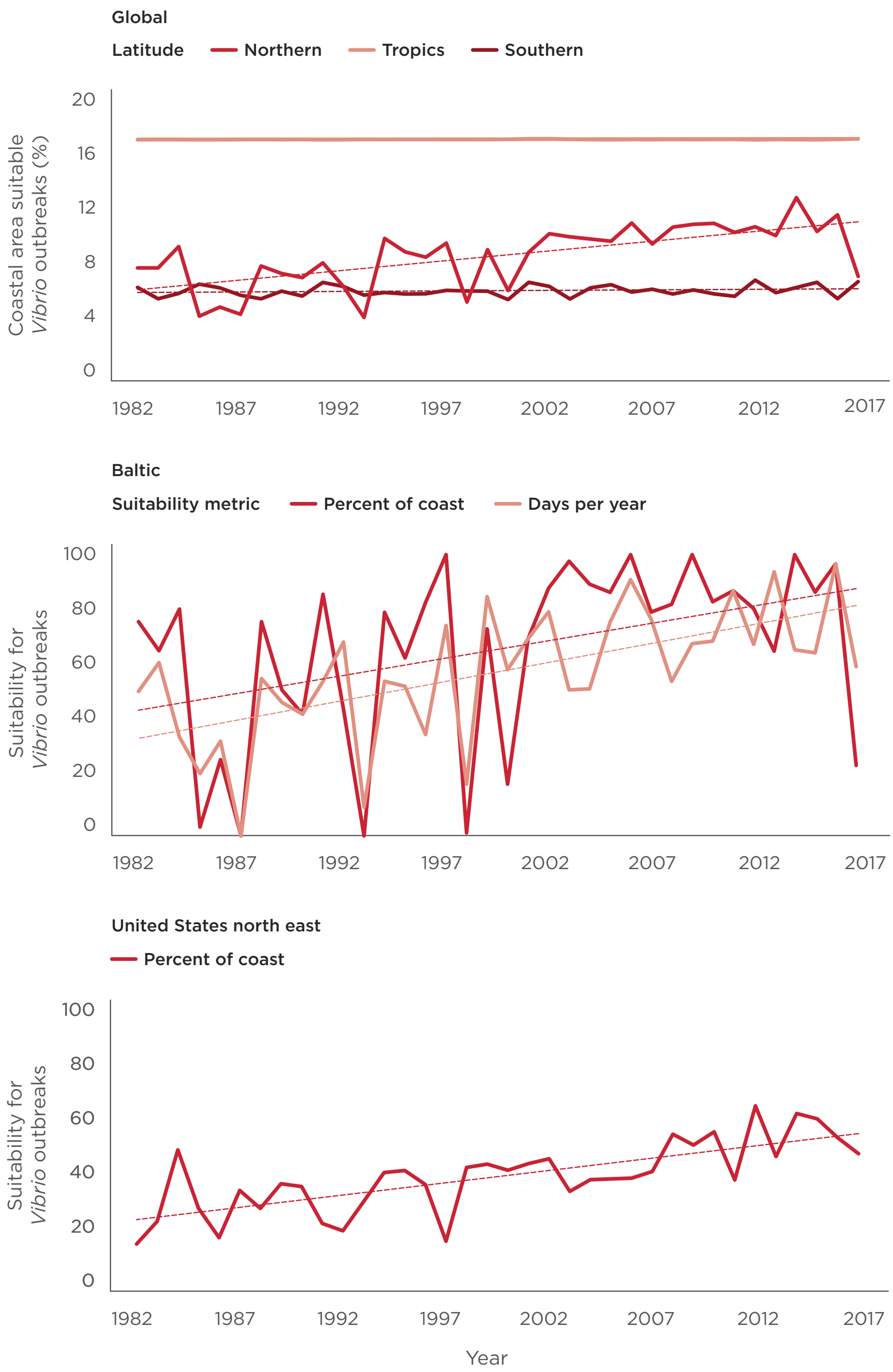
Note: Despite the increases in environmental suitability for dengue shown in Figure 2, improved public health measures have, on average, lowered vulnerability to dengue outbreaks across most regions since 2010, although some recent reversals in this trend are observed in the more vulnerable regions. For details on methodology and expanded interpretations, see the Lancet Countdown on Health and Climate Change.[109]

Figure 4. Number of malaria transmission months, by region, over time



Note: The number of suitable months a year for malaria transmission during the period 1950–2017, as determined by combinations of temperature, rainfall, and humidity, are increasing predominantly in the African highlands (ie, elevation >=1,500 m). No change or subtle declines in environmental suitability are observed in other regions. For details on methodology and expanded interpretations, see the Lancet Countdown on Health and Climate Change.[110]

Figure 5. Environmental suitability for *Vibrio* pathogen, by region, over time



Note: Change in environmental suitability for pathogenic *Vibrio* outbreaks as determined by observed correlations with sea surface temperatures and ocean salinity. This model suggests that suitability is increasing predominantly in the northern hemisphere (top: northern latitudes=40–70°N; tropical latitudes=25°S–40°N; southern latitudes=25–40°S). More detailed analysis by region shows, for example, that the Baltic Sea (middle) and the US north east coast (bottom) are also increasingly suitable for *Vibrio* outbreaks due to climate change. For details on methodology and expanded interpretations, see the Lancet Countdown on Health and Climate Change.[111]

Challenges

Each CSID indicator aims to capture the environmental suitability of disease transmission by mathematically linking preferred conditions for transmission with climate input data. This allows the long-term assessment of how environmental suitability for disease transmission has changed in recent decades, providing an initial step towards the attribution of disease risk to anthropogenic climate change.

Attribution of the underlying climate trends to human greenhouse gas emissions is highly robust;[112] however, it remains difficult to isolate the specific fraction of observed cases of each disease to climate change at large spatial scales given the range of other environmental and socioeconomic covariates at play. These include health inequality (that is, potential for the population to be harmed by a disease due to differential access to healthcare), land use, biodiversity, urbanization, travel and tourism, and global trade. Many of these factors are themselves influenced by climate change and exhibit strong spatial and temporal heterogeneities, illustrating the depth of the complexity of resolving realized climate change impacts on CSID burdens at continental or global scales.[113]

In addition, this set of indicators comprises several different methods (for example, threshold based, mechanistic, correlative models), data sets (for example, baseline gridded climate data), metrics (such as percentage change versus raw change in suitability, indices of environmental suitability versus specific metrics such as vectorial capacity), and temporal windows (for example, baseline period, length of time series).

Different methods reflect the project's participatory, in kind, reformulation approach. However, a more systematic effort is needed to prioritize formally and objectively which diseases should be tracked, to develop standardized methodologies across diseases (when possible), and link outcomes to trends in other sectors, such as food security and access to healthcare, for a range of downstream uses.

