An Acad Bras Cienc (2020) 92(1): e20191375 DOI 10.1590/0001-3765202020191375
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

BIOLOGICAL SCIENCES

Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health

JOEL HENRIQUE ELLWANGER, BRUNA KULMANN-LEAL, VALÉRIA L. KAMINSKI, JACQUELINE MARÍA VALVERDE-VILLEGAS, ANA BEATRIZ G. DA VEIGA, FERNANDO R. SPILKI, PHILIP M. FEARNSIDE, LÍLIAN CAESAR, LEANDRO LUIZ GIATTI, GABRIEL L. WALLAU, SABRINA E.M. ALMEIDA, MAURO R. BORBA, VANUSA P. DA HORA & JOSÉ ARTUR B. CHIES

Abstract: Amazonian biodiversity is increasingly threatened due to the weakening of policies for combating deforestation, especially in Brazil. Loss of animal and plant species, many not yet known to science, is just one among many negative consequences of Amazon deforestation. Deforestation affects indigenous communities, riverside as well as urban populations, and even planetary health. Amazonia has a prominent role in regulating the Earth's climate, with forest loss contributing to rising regional and global temperatures and intensification of extreme weather events. These climatic conditions are important drivers of emerging infectious diseases, and activities associated with deforestation contribute to the spread of disease vectors. This review presents the main impacts of Amazon deforestation on infectious-disease dynamics and public health from a One Health perspective. Because Brazil holds the largest area of Amazon rainforest, emphasis is given to the Brazilian scenario. Finally, potential solutions to mitigate deforestation and emerging infectious diseases are presented from the perspectives of researchers in different fields.

Key words: Amazon rainforest, biodiversity, emerging infectious disease, deforestation, pathogens, public health.

INTRODUCTION

The Amazon Basin is the largest river system in the world, encompassing more than 7 million square kilometers distributed between Brazil, Bolivia, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela. With enormous biodiversity, most of Amazonia is located in Brazil, representing the largest biome of a country know by its thriving nature (Garda et al. 2010, Peres et al. 2010, Latrubesse et al. 2017, Metzger et al. 2019).

Amazonia is a unique biome in many aspects, with importance in different spheres of life. This biome's huge diversity of animal and plant species is *per se* a strong justification for its preservation. In addition, many benefits to human life come from direct or indirect interactions with Amazon ecosystems. Indigenous and traditional peoples live and preserve ecosystems and their cultures through the forest. For urbanized communities, among other benefits, the Amazon forest is a source of food, chemical compounds for the development of medicines, and raw materials for a wide variety of industries. The

Amazon rainforest is also crucial for maintaining planetary health due to its pivotal role in regulating the Earth's climate. In a broader perspective, protecting Amazon ecosystems is essential for biodiversity preservation, climate regulation, energy production, food and water security; it is also important for pollination, natural/biological control of pests, the region's economy and human health, not forgetting to mention its aesthetic and cultural value. Amazon ecosystems have an important role for the dynamics and control of zoonotic diseases and vector-borne infections, a very important, although sometimes neglected, point which will be discussed in detail throughout this article (Suffredini et al. 2004, Alho 2012, Bieski et al. 2015, Baker & Spracklen 2019, Metzger et al. 2019, Moraes et al. 2019, Valli & Bolzani 2019).

Global warming is an aspect of climate change that has consequences for the spread of human infections (Shuman 2010, Watts et al. 2018). "Climate change" refers to changes in climate properties (temperature, precipitation, extreme events, and wind patterns) that persist for a long period of time (decades or longer) (Liang & Gong 2017). The Earth's average temperature is increasing at least in part due to anthropogenic actions, such as the emission of greenhouse gases from industries and extensive use of fossil fuels (Levitus et al. 2001, Huber & Knutti 2012, Powell 2015, Letcher 2019).

A robust body of evidence shows that deforestation of Amazon forest is a fundamental driver of climate change (Shukla et al. 1990, Werth & Avissar 2002, Malhi et al. 2008, Khanna et al. 2017, Lovejoy & Nobre 2018, Baker & Spracklen 2019). About 20% of the original Amazon forest cover in Brazil has already been deforested (INPE 2019). Recently, policies, laws, agreements, funds, and practical actions focused on Amazon protection have been weakened in Brazil, encouraging deforestation (Carvalho et al. 2019, Ferrante & Fearnside 2019, Pereira et al. 2019, Seymour & Harris 2019). It is evident that, after a period when conservation policies were intensified in Brazil, which resulted in positive impacts on Amazon protection (West et al. 2019), deforestation in the region started to grow again (Artaxo 2019, Fearnside 2019). Along with environmental problems and the weakening of environment-related policies, lack of science funding will also cause economic losses for the country (Magnusson 2019). The current degradation status of the Amazon rainforest is already very serious, but, if this situation is not appropriately handled, the forest and climate situation on Earth will become increasingly worrying.

The association between anthropogenic action in the Amazon rainforest, climate change, alterations in vector dynamics, human migration, genetic changes in pathogens and the poor social and environmental conditions in many Latin-American countries can give rise to the "perfect storm" for the emergence and re-emergence of human infectious diseases in Brazil and other Amazonian countries. The recent Zika virus epidemic and the spread of dengue, chikungunya and yellow fever cases are just a few examples of diseases that affect countries in the Amazon region and even other regions of the globe (Ellwanger & Chies 2016, Lima-Camara 2016, Schuler-Faccini et al. 2016, Donalisio et al. 2017, Goldani 2017, Gregianini et al. 2017). Amazonian fauna hosts a huge diversity of well-known pathogens, as well as many other potential new or even unknown pathogens (Vasconcelos et al. 2001, Abrahão et al. 2010, Dornas et al. 2014, Bonato et al. 2015, Soares et al. 2015, Barros et al. 2018, da Silva et al. 2018, Fernandes et al. 2018, Farikoski et al. 2019, Franco Filho et al. 2019, Medeiros & Vasconcelos 2019). Although several of these pathogens may have low epidemic potential in humans, this abundance of microorganisms in the Amazon region indicates that emergence of new infections from the forest is a constant threat to human health.

