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Climate Change, Environmental Alterations, and the Emergence of Parasitic Zoonoses: A One Health Review of Transmission, Host Dynamics, and Surveillance

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Abstract:

Background information: Zoonotic infections, which are caused by protozoa and helminths that can go from vertebrates to humans, are one of the infections that are keenly susceptible to climate change because they need ectothermic vectors, intermediate hosts, and free-living stages for their lifecycle. Climate change, due to human activity like temperature rise, change in precipitation, extreme weather, land-use change, loss of biodiversity, and human movements is affecting the transmission of this group of parasites.

Aim: The purpose behind this review is to evaluate the information available on the impact of climatic and non-climatic changes on the transmission of parasitic zoonoses through the lenses of transmission ecology, host dynamics, and geography; furthermore, it involves investigation of methods of surveillance which is necessary for the detection of these infections.

Method: The authors make a structured narrative review of the literature indexed in PubMed/MEDLINE, Scopus, and Web of Science databases, in addition to reports from the Intergovernmental Panel on Climate Change, World Health Organization, and quadripartite One Health organizations.

Results: In general, temperature interacts with the parasites and influences their non-linear, unimodal thermal performance curves that determine the rates of development, vector capacity, and survival; thereby, the rise of the temperature may extend transmission at the cold ends while reducing it in the warm edges. As for precipitation extremes, they generate pulses of water-borne protozoa (e.g. Cryptosporidium, Giardia, Toxoplasma gondii), while droughts and water development alter snail-borne trematodiases. The documented and expected changes in the distribution of parasites include the northward movement of Leishmania infantum and its phlebotomine vectors in Europe and North America, the occurrence of Dirofilaria spp. in previously free parts of Europe, the occurrence of hybrid urogenital schistosomiasis in Corsica, the accelerated development of Arctic nematodes, and the spillover of zoonotic malaria (Plasmodium knowlesi and P. simium) caused by deforestation. The impacts of climate change are enhanced by changes in host ranges, urbanisation of wildlife reservoirs, changes in land use, and displacement due to conflicts.

Conclusions. Climate change is a threat multiplier. Integrated One Health surveillance that combines veterinary, medical, entomological, and environmental data and is supported by molecular

tools, environmental DNA, remote sensing, and mechanistic models is critical for timely warning. Key gaps include absence of baseline data over a long period of time, lack of attribution studies, absence of research in low and middle-income countries, and lack of integration across sectors.

Keywords: Climate change; One Health; parasitic zoonoses; vector-borne diseases; leishmaniasis; schistosomiasis; echinococcosis; toxoplasmosis; surveillance; environmental change.

Introduction

Zoonoses account for the majority of emerging infectious disease events recorded in humans. An analysis of 335 emerging infectious disease events between 1940 and 2004 found that 60.3% were zoonotic and that 71.8% of these originated in wildlife [1]. A census of 1,415 human pathogens similarly showed that 61% are zoonotic and that zoonotic pathogens are about twice as likely to be associated with emergence as non-zoonotic pathogens [2]. Parasites, including protozoa and helminths, represent a substantial fraction of this zoonotic burden, yet they receive less attention in emergence research than viruses and bacteria [3].

Climate change is occurring faster than ever in the history of man. According to the Intergovernmental Panel on Climate Change (IPCC), average temperature for the period from 2011 to 2020 was about 1.1°C above the baseline of 1850 to 1900, asserting that anthropogenic causes is responsible for the global surface temperature increase [4]. The process of warming was accompanied by the increase in frequency and severity of heat waves, heavy precipitation, droughts and seasonality changes, the health consequences of which have already been observed [5]. A systematic literature assessment revealed that about 58% of all known pathogenic human diseases (218 out of 375) have been affected by at least one climate-related disaster at some point [6]. Projections of mammal re-distribution indicate that the warming process will create thousands of new host-to-host contacts and cause transmission of pathogens between species by 2070 [7].

Climate change does not occur in isolation. It interacts with deforestation, agricultural intensification, urbanisation, dam building, biodiversity loss, globalized trade, wars and forced migrations [8]. Among the first scientists to present an argument for the necessity to see environmental changes as a whole and consider their influence on disease characteristics were Patz and colleagues, who were the first to argue that the environment affects the appearance of parasitic diseases through physical changes in vector habitat, host population and people [9]. Further reviews consistently introduced the idea that parasitic zoonoses can be viewed as the indicators of environmental changes due to the fact that all the stages of these parasites' life cycle are influenced directly by temperature and humidity level [10,11].

The burden of these infections is considerable. The World Health Organization (WHO) Foodborne Disease Burden Epidemiology Reference Group estimated that 11 foodborne parasitic diseases caused millions of disability-adjusted life years globally in 2010, with zoonotic toxoplasmosis, echinococcosis, cysticercosis and food-borne trematodiases among the leading contributors [12]. Many parasitic zoonoses are also classified as neglected tropical diseases, concentrated in poor and marginalised communities that are most exposed to climate hazards and least able to adapt [13].

According to One Health High-Level Expert Panel document, One Health is an integrated, holistic approach orientated towards efficacious sustainable balance and optimising the health of all constituents including humans, animals, and environment [14]. Parasitic zoonoses point to the necessity of such integration, as transmission of such diseases relies on the interactions of various components of the system including wildlife, domestic animals, vectors, humans, and environment [15,16]. Even though there are rapidly growing literature surrounding the topic of climate change and infectious diseases, the studies tend to focus only on several vector-borne viral and bacterial diseases

mostly in high-income settings [17]. This fact is of great importance as the roadmap published by WHO for the years 2021–2030 refers specifically to climate change being one of the factors aggravating the efforts to reach the elimination goals [18].

The current review tackles three possible issues. Firstly, how do environmental and climatic changes impact the transmission of parasitic zoonoses? Secondly, how are these changes affecting the dynamics between intermediate hosts, reservoirs, and the final hosts directly, or indirectly, related to humans? Thirdly, what are the best One Health approaches for monitoring such situations? The articles were organized based on the transmission route: wire-facilitated protozoa and filariae, waterborne and foodborne protozoa, and helminths with environmental or snail-related phases.

Review methodology

This article is a systematic narrative review and is utilized as a means to guarantee the integration of the fragmented types of evidence from fields like ecology, parasitology, epidemiology, and climate science instead of just calculating the effect sizes [19]. The work and writing of this article were carried out according to the guidance of SANRA in the process of its research [20]. Certain elements of PRISMA 2020 statement have also been adopted to improve the transparency of the research [21].