Data sharing, use, and public health application

A wide range of public health stakeholders, ranging from the Global Climate and Health Alliance to the International Council of Nurses and the Royal College of Physicians, are increasingly engaged in climate change as a health issue. These professionals depend on both the generation of new medical evidence to drive this agenda forward, and the presentation of evidence in a way that they readily understand and can amplify to help drive mitigation (for example, actions to reduce greenhouse gas emissions of healthcare infrastructure and services) and adaptation strategies (such as identifying CSID hotspots, designing surveillance networks, and early warning systems) to prepare for the changing risks from CSIDs to reduce their impacts.

Improving access to robust climate change risk assessments for health exposures and outcomes allows users to explore and appreciate the spatial and temporal heterogeneities in climate-related health risks relevant to local and co-ordinated management. For instance, the Lancet Countdown CSID indicators can be explored through an online visualization platform[114] to highlight geographic areas that may be experiencing increases or decreases in disease risk, identify locations that require more research for a more accurate understanding of CSID risk, or highlight human populations where inequity gaps require urgent intervention to reduce vulnerability to emerging climate change related public health threats.

Accessible data-sharing platforms provide a powerful avenue for users to visualize and interact with data, to appreciate the current situation in the context of the longer-term trajectory, and to evaluate the growing momentum of certain trends through time, and see the often invisible build-up towards potential health crises. They also highlight the potential downstream impacts that greenhouse gas emissions today could have on health outcomes in the future.

Furthermore, given the scale and pace of the challenge that climate change presents, CSID indicator outputs must be paired with dedicated efforts to ensure that they are translated into languages and formats that a wide range of audiences understand, ideally co-designed with policymakers and potential users. The development of an extensive network of policy and research partners is necessary to link key health bodies (such as the World Health Assembly, the World Health Summit, and the United Nations Framework Convention on Climate Change's decision-making body) with health scientists and practitioners. Similarly, scientific literature must be paired with policy briefings, engaging narrative, and creative outputs if it is to engage across disciplines and help to draw out the local media and policy stories that may otherwise be hidden (for examples, see Lancet Countdown on Health and Climate Change).[115]

Collaborations and investment

Climate change is increasingly being recognized as a public health emergency.[116] Health risks and impacts will continue to grow unless the global community raises its collective ambition to meet the Paris Agreement, which aims to keep the world below 2°C warming, and preferably below 1.5°C.[117] This goal, however, requires evidence-based, transformative, and immediate action to curb greenhouse gas emissions.

While monitoring changes in climate under the Paris Agreement is crucial, equally important is the monitoring of potential health risks related to climate change. Better data for tracking infectious disease in a warming world requires a robust evidence base, recognizing that the challenges posed by climate change to health are substantial in size, complexity, and scope.

Initiatives to track the impacts of climate change (including increased variability in extreme events) and the effects of adaptation efforts on CSIDs have recently emerged to meet this challenge. The development and implementation of indicators calls for international, multidisciplinary research collaborations dedicated to monitoring, analyzing, anticipating, and communicating the links between climate change and health across the world.

Greater investment is required to help such initiatives realize their full potential to accurately identify the contribution of climatic drivers of infectious disease risk across space and time. In turn, identification and dissemination of climate–disease trends will signpost researchers, policymakers, health professionals, and the general public towards more informed, preemptive mitigation and adaptation actions to guide public health practice to an accelerated response to what has been termed by WHO as the "greatest global health threat of the 21st century."[118]

Key recommendations

Development, standardization, and implementation of climate change and health indicators requires multidisciplinary research collaborations and major investment.

- A systematic assessment of climate-sensitive infectious diseases is required to prioritize diseases for tracking.
- Standardized methodologies across diseases are needed with outcomes linked to trends in other sectors.
- Indicator outputs should be accessible and translated into languages and formats for diverse audiences, co-designed with policymakers and users.
- Scientific reports should be paired with policy briefings, engaging narrative, and creative outputs to maximize media coverage and policy engagement.

SECTION 3. SCALING UP CROSS-BORDER CO-OPERATION TO TACKLE CLIMATE AND DISEASE THREATS

Ingrid Torjesen

Climate change and infectious diseases do not respect borders, and tackling the threats they present requires dialogue, co-operation, and collaborative working. The challenges this poses cannot be underestimated in a region like the Middle East, beset by political differences, a long history of conflict, and huge displaced populations. The region is one of the most vulnerable in the world to the effects of climate change, and it is already experiencing increasing temperature rises, reduced rainfall, and increasingly arid conditions.

These conditions have contributed to the recent surge of vector-borne diseases such as leishmaniasis, the re-emergence of West Nile fever, and the rise in foodborne diseases such as salmonellosis in the region. To tackle these, and emerging communicable diseases such as COVID-19 and Middle East Respiratory Syndrome (MERS), requires data sharing and co-operation among researchers and governments across political borders. Various diplomatic bridges exist, but these will have to be expanded and replicated. One long-standing initiative is the Middle East Consortium on Infectious Disease Surveillance (MECIDS). It was established in 2003, with funding and support from the Nuclear Threat Initiative, a US NGO.

The aim of MECIDS is to improve laboratory capacity and infectious disease control among three neighboring territories: Israel; Jordan; and the Palestinian National Authority. It was prompted by the WHO revision to the International Health Regulations, which set rules for improving communication between WHO and member states and mandated that every country has the laboratory capacity to rapidly identify outbreaks,[119] and to improve biosecurity after the 11 September 2001 terrorist attacks, to enable rapid response to intentional misuse of a pathogen.

Israel is considered part of WHO's European region rather than the Eastern Mediterranean region, and opportunities for dialogue between the three governments through WHO were limited. The consortium set out to develop dialogue among academia and the health ministries of the three partners on infectious disease surveillance. It created a channel for the exchange of information and a way to respond rapidly in the event of an emerging situation, such as the 2009 flu pandemic and outbreaks of Severe Acute Respiratory Syndrome (SARS) or MERS.

Salmonellosis as prototype infection

The consortium has developed a continuous surveillance system for foodborne diseases, which can easily be transmitted across borders through the exchange of food and displaced populations, for which salmonellosis was the prototype infection. Each of the three territories has a network of sentinel laboratories feeding into one of three central reference laboratories and data analysis units and, in turn, these feed into a regional data analysis unit in Jordan.[120] The consortium is also increasing surveillance of resurging vector-borne diseases, such as leishmaniasis and West Nile fever.

Climate change is raising the incidence of all these infectious diseases. As temperatures rise, food spoils and bacteria multiply faster, and there have been increases in the populations of sand fly, mosquito, migratory bird, and rodent vectors.

