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Climate change and emerging zoonotic parasitic and viral diseases: A critical review of a shifting paradigm

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Abstract

The accelerating pace of human-driven climate change is fundamentally transforming the ecological and evolutionary environments in which infectious diseases emerge, marking the 21st century as an era dominated by pandemic threats. This review critically combines current knowledge on the link between climate change and the rise of zoonotic parasitic and viral diseases. We argue that climate change functions not just as a single cause but as a powerful threat multiplier, working alongside land-use change, biodiversity loss, and globalisation to break down the ecological barriers that traditionally separated human, domestic animal, and wildlife pathogen reservoirs. Through a comparative analysis of vector-borne diseases, directly transmitted zoonoses, and parasitic infections, we highlight the complex mechanisms, such as changes in vector distribution, longer transmission seasons, host immune suppression, and pathogen evolution, that increase this risk. Our review shows that while the effects on viral diseases such as dengue, chikungunya, and emerging coronaviruses have received much attention, the significant yet more subtle influence on parasitic diseases such as leishmaniasis, trypanosomiasis, and soil-transmitted helminths is equally important. We conclude that a simple, one-way model of climate-driven disease emergence is inadequate. Instead, a more advanced, interdisciplinary approach that combines climate science, veterinary medicine, ecology, and public health is necessary. Future preparedness should shift from reactive outbreak management to proactive, systems-based surveillance that anticipates and reduces risks at the human-animal-environment interface.

Keywords: climate change, zoonotic diseases, emerging infectious diseases, vector-borne diseases, parasitology, virology, One Health, disease ecology, pandemic preparedness

Introduction

For most of human history, the emergence of infectious diseases has been a unpredictable and often devastating force, shaping civilizations and exposing vulnerabilities in our relationship with nature. Today, we face a unique moment. The merging of unprecedented global connectivity, intense agricultural practices, and rapid biodiversity loss has created a perfect storm for new pathogen emergence. Yet, all these factors are overlaid and worsened by climate change, a planetary-scale event that is fundamentally destabilizing ecological systems that have long influenced pathogen behaviour. The Intergovernmental Panel on Climate Change (IPCC) has clearly stated that climate change poses a direct threat to human health, with one of its most important and complex effects being the change in infectious disease patterns [1]. This is not a future threat; it is a current reality, with changing ranges of vectors, longer transmission seasons, and the spillover of new pathogens from wildlife to humans increasingly documented.

The concept of zoonotic diseases, which originate in animals and can be transmitted to humans, is central to this discussion. It is estimated that over 60% of emerging infectious diseases are zoonotic, with most coming from wildlife [2]. Historically, barriers have kept these pathogens within their natural reservoir hosts, but these barriers are increasingly being breached, mainly due to ecological disruption. Climate change is a key factor driving this disruption. By changing temperature and rainfall patterns, it affects the survival, reproduction, and spread of vectors such as mosquitoes, ticks, and sandflies. It also impacts the life cycles of parasites, from egg development in the environment to the multiplication of viruses within arthropod vectors. Additionally, climate-induced habitat loss and resource scarcity push wildlife and domestic animals closer to humans, creating new opportunities for pathogen spillover [3, 4]. This complex web of interactions requires viewing climate change not just as an added risk, but as a fundamental ecological force that reshapes disease dynamics.

Over the past two decades, a significant body of literature has emerged attempting to model, predict, and document these impacts. Early research primarily focused on malaria, with studies demonstrating the strong temperature-dependent relationship between Anopheles mosquito biology and Plasmodium parasite development [5]. This foundational work established a clear mechanistic link, showing that even modest increases in temperature could expand the altitudinal and latitudinal ranges of malaria transmission [6]. At the same time, the re-emergence of dengue fever in regions previously free of Aedes aegypti was associated with warming temperatures and urbanization, providing a template for understanding the expansion of arboviral diseases [7]. More recently, research has broadened to include the impact of climatic extremes. Droughts, for example, can concentrate water sources, creating optimal breeding grounds for some vectors and causing wildlife to congregate near human settlements, thereby increasing the risk of viral spillover events such as those seen with Nipah virus [8]. Floods, in contrast, can lead to outbreaks of leptospirosis and water-borne parasitic diseases by overwhelming sanitation infrastructure [9].