Information sources and search strategy

The journals searched were PubMed/MEDLINE, Scopus and Web of Science Core Collection, covering publications from year 2000 to that of submission date. The search string was, therefore, formulated from three major blocks of concepts, namely (i) climate and environment concepts like "climate change," "global warming," temperature, precipitation, drought, flood*, land use, deforestation, urbanization and urbanisation; (ii) parasites including parasit*, protozo*, helminth*, trematod*, cestod*, nematod* and other particular genera represented in Table 2; and (iii) zoonotic transmission concepts like zoono*, "One Health," reservoir, wildlife, vector, intermediate host. The reference lists of essential reviews were tracked backward for citations, and higher citations from fundamental papers were traced forward as well. Greys were obtained from the literature provided by IPCC, WHO, FAO, UNEP and WOAH.

Eligibility and synthesis

The sources approved consisted of original field, laboratory and modeling investigations, systematic reviews and credible reports which explained the influence of climatic or environmental factors on any zoonotic parasite, its host organisms or vectors or its surveillance. Research on strictly anthroponotic parasites has only been used if it provided explanation of a mechanism applicable to zoonotic relatives, for instance, the thermal ecology of malaria transmission. The information was classified into (a) observed correlation or described movement of the range, (b) experimental proof of the mechanism and (c) model projections. This subdivision is maintained in the entire paper since mixing the projected and the real changes is a well-known limitation of the literature focused on climate and health.

The authors should include in their manuscript the final search date, the count of records reviewed, included, and if the journal requests it, a PRISMA-style flowchart. Each reference should be verified in Scopus or PubMed before submission.

Climatic and environmental drivers: mechanisms acting on parasites, vectors and hosts

The way climate affects parasitic zoonoses is seen through direct impacts on both parasites and their vectors, and indirect effects on the hosts, ecosystems and human behaviour [22,23]. Consequently, the outcome is very rarely a straightforward increase/risk of infection, since different elements of the transmission cycle will be impacted differently or even non-linearly [24]. Table 1 gives an overview of the principal drivers involved along with mechanisms relevant for this case.

Temperature and thermal performance

Almost every trait relevant to transmission by an ectotherm—development rate, survival, biting rate, fecundity and the extrinsic incubation period of the parasite—follows a unimodal thermal performance curve with a lower threshold, an optimum and an upper critical limit [25]. Mordecai and colleagues showed that combining these trait curves into a temperature-dependent basic reproduction number predicts an optimum for *Plasmodium falciparum* transmission by *Anopheles* of about 25 °C, considerably lower than earlier models had assumed [26]. The same framework, applied across mosquito-borne pathogens, shows optima between roughly 23 and 29 °C [25]. A key implication is that warming should increase transmission where current temperatures are below the optimum, for example at high altitudes and latitudes, and decrease it where temperatures already exceed it.

The asymmetry is confirmed through the evidence found from malaria in highlands. The study of altitudinal profile of malaria cases in Ethiopia and Colombia indicates that, in the warm years, the epidemic shifted to overall higher altitude and in the cool years - to lower [27]. Malaria is an anthropozoonosis in these regions, but still the pattern can be applied to the Plasmodium species belonging to the category *of zoonosis* as well as to other protozoan agents having vectors.

The understanding of the role played by temperature in the metabolic development of helminths and their intermediate hosts is similar and based on metabolic theory. In a study, Molnár and his team proved that an increase in temperature can shorten the larval development period and enhance mortality, but at the same time, the influence of temperature is moderated by where in the curve of development a helminth larva and which season it is currently in [28]. On the Arctic territory, the development of the muskox lungworm Umingmakstrongylus pallikuukensis has recently become shorter due to warming, allowing the larvae to become infectious in one season instead of two [29]. The thus described phenomenon of crossing the threshold results in drastic changes in helminth transmission.

Temperature also affects evolutionary abilities in terms of switching hosts. In line with the Stockholm Paradigm, many parasites still hold the hidden opportunity of using hosts which they do not currently infect, and thus, environmental events stimulated by climate change help them meet with these host species, thus creating emergence events [30,31].

Precipitation, humidity and extreme events

Rainfall and humidity define the availability of sites for breeding of vectors and snails, survival of eggs, cysts, and oocysts in soil and water, and movement of the infective forms of helminths from land to water [32]. Heavy rains role in the transportation of feces into surface water and flooding of water treatment plants [33]. In the US, about 51% of waterborne disease outbreaks from 1948 till 1994 were preceded by precipitation events that took place during the 90th percentile [34]. Multiple reviews concerning food- and water-borne diseases in Europe and seasonality of zoonotic enteric pathogens prove the importance of rain and temperature for the infection of protozoans [35,36].

The impacts of drought are multifaceted. Drought can lead to the concentration of hosts and parasites at diminishing locations of water, increased interactions among wildlife, livestock and human beings, and alteration of how water storage containers are used while creating far less habitat for aquatic snails and some vectors, therefore, the outcome will be as per the ecology in place and human activity.

Land-use change, water development and biodiversity

Environmental changes that are not climate-related often result in much more significant and immediate changes than climate changes do themselves. For instance, the devastation in the Amazon in Peru has opened sunlit breeding grounds for Anopheles darlingi, which was over 278 times more likely to bite humans in deforested areas as compared to areas with compact forests [37]. Moreover, global studies of newly appeared zoonoses indicate that the emergence of new viruses is likely to occur

in the tropics in areas of use of the land with a lot of various mammals [38]. It should be noted that converting land to agriculture and urban development influences the composition of host communities as well because there is an increase in the proportion of some species in ecosystems with human activities, mostly rodents, bats, and passerines [39].

The identified changes influence the frequency of human-wildlife interaction, which is a prerequisite for spillover events [40]. An example of this is the development of water resources: the building of irrigation systems and dams contributes to the increased possibility of contracting schistosomiasis by 2.4-2.6 times for people who live near dams [41]. The migration of predatory river prawns blocking by dams has been associated with increased risk of schistosomiasis infection in large populations in Africa [42].

Host physiology and immunity

The immune system is weakened by environmental stressors, including heat, food shortage, and pollution, making individuals more vulnerable to infection and the shedding of parasites [43]. Cohen et al. examined over 7000 surveys of hosts and parasites, showing that the infection risk in cool climate wildlife became higher as the temperature increased and became lower in warm wildlife species in line with the thermal mismatch hypothesis, which says that small parasites have lower range of temperature tolerability than their hosts do [44]. Interaction of the host-related changes with changes in vectors and parasites is what makes it difficult to predict wildlife disease dynamics [45].