MECIDS also provides training and networking opportunities for epidemiologists and laboratory technicians through summer schools and virtual events to build capacity and collaboration among the workforce. It claims that its success in this challenging political environment is down to the involvement of both academia and the three territories' health ministries, so that it had the power to bring real change.

Models of working in Africa and Asia

The model has been extended and copied to other regions with political tensions and conflict, such as the Balkans and in Africa and Asia. This has been enabled through Connecting Organizations for Regional Disease Surveillance, an overarching organization also set up with the support of the Nuclear Threat Initiative and currently part of Ending Pandemics, an NGO aiming to find and stop pandemics before they spread.

In future MECIDS hopes to work with other neighboring countries, perhaps including more permanent partners. Many other organizations are keen to enable more co-operation in the region to tackle common environmental and health threats.

The Gulf Cooperation Council, a forum of Arab states, is conversing on health security, infectious diseases, environmental health, and climate change – as well as how to shift Gulf economies from high to low carbon and towards more sustainable development.

The World Bank's stated aim is global poverty reduction and it funds projects at the nexus of climate change and infectious disease. Campaigners lambast it for continuing to subsidize fossil fuel extraction, despite the bank screening all potential projects as part of its Climate Change Action Plan.[121]

More than 10 years ago the World Bank helped to establish a platform to promote health policy dialogue and health system strengthening across the region – the Middle East and North Africa Health Policy Forum. Its initial focus was on health governance, service delivery, and quality of care, and it also has a keen interest in climate change and infectious diseases. The World Bank has tools that could be used to assess vulnerability at country level to the impact of climate change on health projections and health systems, which it has offered to the forum. These tools could highlight synergies between countries that regional-level projects could target.

The World Bank says that its initiatives in Africa could be replicated in the Middle East and North Africa. These include the Africa Centres for Disease Control and Prevention, which focus on strengthening regional and continental infectious disease detection and response systems for public health emergency with cross-border or regional implications. It is mandated to deploy responders in consultation with affected member states.

Another initiative is the Regional Disease Surveillance Systems Enhancement, which strengthens national and regional capacity for collaborative disease surveillance and epidemic preparedness in West Africa, including data sharing and an early warning system for outbreaks.

Key recommendations

- Countries in the Middle East need to increase collaboration among governments and researchers to tackle looming threats from the impact of climate change on infectious disease.
- Existing diplomatic bridges, and multilateral projects in the region and beyond that are tasked with disease surveillance and responding to outbreaks, should be replicated and scaled up.

“EVERY COUNTRY AND EVERY REGION MUST ACT IN CONCERT”

“The global COVID-19 pandemic is a powerful reminder that we must look at evolving scientific data to make informed policy and program decisions, and we must act in open, collaborative, and constructive ways across borders. If not, the results can be catastrophic,” physician and public health administrator Margaret Hamburg told *The BMJ*. She is former foreign secretary of the US National Academy of Medicine and the immediate past board chair and president of the American Association for the Advancement of Science, and she sits on the board of the NGO that established the Middle East Consortium on Infectious Disease Surveillance in 2003.

She continued, “Climate change – and its widespread implications, including for health – represents an even more devastating ‘pandemic in slow-motion’. Now is the time to take it seriously, and every country and every region must act in concert, knowing that we are all in this together.”

Tamer Rabie, lead health specialist at the World Bank’s Health, Nutrition and Population global practice, told *The BMJ*: “Climate change can act as a stress multiplier to existing health challenges in the [Middle East] region, adding additional pressures on already scarce resources. The region presents a unique context that requires concerted efforts that would allow working across countries while addressing the underlying political economies.”

MECIDS is “a ready-made prime example” of the type of initiative that can work in the Middle East, he points out.

Sari Husseini, MECIDS’s executive officer and a Palestinian, told *The BMJ*:

“The Ministries of Health of Jordan and Israel remain active participants in MECIDS, with the Palestinian Health Ministry acting as an active participant until 2016, when it formally removed itself. However, key Palestinian public health professionals, many of whom are in close contact with the ministry, remain directly involved in MECIDS, allowing the organization to retain its distinctive tripartite character.

“MECIDS is the only active trilateral health project among Palestinian, Israeli, and Jordanian Health professionals. MECIDS has been holding virtual meetings to exchange information and determine a work plan and to develop a media awareness campaign regarding COVID-19, focusing on World Health Organization guidelines,” she said.

“An efficient and successful containment of COVID-19 will require increased co-ordination between government officials across the Middle East and North Africa region, outside of Israel, West Bank/Gaza, and Jordan. For this reason, MECIDS seeks to interface with foreign public health officials from extraneous countries in the region, for example, Egypt and the Gulf Cooperation Council.”

Daniel Cohen, chair of the MECIDS board and professor and acting head of the Tel Aviv University School of Public Health, Israel, told *The BMJ*:

“We exchange information continuously. It is so important to share information and to have data to respond to. We didn’t want just to be an NGO. And, if you do research, you can have partners in academia, no problem,” he says. But the consortium wanted the power to have its findings applied by including government. “That was the importance of having those who can take decisions and do interventions on board.” At times of increased tension, the balance of involvement of the ministries and academia among the partners can alter. “In these situations academia takes the lead, and the NGOs are more predominant,” Cohen explains. “At other times the ministries are more active.”

“Dealing with health concerns and threats has brought people together,” thinks Cohen.

SECTION 4. CONCLUSION: STRATEGIES TO REDUCE THE HEALTH RISKS ASSOCIATED WITH CLIMATE CHANGE

Climate change is increasingly recognized as a public health emergency that poses health challenges that are substantial in size, complexity, and scope – especially infectious disease.[122] A 'wait and see' approach is short-sighted and has invited unnecessary risk, and a change of course is needed. Below, we outline some 'low regrets' strategies to reduce the health risks associated with climate change by improving the ability to anticipate and engage with infectious disease risks effectively (as outlined in Figure 6).

1. Increase cross-border co-operation

Infectious diseases do not recognize political borders. Countries will need to increase collaboration among governments and researchers to tackle looming regional and global threats from the impact of climate change on infectious disease. Existing diplomatic solutions should be expanded, and the many multilateral projects that are tasked with disease surveillance and responding to outbreaks are blueprints for co-operation that should be replicated and scaled up.