Despite this increasing evidence, the literature often remains isolated. Virologists, parasitologists, climate modelers, and public health officials usually work in separate areas, leading to a fragmented understanding of the overall threat. Additionally, much of the discussion has focused on viral diseases, especially those with pandemic potential, which may hide the significant, ongoing, and debilitating impact of emerging parasitic diseases. This review aims to offer a thorough and critical summary of the current knowledge on how climate change drives emerging zoonotic parasitic and viral diseases. We will analyze the mechanisms by which climate factors affect pathogen and host interactions, compare the effects on viral and parasitic systems, and assess the effectiveness of existing surveillance and mitigation strategies. By combining insights from various disciplines, we seek to create a more comprehensive understanding of the challenge and emphasise the importance of a unified, interdisciplinary "One Health" approach to protecting global health amid a rapidly changing climate.

Mechanisms of Climate-Driven Emergence: A Complex Interplay

The pathways connecting climate change to disease emergence are rarely straightforward. They form a complex system of interacting variables where climate functions as a primary regulator, but its effects are influenced by ecological context, host biology, and pathogen adaptability. Understanding these mechanisms is crucial for predictive modeling and the development of targeted interventions.

1. Impacts on Vectors and Transmission Dynamics

For vector-borne diseases, the influence of climate is the most direct and well understood. Arthropod vectors, being poikilothermic (cold-blooded), have metabolic, developmental, and behavioral rates that are closely linked to ambient temperature. The basic reproductive number (R_0) for a vector-borne pathogen depends on vector density, survival, pathogen incubation period within the vector, and biting rate, all of which are affected by temperature. A key synthesis by Mordecai *et al.* [10] showed that diseases like dengue, malaria, and Zika have a non-linear, unimodal relationship with temperature. Transmission is optimized within a specific thermal range (usually between 20-30°C), with temperatures outside this range potentially limiting it. Climate change does not simply "increase" risk uniformly. In areas already at the upper thermal optimum, further warming may actually decrease transmission, while in temperate and high-altitude regions, warming can create new environments conducive to transmission. This pattern is evident in the northward spread of Aedes albopictus (the Asian tiger mosquito) across Europe and North America, driven by milder winters and warmer summers [11, 12]. This vector is capable of transmitting chikungunya, dengue, and Zika viruses, placing billions of people in formerly low-risk zones at new risk.

Table 1: Projected Shifts in Vector Distribution and Associated Pathogens under Climate Change Scenarios

Vector Species	Pathogen(s)	Observed/Projected Geographic Shift	Climatic Driver	Reference(s)
Aedes aegypti	Dengue, Zika, Chikungunya	Expansion into southern Europe, high-altitude regions of East Africa, and central Asia	Warmer winters, increased urbanisation	[7, 11, 13]
Aedes albopictus	Chikungunya, Dengue	Established in southern Europe, expanding into central and northern Europe; Northward expansion in the USA	Milder winters, increased mean annual temperature	[12, 14]
Ixodes scapularis	*Borrelia burgdorferi* (Lyme), Anaplasmosis	Northward expansion into Canada; increased abundance in the northeastern USA	Shorter winters, earlier spring onset	[15, 16]
Phlebotomus spp.	*Leishmania* spp.	Expansion into southern and central Europe; northward shift in the Middle East	Warmer winters allow overwintering, and altered precipitation	[17, 18]

Changes in precipitation patterns add another layer of complexity. While increased rainfall can create new breeding sites for mosquitoes, severe droughts can also concentrate vectors and their hosts around shrinking water sources, increasing contact rates. For ticks, which require high humidity to survive, changes in precipitation can be a key factor in determining habitat suitability [15]. The interaction of temperature and precipitation creates a dynamic landscape of risk that varies greatly across different times and places.