The link between "environmental imbalances" and "emerging infectious diseases" is already well established in the literature (Daszak et al. 2001, Weiss & McMichael 2004, Jones et al. 2008). However, descriptions and discussions regarding the factors involved in the emergence of infectious diseases due to deforestation specifically in the Amazon region are still scarce. As an attempt to foster this discussion, we review problems and activities associated with the Amazon deforestation and their impacts on the dynamics of infectious diseases and on human/public health.

Many examples cited in this article refer to the Brazilian context. However, such examples can be, at least in part, extrapolated to other countries in the Amazon region due to the similarity of social and environmental aspects. Finally, a problem as complex as the impact of Amazon deforestation on infectious diseases needs to be addressed using the One Health concept, in which characteristics of human, environmental, and animal health are considered in a unified way to detect, understand, and solve public health problems (Lee & Brumme 2013, Halliday et al. 2015, Ellwanger et al. 2017, Destoumieux-Garzón et al. 2018). This article therefore approaches Amazon deforestation and the impacts on infectious diseases from different fields and perspectives, such as genetics, human health, microbiology, veterinary medicine, public health, and ecology (Table I). The selection of the studies included in Table I respected the authors' suggestions, which were based on each author's background in a given field of study. Following this approach, the studies in Table I exemplify, from different disciplines, how the Amazon deforestation can impact different aspects of infectious diseases.

PROBLEMS AND ACTIVITIES ASSOCIATED WITH AMAZON DEFORESTATION AND THEIR IMPACTS ON INFECTIOUS DISEASES

Climate change and extreme weather events

The Amazon rainforest plays a pivotal role in regulating Earth's climate (Bonan 2008, Malhi et al. 2008). In this sense, Amazon deforestation leads to regional and global average temperature rise (Baker & Spracklen 2019, Cohn et al. 2019, Prevedello et al. 2019), and changes in the Amazon biome are associated with an increase in the frequency of extreme weather events, such as droughts, altered rain patterns, heat waves, cold waves, and severe storms (Nepstad et al. 2008, Sena et al. 2014, Wu et al. 2016, Stoy 2018, Leite-Filho et al. 2019). Deforestation also facilitates forest fires, since degraded areas are naturally more susceptible to combustion. Intentional fires are a frequent problem in the Amazon region (Alencar et al. 2006, 2015, Nepstad et al. 2008, Escobar 2019). Pollutants resulting from deforestation and agricultural fires represent a serious health threat in a broad perspective. Particulate matter emitted from the burning of biomass in the Amazon region exposes humans to an increased risk of DNA damage, gene mutations, inflammation, and cancer (de Oliveira Alves et al. 2017, de Oliveira Galvão et al. 2018). Not surprisingly, the incidence of respiratory diseases in the southern portion of the Amazon region increased substantially in 2019 (Barcellos et al. 2019). Fires and extreme weather events cause damage to the forest ecosystem, creating a cycle of destruction.

The most recent assessment report of the Intergovernmental Panel on Climate Change (IPCC) estimates that under the most likely scenario in the absence of dramatic mitigation actions (scenario RCP8.5) global average temperature would increase by 4.8 °C at the end of this century as compared to the 1996-2005 period, while in the Amazon during the dry months from June to August the average increase would be 6-8 °C (IPCC 2013, p. 1343). This would have significant impacts on human health, including the worsening of chronic health conditions, as well as the spread of infections (Balbus et al. 2016, Hacon et al. 2018). Climate change resulting from deforestation of the Amazon rainforest and other tropical forests may favor the emergence of parasitic, fungal, viral and bacterial infections through the following basic mechanisms: first, by climate-derived ecological disturbances interfering with the maintenance of pathogens in their natural environments and hosts; second, by favoring the presence, distribution and proliferation of disease vectors in forest and urban areas, and third, by changes in temperature and rainfall patterns favoring pathogens' survival and reproduction and/or their ability to infect the human host. Changes in temperature also modify the ability of pathogens to infect vectors and to replicate in these animals (Patz et al. 2000, Hales et al. 2002, Vittor et al. 2006, Barcellos et al. 2009, Altizer et al. 2013, Confalonieri et al. 2014, Carvalho et al. 2015, Flahault et al. 2016, Samuel et al. 2016, Wu et al. 2016, Lorenz et al. 2017, Nava et al. 2017, Casadevall et al. 2019, Duarte et al. 2019a, Duarte & Giatti 2019, Khan et al. 2019, Rao et al. 2019, Silva et al. 2019). For example, if the average temperature of a given region increases, the spread of disease vectors, such as mosquitoes, could be favored, and this spread could lead to the colonization of new geographical areas previously inaccessible to these vectors. Favorable temperatures for replication of pathogens in vectors also contribute to increase vectorial capacity, resulting in greater spread of infections in humans. Moreover, the rise of temperatures and the intensification of extreme rain can contribute to higher survival and spread of pathogens that cause successive diarrheal diseases among humans (Checkley et al. 2000, Duarte et al. 2019a). This is a particularly worrying scenario given the rapid unplanned urbanization and the lack of basic sanitary conditions in the Amazon region (Freitas & Giatti 2009). Also, humans who enter habitats of pathogens and become infected with a certain pathogen may subsequently introduce the infection into urban environments.

The dynamics of soil-transmitted helminths is also strongly influenced by deforestation and climate change (Weaver et al. 2010, Hernandez et al. 2013, Seo et al. 2016, Blum & Hotez 2018). Helminth diseases are important problems in the Amazon region (Souza et al. 2007, Hotez et al. 2008, Confalonieri et al. 2014, Gonçalves et al. 2016).