2. Reduce greenhouse gas emissions in all sectors, including healthcare

Health risks and impacts will continue to grow unless the global community raises its collective ambition to meet the Paris Agreement targets, which aim to keep the world below 2°C warming, and preferably below 1.5°C.[123] However, this goal requires evidence-based, transformative, and immediate action to curb greenhouse gas emissions. Globally, the health sector emits 4 percent of the world's greenhouse gases, which is more than aviation or shipping.[124] Reduced emissions of greenhouse gases is a by-product of the response to the COVID-19 pandemic.[125] While COVID-19 holds the world's attention, health systems can seize the opportunity to promote further greening during recovery efforts.[126]

3. Increase funding for climate and health

Nations should invest in strategies to further establish links between climate change and health and tackle climate-related health risks. The discipline of climate and health is systematically deprived of funding for training, research, and development and testing of interventions.[127] Despite some positive recent developments, there is a lack of investment in climate and health from major global health funders.

4. Frame the problem with a transdisciplinary lens

Interdisciplinary and intersectoral concepts are proposed for tackling global health threats, such as EcoHealth, One Health, planetary health, planetary epidemiology, and planetary wellbeing.[128,129] These concepts share the notion that the health of humans, plants, and animals and the planet are inextricably linked. Other frameworks are based on social determinants of health.[130,131] These concepts are widely embraced but not fully realized. Transdisciplinary teams that include climate scientists and meteorologists as well as health professionals can create a merged community of practice. They can design more robust surveillance systems, develop innovative methodologies and effective communication strategies in city, national, and international settings.[132,133]

5. Incorporate environmental information into public health practice

The global response to climate change and its effects needs better information to support decision-making. The development and implementation of indicators integrating climate data into the surveillance of infectious diseases calls for international, multidisciplinary research collaborations dedicated to monitoring, analyzing, anticipating, and communicating the links between climate change and health worldwide. Greater investment is required to help such initiatives realize their full potential. In turn, identification and dissemination of climate–disease trends will signpost researchers, policymakers, health professionals, and the general public toward more informed, preemptive mitigation and adaptation actions, and guide public health practice to an accelerated response.[7]

6. Invest in modeling tools that predict future epidemics

Computer models can help disentangle and quantify the role of multiple infectious disease transmission risk factors, including climatic and environmental factors, human mobility, socioeconomic status, asymptomatic infections, and background immunity. Models can also provide insight into which modifiable factors are most important for achieving management goals. Predictive modeling can help decision-makers understand where infections will emerge or spread, or when future epidemics might occur. Early warning systems for outbreaks of diseases combine novel data streams, including seasonal forecasts and local seroprevalence data.[134]

7. Align with local priorities and capacity needs

Modeling approaches and processes for evaluating future climate change effects on infectious disease must be co-designed in partnership with public health climate practitioners, and aligned with local priorities and capacities to identify the most appropriate challenges and solutions and tackle cross-sectoral problems.[135]

8. Communicate, disseminate, and educate

User-friendly interfaces are key to effective communication, to visualize and share results. They also provide access to the modeling to allow models to be scrutinized and reproduced.[136] It is also essential to educate policymakers and other stakeholders about the modeling processes, important ways modeling can support decisions, and how to interpret the findings.[137,138]

9. Invest in technology and widespread data availability

Data science and software engineering are key components of any transdisciplinary epidemiological taskforce. Data transparency and availability are essential. Systems for monitoring, surveillance, and disease control depend on the latest technologies and how they allow integration of data across disciplines.

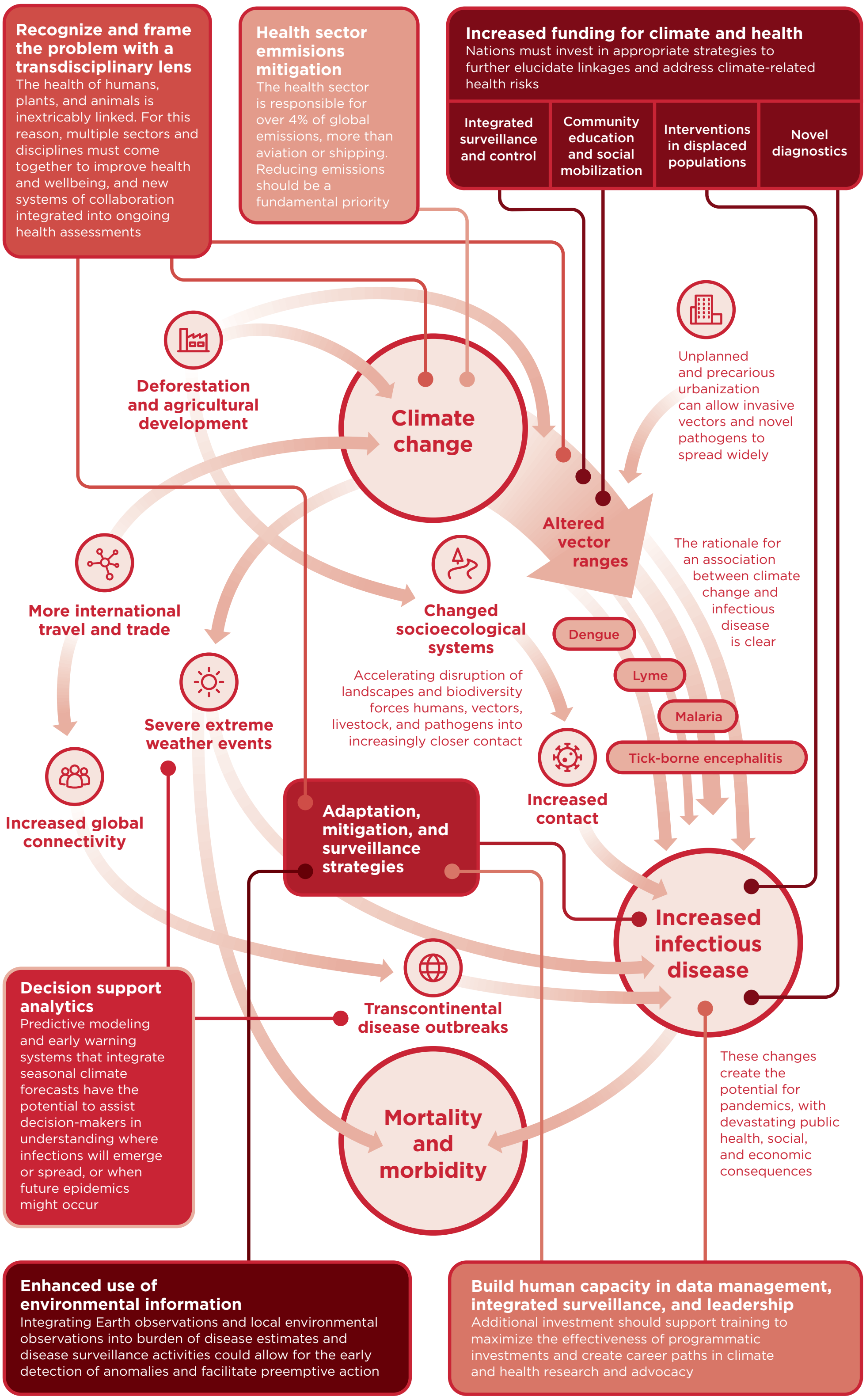
10. Build human capacity in data management, integrated surveillance, and leadership