Results and Discussion

Thermal Ecology and Vector-Borne Parasitic Zoonoses

Climate-driven temperature shifts non-linearly affect the transmission dynamics of vector-borne parasitic zoonoses. Under unimodal thermal performance curves, parasite development rates, extrinsic incubation periods, and vector survival increase up to a specific thermal optimum before sharply declining above critical thermal limits.

- **Leishmaniases:** Geographic range shifts of *Phlebotomus perniciosus* and *P. neglectus* toward northern Europe (e.g., Germany and northern Italy) have driven local infection cases of canine leishmaniasis (*L. infantum*) in previously non-endemic areas. Furthermore, environmental modifications such as urban green park developments (e.g., the Fuenlabrada outbreak in Madrid) led to population explosions of reservoir hosts (*Lepus granatensis* hares) that interacted with *Phlebotomus* vectors, demonstrating how urban green infrastructure can unintentionally create novel transmission interfaces.
- **Dirofilariasis:** Ambient heat accumulation exceeding the 14°C threshold accelerates the larval development of *Dirofilaria immitis* and *D. repens* within mosquitoes. The invasion of competent vectors such as *Aedes albopictus*, alongside the transport of infected dogs, has facilitated the spread of *D. repens* into Central, Eastern, and Northern Europe.
- **Zoonotic Malaria:** Outbreaks of *Plasmodium knowlesi* in Southeast Asia (e.g., Sabah, Malaysia) and *P. simium* in the Atlantic Forest of Brazil indicate that land-use change and forest-edge clearing serve as primary drivers for pathogen spillover from non-human primates to humans, outweighing temperature effects alone.

Hydrological Dynamics and Water- and Food-borne Protozoa

Hydrological changes, including altered precipitation patterns and extreme weather events, serve as major catalysts for the dissemination of enteric and tissue-dwelling protozoa. Cysts and oocysts of *Cryptosporidium parvum*, *Giardia duodenalis*, and *Toxoplasma gondii* exhibit prolonged environmental persistence and resistance to conventional chlorination.

- **Cryptosporidiosis and Giardiasis:** Heavy precipitation and flooding enhance surface runoff,

transporting faecal contamination from livestock catchments into public drinking water supplies. This escalates outbreak risks, particularly in regions with high livestock density utilizing surface water sources.

- **Toxoplasmosis (Land-to-Sea Pathway):** The movement of *T. gondii* oocysts from terrestrial environments into coastal waters via freshwater runoff has been linked to infections in marine mammals, such as southern sea otters (*Enhydra lutris nereis*) in California through the ingestion of filter-feeding invertebrates. In the Arctic, sea-ice loss and the northward range expansion of felids threaten to alter pathogen exposure among Indigenous communities relying on marine mammals for food.

Climate-Driven Alterations in Helminth Life Cycles

Zoonotic helminths are highly sensitive to microclimatic humidity, temperature variations, and intermediate host availability.

- **Schistosomiasis and Hybridisation:** Elevated temperatures expand the suitable habitats of freshwater snail vectors (*Bulinus truncatus*) toward higher latitudes and altitudes. The urogenital schistosomiasis outbreak in Corsica, France, highlighted the epidemiological threat of hybridisation between human (*S. haematobium*) and livestock (*S. bovis*) schistosomes, producing hybrid strains with broader host ranges and heightened adaptability. Concurrently, dam construction and agricultural irrigation deplete natural snail predators (such as river prawns), exacerbating infection risks for nearby human populations.
- **Echinococcosis:** The establishment of synanthropic red fox populations (urbanisation of *E. multilocularis*) and pasture degradation from overgrazing on the Tibetan Plateau have increased intermediate small mammal host densities, resulting in some of the highest human alveolar echinococcosis incidences globally.
- **Arctic Nematodes:** Accelerated warming in Arctic regions has shortened the larval development period of protostrongylid nematodes (e.g., *Umingmakstrongylus pallikuukensis*) in muskoxen, enabling larvae to reach infectivity within a single season rather than two.

Host Dynamics and Barriers to Zoonotic Spillover

Climatic and environmental alterations systematically dismantle the hierarchical barriers to zoonotic spillover:

1. **Host Range Shifts:** Terrestrial species are shifting poleward and upslope at median rates of 16.9 km/decade and 11.0 m/decade, respectively. These range shifts assemble novel host species combinations, facilitating parasite-host encounters and driving host-switching opportunities in accordance with the Stockholm Paradigm.
2. **Biodiversity Loss:** Habitat destruction alters host community composition by reducing specialist diversity while favoring resilient, synanthropic zoonotic reservoirs (such as rodents hosting *Leishmania*, *Echinococcus*, and *Babesia*).
3. **Human Mobility and Trade:** Climate-induced displacement, conflict, and global wildlife/pet trade introduce susceptible human populations into endemic areas or transport infected hosts and vectors into previously non-endemic regions.

Operationalising One Health Surveillance and Research Gaps

To detect changing transmission boundaries before human clinical cases accumulate, integrated One Health surveillance frameworks must be operationalised:

- **Advanced Surveillance Technologies:** Environmental DNA (eDNA) sampling in water bodies offers superior sensitivity for detecting *Schistosoma* larvae and snail intermediate hosts compared to traditional manual surveys. Combining spatial epidemiology (Remote Sensing & GIS) with mechanistic models derived from parasite thermal performance curves enhances predictive

mapping of emerging transmission hotspots.

- **Sentinel Animal Surveillance:** Systematic serological monitoring of domestic dogs (*Leishmania*, *Dirofilaria*) and wildlife carcass screening (*Echinococcus*, *Trichinella*) provide vital early warning signals prior to human disease manifestation.
- **Challenges and Knowledge Gaps:** Major limitations include the lack of long-term baseline data required for climate attribution studies, significant geographic research bias favoring European and North American settings (despite LMICs in Asia, Africa, and the Middle East bearing the highest burden), and institutional silos between human, animal, and environmental health sectors that impede multi-sectoral data sharing.

