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Tackling climate change and deforestation to protect against vector-borne diseases

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The spread of vector-borne infectious diseases is driven by a complex array of environmental and social drivers, including climate and land-use changes. Global and regional action is urgently needed to tackle carbon emissions and deforestation to halt future outbreaks.

In the past five years, unprecedented outbreaks of vector-borne infectious diseases have occurred worldwide, often in association with climatic and land-use change events. For example, Peru has experienced the largest dengue outbreak in its history this year, which coincided with Cyclone Yaku and a localized El Niño that caused unusually warm and wet conditions. Other climate extremes, such as Pakistan's record-breaking monsoon season and catastrophic flooding in 2022, led to major outbreaks of dengue and malaria. Animals are also affected by these change events. Unprecedented outbreaks of Japanese encephalitis[1] virus occurred in Australian piggeries in previously naive temperate regions and coincided with La Niña, which brought increased rainfall and warmer sea-surface and air temperatures in the summers of 2021 and 2022. In Brazil, the Yanomami Indigenous territory has experienced a humanitarian crisis marked by malaria, hunger, water contamination and violence following forest encroachment, mining and deforestation.

The associations between temperature, rainfall and vector-borne disease have been well documented. Yet the links between climate, environmental degradation, social inequality and disease transmission are complex and often difficult to predict and isolate. In this Comment, I argue that mechanistic links between global change and vector-borne disease should spur immediate action to halt climate change and deforestation to protect biodiversity and human health.

Environmental and social drivers of vector-borne disease

The rate of anthropogenic environmental change is outpacing the rate at which we can understand and mitigate vector-borne disease outbreaks. This is partly due to underinvestment and a lack of focus on integrative study and the promotion of human, animal, plant and ecosystem health: that is, One Health.

For a vector-borne disease outbreak to occur, four processes must align: (1) climate and habitat must be suitable for vectors to be abundant; (2) vectors must frequently come into contact with people and, for certain pathogens, with reservoir hosts; (3) disease-causing pathogens must be introduced into vector populations that are competent to acquire and transmit the pathogens; and (4) humans must be susceptible to infection (Fig. 1). These processes are affected by temperature, water availability, socioecological conditions and host susceptibility.

Temperature profoundly affects vector-borne disease transmission because it affects vector development, reproduction, survival and biting, as well as pathogen development and infection probability. Each of these vector and pathogen traits depends nonlinearly on temperature, resulting in an overall relationship between temperature and transmission that peaks at an intermediate optimal temperature (ranging from 23 °C to 29 °C for mosquito-borne diseases)[2].