Extreme weather events have substantial economic consequences and destabilize the order and functioning of affected human communities, especially in developing countries. This destabilization causes multiple problems in terms of environmental sanitation, creates social instability, and weakens the public health system. This is aggravated by the fact that public health facilities in Amazonian countries are precarious even before a climate disaster occurs. Together, these consequences contribute to the emergence and spread of zoonotic diseases, new human infections, and proliferation of endemic diseases (Epstein 2001, Mirza 2003, Hendrix & Salehyan 2012, Scheffran et al. 2012, Maystadt & Ecker 2014, Watts et al. 2015, Ma & Jiang 2019, Ridde et al. 2019).

Table I. Selected examples of problems and phenomena associated with Amazon deforestation and their impacts on infectious diseases.

Problem or phenomenon	Effect or disease	References
Deforestation and civil disorder may promote the emergence of Paracoccidioidomycosis cases in the Amazon region.	Infection occurs through inhalation of spores released by *Paracoccidioides* spp. that are found in the soil. Paracoccidioidomycosis outbreaks have been reported in areas with massive deforestation. In addition, civil disorders faced after climate change have already been associated with the emergence of Paracoccidioidomycosis. Amazon deforestation with soil removal can increase the exposure of people to spores, causing new disease outbreaks. Climate change resulting from Amazon deforestation may predispose different regions of Latin America to new Paracoccidioidomycosis outbreaks.	Barrozo et al. (2010), Marques-da-Silva et al. (2012), do Valle et al. (2017)
Mining activities cause profound environmental changes including water and soil pollution and deforestation, disrupting the ecological balance in the areas and increasing the incidence of infectious diseases.	High prevalence of malaria and hantavirus pulmonary syndrome has been detected among gold miners in the Amazon region. Malaria transmission is associated with mining activity; this association is especially evident among people working in illegal gold mines.	Bauch et al. (2015), Sanchez et al. (2017), Terças-Trettel et al. (2019)
Emergence and re-emergence of arboviral diseases spreading from the Amazon forest to large Brazilian metropolitan areas.	Emerging viral diseases vectored by arthropods, which are often under epizootiological equilibrium in non-human primate populations in the forest, may have their transmission facilitated to human settlers due to loss of habitats of the natural hosts and reallocation of primatophylic mosquitoes. These viruses may jump to urban areas from these first human cases.	Rezende et al. (2018), Favoretto et al. (2019)
Increase in the spread and impact of waterborne diseases.	Lack of vegetation cover, recent urbanization, and alterations in the hydrological cycle may contribute to an enhanced spread of waterborne diseases. This is worsened due to the poor sanitary conditions both in small villages and in metropolitan areas in the region. Floods, extreme events and poor sanitary conditions may lead to epidemics of viral, bacterial and protozoal diseases.	Martins et al. (2015), Vieira et al. (2016), Vieira et al. (2017)
Presence of deforested areas, livestock, highways or mining.	Increase in rabies outbreaks or bat attacks in animal or human population.	Schneider et al. (2001), Carvalho-Costa et al. (2012), Fernandes et al. (2013), de Andrade et al. (2016)
Deforestation followed by changes in water and soil physicochemical properties select fungi adapted to novel ecological niches.	Deforestation will impact water and soil environments (for example, elevating temperature and altering pH). Fungi adapted to this novel ecological niche, which is similar to the high basal temperatures of mammals, could be selected promoting the emergence of novel pathogenic fungi. This has already been suggested for the rise of the environmental fungus *Candida auris* as a human pathogen on three continents, including South America, and has been suggested as contributing to the emergence of the known human pathogen *Cryptococcus gattii*, an ancient Amazon environmental fungus.	Hagen et al. (2013), Lockhart et al. (2017), Casadevall et al. (2019)

Table I. (continuation)

Problem or phenomenon	Effect or disease	References
Presence of gold mining.	Cutaneous leishmaniasis incidence increase in the human population.	Rotureau et al. (2006)
Fluctuation of prices of commodities, migrations and ecological impacts.	The increase or decrease in prices of commodities can induce migration to and from the Amazon region, and these processes are associated with ecological impacts that can cause the spread of infectious diseases. For example, in the 1970s, a substantial increase in the international price of gold contributed to a considerable migration of gold diggers from Maranhão State to other states in the Amazon region. After the 1980s, a severe decrease in the price of this commodity resulted in the inverse migration and successive reintroduction of malaria in many different municipalities in Maranhão State.	Becker (2004), Varga (2007)
Presence of deforested areas.	Increase the mean abundance and distribution of the Chagas disease vector *Rhodnius pallescens*.	Gottdenker et al. (2011)
Deforestation-induced contact of humans with forest areas.	Increase in leishmaniasis cases.	Desjeux (2004), Alvar et al. (2006), Palatnik-de-Sousa & Day (2011)
Deforestation and migratory flows can contribute to occurrence of acute Chagas disease cases.	High deforestation and high density of acute Chagas disease were related to a possible adaptation process of Chagas disease to urban environments. The dynamics of occupation implied the formation of new urban and periurban centers in environmentally fragile areas and the occurrence of the disease by oral or vector transmission. Infection through the oral route is increasing, establishing a different epidemiological cycle.	Sousa Júnior et al. (2017), Santos et al. (2018)

Habitat loss and pathogen spillover

Deforestation and uncontrolled urbanization are linked to habitat fragmentation and lack of adequate supplies of food and water. This ecological situation induces wildlife migration to alternative habitats, which can include both urbanized and de-urbanized environments. Human activities in forest areas put humans in close contact with wildlife (Mackenstedt et al. 2015, Wilkinson et al. 2018). As a consequence, humans have closer interactions with wild species and their pathogens, facilitating the occurrence of classic zoonotic diseases and the "jump" or "shift" of new pathogens between different host species, an event called "spillover."