Table 1. Principal climatic and environmental drivers of parasitic zoonoses and their mechanisms

Driver	Main mechanism	Illustrative parasites	Expected direction	Key references
Rising mean temperature	Faster development and extrinsic incubation; longer transmission seasons; poleward and upward range shifts of vectors	*Leishmania*, *Plasmodium knowlesi*, *Dirofilaria*, Arctic protostrongylid nematodes	Increase at cool margins; decrease above thermal optimum	[25–29]
Heavy precipitation and flooding	Mobilisation of faecal oocysts and cysts; contamination of drinking water	*Cryptosporidium*, *Giardia*, *Toxoplasma gondii*	Outbreak pulses after extreme events	[33–36]
Drought	Aggregation of hosts at water; altered water storage; loss of snail habitats	*Schistosoma*, *Fasciola*, *Echinococcus*	Variable, context dependent	[32]
Deforestation and agricultural expansion	New vector breeding sites; human entry into sylvatic cycles; changed host communities	*P. knowlesi*, *P. simium*, *Trypanosoma cruzi*, *Leishmania*	Increased spillover	[37–40]
Dams and irrigation	Expansion of snail habitats; loss of snail predators	*Schistosoma* spp., *Fasciola* spp.	Increase	[41,42]
Urbanisation	Synanthropic reservoirs; peri-urban vector habitats	*Echinococcus multilocularis*, *L. infantum*, *T. cruzi*	Increase in peri-urban transmission	[39,40]
Host stress and immunity	Reduced resistance; increased parasite shedding	Multiple wildlife parasites	Increase in susceptible hosts	[43–45]

Vector-borne parasitic zoonoses

Parasites that are transmitted by vectors have been the most explored group in the climate-health literature because their arthropod vectors are ectothermic animals whose distribution, abundance, activity, and efficiency depend on temperature and humidity [46,47]. This part of the paper is going to discuss five groups of diseases that show the greatest evidence of climate or environmental influence, which include leishmaniasis, American trypanosomiasis, zoonotic malaria, tick-borne Babesiosis and dirofilariasis.

Leishmaniases

Leishmaniasis refers to a group of *diseases caused* by around twenty Leishmania species with transmission via phlebotomine sand flies, where most forms are zoonotic diseases, with the involvement of dogs, rodents, hyraxes and other mammals . It has been estimated that there are around 0.7-1.2 million cases of cutaneous leishmaniasis and 0.2-0.4 million cases of visceral leishmaniasis globally each year [48]. The processes of development, survival, and activity of sand flies in different

seasons depend on temperature, including their duration of the parasite [49,50].

In southern Europe, leishmaniasis caused by L. infantum is endemic due to the *role of domestic* dogs as the main reservoirs of this parasite. The evidence supporting the north *expansion of such* important *vector species* as Phlebotomus perniciosus and P. neglectus has been provided not only in southern Europe but also in northern Italy and Germany and other countries previously thought to be free of this nuisance, where local cases of infection in dogs also occurred in a lot of cases [50,51]. Ready came to a conclusion that climate change has a high probability of being one of the reasons for the spread of the infection to the north, even though the process was very complex [51].

The outbreak in Fuenlabrada, south-western Madrid, which began in 2009 and became the largest community outbreak of leishmaniasis reported in Europe, illustrates the role of environmental alteration. More than 400 cases were recorded between 2009 and 2012 [52]. The outbreak was linked not to dogs but to hares (*Lepus granatensis*) and rabbits whose populations expanded in a newly created green park adjacent to urban development, providing abundant blood meals for *P. perniciosus* [52,53]. This event demonstrates how urban green infrastructure, intended to improve the environment, can unintentionally create new transmission interfaces.

The models of ecological niche in the Americas anticipate that climate change will bring about the northward expansion of the sand fly habitats and the *habitats of* rodent carriers of L. mexicana into the USA [54], while the range *of the Lutzomyia* flaviscutellata species, *a transmitter* of L. amazonensis, will expand towards the south in South America [55]. In the MENA region, regional conflicts and migrations, especially in Syria, Iraq, Libya and Yemen, coupled with the destruction of health and sanitation facilities, resulted in a rise in the epidemics of zoonotic and anthroponotic cutaneous leishmaniasis confirming that in the short-term social factors may outweigh the impact of climate [56].

American trypanosomiasis (Chagas disease)

Chagas disease, a disease caused *by the pathogen* Trypanosoma cruzi, has been transmitted mainly by triatomine bugs and has affected more than 6 7 million people worldwide mostly living in Latin America, along with more than 100 species of mammals identified as a reservoir of this disease [57]. In the United States, the climate envelope model predicts some geographical *changes in the* distribution *of several* triatomine species, including Triatoma gerstaeckeri and Triatoma sanguisuga [58]. According to the recent laboratory studies, there is a correlation between rising temperatures and decreased *development time* of the vector *Rhodnius* prolixus that also causes significant acceleration of metacyclogenesis in T. cruzi [59]. Both deforestation and the transformation of sylvatic habitats into peridomestic ones have increased the chances for triptomines to get into peridomestic environments and have changed the community structure of host organisms.

Zoonotic malaria

People are infected by different species of Plasmodium belonging to the group of simians. The parasite known as Plasmodium knowlesi, which attacks long-tailed and pig-tailed macaques, gained attention as a major pathogen making humans ill with malaria after a big outbreak was discovered in Sarawak, Malaysian Borneo, in 2004 [60]. P. knowlesi is now the most prevalent malarial pathogen in Malaysia. What was studied in Sabah showed that the risk for humans to catch malaria is connected to forest clearing that is taking place around the villages and forest cover [61]. The P. simium malarial parasite which attacks howler monkeys was found to be responsible for malaria outbreak in the Atlantic Forest of Rio de Janeiro, Brazil, in 2015-2016; it had been misdiagnosed as P. vivax before this outbreak [62]. The above-mentioned cases illustrate that the driver of zoonotic malaria outbreak is land use change rather than temperature increase, however, temperature can change the behavior of vectors.

Tick-borne babesiosis

Although ticks are different from other insects in terms of their life cycle duration, off-host periods,

and microclimatic humidity sensitivity [63,64], it is established that warming has led to the northward *movement* and altitude increase of *Ixodes* scapularis in North America and of I. ricinus in Europe *[65,66]. Human* babesiosis, which is mostly *due to* Babesia *microti in* the USA and B. divergens and B. venatorum in Europe, has been transmitted by ticks from rodents, cattle, or deer as host animals. This infection's occurrence has been increasing in the northeastern USA [67]. Therefore, it has not yet been clearly understood how climate influences tick density in terms of the roles of reforestation, deer population growth, and rural-urban development.