2. Impacts on Pathogen Biology and Host-Pathogen Interactions

Climate change affects not only the vector but also the pathogen itself. For viruses, warmer temperatures can speed up the extrinsic incubation period (EIP), which is the time it takes for a virus to replicate within the mosquito and become transmissible. A shorter EIP means more mosquitoes become infectious within their lifespan, significantly increasing transmission potential [10, 19]. Modelling studies for dengue and West Nile virus have shown a strong link between temperature anomalies and outbreak severity.

The impact on parasitic diseases is equally significant but often more complicated because of multi-host life cycles. For soil-transmitted helminths (STH) like Ascaris lumbricoides and hookworms, the development and survival of eggs and larvae in the environment are highly sensitive to temperature and moisture. Warmer and wetter conditions, especially in areas with poor sanitation, can speed up larval development and extend the period of environmental infectivity, resulting in higher transmission rates [20]. Conversely, extreme heat or drought can dry out and kill free-living larval stages, highlighting the non-linear effects of climate.

Table 2: Influence of Climatic Variables on Key Parasitic Life Cycle Stages

Parasite	Life Cycle Stage	Climatic Factor	Effect on Transmission	Reference(s)
Plasmodium falciparum	Sporogony in *Anopheles*	Temperature	Increased temperature (up to optimum) shortens sporogonic cycle, increases transmission	[5, 10]
Leishmania spp.	Promastigote in sandfly	Temperature	Affects development rate; thermal stress can alter vector competence	[17, 21]
Cryptosporidium spp.	Oocyst in environment	Precipitation, Flooding	Heavy rainfall and floods increase runoff and contamination of water sources	[9, 22]
Fasciola hepatica	Miracidium, Cercaria	Temperature, Moisture	Warmer, wetter conditions prolong survival of free-living stages in snail intermediate host	[23, 24]
Trichinella spp.	Larva in environment	Temperature	Freeze-thaw cycles can affect larval survival in carcasses, impacting sylvatic cycles	[25]

For protozoan parasites, climate influences the distribution and population dynamics of intermediate hosts. The liver fluke Fasciola hepatica, for instance, depends on amphibious snail species as an intermediate host. Climate models project an expansion of suitable snail habitat in higher latitudes and altitudes due to warmer, wetter conditions, leading to increased risk of fascioliasis in livestock and humans [23]. Similarly, the distribution of Leishmania is closely linked to its sandfly vector, and climate-driven changes in sandfly ecology are a main factor in the disease's emergence in non-endemic areas [18].

3. Host Ecology, Behaviour, and Immune Function

Climate change significantly affects wildlife and domesticated animals by changing their distribution, behaviour, and vulnerability to infection. As habitats shift due to changing vegetation zones, animal populations relocate to new areas, often carrying their pathogens with them. This can cause new pathogen-sharing events between species that previously lived separately, a process known as "pathogen spillover" [3]. Habitat and food resource loss caused by climate-related extremes like drought compels animals, especially bats and rodents which are key reservoirs for many emerging viruses, to forage closer to human and agricultural areas [4, 8]. This spatial convergence raises the chances of cross-species transmission.

Furthermore, growing evidence shows that climate-induced stress can directly weaken the immune systems of wildlife and domestic animals, making them more prone to infection and more likely to shed pathogens. Nutritional stress from food shortages, heat stress, and the physiological demands of migration or dispersal can all cause immunosuppression [26]. This leads to a situation where reservoirs not only come into closer contact with humans but are also more infectious during those encounters. The interaction between climate-driven stress and immune function is a critical yet under-researched area that likely plays a significant role in many spillover events.

Climate Change and Emerging Viral Zoonoses

The connection between climate change and emerging viral diseases has received significant attention, especially after the COVID-19 pandemic. Although SARS-CoV-2 itself is not directly associated with a specific climate event, its emergence is closely linked to broader factors like increased human-wildlife contact caused by land-use change and habitat disruption, which are deeply connected to ecological instability worsened by climate change [27].