The public health community's awareness of climate-related epidemiological and assessment tools remains low.[139] Sustained funding is essential: for risk assessment, intervention development, program evaluation, and implementation; to train the next generation of climate and health leaders and encourage interdisciplinary collaborations; to maintain longer-term projects for sustained impact; and to learn about implementation strategies. Also, funders should prioritize support for surveillance that incorporates environmental information and skills training for interdisciplinary practice.[140]

Key recommendations

- Prioritize decarbonization, including in the health sector and global health practice.
- Increase funding for climate and health research and practice.
- Encourage a transdisciplinary approach and support interdisciplinary activity.
- Incorporate environmental information into public health practice and assessments.
- Invest in decision support modeling tools and communication.
- Build human capacity in data management, integrated surveillance, and leadership.

Figure 6. Roadmap for action in climate change and infectious diseases



ACKNOWLEDGMENTS

The Forum Advisory Board for this report was co-chaired by:

- Jeremy Hess, Professor in Emergency Medicine, Environmental and Occupational Health Sciences, and Global Health; and Adjunct Professor, Atmospheric Sciences; and Director, Center for Health and the Global Environment (CHanGE), University of Washington
- Rachel Lowe, Associate Professor and Royal Society Dorothy Hodgkin Fellow, Centre on Climate Change and Planetary Health and Centre for Mathematical Modelling of Infectious Diseases, London School of Hygiene & Tropical Medicine

Sincere thanks are extended to the members of the advisory board of the WISH 2020 Forum on Climate Change and Communicable Diseases, who contributed their unique insights to this report:

- Muna Al Maslamani, Medical Director of Communicable Disease Center / Assistant Head of Infectious Diseases Division–Medicine Department at Hamad General Hospital, Hamad Medical Corporation
- Laura-Lee Boodram, Head of Vector-borne Diseases, Caribbean Public Health Agency
- Shlomit Paz, Head of the Department of Geography and Environmental Studies, University of Haifa
- Anna Stewart Ibarra, Scientific Director of the Inter-American Institute for Global Change Research (IAI)
- Judith Wasserheit, Chair, Global Health; Professor, Global Health; Professor Medicine – Allergy and Infectious Diseases; and Adjunct Professor, Epidemiology, University of Washington

We also extend our thanks for the contributions to this report made by:

- Luis E Escobar, Assistant Professor of Disease Ecology, Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
- Kris A Murray, Associate Professor of Environment and Health, MRC Centre for Global Infectious Disease Analysis and Grantham Institute, Imperial College London; MRC Unit The Gambia; and Centre on Climate Change and Planetary Health, London School of Hygiene & Tropical Medicine, London
- Joacim Rocklöv, Professor of Epidemiology and Public Health, Department of Public Health and Clinical Medicine, Umeå University, Umeå, Sweden

- Jan C Semenza, Professor and Head of the Health Determinants Programme, Scientific Assessment Section, European Centre for Disease Prevention and Control, Solna
- Ingrid Torjesen, Journalist, London
- Nick Watts, Executive Director of Lancet Countdown on Health and Climate Change, Institute for Global Health, University College London, London

A conflict of interest statement is available for all authors on bmj.com.

ARTICLE CITATIONS

Section 1

Hess J, Boodram L, Paz S, Stewart Ibarra AM, Wasserheit JN, Lowe R. Strengthening the global response to climate change and infectious disease threats. BMJ 2020; 371: m3081

Section 2

Murray KA, Escobar LE, Lowe R, Rocklöv J, Semenza JC, Watts N. Tracking infectious diseases in a warming world. BMJ 2020; 371: m3086

Section 3

Torjesen I. Scaling up cross-border co-operation to tackle climate and disease threats. BMJ 2020; 371: m3145

REFERENCES

1. Costello A, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *The Lancet*. 2009; 373, P1693–1733.

2. Wu X, et al. Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment International*. 2016; 86, P14–23.

3. Eckelman MJ, Sherman JD. Estimated global disease burden from US health care sector greenhouse gas emissions. *American Journal of Public Health*. 2018; 108(S2), S120–122.

4. McMichael AJ, et al. Global environmental change and health: Impacts, inequalities, and the health sector. *BMJ*. 2008; 336, P191–194.

5. Intergovernmental Panel on Climate Change. *Climate Change 2007 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC*. Cambridge: Cambridge University Press; 2007.

6. Intergovernmental Panel on Climate Change. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press; 2012.

7. Intergovernmental Panel on Climate Change. *Climate Change 2014 – Impacts, Adaptation and Vulnerability*. Geneva: Intergovernmental Panel on Climate Change; 2014.

8. Ebi KL, Semenza JC, Rocklöv J. Current medical research funding and frameworks are insufficient to address the health risks of global environmental change. *Environmental Health*. 2016; 15, P108.

9. Papworth A, Maslin M, Randalls S. Is climate change the greatest threat to global health? *The Geographical Journal*. 2015; 181, P413–422.

10. Kovats S, Haines A. The potential health impacts of climate change: An overview. *Medicine and War*. 1995; 11, P168–178.

11. Githeko AK, et al. Climate change and vector-borne diseases: A regional analysis. *Bulletin of the World Health Organization*. 2000; 78, P1136–1147.

12. Ogden NH, Lindsay LR. Effects of climate and climate change on vectors and vector-borne diseases: Ticks are different. *Trends in Parasitology*. 2016; 32, P646–656.

13. Parham PE, et al. Climate, environmental and socio-economic change: Weighing up the balance in vector-borne disease transmission. *Philosophical Transactions of the Royal Society London B: Biological Sciences*. 2015; 370, 20130551.

14. Semenza JC, et al. Determinants and drivers of infectious disease threat events in Europe. *Emerging Infectious Diseases*. 2016; 22, P581–589.

15. GBD 2017 DALYs and HALE Collaborators. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*. 2018; 392, P1859–1922.

16. Caminade C, McIntyre KM, Jones AE. Impact of recent and future climate change on vector-borne diseases. *Annals of the New York Academy of Sciences*. 2019; 1436, P157–173.

17. Liang L, Gong P. Climate change and human infectious diseases: A synthesis of research findings from global and spatio-temporal perspectives. *Environment International*. 2017; 103, P99–108.