Dirofilariasis

Dirofilaria immitis and *D. repens* are mosquito-borne filarial nematodes affecting dogs, some carnivores, and humans. When they infect humans, they cause pulmonary or subcutaneous lesions. Before the mosquito can transmit the larvae, an ambient temperature must be above a threshold value of 14 °C. The temperature theory has been successfully implemented for mapping the disease transmission period in Europe [68]. The two nematode species have invaded Central, Eastern, and Northern Europe, and D. repens *has become* the most commonly reported cause of human dirofilariasis in this continent [69,70]. The invasion of the competent vector *Aedes albopictus* and the spread of infected dogs had an additional effect due to the overall warming climate [70].

Synthesis

Across vector-borne parasitic zoonoses, the evidence suggests three general patterns. First, observed changes are concentrated at the cooler latitudinal and altitudinal margins of current distributions, consistent with thermal performance theory [25,71]. Second, non-climatic drivers—land-use change, urban green spaces, animal movement and conflict—often act as the proximate trigger of outbreaks. Third, the evidence base is dominated by correlative niche models, which project suitability rather than transmission and seldom incorporate host immunity, vector competence or human behaviour [72].

Water- and food-borne protozoan zoonoses

Protozoa belonging to enteric and tissue-dwelling species that possess resistant forms of transmission are severely affected by hydrological changes. Their cysts and oocysts can persist in soil and water for months, and they are resistant to conventional methods of chlorination such *as Cryptosporidium.* The species can exist in large numbers in the organism of animals. The effect of climate on these organisms is mainly felt through the pathway taken by the feces from hosts to water, food, and human beings [33,35].

Cryptosporidiosis

Cryptosporidium is one of the leading causes of moderate to severe diarrhea in children in low and lower-middle income countries. According to the Global Enteric Multicenter Study (GEMS), cryptosporidium is one of the four microorganisms that are primarily linked with moderate to severe diarrhea among children aged under in sub-Saharan Africa and South Asia, and it is associated with increased mortality with these cases [73,74]. C. parvum is the primary *zoonotic* organism, being discovered in pre-weaned calves, whereas C. hominis is *mostly an* anthroponotic microorganism [75]. The Milwaukee outbreak of 1993, in which close to 403,000 people became infected via the municipal water supply, was the largest known waterborne disease outbreak in the US and took place after a series of heavy rains and snowmelt, leading to an increase in the turbidity of source water [76]. Numerous studies conducted since then have correlated the occurrence of outbreaks of cryptosporidiosis with excessive rainfall, floods, and agricultural runoff, while a systematic review of zoonotic enteric diseases showed that cryptosporidiosis has a strong seasonal pattern with respect to temperature and precipitation in various places around the globe [36]. Thus, climate forecasts for increased precipitation suggest that the frequency of contamination incidents will also increase, especially since water supply systems using surface water in areas with high livestock density will be more affected by precipitation

events [35].

Giardiasis

Giardia duodenalis includes assemblages that infect various hosts, where assemblages A and B infect humans, livestock, pets and wildlife like beavers [77]. Similar to Cryptosporidium, the organism cysts move through surface runoff and can survive longer at lower temperatures. Human giardiasis varies greatly depending on the region's zoonotic origins, necessitating identification of the transmission type through molecular typing [77]. Therefore, climate change effects on giardiasis are essentially mediated through increased precipitation, flooding, and irrigation practices.

Toxoplasmosis

T. gondii could infect almost all warm-blooded animals, but oocyst-shedding hosts are strictly represented by felids. Oocyst survival is influenced by temperature and soil humidification but is best achieved in warm and humid conditions and impeded by freezing and drying [78,79]. Human and animal seroprevalence is higher in warm and humid areas as compared to the hot and dry, and cold regions in line with environmental viability of oocysts [78]. Warmer and wetter conditions might promote environmental transmission at higher latitudes, whereas drier conditions will have an opposite effect [79,80].

The land-to-sea movement of oocysts provides a striking example of a One Health pathway. Southern sea otters (*Enhydra lutris nereis*) in California were found to be at higher risk of *T. gondii* infection when they lived near sites of maximal freshwater runoff, implicating oocysts washed from land into coastal waters and concentrated by filter-feeding invertebrates [81]. Waterborne transmission to humans is also documented: an outbreak in Victoria, British Columbia, in 1995 was associated with a municipal water supply contaminated, probably by cougar or domestic cat faeces, after heavy rainfall [82]. In the Arctic, warming, changes in sea ice and northward movement of felids and other hosts may alter the exposure of Indigenous communities who rely on marine mammals and wildlife for food [83].

Synthesis

The pathway for the water- and food-borne protozoan organisms is mainly hydrological in nature: heavy precipitation and flooding transport oocysts and cysts from animal faeces into water, while drought can lead to virus concentration in small water sources. The exposure is affected by water distribution systems and livestock management practices. Due to many infections being undiagnosed and unreported, especially in low- and middle-income countries, surveillance systems may not show signs of climate-related changes unless they incorporate environmental and veterinary data (see Section 8).

Helminthic zoonoses

Zoonotic helminths include a number of trematodes, cestodes and nematodes, whose life cycles often imply free-living larval forms, molluscan or arthropod intermediate hosts, and predator-prey transfer of parasites from wildlife to domestic animals. All these factors make many helminths sensitive to changes in space and environment, temperature, humidity and host community composition [84,85].

Echinococcosis

Among the most detrimental *food-borne zoonotic* parasitic diseases are cystic echinococcosis *(Echinococcus* granulosus sensu lato) and alveolar echinococcosis (E. multilocularis) [12,86]. *E. granulosus* s.l. is mainly transmitted between dogs and livestock while *E. multilocularis* is transmitted between foxes and other canids on the one hand, and small mammals on the other hand; humans are infected with Echinococcus after consuming contaminated food or water. Climate changes may alter echinococcosis transmission transmission conditions like ocyst survival (eggs are sensitive to dryness and high temperature), changing livestock management practices under the effect of drought, and land

cover changes changing the number of rodent intermediate hosts [87].

The spread of E. *multilocularis remains* stable in Europe and North America; the latest findings showed E. multilocularis presence in the regions where it was previously considered absent and the emergence of the European strain in Canada [88]. Urbanization process and thus formation of urban red fox populations led to emergence of urban peri-urban transmission cycles in many European cities, resulting in contact of infected definitive hosts with humans and domestic dogs [89]. Over the Tibbet Plateau, excessive grazing and subsequent biodiversity loss resulted in availability of small mammal species which serve as intermediate hosts more frequently and brought about the highest human alveolar echinococcosis incidences worldwide [86,87].