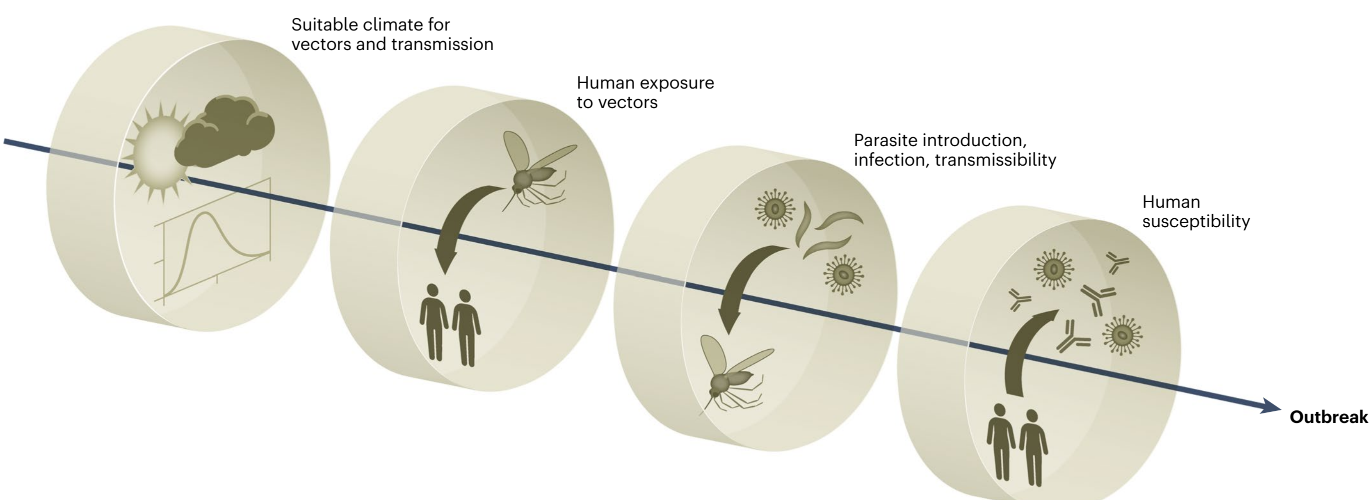

Fig. 1 | Multiple conditions must align to cause a vector-borne disease outbreak. Climate suitability for vectors and transmission; human exposure to vector bites; pathogen introduction, infection and transmissibility in vector populations; and human susceptibility.

Temperatures below and above this optimum impede transmission. As a result, warming temperatures often promote transmission, particularly in cool seasons and temperate and subtropical areas. However, excessively warm temperatures can inhibit transmission due to death of mosquitoes before they can contribute to onward transmission[2]. Dengue, chikungunya and Zika viruses transmitted by *Aedes aegypti*, with their high (29 °C) thermal optimum, are particularly prone to warming-driven expansions[2]. Meanwhile, malaria, with its cooler (25 °C) optimum, experiences warming-driven shifts into temperate, subtropical and high-elevation regions[2,3]. Tick-borne diseases such as Lyme disease are also expanding in geographic range, season length and outbreak size due to warming temperatures, especially during winter[4]. Changes in land use can exacerbate this as urban and deforested areas may have warmer microclimates that can promote local transmission, even when broader regional conditions are unsuitable[5].

Rainfall is intimately but variably linked to vector-borne disease transmission due to its role in vector habitat formation for immature development and in moderating humidity and desiccation. Mosquito species' preferences for breeding habitat range from containers to puddles to salt marshes. Rainfall increases the availability of many of these habitats, but excessive rainfall can flush the larval habitat. On the other hand, drought and unreliable access to clean piped water and trash collection services can promote human water storage practices that provide a habitat for human-associated *A. aegypti* mosquitoes, fuelling arbovirus transmission[6,7]. Land-use practices such as deforestation, mining, agriculture and dam construction, which disturb the ground and allow water collection, can create additional vector-breeding habitats[8]. Tick survival and activity also depends on humidity, which may or may not be tightly correlated to rainfall.

Socioecological conditions that promote human contact with vectors are a prerequisite for vector-borne disease outbreaks. People living in marginalized or inequitable housing and working conditions are often disproportionately exposed to vector bites. For example, the abundance and human biting rates of trypanosome-transmitting triatomine bugs are linked to housing conditions that optimize temperature, humidity and host access, as well as structural determinants such as socioeconomic status and economic stability[9]. Mosquitoes breeding in domestic containers can easily enter homes through unsealed windows and doors that are left open for ventilation in the absence of electricity and air conditioning. Agricultural workers, loggers and miners may be exposed to mosquito bites while working at the interface of wild and human-managed lands, often driven by outside corporate pressures. Human mobility further exacerbates human–vector contact and can introduce pathogens for transmission through local vector populations.

Finally, large susceptible host populations can fuel outbreaks. Of the major vector-borne diseases affecting humans, only yellow fever and Japanese encephalitis have vaccines that are widely available, long-lasting and highly effective. Complex interactions between the human immune system and the pathogens that cause dengue, malaria, Zika and Lyme disease have complicated and slowed vaccine development. For zoonotic diseases, susceptibility of animal reservoir hosts can also drive epidemic dynamics. Many of these pathogens produce only short-term protective immunity against reinfection, resulting in interannual cycles of outbreaks driven by both climatic and immunological conditions. For dengue, antibody-dependent enhancement makes repeated outbreaks within populations increasingly severe. Nevertheless, a new safe and effective malaria vaccine will soon be rolled out in 12 African countries, promising progress toward malaria elimination, but the need for regular boosting currently limits its widespread accessibility. Because many vector-borne diseases lack long-lasting immunity through infection or vaccination, environmental change remains a potent driver of epidemic dynamics.

A call to action

Vector-borne disease outbreaks will continue to emerge and expand as: (1) the climate warms and becomes more suitable for vector transmission cycles, especially in currently cooler regions and seasons, and during heat waves; (2) the climate becomes more variable, altering patterns of rain, drought, flooding and storms, affecting water storage behaviour and threatening infrastructure such as dams, levees and sewer systems; (3) social systems are disrupted through displacement, conflict, climate-driven migration, inadequate infrastructure, and inequitable access to healthcare and healthy living spaces; and (4) natural lands are converted and degraded through industrial agriculture, mining and resource extraction, decimating biodiversity and health. Immediate action is needed to halt climate change and deforestation, as well as the biodiversity losses and human health costs that they impose.

Science already makes it clear that environmental change is driving shifts in vector-borne disease that, although nuanced, are strong and quantifiable and can be used to predict and mitigate health consequences. Bridging from science to policy implementation is a key frontier. Existing conservation initiatives aimed at safeguarding biodiversity and ecosystem function should be examined for their potential to contribute to vector-borne disease control. Examples of these conservation-oriented programmes include the Bonn Challenge, the 30×30 initiative[10], Payments for Ecosystem Services[11], and Project Finance for Permanence[12]. Monitoring the impacts of these programmes, including any potential risks, on vector-borne disease could provide a fuller picture of the benefits of conservation for health. Policy analyses that account for the cost effectiveness of climate mitigation – including the social cost of carbon, a measure of the net economic costs from one additional ton of carbon dioxide emissions, which is increasingly used in US government climate policy – should incorporate the costs of vector-borne diseases quantified using causal analyses[13]. Judicial systems and international climate policy should incorporate climate-mediated health impacts into loss and damage calculations and prioritize the needs of the most climate-vulnerable communities for compensation. More detailed predictive models of when and where anthropogenic climate and land-use change will exacerbate vector-borne disease transmission are critically needed, and major data gaps (particularly in Africa and South Asia) should be closed to allow their widespread application. Co-production of research and decision-support tools such as models, software and maps between scientists, policymakers and those affected by policy are critical[13].

Success at the global scale requires scaling up of programmes that are successful at local and regional levels. India's National Green Tribunal legally enforces forest and natural resource protection, including compensation for damages to people and property. Costa Rica and China, among others, have instituted payment for ecosystem services programmes that have reduced land degradation and promoted health and environmental benefits. Public pressure can play an important role in climate policy decisions, such as the recent vote in Ecuador to ban oil drilling in some Indigenous territories in the Amazon. Conversely, ambitious disease control goals – such as Brazil's 2022 plan to eliminate malaria transmission by 2035 – cannot be met without controlling the underlying processes of environmental degradation that are driving transmission. Planetary health approaches that work with local communities to improve environmental sustainability, health, and access to healthy food and water should be studied and implemented in more settings[14]. Expansion of infrastructure, public health, and housing improvement[15] campaigns should be planned with climate resilience, vector-borne disease prevention and environmental justice in mind. Governments at local and national levels must immediately commit to and implement pledges to halt carbon emissions and deforestation to protect human and planetary health.

Judicial systems must hold those profiting from environmental degradation financially and morally accountable. International governing bodies, non-governmental organizations and multilateral development banks must plan for the health consequences of climate change by investing in prevention, surveillance and rapid responses to outbreaks alongside conservation and restoration of ecosystems. Finally, international climate and environmental agreements must ensure accountability: mechanisms to enforce commitments, collect and equitably distribute funding for loss and damage, and to penalize corporations and governments that continue to pollute and degrade the Earth's systems on which all of life depends.

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