1. Arboviruses: Dengue, Chikungunya, and Zika

Arboviruses (arthropod-borne viruses) are the clearest and best-documented examples of climate-driven emergence. The global spread of Aedes mosquitoes has been accompanied by a dramatic increase in dengue cases, which have risen 30-fold over the past 50 years [28]. Climate suitability models have been highly effective at predicting this expansion. For example, a study by Bhatt *et al.* [13] mapped the global distribution of dengue risk, demonstrating that climate is the main factor determining the disease's niche. The model showed that over half of the world's population is now at risk, and climate change is expected to further expand the geographic range and lengthen the transmission season in many areas.

Chikungunya virus (CHIKV) offers a compelling example of how climate change can promote the emergence of a previously obscure pathogen. A mutation in the CHIKV genome enabled it to be transmitted more efficiently by Aedes albopictus, a vector whose range is rapidly expanding due to climate change. This adaptation, along with the mosquito's spread, resulted in the explosive outbreak in La Réunion in 2005-2006 and its subsequent establishment in Europe, where local transmission was first documented in Italy in 2007 [14]. This event highlights the dangerous synergy between viral evolution and climate-driven vector expansion.

2. Climate Extremes and Viral Haemorrhagic Fevers

Climate variability, especially the El Niño-Southern Oscillation (ENSO), strongly influences outbreaks of viral haemorrhagic fevers (VHFs) like Rift Valley Fever (RVF) and Hantavirus. For RVF, which is spread by mosquitoes and infects both livestock and humans, heavy rainfall and flooding linked to El Niño events create large mosquito breeding areas in dry and semi-dry regions of Africa and the Arabian Peninsula. This leads to rapid growth of the virus in mosquito populations, causing significant outbreaks in livestock and spilling over into humans [29]. Predictive models using satellite data on rainfall and vegetation have proven highly effective in forecasting RVF outbreaks, enabling proactive vaccination efforts [30].

Hantavirus pulmonary syndrome (HPS), caused by rodent-borne hantaviruses, is a well-known example. Outbreaks often follow periods of heavy rainfall that increase food sources for rodents (such as seeds), leading to a population boom in reservoir species. A subsequent drought or the end of this resource abundance can then drive these stressed but numerous rodents to invade human homes for food and shelter, significantly raising human exposure [31]. This pattern has been observed in the southwestern United States, where ENSO cycles greatly affect HPS outbreak risk [32].

3. Emerging Coronaviruses and the Climate Nexus

The emergence of SARS-CoV, MERS-CoV, and SARS-CoV-2 has raised urgent questions about the role of environmental factors. Although the direct impact of climate on the spillover of these viruses is less mechanistic than for vector-borne diseases, the underlying drivers are closely connected. Bats, believed to be the ancestral hosts for many coronaviruses, are highly sensitive to climate change. Changes in roosting conditions, food availability (such as insect populations for insectivorous bats), and habitat fragmentation can cause physiological stress, alter viral shedding patterns, and bring bats into closer contact with humans and intermediate hosts like civets or camels [4, 27]. A recent global analysis indicated that climate change may influence the distribution of bat species with high coronavirus diversity, creating "hotspots" of spillover risk in Southeast Asia, parts of Africa, and South America [33]. This analysis suggests that climate-driven changes in the world's bat communities are ongoing processes that increase the chances of viral sharing and, ultimately, emergence.

Table 3: Comparative Analysis of Climatic Drivers for Key Emerging Viral Zoonoses

Virus Family	Disease Example	Primary Reservoir	Primary Vector	Key Climatic Driver(s)	Reference(s)
Flaviviridae	Dengue, Zika	Primates, Humans	*Aedes* mosquitoes	Temperature, Precipitation (for breeding), Humidity	[7, 10, 13]
Togaviridae	Chikungunya	Primates, Rodents	*Aedes* mosquitoes	Temperature (vector expansion), Extreme weather events	[12, 14]
Bunyaviridae	Rift Valley Fever	Livestock, Wildlife	*Culex/Aedes* mosquitoes	Extreme rainfall (El Niño), Flooding	[29, 30]
Hantaviridae	Hantavirus (HPS)	Rodents	None (direct contact)	Rainfall (food boom), subsequent drought (forced human contact)	[31, 32]
Coronaviridae	SARS, MERS, COVID-19	Bats (likely)	None (direct spillover)	Habitat loss (synergistic), climate-induced stress in bats, altered species distribution	[4, 27, 33]