Pathogen spillover can introduce new infections in the human population. In this process, many physical, molecular and ecological barriers must be overcome by the pathogen during the jump between different hosts. In other words, spillover is a complex event that depends on the phylogenetic distance between hosts, the frequency and intensity of contacts between species, and genetic factors of both pathogens and hosts, among other factors. Although complex, this phenomenon is common in the history of humankind; accordingly, most human infectious diseases originate from wild animals, which served as sources of pathogens (Taylor et al. 2001, Kruse et al. 2004, Olival et al. 2017, Plowright et al. 2017, Ellwanger & Chies 2018a, 2019). Following spillover, if the pathogens encounter favorable conditions, the infection is disseminated among humans (Morse 1995).

Some pathogens are capable of infecting a broad host range and can easily adapt to new hosts, including humans. This kind of adaptation will be more common with generalist than with specialist pathogens. Specific characteristics, such as the RNA genome (high mutation rates) or transmission by vectors, give pathogens a greater plasticity to infect new hosts and find new ecological niches (Nichol et al. 2000, Johnson et al. 2015). However, not all pathogens establish sustained transmission among humans following a spillover event. The characteristics that make a pathogen transmissible between different species may differ, at least in some aspects, from those that increase transmissibility among humans. Regarding viral infections, human-to-human transmission occurs more easily a) with pathogens showing the capacity to cause chronic and non-lethal infections, b) with airborne/respiratory viruses, and c) by non-segmented, non-enveloped, and non-vector-borne viruses (Geoghegan et al. 2016, Walker et al. 2018). However, vector-mediated transmission can sustain viral epidemics among humans; the endemicity of dengue in Brazil, malaria in the Amazonian region, and Zika virus in Latin America illustrate this aspect.

Habitat loss and the related invasion of wild animals and/or its vector-associated fauna to urban areas lead to domestic animals such as dogs and cats encountering wild species more often and may serve as "bridges" for the circulation of pathogens between wild animals and humans (Ellwanger & Chies 2019). Close contact between wildlife, humans and domestic animals will occur more intensely in urban areas near the forest (Whiteman et al. 2007, Ellwanger & Chies 2019). For example, bat-transmitted human rabies occurs frequently in the Amazon region (da Rosa et al. 2006, Mendes et al. 2009, Gilbert et al. 2012, Vargas et al. 2019). These cases are probably associated with deforestation, livestock and agricultural expansion in the region and the associated increase of the contact of humans with wildlife (Schneider et al. 2001, Dantas-Torres 2008). Therefore, the current Amazonian landscape, characterized by rainforest, environmental degradation, and close contact of humans and domestic animals with wild species, is quite favorable for pathogen spillover.

Vector dynamics

In some specific macro- and micro-regions around the world, climate change may decrease the presence of disease vectors, especially mosquitoes. Extreme temperatures can be detrimental to the development of mosquitoes, and extreme weather events, such as droughts, can limit mosquito-breeding sites. However, in most cases, deforestation, the increase in global average temperature and other climate changes will favor the proliferation of disease vectors (for example, *Aedes aegypti* and *Aedes albopictus*) in different regions of Brazil and in other Amazonian countries. These changes can facilitate the transmission of arboviruses, such as Chikungunya, Dengue, Yellow fever, Oropouche, Mayaro, Rocio, Saint Louis, West Nile, and Zika virus infection (Hales et al. 2002, Lima-Camara 2016, Wu et al. 2016, Burkett-Cadena & Vittor 2018, Lorenz et al. 2017, Hacon et al. 2018, Klitting et al. 2018, Sakkas et al. 2018, Tesla et al. 2018, Khan et al. 2019, Kraemer et al. 2019, Rao et al. 2019). As an example, yellow fever is a disease traditionally associated to the forest, but it can easily adapt to the urban environment and the risk of re-emergence of yellow fever in urban areas is therefore of concern, especially in cities near forest areas. In South America mosquitoes of the genera *Haemagogus* and *Sabethes* are involved in the sylvatic cycle of yellow fever, and *A. aegypti* is involved in the urban cycle of transmission of this disease (Cardoso et al. 2010, Klitting et al. 2018).

As a counterpoint to the restrictions discussed above, higher temperature and rainfall may shorten the development time of mosquito larvae, favoring their proliferation (Lima-Camara 2016, Wu et al. 2016). Moreover, an increase in the frequency of extreme weather events, such as severe storms and floods, will favor the introduction and dissemination of disease vectors specifically in urban environments due to an increase in mosquito breeding sites, thus aggravating the transmission of infectious diseases (Lima-Camara 2016, Wu et al. 2016, Khan et al. 2019, Rao et al. 2019). The effects of climate change on vectors can be minimized or exacerbated according to human activities, such as those concerning land use and urbanization (Mordecai et al. 2019).

When recent data are compared with those from 1990, climate change has already increased vectorial capacity for dengue transmission by 3% for *A. aegypti* and by 5.9% by *A. albopictus*. These data suggest that continuous climate change may aggravate the epidemiological situation of arboviruses (Watts et al. 2018). Vectors of parasitic diseases such as malaria and leishmaniasis may also be affected by climate change (Githeko et al. 2000, Carvalho et al. 2015, Peterson et al. 2017) and deforestation. In this regard, Amazon deforestation has been associated with a higher human-biting rate of *Anopheles darlingi*, an important malaria-transmitting vector (Vittor et al. 2006); consequently, malaria transmission is linked to Amazon deforestation (MacDonald & Mordecai 2019). Leishmaniasis is caused by parasites of the genus *Leishmania* and is another disease strongly associated with the forest environment. Notably, human entry into the forest for deforestation exposes humans to sandfly (phlebotomine) bites, which transmit leishmaniasis (Desjeux 2004, Alvar et al. 2006, Palatnik-de-Sousa & Day 2011).