18. Lowe R, et al. Nonlinear and delayed impacts of climate on dengue risk in Barbados: A modelling study. *PLoS Medicine*. 2018; 15, E1002613.

19. Jones KE, et al. Global trends in emerging infectious diseases. *Nature*. 2008; 451, P990–993.

20. Plowright RK, et al. Pathways to zoonotic spillover. *Nature Reviews Microbiology*. 2017; 15, P502–510.

21. Fornace KM, et al. Environmental risk factors and exposure to the zoonotic malaria parasite *Plasmodium knowlesi* across northern Sabah, Malaysia: A population-based cross-sectional survey. *The Lancet Planetary Health*. 2019; 3, E179–186.

22. Waitz Y, et al. Temperature effects on the activity of vectors for *Leishmania tropica* along rocky habitat gradients in the Eastern Mediterranean. *Journal of Vector Ecology*. 2018; 43, P205–214.

23. Waitz Y, et al. Effects of land use type, spatial patterns and host presence on Leishmania tropica vectors activity. *Parasites & Vectors*. 2019; 12, P320.

24. El Zowalaty ME, Järhult JD. From SARS to COVID-19: A previously unknown SARS-CoV-2 virus of pandemic potential infecting humans – call for a One Health approach. *One Health*. 2020; 100124.

25. Ebi KL, et al. Detecting and attributing health burdens to climate change. *Environmental Health Perspectives*. 2017; 125, 085004.

26. Gubler DJ. Dengue, urbanization and globalization: The unholy trinity of the 21st century. *Tropical Medicine and Health*. 2011; 39(supp), P3–11.

27. Rocklöv J, Tozan Y. Climate change and the rising infectiousness of dengue. *Emerging Topics in Life Sciences*. 2019; 3, P133–142.

28. Liu Y, et al. Reviewing estimates of the basic reproduction number for dengue, Zika and chikungunya across global climate zones. *Environmental Research*. 2020; 182, 109114.

29. Ogden NH. Climate change and vector-borne diseases of public health significance. *FEMS Microbiology Letters*. 2017; P364.

30. Medlock JM, Leach SA. Effect of climate change on vector-borne disease risk in the UK. *The Lancet Infectious Diseases*. 2015; 15, P721–730.

31. Siraj AS, et al. Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. *Science*. 2014; 343, P1154–1158.

32. Ogden NH. Climate change and vector-borne diseases of public health significance. *FEMS Microbiology Letters*. 2017; P364.

33. Ogden NH, et al. Estimated effects of projected climate change on the basic reproductive number of the Lyme disease vector *Ixodes scapularis*. *Environmental Health Perspectives*. 2014; 122, P631–638.

34. Robert MA, et al. Arbovirus emergence in the temperate city of Córdoba, Argentina, 2009–2018. *Scientific Data*. 2019; 6, P276.

35. Paz S. Climate change impacts on West Nile virus transmission in a global context. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*. 2015; 370, 20130561.

36. Lillepold K, et al. More arboviral disease outbreaks in continental Europe due to the warming climate? *Journal of Travel Medicine*. 2019; 26, TAZ017.

37. Rocklöv J, et al. Using big data to monitor the introduction and spread of chikungunya, Europe, 2017. *Emerging Infectious Diseases*. 2019; 25, P1041–1049.

38. Caminade C, et al. Global risk model for vector-borne transmission of Zika virus reveals the role of El Niño 2015. *Proceedings of the National Academy of Sciences of the United States of America*. 2017; 114, P119–124.

39. Kraemer MUG, et al. Past and future spread of the arbovirus vectors *Aedes aegypti* and *Aedes albopictus*. *Nature Microbiology*. 2019; 4, P854–863.

40. Semenza JC, et al. Climate change projections of West Nile virus infections in Europe: Implications for blood safety practices. *Environmental Health*. 2016; 15(supp 1), P28.

41. Trisos CH, Merow C, Pigot AL. The projected timing of abrupt ecological disruption from climate change. *Nature*. 2020; 580, P496–501.

42. Bálint M, et al. Cryptic biodiversity loss linked to global climate change. *Nature Climate Change*. 2011; 1, P313–318.

43. Pires APF, et al. Interactive effects of climate change and biodiversity loss on ecosystem functioning. *Ecology*. 2018; 99, P1203–1213.

44. Aguirre AA. Changing patterns of emerging zoonotic diseases in wildlife, domestic animals, and humans linked to biodiversity loss and globalization. *ILAR Journal*. 2017; 58, P315–318.

45. Cotar AI, et al. Transmission dynamics of the West Nile virus in mosquito vector populations under the influence of weather factors in the Danube Delta, Romania. *Ecohealth*. 2016; 13, P796–807.

46. Leigh J, et al. *Is Global Capacity to Manage Outbreaks Improving?* Geneva: Graduate Institute of International and Development Studies; 2018.

47. Fanzo J, et al. The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security*. 2018; 18, P12–19.

48. Brzoska M, Fröhlich C. Climate change, migration and violent conflict: vulnerabilities, pathways and adaptation strategies. *Migration and Development*. 2016; 5, P190–210.

49. Pichler PP, et al. International comparison of health care carbon footprints. *Environmental Research Letters*. 2019; 14, 064004.

50. Intergovernmental Panel on Climate Change. *Global warming of 1.5°C*. Geneva: Intergovernmental Panel on Climate Change; 2018. www.ipcc.ch/sr15 [accessed 14 September 2020].

51. Pichler PP, et al. International comparison of health care carbon footprints. *Environmental Research Letters*. 2019; 14, 064004.

52. NHS Sustainable Development Unit. *NHS England Carbon Emissions: Carbon footprinting report*. Stockholm: Stockholm Environment Institute; 2009.

53. Watts N, et al. The Lancet Countdown: Tracking progress on health and climate change. *The Lancet*. 2017; 389, P1151–1164.

54. Castro MC, et al. Development, environmental degradation, and disease spread in the Brazilian Amazon. *PLoS Biology*. 2019; 17, E3000526.

55. Dieleman JL, et al. The G20 and development assistance for health: Historical trends and crucial questions to inform a new era. *The Lancet*. 2019; 394, P173–183.

56. Eckelman MJ, Sherman JD. Estimated global disease burden from US health care sector greenhouse gas emissions. *American Journal of Public Health*. 2018; 108(S2), S120–122.

57. Lowe R, et al. Dengue outlook for the World Cup in Brazil: An early warning model framework driven by real-time seasonal climate forecasts. *The Lancet Infectious Diseases*. 2014; 14, P619–626.

58. Nissan H, et al. On the use and misuse of climate change projections in international development. *WIREs Climate Change*. 2019; 10, E579.