Climate Change and Emerging Zoonotic Parasitic Diseases

While viral diseases often attract attention due to their pandemic potential, parasitic diseases cause a significant, long-lasting, and often overlooked burden on global health, especially in low- and middle-income countries. Climate change is a major factor influencing their evolving epidemiology by directly impacting parasite life cycles, vector biology, and the resilience of host populations.

1. Vector-Borne Parasitic Diseases: Leishmaniasis and Malaria

Leishmaniasis, transmitted by the bite of infected female sandflies, is a disease on the rise. Historically limited to tropical and subtropical regions, it is now appearing in areas of Europe that were previously non-endemic, including Spain, Italy, and France [17]. The northward expansion of sandfly vectors like Phlebotomus perniciosus is directly linked to rising temperatures that enable these vectors to survive and reproduce in more temperate zones. Additionally, climate change promotes the spread of reservoir hosts. For zoonotic visceral leishmaniasis in the Americas, climate models forecast a substantial increase in suitable habitats for both the sandfly vector and the reservoir rodent Didelphis (opossum) under future climate scenarios, potentially introducing the disease to urban centers in the southern United States [34]. The situation is further complicated by the ability of the parasites to adapt to new vectors and changing climates, making risk assessment an ongoing challenge.

Malaria, despite centuries of research, remains a disease whose future under climate change is highly debated. Early models predicted a significant expansion of malaria into currently temperate regions [6]. However, more detailed current models suggest a more complex situation. While the altitudinal limits of malaria transmission are indeed rising in the East African highlands due to warming, this is not a consistent trend [35]. Socioeconomic factors, vector control programs (such as insecticide-treated nets), and urban development have shown to be strong opposing forces in many areas. The biggest threat may not be a simple range expansion but rather an increase in transmission intensity and seasonality in areas already affected, and the re-introduction of malaria into regions where control efforts have declined but climate conditions are becoming more favourable [36].

Table 4: Observed and Projected Impacts of Climate Change on Major Vector-Borne Parasitic Diseases

Disease	Vector	Impact	Geographic Region	Climatic Driver	Reference(s)
Visceral Leishmaniasis	*Lutzomyia longipalpis*	Range expansion into new areas of South and Central America	Brazil, Southern USA (projected)	Increased temperature, altered precipitation	[34, 37]
Cutaneous Leishmaniasis	*Phlebotomus* spp.	Northward range expansion; longer transmission season	Southern Europe, Mediterranean Basin	Warmer winters, extended summer seasons	[17, 18]
Malaria	*Anopheles* spp.	Altitudinal range expansion; changes in transmission seasonality	East African highlands, Ethiopian highlands	Increased minimum temperatures	[35, 38]
Malaria	*Anopheles* spp.	Range contraction at lower latitudes due to excessive heat	West Africa (projected)	Temperatures exceeding thermal optimum for vector/parasite	[10, 36]

2. Food and Water-Borne Parasitic Diseases

Climate change significantly affects food and water safety by enabling the emergence of parasitic diseases through contamination routes. Cryptosporidium and Giardia are protozoan parasites responsible for causing severe diarrheal diseases worldwide. Their sturdy oocysts and cysts are transmitted via the fecal-oral pathway, often through contaminated water. The rise in frequency and severity of extreme weather events, such as heavy rainfall and flooding, is a key factor behind waterborne outbreak. These events overwhelm aging sanitation systems, wash fecal matter from farms and wildlife into surface waters, and weaken drinking water treatment facilities [9, 22]. The 1993 Milwaukee cryptosporidiosis outbreak, one of the largest waterborne disease outbreaks in U.S. history, was triggered by heavy spring rains and snowmelt—a pattern increasingly seen with climate change [39].

Food-borne parasitic diseases are also highly affected by climate change. Rising temperatures can prolong the crop growing season and influence the survival of pathogens in the environment. For example, the coccidian parasite Toxoplasma gondii produces environmentally resistant oocysts shed by cats into the soil. Warmer, wetter conditions can boost the survival and sporulation of these oocysts, which can then contaminate produce or be eaten by livestock, causing human infections [40]. Similarly, anisakiasis, caused by nematodes of the Anisakis genus, is an emerging risk in areas where raw or undercooked seafood consumption is rising. Climate change impacts the distribution of marine mammals (definitive hosts) and fish (intermediate hosts), as well as larvae survival in the marine environment, potentially increasing the prevalence of these parasites in new fishing areas [41].

3. The Subtle Emergence of Soil-Transmitted Helminths and Echinococcosis

The impact of climate on soil-transmitted helminths (STH) is often overlooked, yet it affects billions of people. The free-living larval stages of hookworms (Necator americanus, Ancylostoma duodenale) and the eggs of Ascaris lumbricoides require specific temperature and moisture conditions for development. Climate models project that in many regions, especially in sub-Saharan Africa and South Asia, the transmission window for these parasites will lengthen, and their geographic range may expand into higher altitudes and latitudes [20]. This could undermine decades of progress made in mass drug administration programs, as the force of infection increases.

Echinococcosis, a zoonotic tapeworm disease transmitted between canids and ungulates, presents a unique case. The life cycle of *Echinococcus multilocularis*, which causes alveolar echinococcosis, a severe liver disease, is intricately linked to the ecology of its rodent intermediate hosts and fox definitive hosts. Climate change influences the populations and distribution of both. For instance, milder winters may lead to increased survival of voles, the primary intermediate host, in boreal and alpine regions, potentially increasing the prevalence of the parasite in fox populations and subsequently the risk of human exposure [25]. This highlights how climate-driven changes in wildlife community composition can have direct, and often unanticipated, consequences for human disease risk.

Discussion: Towards a Systems-Based Approach for a Warming World

The evidence synthesized in this review depicts profound and ongoing change. Climate change is not just an incremental stressor but a fundamental force that rewrites the rules of disease ecology. Its effects are widespread, impacting pathogens, vectors, and hosts across terrestrial and aquatic ecosystems. However, the story is not one of simple, deterministic doom. The relationship is marked by non-linearity, complexity, and significant spatial and temporal heterogeneity. In some areas, climate change will increase risk; in others, it may make environments unsuitable for disease transmission. The main challenge for science and policy is to move beyond simplified generalizations and develop the ability to understand and respond to this complexity.

A critical insight from this review is the artificial distinction often drawn between viral and parasitic diseases in research and policy frameworks. While the mechanisms may differ, the underlying driver of ecological disruption is the same. Both groups of pathogens are experiencing range shifts, increased transmission potential, and novel host encounters as a result of climate change. A unified framework is essential. This requires dismantling disciplinary silos and fostering genuine collaboration between virologists, parasitologists, ecologists, climatologists, and public health practitioners. The "One Health" approach, which recognizes the interconnectedness of human, animal, and environmental health, provides the ideal conceptual framework for this integration [42]. However, One Health must move beyond rhetoric and be operationalized through sustained funding, joint training programs, and integrated surveillance systems.

The current surveillance paradigm is largely reactive. Public health systems wait for a rise in human cases before mounting a response. In a world of accelerating ecological change, this is no longer sufficient. We need to build predictive intelligence. This involves harnessing the power of climate and environmental data from satellite imagery to weather station networks to forecast disease risk before outbreaks occur. The success of RVF early warning systems in East Africa demonstrates the potential of such an approach [30]. Extending this to a broader range of diseases requires not only technological capacity but also a deep understanding of the local ecological context. A model predicting dengue risk in Bangkok will not be directly applicable to a rural community in the Peruvian Andes. Locally validated, context-specific models are essential.

Furthermore, addressing the root cause climate change itself must be recognized as the ultimate public health intervention. Mitigation efforts to reduce greenhouse gas emissions are, in the long term, the most effective strategy for reducing the burden of climate-sensitive diseases. Simultaneously, adaptation strategies are urgently needed to manage the risks that are already unavoidable. These include strengthening health systems, particularly in low-resource settings that are often on the front lines of emergence; improving water, sanitation, and hygiene (WASH) infrastructure to build resilience against water-borne diseases; and integrating climate risk into land-use planning to reduce human-wildlife conflict and spillover potential.

Finally, a critical analytical lens must be applied to the existing body of research. Much of the literature is dominated by studies from high-income, temperate countries, creating a significant geographic bias. The regions most vulnerable to both climate change and emerging infectious diseases such as sub-Saharan Africa, Southeast Asia, and the Amazon basin are often the most data-poor. This knowledge gap hinders our ability to make accurate global risk assessments and to allocate resources effectively. Future research must prioritize filling these data gaps, building long-term ecological monitoring programs in biodiverse and climatically vulnerable regions, and ensuring that the benefits of new modeling techniques are equitably shared.

Conclusion

This review has traversed the complex and interconnected landscape of climate change as a driver of emerging zoonotic parasitic and viral diseases. We have moved beyond the simplistic narrative of a warming planet simply "breeding more disease," revealing instead a sophisticated and often counterintuitive reality. Climate change acts as a relentless force, reshaping the ecological theater where the drama of pathogen emergence unfolds. It expands the geographic stage for vectors like *Aedes* mosquitoes and *Ixodes* ticks, bringing viruses like dengue and chikungunya into temperate cities. It alters the scripts, accelerating the development of parasites in their vectors and hosts, and lengthening the seasons of risk for diseases from malaria to leishmaniasis. Most critically, it dismantles the backstage barriers that historically separated wildlife pathogens from human populations, forcing stressed reservoir species into unprecedented contact with our homes and livestock, as evidenced by the spillover of coronaviruses and henipaviruses.

The analysis demonstrates that the impact on viral and parasitic diseases, while distinct in mechanism, is convergent in outcome: a global landscape of increased disease risk, marked by unpredictability and surprise. The emergence of chikungunya in Europe and the altitudinal rise of malaria in East Africa are not isolated incidents but symptoms of a systemic global transformation. This transformation is characterized by non-linearity, where extreme weather events like droughts and floods can trigger explosive outbreaks, and by ecological cascades, where the movement of one species triggers a ripple effect of pathogen sharing.

The path forward demands a fundamental paradigm shift. We can no longer afford to treat disease emergence as a series of discrete events to be managed in isolation. The evidence compels us to view it as a dynamic process intrinsically linked to the health of our planet. This requires an urgent and decisive move towards a proactive, systems-based strategy. The "One Health" approach must be operationalized with renewed vigor, integrating advanced climate and ecological modeling with public health surveillance to create true early warning systems. Investments must be redirected to strengthen the resilience of health systems in the most vulnerable regions, recognizing that global health security is only as strong as its weakest link. Furthermore, the scientific community must confront its own biases, expanding research efforts into data-sparse, high-risk regions to build a truly global and equitable understanding of risk.

Ultimately, the narrative of climate change and emerging diseases is a cautionary tale about the unintended consequences of our relationship with the natural world. It underscores the profound truth that human health cannot be divorced from the health of animals and the environment. The decisions we make today to curb emissions, to protect natural habitats, to build sustainable agricultural systems, and to invest in integrated health security will determine the contours of infectious disease risk for generations to come. To fail to act is to accept a future defined by increasingly frequent, severe, and unpredictable disease emergencies, a future where the barrier between human civilization and the microbial world is irrevocably breached. A thoughtful, intelligent, and urgent response is not just a scientific imperative; it is a fundamental necessity for the survival and well-being of our species.

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