Schistosomiasis and hybrid schistosomes

The Schistosoma parasite relies on freshwater snails, and temperatures will have an impact both on the snails themselves and the life cycle of the parasite within them [84]. The important zoonotic advancement is the Schistosoma japonicum which affects more than 40 species of mammals including cattle in Asia and hybrids of schistosomes meanwhile present in parts of Africa and Europe. The occurrence of urogenital schistosomiasis in Corsica, France beginning in 2013 has been related to the hybrid of S. haematobium and S. bovis that was spread by snails from the genus Bulinus truncatus [90]. The hybridization of animal and human schistosome species is also known from West Africa and can lead to the transmission of the disease, drug resistance as well as greater host diversity [91,92].

The modeling studies indicate that the transmission of schistosomiasis may either increase or decrease []. For instance, the mechanistic *model shows* that S. mansoni transmission risk will increase as the temperature rises but some areas may become too hot for the transmission to occur [93]. The review of the climate and schistosomiasis impact proved that the temperature rise will benefit schistosomiasis transmission at higher altitudes and latitudes [94]. The influence of dams and crops irrigation is well-studied and documented [41,42].

Fascioliasis

Fascioliasis is a disease *caused by the parasites Fasciola hepatica,* Fasciola gigantica and mainly affects ruminants and livestock but has caused infections among humans in the countries of Andean region, Egypt and Iran [95]. The development of the parasite hinges on temperature and moisture in the lymnaeid snail and the environment, and prediction methods based on climate indicators have been in use in veterinary medicine for many years [84]. In Britain, climate-driven models have predicted that fascioliasis will spike in some places that experience warmer and wetter conditions, while areas subjected to dry summers may reduce risks [96]. The example of the Bolivian Altiplano is relevant due to its significant human prevalence (one of the highest in the world), with irrigation and the adaptation of Galba truncatula to the local *environment accounting* for the perpetuation of transmission [95].

Trichinellosis, anisakidosis and Arctic helminths

Trichinella species are kept alive in sylvatic cycles that involve carnivores and scavengers and that are responsible for human outbreaks through the consumption of meat (the consumption of undercooked meat of wild boars, bears, walruses, etc.) [97]. The issue with the freeze-tolerant T. nativa in Arctic communities results from traditional consumption methods, climate change, and wildlife and marine mammal distribution [83,97]. Anisakid nematodes come from the marine food web that involves the definitive hosts (cetaceans and pinnipeds) and results in human anisakidosis through the consumption of raw or undercooked fish and squid. Changes in the ocean temperature and food web structure brought about by marine mammals will change the abundance and distribution of Anisakis spp. along with altered consumer attitude with respect to raw fish [98].

Table 2. Selected parasitic zoonoses and evidence of climate or environmental influence

Parasite (disease)	Transmission route	Main climate or environmental drivers	Evidence type	References
Leishmania infantum (visceral and cutaneous leishmaniasis)	Sand flies; dogs, hares and other reservoirs	Temperature; urban green spaces; animal movement; conflict	Observed range change; outbreak investigation; niche models	[50–56]
Trypanosoma cruzi (Chagas disease)	Triatomine bugs; >100 mammal reservoirs	Temperature; deforestation	Niche models; experimental	[57–59]
Plasmodium knowlesi, *P. simium* (zoonotic malaria)	*Anopheles*; macaques, howler monkeys	Deforestation; forest-edge exposure	Observed spatial association; outbreak	[60–62]
Babesia microti, *B. divergens* (babesiosis)	*Ixodes* ticks; rodents, cattle, deer	Temperature; humidity; reforestation	Observed range change	[63–67]
Dirofilaria immitis, *D. repens*	Mosquitoes; dogs	Heat accumulation; invasive *Aedes albopictus*	Observed range change; degree-day models	[68–70]
Cryptosporidium parvum	Water, food; calves	Extreme rainfall; runoff	Outbreak investigation; time series	[73–76]
Giardia duodenalis (assemblages A, B)	Water; livestock, pets, wildlife	Rainfall; flooding	Time series; molecular typing	[77]
Toxoplasma gondii	Oocysts in soil and water; meat	Temperature; humidity; runoff	Seroprevalence gradients; outbreak investigation	[78–83]
Echinococcus multilocularis, *E. granulosus* s.l.	Eggs from canids	Land-cover change; urban foxes; pasture degradation	Observed range change	[86–89]
Schistosoma spp. and hybrids	Freshwater snails; livestock, rodents	Temperature; dams; irrigation	Outbreak; mechanistic models	[41,42,90–94]
Fasciola hepatica, *F. gigantica*	Lymnaeid snails; livestock	Temperature; rainfall; irrigation	Climate forecasting models	[84,95,96]
Trichinella spp., *Anisakis* spp.	Wild meat; marine fish	Wildlife and marine food-web change	Observational; expert review	[97,98]

Host dynamics at the human–animal–environment interface

Parasite emergence ultimately requires that an infectious stage reaches a susceptible human. Plowright and colleagues described zoonotic spillover as a hierarchy of barriers—pathogen pressure from reservoir hosts, survival and dispersal of the pathogen, human exposure and human susceptibility—each of which must be overcome [99]. Climate and environmental change can lower several of these barriers simultaneously by changing the distribution, density, behaviour and immunity of hosts.

Range shifts and novel host assemblages

Species are moving poleward and upslope in response to warming. A meta-analysis estimated median rates of range shift of 16.9 km per decade in latitude and 11.0 m per decade in elevation across terrestrial taxa [100]. Because species shift at different rates, communities are reassembled into new combinations, bringing parasites into contact with hosts they have not previously encountered [101]. Carlson and colleagues projected that such shifts in mammals will produce many first encounters between species, concentrated in high-elevation, species-rich areas of Africa and Asia [7]. For multi-host parasites with broad host ranges, such as *T. gondii*, *T. cruzi*, *Leishmania* spp. and *Echinococcus* spp., new host assemblages may create new reservoir communities and, as predicted by the Stockholm Paradigm, opportunities for host switching [30,31].

It should be added that phenological mismatches bring about new complications. Shifts in the timing

of vector emergence, breeding and flying practices of animals may change the level of overlap between infective stages and hosts that may be infected. In the permafrost zone, earlier spring and later autumn lengthen the period for which free-living larvae and intermediate host are active, as a result of which the lifecycle of parasites may change from multi-year to annual completion [29,83].