When addressing malaria, deforestation and climate change can either increase or decrease the spread of the infection, depending on the amount of forest cover, rainfall patterns, temperature ranges, and landscape characteristics (Githeko et al. 2000, Olson et al. 2009, Tucker Lima et al. 2017, Laporta 2019). Looking specifically at the deforestation factor, the initial process of deforestation generally increases human contact with malaria vectors, causing higher rates of infection. However, after an advanced stage of deforestation is reached, human contact with the vectors can decrease, reducing opportunities for disease transmission (Tucker Lima et al. 2017). Finally, urbanization and peri-urbanization of transmission cycles of malaria are also affected by deforestation and climate change, representing common issues in the Amazon region (Takken et al. 2005, Tauil 2006, Gil et al. 2007, Tada et al. 2007, Costa et al. 2010, Oliveira-Ferreira et al. 2010, Almeida et al. 2018).

Agricultural intensification and land-use change

Agriculture and land-use change are extensive phenomena in Amazonia. The intensification of these activities has promoted significant alterations in the region. In Brazil, the supervision of agricultural activities in Amazonia is flawed and allows intensified conversion of forest to agriculture and cattle pasture (Barona et al. 2010, Machovina et al. 2015, Carvalho et al. 2019, Seymour & Harris 2019).

Agricultural practices are associated with the emergence of viral, bacterial, and parasitic infections since these activities can, among other mechanisms, affect the maintenance of pathogens in their natural hosts, alter the dynamics and population number of vectors and increase the ecological contact of humans with pathogens (Patz et al. 2000, 2004, Foley et al. 2005, Wilcox & Ellis 2006, Jones et al. 2013, Gottdenker et al. 2011, 2014). Incidence of malaria has been linked to extractive activities and agricultural settlements in the Amazon forest. Malaria in some areas is closely associated with deforestation and unplanned development of new agricultural settlements (Guimarães et al. 2016, Souza et al. 2019). We can speculate that deforestation for pasture and agriculture is the main factor contributing to the emergence of infectious diseases in the Amazon region. These land-use transformations occur on a large scale and are directly linked to various known drivers of infectious diseases, such as habitat loss and human insertion in forest environments. Lack of sanitation and health facilities add complexity to this situation.

Mining

Mining is another major driving force of deforestation in Amazonia and is also a constant source of conflicts between indigenous populations and invaders. The Amazon region is well known for its mineral resources, which include copper, tin, nickel, bauxite, manganese, iron and gold. Mining has a great impact on the environment; besides deforestation resulting from the mining activities within mining lease areas, extensive deforestation also occurs off-lease as a consequence of population growth, urban expansion, infrastructure construction, industrial growth and other factors associated with greater economic activity (Sonter et al. 2017).

Informal mining is associated with water and soil pollution. Also, people living near mining sites or working in informal mines are more exposed to mosquitoes. The disease burden associated with mining includes mercury intoxication, respiratory diseases, diarrhea, vector-borne diseases such as malaria and other infectious diseases (Bauch et al. 2015, Terças-Trettel et al. 2019).

Rainfall, flooding, and water contamination

Altered rainfall patterns and floods are consequences of extreme weather events associated with Amazon deforestation and climate change. Climate change is associated with current and projected extreme hydrological events in the Amazon region (Marengo & Espinoza 2016, Sorribas et al. 2016).

The risk of infection and the spread of malaria in the Amazon region are influenced by rainfall patterns and river water levels (Olson et al. 2009, Wolfarth-Couto et al. 2019). The presence of pathogens in water (considering quantity and diversity) is modified by hydrological events, modulating the exposure of humans to such pathogens. As a result, many infectious diseases spread during rainfall, periods of high river levels and floods, including leptospirosis and gastroenteritis, which are important public health problems not only in the Amazon region but also in other parts of Brazil (Gracie et al. 2014, Rodrigues et al. 2015, Nava et al. 2017, Vieira et al. 2016, 2017, Duarte et al. 2019b, Duarte & Giatti 2019, Naing et al. 2019, Péres et al. 2019).

Rapid population growth from migration to urban areas is associated with poor sanitation and water pollution, which are common in Amazon cities (Goveia et al. 2019, Mendes et al. 2019). This scenario contributes to the transmission of various water-borne diseases, including gastroenteritis and viral hepatitis. These diseases have very important economic impacts in the Amazon region because, in addition to directly affecting the health of infected individuals, water-borne diseases also overload the public health system and cause workday losses (Constenla et al. 2008, Braga et al.

2009, Machado et al. 2013, Prado & Miagostovich 2014, Duarte et al. 2019b). Water-related issues in the Amazon region also facilitate the spread of mollusks that are part of the schistosomiasis transmission cycle (Goveia et al. 2019).

Human agglomeration, urbanization and de-urbanization

Historically, the expansion and clustering of population in towns, villages, and cities were factors that allowed the emergence of epidemics among humans (Waldman 2001, Bañuls et al. 2013, Zanella 2016). Currently, urbanization has critical importance for the emergence and maintenance of epidemics as well as the occurrence of zoonotic diseases. Increased interaction among humans from different places and the facilitated proliferation of vectors and pathogen reservoirs in the urban context explain, at least in part, how urbanization affects the spread of infectious diseases (Morse 1995, Neiderud 2015, Zahouli et al. 2017, Li et al. 2014, Tian et al. 2018). Urbanization usually decreases forest cover and may increase the risk of infectious diseases. For example, reduced forest cover and urbanization were associated with higher rates of Zika virus infection and Zika-linked microcephaly cases in Brazil (Ali et al. 2017).

Urbanization represents a paradox concerning infectious diseases. Urban environments contribute to the spread of disease due to human agglomeration. On the other hand, urban areas provide better access to health services, which is a mitigating factor for the problems caused by infectious diseases, especially in high-income countries (Vlahov et al. 2005, Neiderud 2015, Segurado et al. 2016). This tug-of-war can remain in relative equilibrium in areas with predominantly urban characteristics but may slide to one side at city/forest interfaces. In these areas, deforestation processes in association with poor health services contribute synergistically to the emergence of infectious diseases, especially in low-income countries.

Degradation of sanitation services and the abandonment of urban areas by the government, a phenomenon known as “de-urbanization” (Eskew & Olival 2018), strongly contribute to the proliferation of vectors and other pests. De-urbanized areas are ideal for the dissemination of infectious diseases (Pignatti 2004, Gulachenski et al. 2016, Eskew & Olival 2018). Urban slums are good examples of de-urbanized environments (Costa et al. 2017), although it can be argued that these communities were never urbanized enough for a de-urbanization process to occur.

Urbanization, de-urbanization, poor sanitation, and deficient healthcare services are common phenomena in Amazonia (Silva 2006, Giatti 2007, Viana et al. 2007, 2016, Carvalho-Costa et al. 2009, Gomes et al. 2009, Gorayeb et al. 2009, Giatti & Cutolo 2012, Johansen & do Carmo 2012, Brierley et al. 2014, Cardoso et al. 2017). Taken together, these factors create the perfect storm for the occurrence of outbreaks and epidemics in the human population living or working in the Amazon region, especially in cities near forest areas and that have deforestation-associated activities.

Hydroelectric dams, waterways and irrigation systems

Amazon deforestation and other perturbations in the forest landscape are fundamental consequences of the construction of hydroelectric dams, waterways and irrigation systems (Sanchez-Ribas et al. 2012, Tundisi et al. 2014, Fearnside 2015). A good example is the Belo Monte hydroelectric power plant, which significantly changed the landscape of the Xingu River in the Brazilian Amazon, flooding an area of 516 km^2 [228 km^2 (44%) corresponding to the original riverbed and seasonally flooded area] (ANA 2019). However, this flooded area is likely to become very much larger, considering the 6140-km^2 Babaquara (or Altamira) dam that, if built, would regulate the flow of the Xingu River to supply water to the Belo Monte hydroelectric power plant during the dry season (Fearnside 2017a). Two other examples of dams with large reservoir areas may be cited: The Marabá Dam, located on the Tocantins River, would have a total of 1115.4 km^2 of flooded area, and the Simão-Alba Dam, located on the Juruena River, would have more than a 1000 km^2 (Fearnside 2015).

The strongest effect of dam construction on the dynamics of infectious diseases concerns vector proliferation. Flooding of hitherto dry areas creates new breeding sites for disease vectors, especially mosquitoes, which contributes to the increase in the cases of various arboviral and parasitic infections (Sanchez-Ribas et al. 2012, Fearnside 2015, Brito et al. 2018).

Construction of hydroelectric dams is often associated with the relocation of communities from areas that will be flooded or significantly impacted by the construction. Both the displaced population and the population migration attracted to areas near dam construction sites are exposed to substantial health risks, as in the case of the Belo Monte Dam (Grisotti 2016). The new settlement areas may be sites of greater vector circulation or habitats of pathogen reservoirs. Also, the specific place where these communities will be relocated may influence the incidence of mosquito-borne diseases as a consequence of wind regimes and direction, which may facilitate or hinder mosquito bites (Fearnside 1999). Since one of the mechanisms that mosquitoes use to locate humans is by detecting CO_2 in the air, the location of houses with respect to wind directions and dispersion of CO_2 can influence the number of malaria cases (Midega et al. 2012, Endo and Eltahir 2018a, b, Ellwanger & Chies 2018b). Proximity to mosquito-breeding sites can also increase the risk of malaria transmission, an effect that depends on wind direction (Midega et al. 2012). It is likely that wind also impacts the incidence of other mosquito-borne diseases, as this factor influences the behavior of the mosquito itself and does not act directly on the pathogens. A recent study (Huestis et al. 2019) has shown that *Anopheles* mosquitoes can be carried over long distances (up to 300 km) by wind currents. The same study found that many of the wind-transported mosquitoes were female and had fed on blood before migration (Huestis et al. 2019). These findings indicate that modifications in mosquito populations in a given location may influence the dynamics of infectious diseases in very distant regions.

Just as dam construction facilitates the spread of infectious diseases, flooding of areas for irrigation purposes may contribute to the proliferation of disease vectors (Sanchez-Ribas et al. 2012). Although not directly related to the Amazon forest, the case of Panama Canal serves as another example of how water-related construction in a rainforest environment can have profound impacts on the spread of infectious diseases. The percentage of workers hospitalized due to malaria during the construction of the Panama Canal reached 9.6%. Yellow fever was another major problem during the canal construction. The spread of the diseases occurred due to human entry into areas where the mosquito vectors were present, as well as due to the proliferation of vectors with the increase of canal-induced breeding sites. An intense US-led mosquito control program in Panama has been very effective in significantly reducing cases of infection, but not completely eradicating the diseases (Stern & Markel 2004, CDC 2015). Finally, construction of dams, hydroelectric power plants, canals, and irrigation systems in forest areas are activities that enhance close contact of humans with wildlife and its associated pathogens, which is an additional risk factor for infectious disease dissemination.

Road construction and expansion of transportation facilities

Dramatic mortality from vector-borne diseases occurred during construction of the Madeira-Mamoré railway from 1907 to 1912 in what is now the Brazilian state of Rondônia (Katsuragawa et al. 2008). The expansion of transportation facilities has continued in the Amazon region in the 1970s. The construction of the Trans-Amazonian Highway (also known as *BR-230*) represents a milestone in this expansion (Fearnside 1986). Construction began in 1970 and, by 1973, approximately 22,000 individuals had migrated to the highway region. This human flow to a forest region put many workers and migrants in contact with vectors of different diseases, including leptospirosis, leishmaniasis, Chagas disease, bacterial infections, malaria, Mayaro fever, yellow fever, and other arboviral diseases (Pinheiro et al. 1974, Smith 1982, Vasconcelos et al. 2001). Many legal and clandestine highways were and continue to be built in the Amazon region to facilitate transportation of workers and of the products from agriculture, ranching and logging.

Road construction improves infrastructure that is frequently associated with better health outcomes because it facilitates access to healthcare (Bauch et al. 2015, Wood et al. 2017). However, construction of roads and the expansion of transportation also contributes to deforestation, forest fires, hunting, and biodiversity loss, and it significantly increases human mobility in the region (Bonaudo et al. 2005, Laurance et al. 2009, Southworth et al. 2011, Barber et al. 2014), with a direct impact on infectious-disease dynamics.

The extensive transit of people between multiple regions promotes the circulation of pathogens, thus facilitating the spread of infectious diseases. For example, the outflow of human immunodeficiency virus (HIV) from African forests to more populated regions at the beginning of the acquired immune deficiency syndrome (AIDS) epidemic was greatly facilitated by the extension of land transport and human mobility, which remain important factors in the spread of HIV and other pathogens (Lagarde et al. 2003, Eisenberg et al. 2006, Tatem et al. 2006, Barcellos et al. 2010). This is also a concern in the Amazon region, as high mobility connects forest regions with urban areas, creating a “bridge” for infections to enter urban environments. Accordingly, the state of Amazonas has the second highest AIDS mortality rate in Brazil (7.8 deaths per 100,000 inhabitants) (Brazil 2018).

Regarding arboviral diseases, it is well-known that the Amazon forest harbors an enormous variety of species that may serve as vectors of such diseases; hence, in case a new pathogen is introduced in the region and encounters a suitable host, the infection is installed.

Human migration

Extreme weather events such as prolonged drought, excessive rainfall, and food shortages induce migration of human populations. Agricultural practices and search for land and rural properties can also stimulate migrations to forest areas. Infrastructure projects and price fluctuations on commodity markets can also contribute to the mobility of significant population contingents in the Amazon region. These demographic changes intensify deforestation (Barbieri & Carr 2005, Garcia et al. 2007, Fearnside 2008). Finally, climate-induced migration is a major challenge to health services worldwide (Reuveny 2007, Ridde et al. 2019).

Migratory events result in the exposure of populations to new pathogens since these populations eventually “invade” environments where pathogens or disease vectors circulate. This is most prominent when the environment in question is highly biodiverse, as in the case of the Amazon rainforest. This problem is aggravated when unvaccinated populations enter areas of vaccine-preventable endemic diseases. In addition to directly affecting the health of unvaccinated individuals, this phenomenon may impact the herd immunity of the vaccinated population. Moreover, migrants may introduce new pathogens in populations not originally affected by the disease (Confalonieri 2000, Coura et al. 2002, Aguilar et al. 2007, Castelli & Sulis 2017, Bartlow et al. 2019, Grillet et al. 2019).

Migratory flows can overwhelm the public health system of the migrants’ destination, affecting prevention and treatment policies for infectious disease (Grillet et al. 2019, Paniz-Mondolfi et al. 2019). The recent sociopolitical crisis in Venezuela has caused an increase in non-autochthonous (imported) cases of malaria registered in Brazil, one of the main destinations of Venezuelan immigrants. Although this example is not directly related to deforestation, it illustrates how migratory movements can directly affect migrants’ health and at the same time have impacts on the health system (Grillet et al. 2019). The recent reintroduction of measles in Brazilian Amazonia by refugees from Venezuela is a recent example of how facilitated transportation, poverty and lack of adequate control measures may favor the spread of infectious diseases (Meneses et al. 2019).

It is clear that the triad “deforestation, migration and emerging infectious diseases” is an important issue when assessing the potential consequences of Amazon deforestation. Moreover, the economic impacts resulting from infectious disease-related overload of public health systems adds to the factors that make combating deforestation a major economic issue.

Hunting and consumption of bushmeat

Deforestation puts humans in close contact with wildlife and is linked with hunting in different ways. Hunting is a common practice in Brazil, with significant impacts on biodiversity. Although most forms of wildlife hunting are banned in the country, controlling this activity is extremely difficult, especially considering the vast extent of the Amazon region (Baía Júnior et al. 2010, Pantoja-Lima et al. 2014, Van Vliet et al. 2014, Chagas et al. 2015, Bragagnolo et al. 2019, Souto et al. 2019). It is estimated that just in the triple frontier area of Amazonia shared by Colombia, Peru and Brazil 473 tons of meat from wild animals (“bushmeat”) are sold per year (Van Vliet et al. 2014). Human consumption of bushmeat, including meat from exotic animals, is traditional in the Amazonian countries (Milner-Gulland et al. 2003, Van Vliet et al. 2014). Also, hunting is often associated with logging operations, which bring workers into contact with disease vectors (Eve et al. 2000).

Wild animals host different known and unknown pathogens with a potential of infecting humans. Hunting and handling (butchering) meat of wild animals puts humans in direct contact with biological fluids of these animals and their pathogens. These practices therefore facilitate spillover events and the emergence of new infections in the human population (Wolfe et al. 2004, 2005a, b, Leroy et al. 2009, Uhart et al. 2013, Aston et al. 2014, Pernet et al. 2014).

Tropical forests such as the Amazon rainforest harbor a wide variety of unknown pathogens. Due to this factor and other social, demographic, and environmental characteristics, Brazil is considered to be a hotspot for the emergence of infectious diseases (Keesing et al. 2010, Allen et al. 2017, Nava et al. 2017). The data mentioned above regarding hunting and bushmeat consumption make hunting-associated spillover events a serious (but still neglected) concern in Brazil.

Prostitution

Deforestation in remote areas such as the Amazon rainforest attracts a diversity of workers from various regions, not only for deforestation, but also for gold-digging and construction of dams and roads. This attraction of people to remote forest areas commonly occurs in socially vulnerable conditions and is associated with increased prostitution and unprotected sex (Parriault et al. 2015, Freire et al. 2018, Lopes et al. 2019, Maciel et al. 2019). As a consequence, in multiple Amazonian regions there are increases in sexually transmitted infections, particularly syphilis and HIV (Zavaleta et al. 2007, Bartlett et al. 2008, Parriault et al. 2015, Benzaken et al. 2017, Mosnier et al. 2018, Costa et al. 2019, Maciel et al. 2019, Neto et al. 2019, Cavalcante et al. 2019).

One of the main factors contributing to the faster spread of HIV in the early 1920s in what is now the Democratic Republic of Congo was the increased number of sex workers in the region, especially in areas of forests that were being cleared for railroad construction (Faria et al. 2014). However, prostitution is often overlooked in studies evaluating the connections between deforestation and infectious diseases. This problem must receive more attention in programs of health promotion for Amazonian populations, with a special focus on sex workers, men who have sex with other men, and other vulnerable groups. The introduction and spread of sexually transmitted infections in indigenous populations in the Amazon region is of particular concern (Bartlett et al. 2008, Orellana et al. 2013, Benzaken et al. 2017).

Loss of animal and plant biodiversity

Environments with high biodiversity harbor many potential new pathogens. At the same time, preserving these environments and their rich biodiversity is, to a certain extent, a way to prevent emerging infectious diseases (Keesing et al. 2010). The relationship between biodiversity and infectious diseases is complex and may seem paradoxical at first, but some precepts are clear: preserved ecosystems act as health promoters, maintaining pathogens in the forest environment. From another perspective, disturbances in highly biodiverse ecosystems facilitate the emergence and spread of new human infections. These basic precepts need to be taken into account in future studies, development projects and political decision-making focused on the Amazon region.

Currently, the loss of animal biodiversity is a serious problem in the Amazon forest. The disappearance of predators can favor increases in the populations of species that act as reservoirs for pathogens. An increase in the population of a given animal species may favor the proliferation of blood-feeding vectors that feed on these animals. In addition, loss of plant biodiversity is linked to the fragmentation of habitats occupied by different animal species. Deforestation and habitat fragmentation threaten animal species and may even cause extinction. Together, the loss of animal and plant biodiversity diminishes and even extinguishes ecological niches occupied by predators, disease vectors, and pathogens. On the other hand, biodiversity loss creates new niches that may be occupied by alternative reservoir species, vectors, hosts, and pathogens (Morens et al. 2004, Pignatti 2004, Aguirre & Tabor 2008, Pongsiri et al. 2009, Ometto et al. 2011, Altizer et al. 2013). In brief, the loss of biodiversity profoundly alters the dynamics of the infections.

Deforestation and habitat loss decrease the quality of life of the human population, since environmental degradation is often accompanied by stress, malnutrition and increased contact with pollutants. These physiological aggressions can affect the immune system, causing immunosuppression and making both humans and other species more susceptible to pathogens, which facilitate the spread of infections between wildlife and humans (Aguirre and Tabor 2008, Becker et al. 2019). The combination of biodiversity loss, habitat fragmentation, and human contact with forest areas creates ideal conditions for the introduction of known and unknown pathogens into the human population.

HOW TO MITIGATE THE IMPACTS OF DEFORESTATION

Problems and activities associated with Amazon deforestation and impacts on infectious diseases are summarized in Figure 1. Brazil and other Amazonian countries have all of the main drivers for the emergence of infectious diseases: rich biodiversity and multiple social and ecological challenges. For these reasons, the emergence of infectious diseases in these countries cannot be completely prevented. However, there are many actions that should be implemented to prevent infectious diseases.

Vulnerability of human health to climate change can be evaluated and measured through different methods (Kovats et al. 2003, Ebi et al. 2006, Confalonieri et al. 2009). Various ways to identify climatic drivers of infectious disease also exist (Metcalf et al. 2017). Identifying the factors that stimulate the emergence of these diseases is therefore essential. Different regions present different challenges in addressing infectious diseases, thus requiring specific solutions.

Inequality-related issues are at the core of several concerns discussed in this article. For example, inadequate patterns of land use and poor sanitation are directly related to deforestation, facilitating the spread of infectious diseases in multiple ways. Reducing social inequality is therefore essential to realistically addressing infectious diseases in Amazonian countries. To achieve this goal, investment in education, environmental sanitation, health facilities, and income generation are fundamental priorities, especially for the most vulnerable populations.

Prevention of infectious diseases also requires a robust monitoring system focused on the circulation of pathogens in the environment, humans, and non-human animals. In the environment, monitoring of pathogens in water, soil and sediments is needed for detection of health risks and for planning sanitation programs, especially in the Amazon region, where public health issues are very common (Staggemeier et al. 2011, Prado & Miagostovich 2014, Spilki 2015). For monitoring in humans and animals, it is necessary to invest in low-cost diagnostic methods that are easy to apply in remote places. Genome-based technologies are emerging for diagnosis and surveillance of infectious diseases and for the study of emerging pathogens (Ellwanger et al. 2017, Gardy & Loman 2018, Gu et al. 2019, