

REVIEW

Open Access



Addressing biodiversity conservation, disease surveillance, and public health interventions through One Health approach in Hainan's tropical rainforest

Li Zhang^{1*} , Shoubai Liu², Wenqiang Guo¹, Chenrui Lv¹ and Xiaomeng Liu¹

Abstract

This review investigates the utilization of the One Health approach to advance sustainable development and enhance health in the Hainan tropical rainforest, which is a unique ecosystem with significant biodiversity and environmental value. The region is confronted with threats arising from human activities and climate change, impacting both the health of the inhabitants and the ecosystem. The Hainan tropical rainforests create an ideal habitat for the transmission of mosquito-borne diseases, such as dengue fever and malaria, between humans and animals. The hot and humid climate creates favorable conditions for mosquito proliferation, while increased human encroachment into forested areas escalates the risk of contact with wildlife reservoirs of these diseases. Proactive surveillance of emerging infectious diseases in the forests and animal populations of Hainan is crucial for early detection and swift response to potential public health hazards. By embracing the interdisciplinary and collaborative principles of the One Health approach, this review aims to safeguard the ecosystem while fostering development. The introduction offers insights into the significance of the One Health concept, its relevance to environmental conservation, human health, and animal health. Subsequently, the paper delves into the practical application of the One Health approach in the Hainan tropical rainforest, using it as a case study. This application entails raising awareness of ecosystem health through educational initiatives and public outreach, implementing effective ecological conservation measures, promoting wildlife conservation efforts, and monitoring and preventing potential disease outbreaks. Furthermore, the paper highlights the importance of the One Health approach in achieving sustainable development in the Hainan tropical rainforest. It also explores potential research directions and associated challenges. By prioritizing the collective well-being of humans, animals, and the environment, the One Health approach offers a means to balance ecosystem conservation and human welfare.

Keywords One Health, Hainan tropical rainforest, Sustainable development, Ecosystem, Health improvement

Introduction

The Hainan tropical rainforest, located on Hainan Island in China, represents a globally significant symbol of remarkable biodiversity and ecological importance [1]. However, the convergence of zoonotic diseases and environmental degradation poses significant challenges to both human health and sustainable development in this area [2]. Specifically, the Hainan tropical rainforest

*Correspondence:

Li Zhang

zhangli302@webmail.hzau.edu.cn

¹ College of Animal Science and Technology, Huazhong Agricultural University, Wuhan 430070, China

² School of Tropical Agriculture and Forestry, Hainan University, Haikou 570228, China



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

is confronted with the prevalence and transmission of diseases such as Dengue Fever, which is propagated by the rapid proliferation of *Aedes aegypti* mosquitoes, and Malaria, facilitated by favorable breeding conditions for Anopheles mosquitoes in the humid rainforest environment [3–5]. There are also concerns regarding the transmission of the COVID-19 virus, as interactions between humans and wildlife, along with unhygienic market conditions, can facilitate zoonotic spillover events [6, 7]. Environmental factors, including climate, ecosystem changes, and human activities, can influence the prevalence and spread of these diseases in the Hainan tropical rainforest [8]. Therefore, it is crucial to maintain ecological balance and implement preventive measures to not only reduce the transmission of these diseases but also safeguard human health and promote sustainable development in the region. In response to these challenges, the One Health approach emerges as an interdisciplinary strategy to address these complex issues. By acknowledging the intricate interconnections between human, animal, and environmental health, researchers and policymakers can develop comprehensive strategies to mitigate risks and foster harmonious coexistence among these components [9].

The concept of One Health is a comprehensive approach that recognizes the interconnections among human health, animal health, and the environment [10, 11]. It emphasizes the collaborative efforts of multiple disciplines to address complex health challenges at the interface of humans, animals, and ecosystems. This approach originated in the early 2000s in response to emerging infectious diseases, with the recognition that many of these diseases are zoonotic, meaning they can be transmitted between animals and humans [12]. The term “One Health” was coined to describe the need for a unified approach that encompasses human and animal health, as well as environmental health [13]. Since its inception, One Health has gained significant recognition and has been endorsed by international organizations such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the World Organization for Animal Health (OIE) [14]. These organizations highlight the importance of interdisciplinary collaboration and the integration of human, animal, and environmental health to achieve optimal health outcomes for all [15]. The implementation of the One Health approach has been widespread. For example, the U.S. Agency for International Development (USAID) initiated the PREDICT project in 2009 as part of the Emerging Pandemic Threats (EPT) program [11]. PREDICT adopts the One Health approach and focuses on early detection and response to potential zoonotic virus threats. It promotes cross-sectoral monitoring and laboratory networks, open data sharing, coordinated

disease outbreak responses, and contributes to national One Health platforms [11]. Initiatives like the “Reinvent the Toilet Challenge,” supported by the Bill and Melinda Gates Foundation, also embrace the One Health perspective [16]. They aim to provide sustainable sanitation solutions for the millions of people worldwide who lack access to safe and affordable sanitation facilities, reducing the risks of zoonotic diseases caused by untreated fecal matter in low- and middle-income countries [17]. One Health has gained recognition in Europe as well, with countries like Austria, Belgium, and France conducting research and educational activities in the field of One Health to combat zoonotic diseases and antimicrobial resistance (AMR) [18, 19]. In Ethiopia, which has a large human and livestock population, multiple sectors have identified the five most important zoonotic diseases from a One Health perspective [20]. This approach aims to strengthen monitoring, develop prevention and control strategies, and conduct joint outbreak investigations for humans and animals [20]. The One Health philosophy acknowledges the intricate connections between human, animal, and environmental health, underscoring the necessity for multidisciplinary collaboration [21]. This holistic approach brings together professionals from diverse fields such as medicine, veterinary science, ecology, epidemiology, and social sciences [22]. Through this collaboration, a deeper understanding of the interwoven relationships between human health, animal health, and the environment can be achieved. By adopting the One Health approach, researchers and policymakers can develop effective strategies for disease prevention, biodiversity preservation, and sustainable development [23].

The Hainan tropical rainforest, renowned for its unparalleled biodiversity and unique ecological characteristics, represents a significant global biodiversity hotspot. This ecosystem is home to numerous endemic and endangered species, thriving under favorable climatic conditions characterized by high temperatures, humidity, and continuous rainfall. Its exceptional species richness and endemism are attributed to these persistent environmental factors. In addition to its ecological significance, the Hainan tropical rainforest plays a vital role in providing essential ecosystem services that support human well-being, including carbon sequestration, water regulation, soil erosion control, and the provisioning of crucial resources [1]. Furthermore, the forest acts as a pivotal carbon sink, contributing significantly to climate change mitigation.

Given the rapid urbanization and economic growth occurring on Hainan Island, it is imperative to prioritize the preservation and sustainable management of the Hainan tropical rainforest [24]. The application of the One Health concept has gained widespread recognition

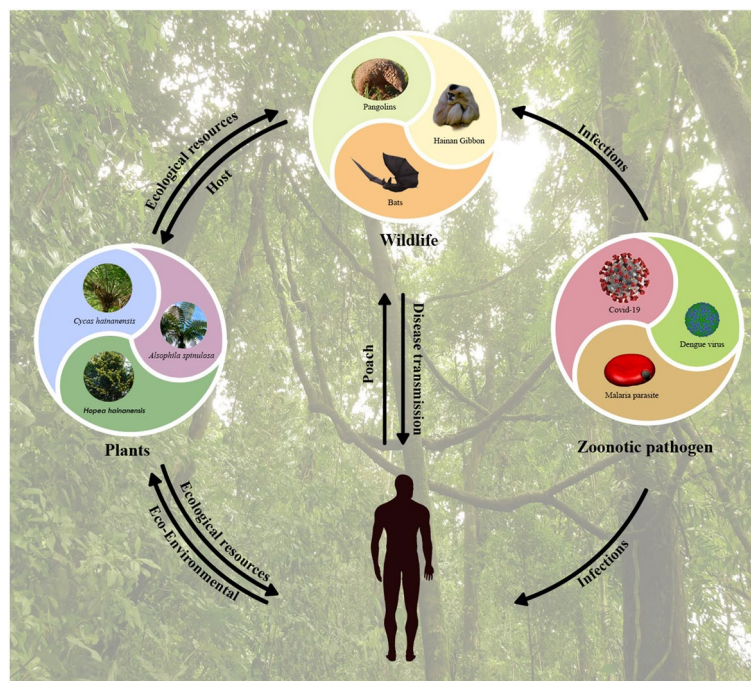


Fig. 1 An overview of the interaction among the main plants, animals, and humans in the Hainan tropical rainforest, as well as the potential spread of zoonotic diseases

and implementation in tropical rainforests conservation. For example, the Maderas Rainforest Conservancy (MRC) has effectively embraced the One Health approach in the Maderas Rainforest demonstrating a steadfast commitment to promoting diversified community service, environmental protection, and conservation education at all levels [25]. Their objectives include safeguarding the forest ecosystem, enhancing the health of local communities and wildlife, and implementing conservation education programs to achieve a sustainable coexistence between the local community and the Maderas Rainforest [25]. Smout et al. recommended the adoption of a One Health approach to manage Australian rainforests as a means reduce the incidence of *Ancylostoma ceylanicum* infections in humans and dogs [26]. In the renowned Amazon rainforest, Lowe et al. observed that rainforest degradation, extreme weather events, and climate change contribute to the proliferation of mosquito-borne diseases such as dengue, chikungunya, and Zika [27]. Additionally, Ellwanger et al. discovered that deforestation in the Amazon rainforest has a significant impact on zoonotic diseases and public health [28]. These researchers strongly advocate for the application of the “One Health” concept to address the challenges faced by the Amazon rainforest. These examples serve as reliable references for implementing the One Health approach in Hainan’s tropical rainforests.

It is crucial to apply the principles and methodologies of the One Health approach to identify and mitigate potential health risks resulting from environmental deterioration and biodiversity loss. By advocating for the coexistence of humans, animals, and ecosystems, a balanced equilibrium can be maintained, ensuring the long-term survival and prosperity of this invaluable region (Fig. 1).

Overview of Hainan tropical rainforest

The distribution and ecological environment of the Hainan tropical rainforest are shaped by its geographic location, climate, and topography. This region is renowned for its exceptional biodiversity and endemic species, encompassing a wide variety of plants and animals [29]. The intricate ecological interactions within this rainforest underscore its ecological importance and emphasize the necessity for conservation and sustainable management.

Geographical distribution and ecological environment of the Hainan tropical rainforest

Hainan Island’s geographical location, with its proximity to the equator and a maritime climate, provides ideal conditions for the development of the Hainan tropical rainforest [30]. The average annual temperature ranges from 21 to 27°C, and the relative humidity remains

consistently high throughout the year, fostering the growth and abundance of various flora and fauna. Moreover, the island receives ample precipitation, with an average annual rainfall of approximately 1800 mm [31].

The Hainan tropical rainforest is located on Hainan Island, situated in southern China between the South China Sea and the Gulf of Tonkin. Covering approximately 4269 km², this region exhibits unique geographical features and diverse ecosystems [32]. The rainforest extends across the central and western parts of the island, encompassing both mountainous terrain and lowland areas.

Main plant and animal species in tropical rainforests, including unique flora and fauna

The Hainan tropical rainforest in Hainan Province is widely recognized for its extensive biodiversity and distinctive array of plant and animal species [1]. This pristine ecosystem serves a vital role in upholding ecological equilibrium and furnishing invaluable ecosystem services. In this section, we will delve into a discussion on several noteworthy plant and animal species that inhabit the Hainan tropical rainforest, highlighting their distinctiveness and significance (see Fig. 2). The selection of these specific species is based on their ecological significance, exclusive presence within the Hainan tropical rainforest, and conservation status as determined by the National Forestry and Grassland Administration [1, 33–35].

Plant communities in the Hainan tropical rainforest

The Hainan tropical rainforest harbors a wide range of plant species, including several endemic ones that are exclusive to this region. *Cycas hainanensis* and Hainan hopea (*Hopea hainanensis*) are notable examples of such endemics [36, 37]. The rainforest’s dense canopy, formed by towering trees that can exceed 30m in height, creates a complex vertical structure, providing diverse microhabitats for a variety of organisms. Numerous plant species contribute to the rich biodiversity of the rainforest.

One prominent tree species in the Hainan tropical rainforest is the Hainan hopea. Known for its hard and durable wood, it serves as a keystone species, providing habitat and contributing to the forest’s structural integrity [38]. The Hainan hopea plays a vital ecological role by supporting various wildlife species through habitat provision and resource availability [39]. Due to its slow growth and limited distribution, it is considered a protected species in China. Conservation efforts are in place to ensure the sustainable management of this iconic plant species in Hainan.

Another representative plant species found in the Hainan tropical rainforest and other parts of China is *Alsophila spinulosa*, commonly known as the Chinese tassel fern [40]. Belonging to the family Cyatheaaceae, this large, perennial fern can reach heights of up to 10m. The delicate and feathery appearance of its fronds, along with their vibrant green color, distinguishes it. *Alsophila spinulosa* thrives in moist and shady environments, often growing in the understory of tropical rainforests [41]. In



Fig. 2 Main plant and animal species in Hainan tropical rainforests. The picture of Hainan peacock pheasant was provided by Xiwen Chen, taken in Jianfengling area of National Park of Hainan Tropical Rainforest

the forest ecosystem, it plays a crucial ecological role by providing habitat for various organisms. Additionally, its fronds contribute to leaf litter, enriching the soil and supporting the growth of other plants. Conservation efforts are in place to protect *Alsophila spinulosa* due to habitat loss and collection for horticultural purposes [42]. The sustainable management of this beautiful fern species and the preservation of its natural habitat are vital for its long-term survival.

Cycas hainanensis, also known as the Hainan cycad or Hainan sago palm, is a species of cycad plant native to the tropical rainforests of China. Belonging to the Cycadaceae family, it exhibits a slow growth rate and retains its evergreen foliage. The plant features a robust trunk and large, pinnate leaves resembling palm fronds. *Cycas hainanensis* thrives in the tropical climate of Hainan Island, particularly in areas with partial shade and well-drained soil. It is commonly found in lowland forests and rocky hillsides. This cycad species holds the status of a living fossil, having existed for millions of years, thus rendering it a significant subject for scientific research and conservation efforts [43]. However, due to habitat loss and illegal collection for ornamental purposes, *Cycas hainanensis* is now classified as a protected species in China. To ensure its survival, conservation initiatives such as habitat preservation, captive breeding, and public awareness campaigns are being implemented.

Dacrydium pierrei, a coniferous tree belonging to the Podocarpaceae family, is characterized by its vibrant green leaves, reminiscent of the plumage of a bird known as the “Lujun bird.” This resemblance has led to its common name. Native to the mountainous regions of central and southern Hainan Island in China [44]. Pierre’s podocarp possesses a unique attribute: when wounded, it exudes red resin, earning it nicknames like “Tears-of-balsam” or “Red pine.” This resinous secretion holds both cultural and commercial significance. To address conservation concerns, protected areas have been established in the primary habitats of *Dacrydium pierrei*, such as Jianfengling and Bawangling [45]. These protected areas employ various measures, including artificial regeneration and facilitation of natural regeneration, to restore and conserve this species.

Animal biodiversity of the Hainan tropical rainforest

The Hainan tropical rainforest harbors a diverse array of remarkable and endangered animal species, including the critically endangered Hainan gibbon (*Nomascus hainanus*). With an estimated population of fewer than 40 individuals, the Hainan gibbon’s presence is crucial for maintaining the ecological equilibrium of

the rainforest [46, 47]. Another endemic subspecies found in this region is the Hainan black crested gibbon (*Nomascus* sp. cf. *nasutus hainanus*), known for its distinctive vocalizations and significant role in seed dispersal, which influences forest regeneration [48, 49].

The Hainan tropical rainforest is also home to other notable animal species such as the Hainan Eld’s deer (*Rucervus eldii hainanus*), a critically endangered subspecies characterized by its light brown or reddish-brown coat with white spots and a distinctive throat mane in males. Habitat loss and poaching have led to its critical endangerment, as recognized by the International Union for Conservation of Nature (IUCN) [50]. Additionally, the Hainan black pig, adapted to the forest environment and displaying a smaller body size, contributes to the rainforest’s unique biodiversity [51].

Among the avian species, the Hainan Partridge (*Arborophila ardens*) stands out as a unique bird endemic to the high-altitude mountainous regions of the Hainan tropical rainforest [52]. Its dense brown feathers with speckled patterns aid in camouflage within the forest environment. While both males and females share a similar appearance, males possess a patch of red bare skin on their heads, adding vibrancy to their overall appearance [53]. Typically observed in pairs or small groups, the Hainan Partridge faces endangerment due to habitat destruction and human disturbance. Consequently, it is assessed as an endangered species by the International Union for Conservation of Nature [1].

The Hainan Peacock Pheasant (*Polyplectron katsumatae*) is another endemic bird species found exclusively in the Hainan tropical rainforest [54]. This pheasant species, belonging to the Phasianidae family, is admired for its striking plumage and elaborate courtship displays [55]. However, like many other pheasant species, the Hainan Peacock Pheasant is vulnerable to habitat loss and hunting pressures. Therefore, it is considered a protected species in China, necessitating conservation efforts through protected areas and raising awareness about the importance of preserving this unique bird [34].

The Hainan tropical rainforest encompasses a wealth of significant plant and animal species, many of which are endemic and play vital roles in maintaining the ecological balance of the region. Protecting and conserving these unique species and their habitats is essential for the sustainable development of the Hainan rainforest ecosystem in the long term. Collaborative efforts involving scientific research, community engagement, and policy support are key to preserving and managing this valuable natural resource.

Microbial communities and their ecological roles in tropical rainforests

Microorganisms play a crucial role in tropical rainforest ecosystems, contributing significantly to vital processes such as the decomposition of organic matter, nutrient cycling, and the stability of the ecosystem. Additionally, microbial communities enhance biodiversity and promote species adaptability, highlighting their essential regulatory role within these ecosystems [56].

Recent studies have shed light on the complex interactions between microbial communities and tropical rainforest ecosystems. For instance, Soong et al. demonstrated that microbial communities are key drivers of carbon cycling in tropical rainforests. Specific microbial taxa play significant roles in regulating carbon storage and release [57]. Furthermore, Deng et al. found a positive correlation between microbial biodiversity in the rhizosphere of tropical plants and plant health and productivity. This highlights the importance of plant-microbe interactions in shaping rainforest ecosystems [58].

Moreover, investigations into the impacts of human activities on microbial communities have yielded valuable insights. Adeniyi et al. revealed that slash-and-burn agriculture leads to a substantial decrease in microbial diversity and alters community composition. This could potentially disrupt vital soil processes [59]. Similarly, Hans et al. highlighted the negative effects of logging on soil microbial communities, resulting in reduced nutrient availability and impaired ecosystem functioning [60].

These findings emphasize the intricate relationships between microbial communities and tropical rainforest ecosystems. Microbes play a fundamental role in sustaining the functionality and resilience of this unique ecosystem by influencing nutrient cycling, maintaining biodiversity, and supporting plant health [61]. Continued research in this field is crucial for further unraveling the specific mechanisms of microbial contributions and their responses to human disturbances. This research will facilitate the development of effective conservation and management strategies.

Public health issues in the Hainan tropical rainforest

The Hainan tropical rainforest is widely recognized for its rich biodiversity and complex ecological interactions, which make it a significant reservoir of distinctive plant and animal species. However, these intricate dynamics also raise concerns about the potential risk of public health issues, including the transmission of diseases. In this section, we will delve into the scientific literature.

Potential disease transmission and risk in the tropical rainforest

To examine and assess the potential health risks associated with the Hainan tropical rainforest. The Hainan tropical rainforest is a dynamic environment where various species, including humans, coexist in close proximity. This setting creates opportunities for the emergence and transmission of infectious diseases. A notable example of zoonotic transmission was reported by Li et al., who observed a steady increase in hantavirus infection cases in Hainan province [62]. The detection of this virus in small mammals highlights the potential risk to individuals venturing into the rainforest. In addition to zoonotic diseases, the presence of vectors such as mosquitoes and ticks in the Hainan tropical rainforest poses an additional risk of vector-borne diseases. Dengue fever, a mosquito-borne viral disease, has been reported in Hainan Province (Fig. 3) [63]. It is primarily spread to humans through the bites of *Aedes* mosquitoes, resulting in an acute infectious illness known as dengue fever [64]. The dengue virus enters the human body via mosquito bites and after replicating in endothelial cells and the mononuclear phagocyte system, it enters the bloodstream, leading to the initial viremia [65]. Common symptoms include persistent fever, headache, muscle and joint pain, and in severe cases, it can be fatal [66]. Hainan Island provides favorable climatic conditions for the breeding of *Aedes* mosquitoes and the transmission of dengue fever [67]. The island has witnessed three major dengue fever epidemics in the past. The first significant outbreak occurred in 1979, with a reported 447,499 cases and a high infection rate of 74% [68]. The second and third outbreaks were caused by serotype 2 of the dengue virus. The second outbreak began in 1985, and due to the failure to sustain control measures, it resulted in a total of 164,244 reported cases by the end of 1988 [68, 69]. Du et al. documented the presence of multiple dengue virus serotypes in mosquitoes collected from the region, highlighting the risk of transmission to humans [70].

One significant public health concern related to tropical rainforest animals is the transmission of parasitic infections. Parasites can be transmitted through various means, including direct contact, ingestion of contaminated food or water, or through vectors. While there have been fewer reported cases in Hainan, it is important to consider the prevalence of parasitic infections in other regions to understand the significance of this issue. A study conducted by MPA et al. in the Amazon rainforest revealed a high prevalence of parasitic infections among indigenous communities [71]. The researchers found that helminths, such as roundworms and tapeworms, were commonly found in humans who had regular contact with animals in the rainforest [72, 73]. These

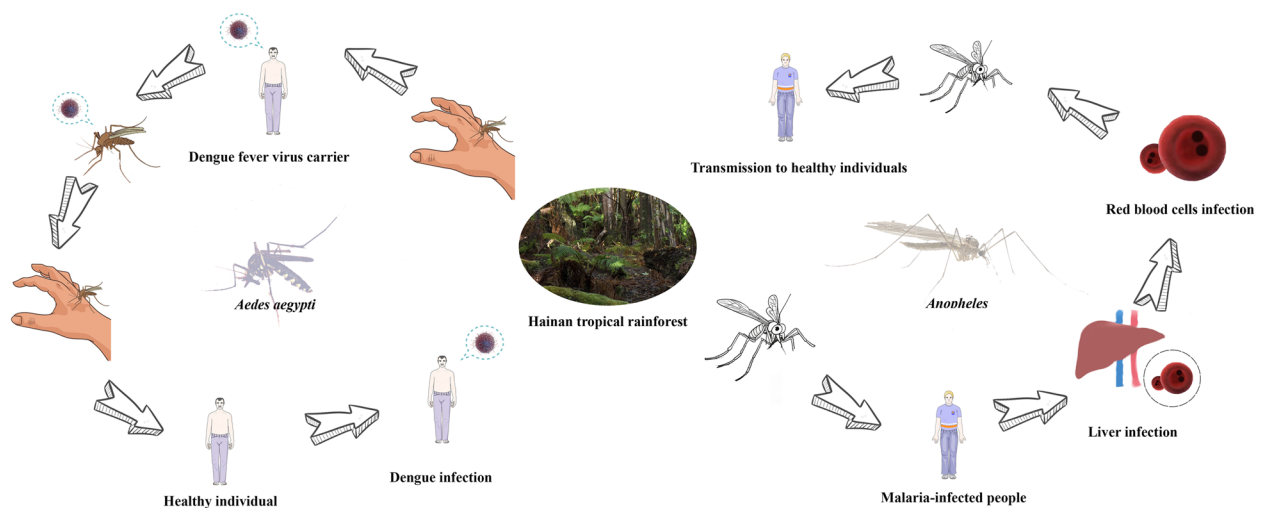


Fig. 3 Dengue fever and malaria in humans, animals and the environment

parasites can cause diseases such as ascariasis and taeniasis, leading to gastrointestinal symptoms and nutritional deficiencies.

Another example of a parasitic infection is malaria, a mosquito-borne disease (Fig. 3). Malaria is an insect-borne infectious disease caused by the transmission of the malaria parasite through mosquito bites. Clinically, it is characterized by recurring episodes of chills, fever, headache, sweating, anemia, and splenomegaly (enlarged spleen). The age-standardized incidence rate (ASR) of malaria increased from 3195.32 cases per 100,000 population in 2015 to 3247.02 cases per 100,000 population in 2019 [74]. The COVID-19 pandemic has had a direct or indirect impact on the treatment of other diseases due to regional lockdowns, medical supply shortages, and social isolation [75–77]. For instance, Zimbabwe experienced a significant increase in malaria cases during the COVID-19 outbreak compared to previous years [78]. From January to June 2020, over 30,000 more malaria cases were reported compared to the same period in 2017, 2018, and 2019 while Zimbabwe only reported 605 COVID-19 cases from March to June 2020 [78]. Regarding recent malaria cases in Hainan, the last reported cases date back to 2015, with only five malaria cases [79]. Since then, Hainan has implemented and adjusted prevention and control measures, successfully achieving the goal of eliminating malaria [79]. While malaria is not exclusive to tropical rainforests, these regions often harbor high mosquito populations, increasing the risk of transmission. The rainforest provides an ideal environment for the survival, reproduction, and transmission of the malaria parasite and its mosquito vectors [80]. The high temperatures, humidity, and abundant water sources create favorable conditions for the mosquito life cycle [81].

Moreover, the rainforest's vegetation offers ample shelter for both the malaria parasite and mosquitoes. A study by Morgan et al. in the Democratic Republic of Congo highlighted the challenges of malaria control in rainforest areas due to the complex interactions between humans, mosquitoes, and the environment [82].

Potential impact of tropical rainforest animals on public health

Tropical rainforests harbor diverse animal species, but these animals can pose public health risks by spreading parasites and viruses to humans. The Hainan tropical rainforest is located in an area where the wildlife trade is prevalent [83]. This wildlife trade and consumption, including non-human primates, reptiles, and bats, may increase the risk of zoonotic disease transmission to humans. The emergence of the Severe Acute Respiratory Syndrome coronavirus (SARS-CoV) in 2002 has been linked to the wildlife trade [84, 85]. Several documented cases in Hainan highlight the potential for zoonotic disease transmission between humans and animals. For instance, Guan et al. identified SARS-CoV-like coronaviruses in specific bat populations on Hainan Island, indicating a potential reservoir for future outbreaks [86]. In this section, we will discuss public health issues related to tropical rainforest animals, focusing on parasite infections and virus transmission (Fig. 4 and Table 1).

Public health associated with Hainan gibbons

As previously mentioned, the Hainan gibbon is an endemic primate species found exclusively on Hainan Island, China. It is considered a rare and endangered species in the region, playing a vital role in the island's ecosystem. Hainan gibbons contribute to the ecological

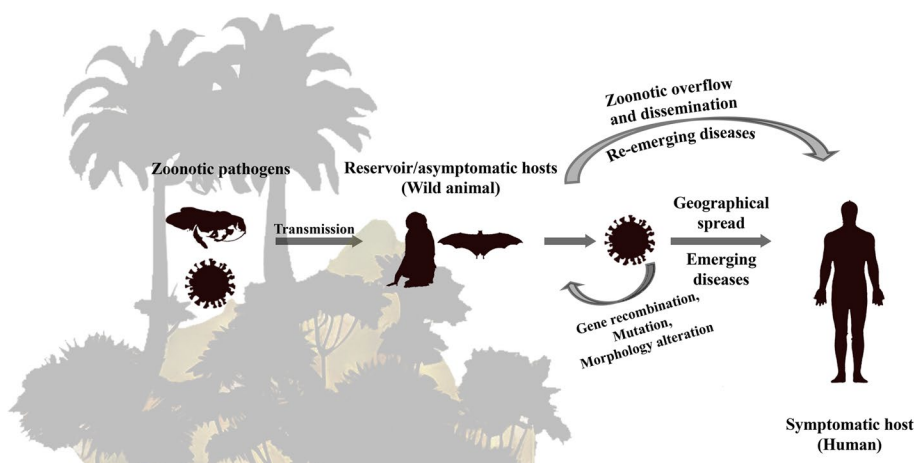





Fig. 4 Potential public health issues associated with tropical rainforests

Table 1 Potential impacts of tropical rainforest animals on public health

Species	Potential Causative Agent	Zoonoses	References
	Mpox virus	Mpox	[87, 88]
	Malaria parasite	Malaria	[89, 90]
	Hendra virus	Respiratory symptoms Nervous system disease	[91]
	Dengue virus	Dengue fever	[92]
	Japanese encephalitis virus	Japanese encephalitis	[93]
	Nipah virus	Fever, headache and cerebral injury	[94, 95]
	Australian bat lyssavirus	Rabies	[96, 97]
	Ebola virus	Ebola hemorrhagic fever	[98, 99]
	SARS-CoV-2	COVID-19	[100–102]
	Hendra virus	Respiratory symptoms Nervous system disease	[103]
	SARS-CoV-2	COVID-19	[85, 104–106]

balance of the forest by consuming and dispersing plant seeds. Protecting their habitat is crucial for maintaining the overall health of the ecosystem [107]. However, it is worth noting that Hainan gibbons may also be hosts or carriers of certain diseases relevant to human health, such as monkeypox (Mpox) [87, 88]. The Mpox virus

enters the body through oral, nasal, or cutaneous routes and replicates at the site of infection before spreading to local lymph nodes [108]. The initial viremia of the virus facilitates its dissemination and colonization in other organs. Close contact, such as face-to-face, skin-to-skin, or oral-to-oral/oral-to-skin contact, including sexual

contact, plays a primary role in Mpox virus transmission, especially when individuals present with Mpox virus rash [108, 109]. In March 2023, a study reported Mpox virus outbreaks in around 103 countries, with a global total of confirmed cases exceeding 86,200 and approximately 105 deaths [110]. The simultaneous occurrence of Mpox and COVID-19 epidemics may contribute to an increased mortality rate, and co-infections could potentially facilitate the emergence of new variants of concern (VOC) of SARS-CoV-2 [110]. Research indicates that certain gibbon populations carry pathogens that may be relevant to human health, highlighting the importance of monitoring and understanding the health status of Hainan gibbons for disease prevention and control [111]. Moreover, gibbons can become infected with *Plasmodium*, a parasite that can potentially transmit malaria [89, 90]. When gibbons are bitten by mosquitoes carrying *Plasmodium*, they become infected with malaria, increasing the risk of human exposure to infected mosquitoes and subsequent transmission to humans. The concept of One Health, which emphasizes the interconnection between human health, animal health, and ecosystem health, underscores the significance of protecting the habitat and well-being of Hainan gibbons for the balanced functioning of the entire ecosystem, the conservation of natural resources, and the provision of sustainable ecosystem services.

Public health associated with bats

Bats, which are common mammals in tropical rainforests, are considered potential hosts for numerous pathogens. For instance, the Hendra virus is a highly fatal infection associated with bats and horses [91]. As far back as 1998, researchers utilized reverse transcription-polymerase chain reaction techniques to identify a significant presence of dengue virus antigen in bats on Hainan Island. This finding strongly suggests that bats serve as reservoirs for the dengue virus [92]. In addition, a study revealed that 88.89% of bats sampled from Hainan tested positive for anti-Japanese encephalitis virus (JEV) antibodies [93]. Furthermore, researchers successfully isolated a novel totivirus-like virus from bat guano samples collected in Hainan, highlighting potential risks of disease transmission [112].

Furthermore, bats are considered to be associated with the Nipah virus, another zoonotic disease causing severe illness in humans [94, 95]. Certain bats can carry the Australian bat lyssavirus, a virus similar to rabies. Direct contact or bites from infected bats can potentially result in human infection with Lyssavirus [96, 97]. These findings emphasize the importance of studying bats as potential reservoirs for emerging viral infections. It is noteworthy that Ebola virus disease outbreaks in Africa originated from wildlife reservoirs,

particularly bats [98, 99]. Ebola virus is a highly severe viral hemorrhagic fever that results in Ebola hemorrhagic fever, characterized by high fever, severe weakness, bleeding, and often multiple organ failure within a few days after infection [113]. Its fatality rate is relatively high, ranging from 50 to 90% [114]. Following infection, there is an incubation period of approximately 2 to 21 days, followed by the sudden onset of flu-like symptoms such as high fever, headache, and muscle pain [113, 115]. The disease then progresses to organ failure and uncontrolled internal and external bleeding [116]. The pathogenic mechanism of Ebola involves its ability to extensively replicate within infected monocytes and macrophages, leading to the disruption of vascular integrity and subsequent bleeding [116]. Additionally, it can directly damage cells in various organs and suppress immune system function. While this virus is limited to African rainforests, it serves as a reminder of the potential for viral spread within tropical rainforest ecosystems. A study conducted by Leendertz et al. investigated the association between bats and Ebola virus transmission, highlighting the role of these animals as natural hosts and sources of human infection [99].