59. Le Quéré C, et al. Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*. 2020; P1–7.

60. Lahcen B, et al. Green recovery policies for the COVID-19 crisis: Modelling the impact on the economy and greenhouse gas emissions. *Environmental and Resource Economics*. 2020; P1–20.

61. Ebi KL, Semenza JC, Rocklöv J. Current medical research funding and frameworks are insufficient to address the health risks of global environmental change. *Environmental Health*. 2016; 15, P108.

62. Patz JA, et al. Climate change and global health: Quantifying a growing ethical crisis. *EcoHealth*. 2007; 4, P397–405.

63. Whitmee S, et al. Safeguarding human health in the Anthropocene epoch: Report of The Rockefeller Foundation-Lancet Commission on Planetary Health. *The Lancet*. 2015; 386, P1973–2028.

64. Butler CD. Planetary epidemiology: Towards first principles. *Current Environmental Health Reports*. 2018; 5, P418–429.

65. Marmot M. Social determinants of health inequalities. *The Lancet*. 2005; 365, P1099–1104.

66. Schulz A, Northridge ME. Social determinants of health: Implications for environmental health promotion. *Health Education & Behavior*. 2004; 31, P455–471.

67. Rivers C, et al. Using "outbreak science" to strengthen the use of models during epidemics. *Nature Communications*. 2019; 10, P3102.

68. Hewitson B, et al. Climate information websites: An evolving landscape. *WIREs Climate Change*. 2017; 8, P51.

69. Lowe R, et al. Dengue outlook for the World Cup in Brazil: An early warning model framework driven by real-time seasonal climate forecasts. *The Lancet Infectious Diseases*. 2014; 14, P619–626.

70. Lowe R, et al. Climate services for health: Predicting the evolution of the 2016 dengue season in Machala, Ecuador. *The Lancet Planetary Health*. 2017; 1, E142–151.

71. Lowe R, et al. Nonlinear and delayed impacts of climate on dengue risk in Barbados: A modelling study. *PLoS Medicine*. 2018; 15, E1002613.

72. Lowe R, et al. Dengue outlook for the World Cup in Brazil: An early warning model framework driven by real-time seasonal climate forecasts. *The Lancet Infectious Diseases*. 2014; 14, P619–626.

73. Lowe R, et al. Climate services for health: Predicting the evolution of the 2016 dengue season in Machala, Ecuador. *The Lancet Planetary Health*. 2017; 1, E142–151.

74. Parham PE, et al. Climate, environmental and socio-economic change: Weighing up the balance in vector-borne disease transmission. *Philosophical Transactions of the Royal Society London B: Biological Sciences*. 2015; 370, 20130551.

75. Rivers C, et al. Using "outbreak science" to strengthen the use of models during epidemics. *Nature Communications*. 2019; 10, P3102.

76. Nissan H, et al. On the use and misuse of climate change projections in international development. *WIREs Climate Change*. 2019; 10, E579.

77. Hewitson B, et al. Climate information websites: An evolving landscape. *WIREs Climate Change*. 2017; 8, P51.

78. Lillepold K, et al. More arboviral disease outbreaks in continental Europe due to the warming climate? *Journal of Travel Medicine*. 2019; 26, TAZ017.

79. Patz JA, et al. Global climate change and emerging infectious diseases. *JAMA*. 1996; 275, P217–223.

80. Castro MC, et al. Development, environmental degradation, and disease spread in the Brazilian Amazon. *PLoS Biology*. 2019; 17, E3000526.

81. Stewart-Ibarra AM, et al. Co-developing climate services for public health: Stakeholder needs and perceptions for the prevention and control of Aedes-transmitted diseases in the Caribbean. *PLoS Neglected Tropical Diseases*. 2019; 13, E0007772.

82. Hewitson B, et al. Climate information websites: An evolving landscape. *WIREs Climate Change*. 2017; 8, P51.

83. Koplan JP, et al; Consortium of Universities for Global Health Executive Board. Towards a common definition of global health. *The Lancet*. 2009; 373, P1993–1995.

84. Dieleman JL, et al. The G20 and development assistance for health: Historical trends and crucial questions to inform a new era. *The Lancet*. 2019; 394, P173–183.

85. Lim SS, et al; GBD 2015 SDG Collaborators. Measuring the health-related Sustainable Development Goals in 188 countries: A baseline analysis from the Global Burden of Disease Study 2015. *The Lancet*. 2016; 388, P1813–1850.

86. Fullman N, et al; GBD 2016 SDG Collaborators. Measuring progress and projecting attainment on the basis of past trends of the health-related Sustainable Development Goals in 188 countries: an analysis from the Global Burden of Disease Study 2016. *The Lancet*. 2017; 390, P1423–1459.

87. Haines A. Global warming and health. *BMJ*. 1991; 302, P669–670.

88. Intergovernmental Panel on Climate Change. *Climate Change: The IPCC 1990 and 1992 Assessments*. Geneva: Intergovernmental Panel on Climate Change; 1992.

89. Shope R. Global climate change and infectious diseases. *Environmental Health Perspectives*. 1991; 96, P171–174.

90. National Aeronautics and Space Administration. *2018 fourth warmest year in continued warming trend, according to NASA, NOAA*. climate.nasa.gov/news/2841/2018-fourth-warmest-year-in-continued-warming-trend-according-to-nasa-noaa [accessed 14 September 2020].

91. McIntyre KM, et al. Systematic assessment of the climate sensitivity of important human and domestic animals pathogens in Europe. *Scientific Reports*. 2017; 7, P7134.

92. Semenza JC, et al. Observed and projected drivers of emerging infectious diseases in Europe. *Annals of the New York Academy of Sciences*. 2016; 1382, P73–83.

93. World Health Organization. *WHO calls for urgent action to protect health from climate change – sign the call*. www.who.int/globalchange/global-campaign/cop21/en [accessed 14 September 2020].

94. Griggs D, et al. Policy: Sustainable development goals for people and planet. *Nature*. 2013; 495, P305–307.

95. Jamison DT, et al. Global health 2035: A world converging within a generation. *The Lancet*. 2013; 382, P1898–1955.

96. Ebi KL, et al. Health risks of warming of 1.5°C, 2°C, and higher, above pre-industrial temperatures. *Environmental Research Letters*. 2018; 13, 063007.

97. Institute for Health Metrics and Evaluation. *Global Burden of Disease (GBD)*. www.healthdata.org/gbd [accessed 14 September 2020].

98. English PB, et al. Environmental health indicators of climate change for the United States: Findings from the State Environmental Health Indicator Collaborative. *Environmental Health Perspectives*. 2009; 117, P1673–1681.

99. English PB, et al. Environmental health indicators of climate change for the United States: Findings from the State Environmental Health Indicator Collaborative. *Environmental Health Perspectives*. 2009; 117, P1673–1681.

100. Centers for Disease Control and Prevention. *Climate Change Indicators*. ephtracking.cdc.gov/showClimateChangeIndicators [accessed 14 September 2020].

101. United States Environmental Protection Agency. *Climate change indicators in the United States*. www.epa.gov/climate-indicators [accessed 14 September 2020].

102. European Environment Agency. *Indicators*. www.eea.europa.eu/data-and-maps/indicators [accessed 14 September 2020].

103. Wellcome Trust. *Tracking global progress on climate change*. wellcome.ac.uk/news/tracking-global-progress-climate-change [accessed 14 September 2020].

104. Inter-Sectoral Impact Model Intercomparison Project. *Simulation Protocols*. www.isimip.org/protocol/#isimip2b [accessed 14 September 2020].

105. Lancet Countdown. *Data Platform: Explore our data*. www.lancetcountdown.org/data-platform [accessed 14 September 2020].

106. Centers for Disease Control and Prevention (CDC). Climate Change Indicators. 2019. https://ephtracking.cdc.gov/showClimateChangeIndicators [Accessed 14 September 2020]

107. Watts N, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet*. 2019; 394, P1836–1878.

108. Watts N, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet.* 2019; 394, P1836–1878.

109. Watts N, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet.* 2019; 394, P1836–1878.

110. Watts N, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet.* 2019; 394, P1836–1878.

111. Watts N, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet.* 2019; 394, P1836–1878.

112. Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press; 2013.

113. Semenza JC, et al. Determinants and drivers of infectious disease threat events in Europe. *Emerging Infectious Diseases*. 2016; 22, 581–589.

114. Lancet Countdown. *Data Platform: Explore our data*. www.lancetcountdown.org/data-platform [accessed 14 September 2020].

115. Lancet Countdown. *Resources*. www.lancetcountdown.org/resources [accessed 14 September 2020].

116. Harmer A, et al. WHO should declare climate change a public health emergency. *BMJ*. 2020; 368, M797.

117. Intergovernmental Panel on Climate Change. *Global warming of 1.5°C*. Geneva: Intergovernmental Panel on Climate Change; 2018. www.ipcc.ch/sr15 [accessed 14 September 2020].

118. World Health Organization. *WHO calls for urgent action to protect health from climate change – sign the call*. www.who.int/globalchange/global-campaign/cop21/en [accessed 14 September 2020].

119. World Health Organization. *Revision of the International Health Regulations. Resolution No. WHA58.3*. www.who.int/csr/ihr/WHA58-en.pdf [accessed 14 September 2020].

120. Faour-Klingbeil D, Todd ECD. Prevention and control of foodborne diseases in Middle-East North African Countries: Review of national control systems. *International Journal of Environmental Research and Public Health*. 2019; 17, P70.

121. World Bank Group. *Climate Change Action Plan*. Washington, DC: World Bank Group; 2016.

122. Harmer A, et al. WHO should declare climate change a public health emergency. *BMJ*. 2020; 368, M797.

123. Intergovernmental Panel on Climate Change. *Global warming of 1.5°C*. Geneva: Intergovernmental Panel on Climate Change; 2018. www.ipcc.ch/sr15 [accessed 14 September 2020].

124. Pichler PP, et al. International comparison of health care carbon footprints. *Environmental Research Letters*. 2019; 14, 064004.

125. Le Quéré C, et al. Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*. 2020; P1–7.

126. Lahcen B, et al. Green recovery policies for the COVID-19 crisis: Modelling the impact on the economy and greenhouse gas emissions. *Environmental and Resource Economics*. 2020, P1–20.

127. Ebi KL, Semenza JC, Rocklöv J. Current medical research funding and frameworks are insufficient to address the health risks of global environmental change. *Environmental Health*. 2016; 15, P108.

128. Whitmee S, et al. Safeguarding human health in the Anthropocene epoch: Report of The Rockefeller Foundation-Lancet Commission on Planetary Health. *The Lancet*. 2015; 386, P1973–2028.

129. Butler CD. Planetary epidemiology: Towards first principles. *Current Environmental Health Reports*. 2018; 5, P418–429.

130. Marmot M. Social determinants of health inequalities. *The Lancet*. 2005; 365, P1099–1104.

131. Schulz A, Northridge ME. Social determinants of health: Implications for environmental health promotion. *Health Education & Behavior*. 2004; 31, P455–471.

132. Rivers C, et al. Using "outbreak science" to strengthen the use of models during epidemics. *Nature Communications*. 2019; 10, P3102.

133. Hewitson B, et al. Climate information websites: An evolving landscape. *WIREs Climate Change*. 2017; 8, P51.

134. Lowe R, et al. Climate services for health: Predicting the evolution of the 2016 dengue season in Machala, Ecuador. *The Lancet Planetary Health*. 2017; 1, E142–151.

135. Parham PE, et al. Climate, environmental and socio-economic change: Weighing up the balance in vector-borne disease transmission. *Philosophical Transactions of the Royal Society London B: Biological Sciences*. 2015; 370, 20130551.

136. Rivers C, et al. Using "outbreak science" to strengthen the use of models during epidemics. *Nature Communications*. 2019; 10, P3102.

137. Nissan H, et al. On the use and misuse of climate change projections in international development. *WIREs Climate Change*. 2019; 10, E579.

138. Hewitson B, et al. Climate information websites: An evolving landscape. *WIREs Climate Change*. 2017; 8, P51.

139. Lillepold K, et al. More arboviral disease outbreaks in continental Europe due to the warming climate? *Journal of Travel Medicine*. 2019; 26, TAZ017.

140. Patz JA, et al. Global climate change and emerging infectious diseases. *JAMA*. 1996; 275, P217–223.

WISH RESEARCH PARTNERS

WISH gratefully acknowledges the support of the Ministry of Public Health

مؤسسة قطر
Qatar Foundation
WISE

مجلس قطر للمباني الخضراء
QATAR GREEN BUILDING COUNCIL
عضو في مؤسسة قطر
Member of Qatar Foundation

RIPHAH
INSTITUTE OF HEALTHCARE IMPROVEMENT & SAFETY

سدرة للطب
Sidra Medicine

thebmj

UPMB
ACTS 1:7-8
"Health in Totality"

UCL

W CHanGE
Center for Health and the Global Environment
UNIVERSITY of WASHINGTON | SCHOOL OF PUBLIC HEALTH

Waitemata
District Health Board
Best Care for Everyone

ISBN 978-1-9139910-7-4

www.wish.org.qa