Biodiversity loss and host community composition

The correlation between biodiversity and disease risk is a subject of hot debate. According to the dilution effect hypothesis, transmission is reduced in diverse communities due to the presence of many poor hosts, and Keesing and co-authors have provided evidence that biodiversity loss leads to the increase of transmission levels [102]. Gibb and co-authors have provided global evidence to support the so-called mechanism according to which, in the cases of human presence, species that exist tend to host zoonotic pathogens, and agriculture leads to the increase of both presence and number of zoonotic hosts [39]. Rodents, as *hosts of Leishmania,* Echinococcus larvae, Babesia *microti are* among the species that thrive when habitats are altered. However, the generality of dilution effects is yet to be proven for parasites with complex life cycles, because it entirely depends on the host species that has disappeared and the one that survived.

Urbanisation and synanthropic hosts

Urbanisation leads to novel changes as wildlife begins to adjust to cities, and food, high concentrations of companion animals and peri-urban agriculture are made available [103]. Urban red foxes sustaining E. multilocularis [89], dogs and hares sustaining L. infantum [52,53], and peridomestic triatomines and opossums sustaining T. cruzi [57] demonstrate that cities are not places of parasite protection but rather parasite transmission. Heat islands may prolong the seasons of vector activity in cities.

Domestic animals, trade and human mobility

Farm animals often serve as intermediaries between wildlife and humans. The comparison of the pathogens shared by human populations and domesticated animals suggests that longer domesticated species share a higher number of antigens with humans and that close and long associations of the two species do play a role [104]. The movement of farm animals around the globe, trade in pets and wildlife, as well as movement of vectors have introduced parasites into new areas, such as the spread of *Aedes albopictus* and the import of dogs carrying Leishmania *and Dirofilaria from endemic* to non-endemic regions of Europe [70,105].

Human mobility is equally important. Climate-related displacement, labour migration and conflict move susceptible people into endemic areas and infected people into non-endemic areas where competent vectors may be present [106]. The epidemics of cutaneous leishmaniasis associated with the Syrian conflict and refugee movements show how displacement, overcrowding and the collapse of vector control can rapidly change the epidemiology of a parasitic zoonosis [56]. Similar risks are anticipated where climate change contributes to food insecurity and migration in the Middle East, Sahel and South Asia.

Host immunity and co-infection

The influence of climate stress on host immunity is experienced in wildlife as well as livestock and human beings. Challenges such as heat stress and malnutrition caused by crop and pasture failures, along with pollution, can lower resistance to infection and enhance the shedding of infectious agents [43,44]. In humans, having HIV co-infection is related to an increase in the risk for visceral leishmaniasis and reactivated toxoplasmosis, and malnutrition is connected with an escalation of infections caused by Cryptosporidium in children [73]. The social factors mentioned above therefore alter the impact of climatic changes on biological populations, and the vulnerable populations are those with little or no access to clean water, sanitation services, pet care, and health care services, bringing about the experience of the disability indicated above.

Surveillance, early warning and One Health integration

Because climate change shifts the places and seasons in which parasites are transmitted, surveillance must detect change at the margins of current distributions and in animal and environmental compartments before human cases accumulate. The quadripartite One Health Joint Plan of Action (2022–2026) of FAO, UNEP, WHO and WOAH identifies integrated surveillance, endemic zoonoses, neglected tropical diseases and vector-borne diseases, and the environment as core action tracks [107]. Translating this framework into operational systems for parasitic zoonoses remains a major challenge.

Integrated human, animal and environmental surveillance

Surveillance within the concept of One Health connects the information contained in public health, veterinary, wildlife, and environmental sectors, making it possible for the signal detected in one sector to give rise to an inquiry in another one [14,108]. Sentinel animal surveillance is particularly useful when it comes to parasitic zoonoses. Serological *tests among* dogs *for L. infantum* or Dirofilaria, monitoring of *foxes for E. multilocularis* and serological analysis of wild and domestic animals for T. *gondii, will be* able to provide data on the problem before any humans are diagnosed with the disease [69,86]. Data derived from animal slaughter inspections relating to cystic echinococcosis and fasciolosis represent an insufficiently informed source of problem statistics that can be related to weather conditions and land use.

Spatial epidemiology, remote sensing and modelling

Currently, due to the availability of variables obtained by satellites such as land surface temperature, vegetation indices, rainfall, soil moisture, and land cover, monitoring of environmental conditions on a vast scale with a high resolution has become possible. Such information and analysis can support global and regional mapping of infectious diseases [109]. Remote sensing and geographical information systems can also be utilized in veterinary parasitology to observe fascioliasis, schistosomiasis, dirofilariasis, and infections caused by ticks [110].

Two primary types of models help predict climate effects in organisms. Correlative ecological niche models, like maximum entropy (MaxEnt), use data on the presence of organisms to figure out how the species will do under future climate [111]. These models work well for groups such as sand flies, triatomines, and snails [54,55,58]. In comparison, mechanistic models are based on fresh data about relationships between temperature and features of parasites and vectors, including degree-day models for *Dirofilaria and* thermal-performance R0 models for vector-borne parasites [25,68]. Mechanistic models are better for predicting performance in novel environments, while the correlative model is useful when data on traits is missing. An increasing number of researchers are suggesting to combine both approaches and use independent monitoring data to validate the predictions [24].

Molecular, genomic and environmental DNA tools

The use of molecular methods is very important to identify species and genotypes of parasites, as well as zoogenic assemblies, and to investigate the origin of their introduction, as well as hybridization [10]. Genotyping helps to distinguish *between* zoonotic C. parvum and *anthroponotic C.* hominis, and between zoonotic and *anthroponotic* assemblages of Giardia [75,77]. The analysis of genomic material *has shown that S. haematobium–S.* bovis hybrids caused the outbreak on Corsica [90,92]. Molecular xenomonitoring is the examination of vectors for the presence of parasite DNA, thus ensuring the presence of infection in the vector population even with a low prevalence in humans.

Environmental DNA (eDNA) methods identify traces of DNA left by organisms in the water, soil, or sediment [112]. In the case of schistosomiasis, the eDNA tests performed on water *samples in Kenya* have successfully found Schistosoma mansoni and its snail hosts more efficiently than traditional snail surveys [113]. *This* technique *can also be applied in* analyzing Fasciola, Cryptosporidium, Toxoplasma oocysts in water samples and for the detection of other parasite vectors.

Early warning systems and community participation

Climate-informed early warning systems use seasonal climate forecasts and surveillance data to predict periods of transmission risk. These systems have been developed for some vector-borne diseases and for veterinary fascioliasis forecasts, but are still uncommon for parasitic zoonoses in low- and middle-income countries. Community based surveillance, participatory epidemiology and citizen science such as reporting of the presence of ticks therefore extends the coverage and builds the capacity of local communities in adapting to change [114]. WHO's Global Vector Control Response 2017-2030 identifies intersectoral action, vector surveillance, and community action as critical aspects of effective vector control [115].

Table 3. Surveillance tools for climate-sensitive parasitic zoonoses

Tool	What it detects	Example applications	Main strengths	Main limitations
Sentinel animal surveillance	Infection in reservoirs and domestic animals	Canine *Leishmania* and *Dirofilaria* serosurveys; fox *E. multilocularis* monitoring	Detects new foci early; links veterinary and human health	Requires veterinary capacity and data sharing
Vector and snail surveillance	Vector presence, density and infection	Sand fly trapping; tick drag sampling; snail surveys	Direct measure of transmission potential	Labour intensive; seasonal
Molecular typing and genomics	Species, genotypes, hybrids and sources	*Cryptosporidium* subtyping; schistosome hybrid detection	Distinguishes zoonotic from anthroponotic transmission	Cost; laboratory infrastructure
Environmental DNA	Parasite and host DNA in water or soil	*Schistosoma* and snail detection in water	Sensitive; scalable; non-invasive	Standardisation; does not prove viability
Remote sensing and GIS	Environmental suitability over large areas	Mapping snail and sand fly habitats	Wide coverage; repeated over time	Needs ground truth; indirect
Correlative and mechanistic models	Current and future suitability or transmission	Niche models; degree-day and R0 models	Scenario analysis; supports planning	Uncertain extrapolation; data gaps
Community and participatory surveillance	Reports of vectors, sick animals and human cases	Citizen tick reporting; participatory livestock surveillance	Local engagement; low cost	Reporting bias; requires feedback loops

Governance and integration

The major obstacles to One Health surveillance seem to be more political than technical. Human and animal health data are usually stored by different ministries that are legally supported and funded separately, which renders environmental agencies absent from the network of surveillance [116]. Effective systems require common definitions, common data platforms, and agreements on data sharing. In countries with limited resources, using surveillance on the district level combined with mobile laboratories and various regional reference laboratories might be less complicated than implementing complex national systems.

Knowledge gaps, challenges and research priorities

Attribution and baseline data

The main scientific challenge is attribution: separating the impact of climate change from the effects of land use, animals' movement, reporting and diagnosing disease, and control interventions. Only a few parasitic zoonotic diseases have consistent and long data about humans, vectors and animals suitable for attribution research. Highland malaria is one of the cases in which it has been demonstrated

that disease incidence corresponds to interannual temperature variations while the fact that warming slowed down in the early 2000s is also observed [27,117]. Similar analyses of leishmaniasis and echinococcosis are missing entirely. Hence, the establishment of experience in standard surveillance on sentinel sites is a prerequisite for successful attribution.

Geographic and taxonomic bias

Research on climate and infectious disease is concentrated in North America and Europe and on a small number of pathogens, whereas the greatest burden of parasitic zoonoses and the greatest climate vulnerability are found in Africa, South and South-East Asia, Latin America and the Middle East [17,118]. Helminth zoonoses, food-borne trematodes and protozoa of wildlife are particularly understudied. In the Middle East and North Africa, where warming is projected to exceed the global average and water scarcity is severe, data on climate effects on cutaneous leishmaniasis, cystic echinococcosis, fascioliasis and toxoplasmosis are scarce despite their high endemicity [56,86].

Mechanistic understanding

Thermal performance curves exist only for few species and parasites or their intermediate hosts making experiments on that topic rare and uncommon [25]. Researches often do not take into account temperature fluctuations, microclimate refugia, the correlation between temperature and humidity, the abilities of parasites and vectors to evolve in the warm climate. The interaction of climate with host immunity, co-infections and nutrition has not been studied well enough yet [43,44]. There is a demand for researches incorporating field observations, experiments and modeling along full lifecycle.

Translating knowledge into action

Even where risks are recognised, translation into adaptation is limited. Priority actions include: incorporating climate-sensitive parasitic zoonoses into national adaptation plans and One Health strategies; integrating veterinary and environmental indicators into early warning systems; strengthening diagnostic capacity in primary care and veterinary services; improving water, sanitation and hygiene and livestock waste management in catchments; and ensuring that development projects such as dams, irrigation schemes and urban green spaces undergo health impact assessment [41,107]. Control programmes for neglected tropical diseases must also anticipate that the boundaries of endemic areas will move, so that elimination achieved in one area is not undermined by introduction from another [18].

Research priorities

1. Integrate monitoring of human beings, domestic animals, wildlife, vectors, and environmental samples in climate-sensitive areas on a prolonged basis.
2. Conduct research on thermal and moisture response parameters of intermediate hosts and vectors.
3. Come up with and test hybrid models that merge mechanistic and correlative characteristics for human behavior and land use.
4. Standardization and implementation of environmental DNA and xenomonitoring techniques on large scale in regular monitoring.
5. Conducting investigations, including attribution studies for zoonotic parasitosis of moderate duration.
6. Work out methods for valuating efficiency of One Health interventions, including deworming dogs in case of echinococcosis, ensuring proper livestock management in case of cryptosporidiosis, and controlling snails in case of schistosomiasis in the context of climate change.
7. Increase research potential and leadership in countries that suffer the most from parasitic zoonoses and climate change.

Conclusions

Climate change is altering the ecology of zoonotic parasitic diseases in a nonlinear way, affecting the development of parasites, the ability of vectors to transmit them, the populations of their intermediate hosts, the persistence of their infectious stages in the environment, and the distribution and activity patterns of their reservoirs. Evidence for this change comes predominantly from the margins of existing *distribution ranges, where, for* instance, *Leishmania infantum,* Dirofilaria spp. and Echinococcus multilocularis have been observed to spread northward in Europe and North America and parasites are developing faster in the Arctic, as well as from outbreaks of waterborne protozoan parasites due to precipitation events. The driving factors, however, remain unchanged for all groups of parasites as a result of land use changes, water development, urbanization, movements of animals, wars, and poverty serving as a more immediate cause of emergence than climate change.

The evidence in question proves the necessity of implementing One Health approach that combines human and animal health, as well as wildlife and environmental monitoring. It combines molecular techniques, genomics, environmental DNA analysis, remote sensing system and modeling techniques based on mechanisms or correlation, while also integrating climate-affected parasitic zoonoses into its adaptation and elimination processes. To achieve effective monitoring of posts arising in changing climatic conditions, it is important to fill the existing gaps in long-term information, mechanism knowledge and research capacity of regions where the phenomenon occurs.

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