Furthermore, the recent COVID-19 pandemic has underscored the risks associated with zoonotic viruses [117]. SARS-CoV-2, also known as severe acute respiratory syndrome coronavirus 2, is the pathogen responsible for causing COVID-19 [118]. Globally, there have been a total of 771,150,460 reported cases of COVID-19. The primary mode of transmission for SARS-CoV-2 is through respiratory droplets [118]. When an infected individual coughs, sneezes, or talks, they can release droplets containing the virus, which can then be transmitted to people in close proximity [119]. Additionally, the virus can spread through direct contact, airborne aerosols, and by touching surfaces contaminated with the virus and subsequently touching the face, particularly the mouth, nose, or eyes [120]. Once a person is infected with SARS-CoV-2, the virus primarily invades the respiratory epithelial cells, triggering the infection. The spike protein of the virus binds to ACE2 receptors on the surface of host cells, facilitating viral entry [121]. Once inside the host cell, the virus replicates and spreads, causing cell damage and triggering an immune response [121]. As of October 6, 2023, according to data from the National Health Commission of China, there have been a total of 10,436 reported cases of novel coronavirus pneumonia (COVID-19) in Hainan Province, resulting in 2 deaths. Although the exact origin of the SARS-CoV-2 virus is still under investigation, it is widely believed to have originated from bats, possibly in tropical rainforest regions [100–102]. The zoonotic spillover event that led

to the initial human infections highlights the importance of studying and understanding the virus ecology within such environments.

Public health associated with pangolins

Pangolins play important roles in various ecosystems and are often considered as significant cultural symbols [6]. Although not traditionally practiced, our field research in Hainan has encountered instances of pangolin meat consumption. In recent years, pangolins have garnered attention due to their potential involvement in the transmission of zoonotic diseases [122]. Zoonotic diseases refer to diseases that can be transmitted from animals to humans, leading to outbreaks and pandemics. Illegal trade and consumption of pangolins have raised concerns about the potential spread of pathogens involved in zoonotic diseases. Researchers have recently identified the presence of Sendai and coronaviruses in Malayan pangolins through viral macro genomics analysis, highlighting the potential risk of these viruses infecting humans [123]. Field et al. found specific Hendra virus antibodies in wild-caught pangolins in Australia, suggesting their potential role in the ecology of the virus [103]. Numerous studies have reported the detection of SARS-CoV-2 in pangolins, indicating the possibility of pangolins acting as intermediate hosts or reservoirs, potentially aiding in the transmission of the virus to humans [85, 104–106]. Xiao et al. (2020) reported the discovery of coronaviruses closely related to SARS-CoV-2 in Malayan pangolins, suggesting that pangolins may serve as intermediate hosts or reservoirs, facilitating the transmission of coronaviruses to humans [85]. While further research is needed to fully understand the exact role of pangolins in the COVID-19 pandemic, the aforementioned studies underscore the importance of monitoring and regulating the trade and handling of these unique animals. Furthermore, pangolins can harbor various parasites, including nematodes, trematodes, and parasite eggs [124]. Consumption of pangolin meat or close contact with pangolins can increase the risk of human infection with these parasites.

The unique environmental conditions in Hainan's tropical rainforest may contribute to the spread and emergence of infectious diseases. The zoonotic transmission of Hantaan virus and the presence of vector-borne diseases like dengue fever and Lyme disease highlight the potential risks. Additionally, the wildlife trade and the identification of SARS-related coronaviruses in bats emphasize the importance of active surveillance and disease prevention measures in the region. Continued research and collaboration are crucial for better understanding and managing disease transmission and risks within Hainan's tropical rainforest.

Analysis of one health practices in Hainan tropical rainforest

One health practice cases in Hainan that address public health problems in the tropical rainforest

One Health practices in addressing public health issues in Hainan tropical rainforests encompass a multitude of actions [125]. Hainan actively promotes disease surveillance and early warning systems, collaborating with experts from the health, veterinary, and environmental monitoring sectors to monitor pathogens and animal-borne diseases in the tropical rainforest region [126]. Through information sharing and data analysis, they can swiftly identify and respond to potential public health threats.

From September to November 1985, an outbreak of dengue fever occurred in the Gan Chong area of Dan County's northern coastal region. During this three-month period, there were a total of 12,449 reported cases, resulting in an incidence rate of 210.68 per 100,000 population and 28 deaths [67]. The incidence fatality rate was 0.47 per 100,000 population, and the case fatality rate was 2.25 per 1000. Since 1987, Hainan has been implementing a comprehensive approach to prevent and control dengue fever, following the principles of the One Health concept [67]. The program primarily focuses on integrated control of the *Aedes aegypti* mosquito in the tropical rainforest [127]. Additionally, Hainan has made efforts to raise public awareness, educate the population about disease impacts, accelerate the development of sanitary cities, enhance vector surveillance, and strengthen customs inspection and quarantine measures [67]. In the third epidemic report of 1991, there were 521 cases, but since then, the transmission and outbreak of dengue fever have been effectively suppressed. Up until 2019, Haikou City reported 251 local cases, with the outbreak lasting just over a month [128]. During the subsequent COVID-19 pandemic, no cases of dengue fever have been reported in Hainan, indicating significant success in controlling the disease [63]. Recently, due to the occurrence of imported cases of dengue fever in multiple provinces in China, Hainan Province, known for its tourism industry, is facing the risk of imported dengue fever transmission. In response, the Office of the Patriotic Health Movement Committee of Hainan Province has implemented comprehensive measures for effective dengue fever prevention and control [67]. These measures include concentrated mosquito eradication campaigns, a special campaign focusing on mosquito control, and ongoing patriotic health initiatives.

Hainan Province is currently in the process of building a comprehensive One Health system, which focuses on institutional and mechanism innovation, interdisciplinary collaborative research, talent development, and

international cooperation [125]. To achieve this, Hainan has initiated collaborative projects with domestic and international universities and established a think tank composed of more than 100 renowned experts from around the world. Furthermore, two collaborative organizations for One Health have been formed. The primary objective of this initiative is to establish research platforms by 2025, particularly in areas such as animal-origin food safety, antimicrobial resistance throughout the entire chain, new drug development technologies, and product research [125]. These platforms will enable the monitoring of zoonotic diseases and other health threats, as well as facilitate data collection and exchange. In addition to research and data management, the initiative aims to enhance the emergency response capabilities of medical institutions. This includes establishing mechanisms for controlling antibiotic use and implementing a comprehensive One Health environmental plan to prevent cross-border transmission of epidemics [67]. By implementing these measures, Hainan Province is actively working towards a more integrated and collaborative approach to address health challenges, promote research and innovation, and safeguard public health.

Hainan places significant emphasis on conserving the tropical rainforest ecosystem. They establish nature reserves and implement land rehabilitation projects to protect and enhance biodiversity [1, 129, 130]. For instance, when the population of Hainan gibbons experienced a drastic decline from approximately 2000 individuals in the early 1950s to fewer than 10 individuals in the late 1970s, Hainan Province took various conservation measures [47]. These measures included vegetation restoration, road closures, and the construction of aerial corridors [131–133]. As a result, the population of Hainan gibbons has now recovered to 37 individuals, making them the only species among the 20 gibbon species worldwide that has achieved a slow population growth rate [134]. Similarly, the population of Hainan Eld's deer also faced a severe decline due to human activities [135]. However, prompt actions were taken to address this issue, including the establishment of protected areas, the prohibition of poaching, and the planting of high-quality forage grass [136]. These efforts have contributed to the gradual recovery of the Hainan Eld's deer population from 26 individuals in the 1980s to over 1000 individuals today [136]. Additionally, they regulate wildlife to reduce interactions between wildlife and humans, thereby mitigating the risk of disease transmission. Hainan has established a coordinated mechanism among health, veterinary, agricultural, and environmental sectors. They develop policies and measures together, promote information sharing, and strengthen outbreak monitoring and control [137]. For example, in response

to five cases of malaria reported in Hainan in 2015, the government implemented an innovative three-layer strategy (TLS) to adjust measures for residents living near the tropical rainforest in Hainan [79]. Under this strategy, a city-level classification system was established to formulate prevention and control measures upon detecting cases. It included layered implementation of vector surveillance, malaria control, and healthcare worker training. Hainan Province successfully achieved the goal of malaria elimination in 2019 and obtained WHO certification for malaria elimination in the field in 2021 [79]. Moreover, Hainan prioritizes public education and engagement by promoting health knowledge and raising public health awareness [138]. Through publicity and educational activities, they enhance public awareness of potential hazards in the tropical rainforest region and encourage participation in environmental protection and public health affairs.

These One Health practice cases demonstrate Hainan's commitment to tackling public health issues in the tropical rainforest. By implementing collaborative mechanisms, ecological conservation measures, and public engagement, Hainan aims to improve community health and safeguard the precious ecological environment in the region.

The inspiring revelations of these cases

One Health practices in Hainan can be attributed to the implementation of an Enhanced Disease Surveillance and Early Warning System, strengthened biodiversity conservation measures, and improved interdepartmental cooperation and information sharing [125]. This comprehensive system effectively identifies and responds to public health threats, thereby minimizing the impact of disease outbreaks. Moreover, Hainan's commitment to biodiversity conservation and ecological restoration has played a significant role in protecting the tropical rainforest ecosystem, thereby reducing the risk of zoonotic disease transmission. The coordination among various departments has also improved preparedness and response to public health emergencies. However, it is crucial to increase public engagement and awareness regarding environmental protection and public health. This can be achieved through targeted campaigns and partnerships with community organizations, which can enhance public participation. Additionally, addressing challenges associated with limited resources is essential to sustain and expand the impact of One Health interventions. To ensure long-term sustainability, it is necessary to integrate One Health practices into broader policies and frameworks, accompanied by continuous evaluation and adaptation. In conclusion, while One Health practices in Hainan have been successful, there is a need for

improvements in public engagement, resource allocation, and long-term strategies to further enhance their effectiveness.

Discussion and future perspectives

The application of the One Health approach has demonstrated its value in addressing public health issues in the Hainan tropical rainforest region. This paper summarizes the main points and findings from previous research to highlight the importance and potential of the One Health approach in tackling public health problems in this area.

By integrating knowledge from various disciplines, including human health, animal health, and environmental health, the One Health approach provides a comprehensive framework for understanding the complex interconnections between ecosystem health and human well-being [12, 139]. It recognizes the interconnectedness of human, animal, and environmental health and emphasizes collaborative efforts among different sectors to prevent and control diseases [140, 141]. Furthermore, the application of the One Health approach in the Hainan tropical rainforest region can help address the specific public health challenges unique to this area. These challenges may include zoonotic diseases, vector-borne diseases, and the impact of environmental degradation on human health. Through interdisciplinary collaboration and resource sharing, the One Health approach can improve disease surveillance, enhance early warning systems, and facilitate effective response strategies [142, 143].

In addition to the Hainan tropical rainforest region, the One Health approach holds significant potential for application in other biodiverse ecosystems worldwide that face similar public health challenges. Regions such as the Amazon rainforest and forests in Sub-Saharan Africa are characterized by high levels of biodiversity and serve as habitats for various animal reservoirs of zoonotic diseases, including malaria, Ebola virus, and Zika virus. By implementing collaborative One Health strategies in these regions, we can enhance infectious disease surveillance, strengthen conservation efforts, and promote sustainable development that prioritizes both human and environmental health [144–146]. Coordinated data-sharing and response protocols across the public health, veterinary, and wildlife sectors, facilitated through the One Health approach, can ensure the rapid identification and mitigation of outbreak threats on a global scale. For example, the Amazon Tropical Bite Research Initiative (ATBRI) aims to establish a collaborative research network spanning nine countries in the Amazon basin (Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela) [146]. This initiative focuses on developing diagnostic kits, drugs, and

vaccines for neglected tropical diseases caused by bites, such as rabies and South American trypanosomiasis. By addressing public health security concerns in the Amazon tropical rainforest, the ATBRI program contributes to safeguarding the region's biosphere [146].

In conclusion, the One Health approach has proven effective in addressing public health challenges in the Hainan tropical rainforest region. Its interdisciplinary nature and collaborative efforts are essential for understanding and mitigating the complex interactions between human, animal, and environmental health. By expanding the application of the One Health approach to other biodiverse ecosystems, we can enhance global infectious disease surveillance, conservation efforts, and sustainable development practices that prioritize the well-being of both humans and the environment.

In addition to the integrated disciplinary approach for conserving the tropical rainforest biosphere, another study aims to develop a tool based on the One Health concept for government utilization in public health security testing [147]. This tool assesses the potential risks of severe zoonotic diseases associated with wildlife trade, providing valuable information for the formulation of stringent regulation and control policies. Furthermore, several urgent plans are underway to address the changes occurring in the tropical rainforest, including the United Nations Decade on Ecosystem Restoration and the accelerated progress towards the Bonn Challenge [148, 149]. These plans aim to restore 350 million hectares of degraded and deforested land by 2030, thereby mitigating the destructive impact of deforestation-induced climate change on the tropical rainforest. Additionally, community participation, outreach, and capacity-building are vital cross-cutting components of effective One Health programs [150]. These initiatives equip local populations with the necessary knowledge and resources to promote health at both the individual and ecosystem levels. While specific ecological, cultural, and socioeconomic contexts may vary, the fundamental principles of One Health, including interdisciplinary cooperation, scientific research, and proactive risk mitigation, are broadly applicable across diverse settings worldwide. Integrating One Health principles into national and global policy agendas is crucial for addressing existing and emerging public health challenges at the interface of humans, animals, and the environment on a global scale.

The urgency and importance of addressing public health issues in the Hainan tropical rainforest region cannot be overstated. It is crucial to emphasize the need for increased efforts from the government, academia, and society at large to promote and support initiatives aimed at sustainable development and health

improvement in this region [151]. Multiple studies and literature reports have highlighted the public health concerns in the Hainan tropical rainforest region. For example, researchers investigated the prevalence of zoonotic diseases in the wildlife of this region, highlighting the potential risks for human health [152, 153]. Additionally, scholars conducted research on the impact of deforestation on vector-borne diseases, demonstrating the close relationship between environmental changes and human health outcomes [154, 155]. In recent years, tropical rainforests have witnessed rapid environmental changes, including deforestation, habitat destruction, and climate change, among others [156]. These changes have had multifaceted impacts on human health [157]. As early as 2000, researchers investigated the correlation between environmental changes in the Amazon rainforest and human health [158]. They found that extensive development and deforestation in the Amazon River basin have led to the emergence of new diseases and the increased difficulty of controlling existing diseases. The excessive exploitation of tropical rainforests can also heighten human contact with wildlife, thereby increasing the risk of zoonotic diseases crossing species barriers and transmitting to humans [159, 160]. Recent outbreaks of new infectious diseases such as Ebola and Zika virus have been closely associated with activities in tropical forest regions [161, 162]. Furthermore, excessive deforestation of rainforests can disrupt the activity of vector organisms like mosquitoes, leading to more frequent occurrences of diseases such as malaria and dengue fever [64]. Additionally, climate change is expanding the geographical distribution range of these diseases. These findings underscore the necessity of adopting a comprehensive One Health approach to address the public health challenges in the Hainan tropical rainforest region. However, it is important to acknowledge that there is still progress to be made in implementing One Health practices in the Hainan tropical rainforest. For example, Wang and Zeng, using the Policy Modeling Consistency (PMC) index model, have pointed out that the policies of the Hainan Tropical Rainforest National Park are not sufficiently effective in terms of social and economic outcomes [126]. In comparison to Hong Kong and Singapore, the policies related to the Hainan Tropical Rainforest National Park lack adequate incentives and strategic guidance, primarily due to the absence of descriptive and predictive macro-strategic design [126]. This observation provides us with valuable recommendations and food for thought. By combining efforts from multiple disciplines, we can develop strategies that promote sustainable development,

protect biodiversity, and improve the overall health and well-being of the local population in Hainan.

Conclusion

The tropical rainforests in Hainan are confronted with several critical public health issues that demand immediate attention. These issues include emerging infectious diseases, vector-borne diseases, and the health consequences of environmental degradation. This review discusses the risks posed to human populations in the region by zoonotic diseases such as hantavirus and potential novel coronaviruses originating from wildlife. Furthermore, the favorable climate in Hainan promotes the proliferation of disease-transmitting mosquitoes, which facilitate the transmission of diseases like dengue fever and malaria between humans and wildlife. Deforestation and habitat destruction have also contributed to the increase in disease vectors.

The implementation of the One Health approach offers an effective framework to address these interconnected challenges. As exemplified by the experiences in Hainan, key components such as enhanced disease surveillance, interdepartmental coordination, ecological conservation, and public engagement play vital roles. By adopting a collaborative and multidisciplinary strategy, early identification of public health threats and their mitigation through rapid response can be achieved. However, sustained efforts are necessary to involve local communities more extensively in environmental and public health initiatives.

The public health issues examined in the Hainan tropical rainforest underscore the relevance of One Health approaches in various ecosystems worldwide. Similar human-animal-environment interfaces, as observed in regions like the Amazon rainforests, can facilitate the emergence and transmission of zoonotic diseases. By implementing integrated surveillance, conservation measures, and community engagement within a One Health framework, effective preparedness and response can be ensured, spanning from remote forests to urban areas. While specific ecological and socioeconomic contexts may differ, the core principles of interdisciplinary collaboration, research, education, and communication inherent in One Health are broadly applicable across different settings. At local, national, and global levels, policy initiatives embracing the One Health approach have immense potential to cultivate resilient communities and environments worldwide. Addressing complex health challenges at the intersection of humans, animals, and nature necessitates a sustained commitment to cross-sectoral partnerships and evidence-based interventions.

Overall, this review emphasizes the urgency of prioritizing ecosystem and public health in Hainan's

tropical rainforests. While progress has been made in applying One Health principles, there are opportunities to strengthen long-term policies and frameworks to promote sustainability. Future priorities involve conducting further research on disease ecology, bolstering conservation measures, and improving health infrastructure and education. The One Health approach will continue to serve as a comprehensive model for balancing human welfare, animal health, and ecological well-being in this unique region.

Acknowledgements

We greatly appreciate the assistance of Dr. Xiaodong Rao from Hainan University, and we would like to thank all those who have advised and helped us, especially those who have studied together in Hainan.

Authors' contributions

L.Z.: Conceptualization, On-site research and Writing—original draft preparation, Methodology; S.L.: On-site research and revision suggestions; W.G., C.L. and X.L.: revision suggestions. All authors have read and agreed to publish this version of the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of interest

The authors declare no conflict of interest.

Received: 18 August 2023 Revised: 5 December 2023 Accepted: 6 December 2023
Published online: 28 March 2024

References

- Zong L. The path to effective national park conservation and management: Hainan tropical rainforest National Park System Pilot Area. *Int J Geoh Heritage Parks*. 2020;8(4):225–9.
- Lu L, Chesters D, Zhang W, Li G, Ma Y, Ma H, et al. Small mammal investigation in spotted fever focus with DNA-barcoding and taxonomic implications on rodents species from Hainan of China. *PLoS ONE*. 2012;7(8):e43479.
- Li Y, Zhou G, Zhong D, Wang X, Hemming-Schroeder E, David RE, et al. Widespread multiple insecticide resistance in the major dengue vector *Aedes albopictus* in Hainan Province, China. *Pest Manag Sci*. 2021;77(4):1945–53.
- Li Y, Zhou G, Zhong S, Wang X, Zhong D, Hemming-Schroeder E, et al. Spatial heterogeneity and temporal dynamics of mosquito population density and community structure in Hainan Island, China. *Parasit Vectors*. 2020;13:1–11.
- Drews SJ, Wendel S, Leiby DA, Tonnetti L, Ushiro-Lumb I, O'Brien SF, et al. Climate change and parasitic risk to the blood supply. *Transfusion*. 2023;63(3):638–45.
- Wang Y, Leader-Williams N, Turvey ST. Exploitation histories of pangolins and endemic pheasants on Hainan Island, China: baselines and shifting social norms. *Front Ecol Evol*. 2021;9:608057.
- Xie X, Huang L, Li J, Zhu H. Generational differences in perceptions of food health/risk and attitudes toward organic food and game meat: The case of the COVID-19 crisis in China. *Int J Environ Res Public Health*. 2020;17(9):3148.
- Heymann DL, Dixon MJMS. The value of the One Health approach: shifting from emergency response to prevention of zoonotic disease threats at their source. *Microbiol Spectr*. 2013;1(1):10–128. <https://doi.org/10.1128/microbiolspec.oh-0011-2012>.
- Gibbs EPJ. The evolution of One Health: a decade of progress and challenges for the future. *Vet Rec*. 2014;174(4):85–91.
- Hernando-Amado S, Coque TM, Baquero F, Martínez JL. Defining and combating antibiotic resistance from One Health and Global Health perspectives. *Nat Microbiol*. 2019;4(9):1432–42.
- Kelly TR, Machalaba C, Karesh WB, Crook PZ, Gilardi K, Nziza J, et al. Implementing One Health approaches to confront emerging and re-emerging zoonotic disease threats: lessons from PREDICT. *One Health Outlook*. 2020;2:1–7.
- Mackenzie JS, Jeggo M. The One Health approach—why is it so important? *Trop Med Infect Dis*. 2019;4:88.
- Zinsstag J, Schelling E, Crump L, Whittaker M, Tanner M, Stephen C. *One Health: the theory and practice of integrated health approaches*. Wallingford: CAB; 2021.
- Rousham EK, Unicomb L, Islam MA. Human, animal and environmental contributors to antibiotic resistance in low-resource settings: integrating behavioural, epidemiological and One Health approaches. *Proc R Soc B Biol Sci*. 1876;2018(285):20180332.
- Filter M, Buschhardt T, Dórea F, de Abechou EL, Günther T, Sundermann EM, et al. One Health surveillance codex: promoting the adoption of One Health solutions within and across European countries. 2021;12:100233.
- Water S. Hygiene: reinvent the toilet challenge. Bill and Melinda Gates Foundation; 2013. https://docs.gatesfoundation.org/documents/Fact_Sheet_Reinvent_the_Toilet_Challenge.pdf. Accessed 1 Aug 2023.
- Kone D. Water, sanitation and hygiene: reinvent the toilet challenge. *ECS Meet Abstr*. 2012;MA2012-01:79.
- Sikkema R, Koopmans MJIE. One Health training and research activities in Western Europe. *Infect Ecol Epidemiology*. 2016;6(1):33703.
- Espinosa-Gongora C, Jessen LR, Dyar OJ, Bousquet-Melou A, González-Zorn B, Pulcini C, et al. Towards a better and harmonized education in antimicrobial stewardship in European veterinary curricula. *Antibiotics*. 2021;10(4):364.
- Pieracci EG, Hall AJ, Gharpure R, Haile A, Walelign E, Deressa A, et al. Prioritizing zoonotic diseases in Ethiopia using a one health approach. *One Health*. 2016;2:131–5.
- Barrett MA, Bouley TA, Stoertz AH, Stoertz RW. Integrating a One Health approach in education to address global health and sustainability challenges. *Front Ecol Environ*. 2011;9(4):239–45.
- Mackenzie JS, McKinnon M, Jeggo M. One Health: from concept to practice. In: Yamada A, Kahn L, Kaplan B, Monath T, Woodall J, Conti L, editors. *Confronting emerging zoonoses*. Tokyo: Springer; 2014. p. 163–89.
- Waltner-Toews D. Zoonoses, One Health and complexity: wicked problems and constructive conflict. *Philos Trans R Soc B: Biol Sci*. 2017;372(1725):20160171.
- Meng H-H, Zhou S-S, Li L, Tan Y-H, Li J-W, Li J. Conflict between biodiversity conservation and economic growth: insight into rare plants in tropical China. *Biodivers Conserv*. 2019;28:523–37.
- Bolt LM, Brandt LSE, Molina RL, Schreier AL. Maderas rainforest conservancy: a One Health approach to conservation. *Am J Primatol*. 2022;84(4–5):e23293.
- Smout FA, Skerratt LF, Butler JRA, Johnson CN, Congdon BC, Thompson RCA. The hookworm *Ancylostoma ceylanicum*: an emerging public health risk in Australian tropical rainforests and indigenous communities. *One Health*. 2017;3:66–9.
- Lowe R, Lee S, Martins LR, Torres CC, Castro MC, Pascual M. Emerging arboviruses in the urbanized Amazon rainforest. *BMJ*. 2020;371:m4385.
- Ellwanger JH, Kulmann-Leal B, Kaminski VL, Valverde-Villegas JM, Veiga ABGD, Spilki FR, et al. Beyond diversity loss and climate change: impacts of Amazon deforestation on infectious diseases and public health. *An Acad Bras Cienc*. 2020;01:92.
- He J, Lin S, Kong F, Yu J, Zhu H, Jiang H. Determinants of the beta diversity of tree species in tropical forests: implications for biodiversity conservation. *Sci Total Environ*. 2020;704:135301.

30. Zhu ZX, Harris A, Nizamani MM, Thornhill AH, Scherson RA, Wang HF. Spatial phylogenetics of the native woody plant species in Hainan, China. *Ecol Evol.* 2021;11(5):2100–9.
31. Lan G, Wu Z, Yang C, Sun R, Chen B, Zhang X. Tropical rainforest conversion into rubber plantations results in changes in soil fungal composition, but underlying mechanisms of community assembly remain unchanged. *Geoderma.* 2020;375:114505.
32. Lan G, Wu Z, Chen B, Xie G. Species diversity in a naturally managed rubber plantation in Hainan Island, South China. *Trop Conserv Sci.* 2017;10:1940082917712427.
33. Mo J, Li J, Liu F, Li X, Li D. A survey of mammals and birds diversity in Jianfengling district of Hainan Province by using camera-trapping. *Sci Silvae Sin.* 2019;55(10):203–10.
34. Chang J, Chen D, Liang W, Li M, Zhang Z. Molecular demographic history of the Hainan peacock pheasant (*Polyplectron katsumatae*) and its conservation implications. *Chin Sci Bull.* 2013;58:2185–90.
35. Bryant JV, Turvey ST, Wong MH, Trowler-Holzer K. Conserving the world's rarest ape: action planning for the Hainan gibbon. *Oryx.* 2015;49(3):391–2.
36. Erhuan W, Donghai L, Xiaobo Y, Yongling Z, Ning Y. Study on distribution characteristics and population dynamics of wild *Cycas Hainanensis* in Hainan Island. *For Ecol Manag.* 2021;4:130.
37. Critchfield WB, Little EL. Geographic distribution of the pines of the world. Washington, DC.: U.S. Department of Agriculture, Forest Service; 1966.
38. Zhang L, Zhang H-L, Chen Y, Nizamani MM, Zhou Q, Su X. Analyses of community stability and inter-specific associations between a plant species with extremely small populations (*Hopea hainanensis*) and its associated species. *Front Ecol Evol.* 2022;10:922829.
39. Chen Y, Zhang H-L, Zhang L, Nizamani MM, Zhou T, Zhang H, et al. Genetic diversity assessment of *Hopea hainanensis* in Hainan Island. *Front Plant Sci.* 2022;13:1075102.
40. Ruibai Z, Xiaobo Y, Donghai L, Chunlin Q, Jianbi L. Study on geographical distribution and distribution characteristics of cyatheaceae in Hainan Island. *For Ecol Manag.* 2018;2:65.
41. Yang Q-J, Li R. Predicting the potential suitable habitats of *Alsophila spinulosa* and their changes. *J Appl Ecol.* 2021;32(2):538–48.
42. Song P, Hong W, Wu C, Feng L, Fan H, Zhu H, et al. Population structure and its dynamics of rare and endangered plant *Alsophila spinulosa*. *J Appl Ecol.* 2005;16(3):413–8.
43. Wu E, Li D, Yang X, Zuo Y, Li L, Zhang P, et al. Population structure of *Cycas hainanensis* and its relationship with forest canopy density. *Biodivers Sci.* 2021;29(11):1461.
44. Wu C, Chen Y, Chen Q, Hong X, Han W, Li X. Characteristics of seed rain and soil seed bank of *Dacrydium pierrei* in Bawangling, Hainan. *J Trop Subtrop Bot.* 2018;26(1):13–23.
45. Wu C, Xu Y, Chen Y, Chen Q, Hong X, Han W, et al. Study on soil seed bank of *Dacrydium pierrei* natural regeneration in Bawangling, Hainan, China. *Forest Res Beijing.* 2018;31(2):83–91.
46. Mootnick A, Chan B, Moisson P, Nadler T. The status of the Hainan gibbon *Nomascus hainanus* and the eastern black gibbon *Nomascus nasutus*. *Int Zoo Yearb.* 2012;46(1):259–64.
47. Deng H, Zhang M, Zhou J. Recovery of the critically endangered Hainan gibbon *Nomascus hainanus*. *Oryx.* 2017;51(1):161–5.
48. Fan P. The past, present, and future of gibbons in China. *Biol Conserv.* 2017;210:29–39.
49. Wei W, Wang X, Claro F, Ding Y, Souris A-C, Wang C, et al. The current status of the Hainan black-crested gibbon *Nomascus sp. cf. nasutus hainanus* in Bawangling National Nature Reserve, Hainan, China. *Oryx.* 2004;38(4):452–6.
50. Wong MH, Mo Y, Chan BPL. Past, present and future of the globally endangered Eld's deer (*Rucervus eldii*) on Hainan Island, China. *Glob Ecol Conserv.* 2021;26:e01505.
51. Rattanonchart S. Present situation of Thai native pigs [dissertation]. Chiangmai: Chiangmai University; 1994.
52. Yang C, Chen X, Zhang Z, Liang W. First report of home range size of Hainan partridge *Arborophila ardens*, a vulnerable species endemic to Hainan Island. *Ornithol Sci.* 2023;22(1):87–92.
53. Rao X, Yang C, Liang W. Breeding biology and novel reproductive behaviour in the Hainan partridge (*Arborophila ardens*). *Avian Res.* 2017;8(1):1–6.
54. Liang W, Zhang Z. Hainan peacock-pheasant (*Polyplectron katsumatae*): an endangered and rare tropical forest bird. *Chinese Birds.* 2011;2(2):111–6.
55. Turvey ST, Ma H, Zhou T, Teng T, Yu C, Archer LJ, et al. Local ecological knowledge and regional sighting histories of Hainan peacock-pheasant *Polyplectron katsumatae*: pessimism or optimism for a threatened island endemic? *Bird Conserv Int.* 2023;33:e25.
56. Warren SD. Microorganisms of the Phyllosphere: origin, transport, and ecological functions. *Front Glob Change.* 2022;5:843168.
57. Soong JL, Fuchslueger L, Marañón-Jimenez S, Torn MS, Janssens IA, Penuelas J, et al. Microbial carbon limitation: the need for integrating microorganisms into our understanding of ecosystem carbon cycling. *Glob Chang Biol.* 2020;26(4):1953–61.
58. Deng Z, Wang Y, Xiao C, Zhang D, Feng G, Long W. Effects of plant fine root functional traits and soil nutrients on the diversity of rhizosphere microbial communities in tropical cloud forests in a dry season. *Forests.* 2022;13(3):421.
59. Adeniyi AS. Effects of slash and burning on soil microbial diversity and abundance in the tropical rainforest ecosystem, Ondo state, Nigeria. *African J Plant Sci.* 2010;4(9):322–9.
60. Ammitzboll H, Jordan GJ, Baker SC, Freeman J, Bissett A. Diversity and abundance of soil microbial communities decline, and community compositions change with severity of post-logging fire. *Mol Ecol.* 2021;30(10):2434–48.
61. Sánchez-Galindo LM, Sandmann D, Marian F, Lauermann T, Maraun M, Scheu S. Differences in leaf and root litter decomposition in tropical montane rainforests are mediated by soil microorganisms not by decomposer microarthropods. *PeerJ.* 2022;10:e14264.
62. Wang Q-W, Tao L, Lu S-Y, Zhu C-Q, Ai L-L, Luo Y, et al. Genetic and hosts characterization of hantaviruses in port areas in Hainan Province, PR China. *PLoS One.* 2022;17(3):e0264859.
63. Yue Y, Liu Q, Liu X, Zhao N, Yin W. Dengue fever in mainland China, 2005–2020: a descriptive analysis of dengue cases and Aedes data. *Int J Environ Res Public Health.* 2022;19(7):3910.
64. Gan SJ, Leong YQ, bin Barhanuddin MF, Wong ST, Wong SF, Mak JW, et al. Dengue fever and insecticide resistance in *Aedes* mosquitoes in Southeast Asia: a review. *Parasit Vectors.* 2021;14(1):1–19.
65. Hasan MJ, Tabassum T, Sharif M, Khan MA, Bipasha AR, Basher A, et al. Comparison of clinical manifestation of dengue fever in Bangladesh: an observation over a decade. *BMC Infect Dis.* 2021;21:1–10.
66. Imad HA, Phumratanaprapin W, Phonrat B, Chotivanich K, Charunwatthana P, Muangnoicharoen S, et al. Cytokine expression in dengue fever and dengue hemorrhagic fever patients with bleeding and severe hepatitis. *Am J Trop Med Hyg.* 2020;102(5):943.
67. Guan Q, Upadhyay A, Han Q. History of dengue fever prevalence and Management in a One Health perspective in Hainan Island, China. In: Sperança M, editor. *Dengue fever in a One Health perspective - latest research and recent advances.* London: IntechOpen; 2023.
68. Wang C, Zhang B, Chen W, Chen Y. A comprehensive report on three epidemics of dengue fever and dengue hemorrhagic fever in Hainan Island. *Disease Surveillance.* 1992;7(6):4. <https://doi.org/10.3784/j.issn.1003-9961.1992.6.151>.
69. Zhao Z, Lin H. Control measures of dengue fever and dengue hemorrhagic fever were analyzed by preventive medicine in South China. *South China J Prev Med.* 1989;3:77–80.
70. Du J, Zhang L, Hu X, Peng R, Wang G, Huang Y, et al. Phylogenetic analysis of the dengue virus strains causing the 2019 dengue fever outbreak in Hainan, China. *Virolog Sin.* 2021;36:636–43.
71. Vasconcelos MPA, Sánchez-Arcila JC, Peres L, de Sousa PSF, dos Santos Alvarenga MA, Castro-Alves J, et al. Malarial and intestinal parasitic co-infections in indigenous populations of the Brazilian Amazon rainforest. *J Infect Public Health.* 2023;16(4):603–10.
72. Salim M, Masroor MS, Parween S. An overview on human helminthic parasitology I. Nematodes, the roundworms. *Int J Med Res.* 2021;7(5):161–6.
73. Rahantamalala A, Rakotoarison RL, Rakotomalala E, Rakotondrazaka M, Kiernan J, Castle PM, et al. Prevalence and factors associated with human *Taenia solium* taeniosis and cysticercosis in twelve remote villages of Ranomafana rainforest, Madagascar. *PLoS Negl Trop Dis.* 2022;16(4):e0010265.

74. Liu Q, Jing W, Kang L, Liu J, Liu M. Trends of the global, regional and national incidence of malaria in 204 countries from 1990 to 2019 and implications for malaria prevention. *J Travel Med.* 2021;28(5):taab046.
75. Zawawi A, Alghanmi M, Alsaady I, Gattan H, Zakai H, Couper K. The impact of COVID-19 pandemic on malaria elimination. *Parasite Epidemiol Control.* 2020;11:e00187.
76. Amimo F, Lambert B, Magit A. What does the COVID-19 pandemic mean for HIV, tuberculosis, and malaria control? *Trop Med Health.* 2020;48:1–4.
77. Osei SA, Biney RP, Anning AS, Nortey LN, Ghartey-Kwansah G. Low incidence of COVID-19 case severity and mortality in Africa; Could malaria co-infection provide the missing link? *BMC Infect Dis.* 2022;22(1):78.
78. Gavi S, Tapera O, Mberikunashe J, Kanyangara M. Malaria incidence and mortality in Zimbabwe during the COVID-19 pandemic: analysis of routine surveillance data. *Malar J.* 2021;20(1):233.
79. Li Y, Huang Y, Chen R, Huang W, Xu H, Ye R, et al. An innovative three-layer strategy in response to a quartan malaria outbreak among forest goers in Hainan Island, China: a retrospective study. *Infect Dis Poverty.* 2022;11(1):1–10.
80. Carrasco-Escobar G, Quellon J, Villa D, Cava R, Llanos-Cuentas A, Benmarhnia T. Time-varying effects of meteorological variables on malaria epidemiology in the context of interrupted control efforts in the amazon rainforest, 2000–2017. *Front Med.* 2021;8:721515.
81. Chaves LSM, Bergo ES, Conn JE, Laporta GZ, Prist PR, Sallum MAM. Anthropogenic landscape decreases mosquito biodiversity and drives malaria vector proliferation in the Amazon rainforest. *PLoS One.* 2021;16(1):e0245087.
82. Morgan CE, Topazian HM, Brandt K, Mitchell C, Kashamuka MM, Muwonga J, et al. Association between domesticated animal ownership and *Plasmodium falciparum* parasite prevalence in the Democratic Republic of the Congo: a national cross-sectional study. *Lancet Microbe.* 2023;4(7):E516–23.
83. Ma H. Local perceptions of biodiversity loss and conservation: insights from rural communities around a key protected area in Hainan, China [dissertation]. London: Royal Holloway, University of London; 2021.
84. Garry RF. The evidence remains clear: SARS-CoV-2 emerged via the wildlife trade. *Proc Natl Acad Sci.* 2022;119(47):e2214427119.
85. Xiao K, Zhai J, Feng Y, Zhou N, Zhang X, Zou J-J, et al. Isolation of SARS-CoV-2-related coronavirus from Malayan pangolins. *Nature.* 2020;583(7815):286–9.
86. Hassanin A, Tu VT, Curaudeau M, Csorba G. The ecological niche of SARS-CoV-2-like viruses in bats, as inferred from phylogeographic analyses of *Rhinolophus* species [Preprint]. 2021. Available from: <https://www.preprints.org/manuscript/202103.0409/v1>.
87. Cho CT, Wenner HA. Monkeypox virus. *Bacteriol Rev.* 1973;37(1):1–18.
88. Arita I, Henderson D. Smallpox and monkeypox in non-human primates. *Bull World Health Organ.* 1968;39(2):277.
89. Gould DJ, Cadigan FC, Ward RA. Falciparum malaria: transmission to the gibbon by *Anopheles balabacensis*. *Science.* 1966;153(3742):1384–4.
90. Cadigan F Jr, Ward R, Puhomchareon S. Transient infection of the gibbon with *Plasmodium vivax* malaria. *Trans R Soc Trop Med Hyg.* 1968;62(2):295–6.
91. Halpin K, Young PL, Field H, Mackenzie J. Isolation of Hendra virus from pteropid bats: a natural reservoir of Hendra virus. *J Gen Virol.* 2000;81(8):1927–32.
92. Zhang H, Yang X, Li G. Detection of dengue virus genome RNA in some kinds of animals caught from dengue fever endemic areas in Hainan Island with reverse transcription-polymerase chain reaction. *Chin J Exp Clin Virol.* 1998;12(3):226–8.
93. Jiang L, Chen S, Zheng X, Ma S, Zhou J, Zhang Q, et al. Detection of serum antibodies against Japanese encephalitis virus in bats in Hainan and Guangdong provinces of China. *J Southern Med Univ.* 2015;35(5):720–3.
94. Epstein JH, Anthony SJ, Islam A, Kilpatrick AM, Ali Khan S, Balkey MD, et al. Nipah virus dynamics in bats and implications for spillover to humans. *Proc Natl Acad Sci.* 2020;117(46):29190–201.
95. Giangaspero M. Nipah virus. *Trop Med Surg.* 2013;1(129):2.
96. Si D, Marquess J, Donnan E, Harrower B, McCall B, Bennett S, et al. Potential exposures to Australian bat lyssavirus notified in Queensland, Australia, 2009–2014. *PLoS Negl Trop Dis.* 2016;10(12):e0005227.
97. Barrett JL. Australian bat lyssavirus [dissertation]. Brisbane: The University of Queensland; 2004.
98. Leroy EM, Kumulungui B, Pourrut X, Rouquet P, Hassanin A, Yaba P, et al. Fruit bats as reservoirs of Ebola virus. *Nature.* 2005;438(7068):575–6.
99. Leendertz SAJ, Gogarten JF, Düx A, Calvignac-Spencer S, Leendertz FH. Assessing the evidence supporting fruit bats as the primary reservoirs for Ebola viruses. *EcoHealth.* 2016;13:18–25.
100. Morens DM, Breman JG, Calisher CH, Doherty PC, Hahn BH, Keusch GT, et al. The origin of COVID-19 and why it matters. *Am J Trop Med Hyg.* 2020;103(3):955.
101. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *J Autoimmun.* 2020;109:102433.
102. Shereen MA, Khan S, Kazmi A, Bashir N, Siddique R. COVID-19 infection: emergence, transmission, and characteristics of human coronaviruses. *J Adv Res.* 2020;24:91–8.
103. Field HE. Hendra virus ecology and transmission. *Curr Opin Virol.* 2016;16:120–5.
104. Han G-Z. Pangolins harbor SARS-CoV-2-related coronaviruses. *Trends Microbiol.* 2020;28(7):515–7.
105. Zhang T, Wu Q, Zhang Z. Probable pangolin origin of SARS-CoV-2 associated with the COVID-19 outbreak. *Curr Biol.* 2020;30(7):1346–51.
106. Liu P, Jiang J-Z, Wan X-F, Hua Y, Li L, Zhou J, et al. Are pangolins the intermediate host of the 2019 novel coronavirus (SARS-CoV-2)? *PLoS Pathog.* 2020;16(5):e1008421.
107. He Q, Yan S, Garber PA, Ren B, Qi X, Zhou J. Habitat restoration is the greatest challenge for population recovery of Hainan gibbons (*Nomascus hainanus*). *Integr Zool.* 2023;18(4):630–46.
108. Karagoz A, Tombuloglu H, Alsaeed M, Tombuloglu G, AlRubaish AA, Mahmoud A, et al. Monkeypox (mpox) virus: classification, origin, transmission, genome organization, antiviral drugs, and molecular diagnosis. *J Infect Public Health.* 2023;16(4):531–41.
109. Patel M, Adnan M, Aldarhami A, Bazaid AS, Saeedi NH, Alkayyal AA, et al. Current insights into diagnosis, prevention strategies, treatment, therapeutic targets, and challenges of monkeypox (mpox) infections in human populations. *Life.* 2023;13(1):249.
110. Aden D, Zaheer S, Kumar R, Ranga S. Monkeypox (Mpx) outbreak during COVID-19 pandemic—Past and the future. *J Med Virol.* 2023;95(4):e28701.
111. Denner J. Transspecies transmission of gammaretroviruses and the origin of the gibbon ape leukaemia virus (GALV) and the koala retrovirus (KoRV). *Viruses.* 2016;8(12):336.
112. Yang X, Zhang Y, Ge X, Yuan J, Shi Z. A novel totivirus-like virus isolated from bat guano. *Arch Virol.* 2012;157:1093–9.
113. Jacob ST, Crozier I, Fischer WA II, Hewlett A, Kraft CS, Vega MA, et al. Ebola virus disease. *Nat Rev Dis Primers.* 2020;6(1):13.
114. Tomori O, Kolawole MO. Ebola virus disease: current vaccine solutions. *Curr Opin Immunol.* 2021;71:27–33.
115. Hoenen T, Grosseth A, Feldmann H. Therapeutic strategies to target the Ebola virus life cycle. *Nat Rev Microbiol.* 2019;17(10):593–606.
116. Baseler L, Chertow DS, Johnson KM, Feldmann H, Morens DM. The pathogenesis of Ebola virus disease. *Annu Rev Pathol.* 2017;12:387–418.
117. Haider N, Rothman-Ostrow P, Osman AY, Arruda LB, Macfarlane-Berry L, Elton L, et al. COVID-19—zoonosis or emerging infectious disease? *Front Public Health.* 2020;8:763.
118. Yang L, Liu S, Liu J, Zhang Z, Wan X, Huang B, et al. COVID-19: immunopathogenesis and immunotherapeutics. *Signal Transduct Target Ther.* 2020;5(1):128.
119. Nile SH, Nile A, Qiu J, Li L, Jia X, Kai G. COVID-19: pathogenesis, cytokine storm and therapeutic potential of interferons. *Cytokine Growth Factor Rev.* 2020;53:66–70.
120. Gusev E, Sarapultsev A, Solomatina L, Chereshev V. SARS-CoV-2-specific immune response and the pathogenesis of COVID-19. *Int J Mol Sci.* 2022;23(3):1716.
121. Hu B, Guo H, Zhou P, Shi Z-L. Characteristics of SARS-CoV-2 and COVID-19. *Nat Rev Microbiol.* 2021;19(3):141–54.
122. Cui X, Fan K, Liang X, Gong W, Chen W, He B, et al. Virus diversity, wildlife-domestic animal circulation and potential zoonotic viruses of small mammals, pangolins and zoo animals. *Nat Commun.* 2023;14(1):2488.

123. Liu P, Chen W, Chen J-P. Viral metagenomics revealed Sendai virus and coronavirus infection of Malayan pangolins (*Manis javanica*). *Viruses*. 2019;11(11):979.
124. Barton DP, Martelli P, Worthington BM, Lam TT-Y, Zhu X, Shamsi S. Nematode and acanthocephalan parasites of confiscated Sunda pangolins, *Manis javanica* Desmarest, 1822 (Mammalia: Pholidota: Manidae), with an updated list of the parasites of pangolins. *Diversity*. 2022;14(12):1039.
125. Liang T, Tan H, Qi Y. One Health practice in Hainan, China. *Asian Pac J Trop Med*. 2023;16(6):241–2.
126. Wang H, Zeng Y. Policy optimization for Hainan tropical rainforest National Park Based on quantitative comparison of regional policies of free trade port areas. *Front Environ Sci*. 2022;10:891432.
127. Zhao Z, Li Z, Wang N, Xu J, Wang C, Chen Y, et al. Environment and community prevention of dengue fever in Hainan Island. *Chin J Vector Biol Control*. 1993;4(5):6.
128. Zeng XP, Chen Q, Wang MC, Li YW, Zeng XY, Lin CY. Comparison of epidemiological characteristics of local and imported cases of dengue fever in Haikou, 2019. *China Trop Med*. 2021;8:779–83.
129. Zhang X, Yan M, Zhang L, Chen B. A study to assess the conservation effectiveness of nature reserves in Hainan, China, from 2000 to 2021. *Forests*. 2023;14(7):1293.
130. Yu B, Chao X, Zhang J, Xu W, Ouyang Z. Effectiveness of nature reserves for natural forests protection in tropical Hainan: a 20 year analysis. *Chin Geogr Sci*. 2016;26:208–15.
131. Chan BP, Lo YF, Hong XJ, Mak CF, Ma Z. First use of artificial canopy bridge by the world's most critically endangered primate the Hainan gibbon *Nomascus hainanus*. *Sci Rep*. 2020;10(1):15176.
132. Xue Q, Zeng X, Du Y, Long WJF. Reproductive phenology and climatic drivers of plant species used as food by the Hainan Gibbon, *Nomascus hainanus* (Primates: Hylobatidae). *Forests*. 2023;14(9):1732.
133. Zhang M, Fellowes JR, Jiang X, Wang W, Chan BP, Ren G, et al. Degradation of tropical forest in Hainan, China, 1991–2008: conservation implications for Hainan Gibbon (*Nomascus hainanus*). *Biol Conserv*. 2010;143(6):1397–404.
134. Liu G, Lu X, Liu Z, Xie Z, Qi X, Zhou J, et al. The critically endangered Hainan gibbon (*Nomascus hainanus*) population increases but not at the maximum possible rate. *Int J Primatol*. 2022;43(5):932–45.
135. Zeng Z, Song Y, Li J, Teng L, Zhang Q, Guo F. Distribution, status and conservation of Hainan Eld's deer (*Cervus eldi hainanus*) in China. *Folia Zool-Praha*. 2005;54(3):249.
136. Wong MH, Mo Y, Chan BP. Conservation, past, present and future of the globally endangered Eld's deer (*Rucervus eldii*) on Hainan Island. *China Glob Ecol Conserv*. 2021;26:e01505.
137. Zhang J, Fedder B, Wang D, Jennerjahn TC. A knowledge exchange framework to connect research, policy, and practice, developed through the example of the Chinese island of Hainan. *Environ Sci Pol*. 2022;136:530–41.
138. Dong Z, Yuan Z, Long F, Wang C, Zhang C, Yang F, et al. A pilot study on green economy policy assessment of the United Nations—taking the assessment of ecological compensation policy in Hainan Province of China as an example. *Environ Strat Plann China*. 2022;22:25–51.
139. Benis A, Tamburis O, Chronaki C, Moen A. One digital health: a unified framework for future health ecosystems. *J Med Internet Res*. 2021;23(2):e22189.
140. McClymont H, Bambrick H, Si X, Vardoulakis S, Hu W. Future perspectives of emerging infectious diseases control: a One Health approach. *One Health*. 2022;14:100371.
141. Rabozzi G, Bonizzi L, Crespi E, Somaruga C, Sokooti M, Tabibi R, et al. Emerging zoonoses: the “one health approach”. *Saf Health Work*. 2012;3(1):77–83.
142. Chen K-T. Emerging infectious diseases and One Health: implication for public health. *Int J Environ Res Public Health*. 2022;19:9081.
143. Dente MG, Riccardo F, Bolici F, Colella NA, Jovanovic V, Drakulovic M, et al. Implementation of the One Health approach to fight arbovirus infections in the Mediterranean and Black Sea region: assessing integrated surveillance in Serbia, Tunisia and Georgia. *Zoonoses Public Health*. 2019;66(3):276–87.
144. Guo F, Bonebrake TC, Gibson L. Land-use change alters host and vector communities and may elevate disease risk. *EcoHealth*. 2019;16(4):647–58.
145. Johnson CK, Hitchens PL, Pandit PS, Rushmore J, Evans TS, Young CCW, et al. Global shifts in mammalian population trends reveal key predictors of virus spillover risk. *Proc Biol Sci*. 1924;2020(287):20192736.
146. Taylor E, Aguilar-Ancori EG, Banyard AC, Abel I, Mantini-Briggs C, Briggs CL, et al. The Amazonian tropical bites research initiative, a hope for resolving zoonotic neglected tropical diseases in the One Health era. *Int Health*. 2023;15(2):216–23.
147. Wikramanayake E, Pfeiffer DU, Magouras I, Conan A, Ziegler S, Bonebrake TC, et al. A tool for rapid assessment of wildlife markets in the Asia-Pacific region for risk of future zoonotic disease outbreaks. *One Health*. 2021;13:100279.
148. Cooke S, Bennett J, Jones H. We have a long way to go if we want to realize the promise of the “decade on ecosystem restoration”. *Conserv Sci Pract*. 2019;1(12):e129.
149. Verdone M, Seidl A. Time, space, place, and the Bonn challenge global forest restoration target. *Restor Ecol*. 2017;25(6):903–11.
150. Daszak P, das Neves C, Amuasi J, Haymen D, Kuiken T, Roche B, et al. Workshop report on biodiversity and pandemics of the intergovernmental platform on biodiversity and ecosystem services. Bonn: IPBES; 2020. Available from: <https://doi.org/10.5281/zenodo.4147317>.
151. Wang W, Pechacek P, Zhang M, Xiao N, Zhu J, Li J. Effectiveness of nature reserve system for conserving tropical forests: a statistical evaluation of Hainan Island, China. *PLoS One*. 2013;8(2):e57561.
152. Li Y, Tang C, Zhang Y, Li Z, Wang G, Peng R, et al. Diversity and independent evolutionary profiling of rodent-borne viruses in Hainan, a tropical island of China. *Virology*. 2023;38(5):651–62.
153. Xia Z-G, Zhang L, Feng J, Li M, Feng X-Y, Tang L-H, et al. Lessons from malaria control to elimination: case study in Hainan and Yunnan provinces. *Adv Parasitol*. 2014;86:47–79.
154. Molyneux D. Patterns of change in vector-borne diseases. *Ann Trop Med Parasitol*. 1997;91(7):827–39.
155. Ku GW, Seto E, Hai WX. Environment and climate change with vector-borne diseases. Proceedings of the 5th international academic conference on environmental and occupational medicine. Duijiangyan; 2010.
156. Lawler OK, Allan HL, Baxter PW, Castagnino R, Tor MC, Dann LE, et al. The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *Lancet Planet Health*. 2021;5(11):e840–50.
157. Ellwanger JH, Chies JA. Candida auris emergence as a consequence of climate change: impacts on Americas and the need to contain greenhouse gas emissions. *Lancet Reg Health*. 2022;11:100250.
158. Confalonieri U. Environmental change and human health in the Brazilian Amazon. *Glob Change Human Health*. 2000;1:174–83.
159. Codeço CT, Dal'Asta AP, Rorato AC, Lana RM, Neves TC, Andreazzi CS, et al. Epidemiology, biodiversity, and technological trajectories in the Brazilian Amazon: from malaria to COVID-19. *Front Public Health*. 2021;9:647754.
160. Gebara MF, May PH, Platais G. Pandemics, conservation, and human-nature relations. *Clim Change Ecol*. 2021;2:100029.
161. Ali S, Gugliemini O, Harber S, Harrison A, Houle L, Ivory J, et al. Environmental and social change drive the explosive emergence of Zika virus in the Americas. *PLoS Negl Trop Dis*. 2017;11(2):e0005135.
162. Leroy EM, Rouquet P, Formenty P, Souquière S, Kilbourne A, Froment JM, et al. Multiple Ebola virus transmission events and rapid decline of central African wildlife. *Science*. 2004;303(5656):387–90.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.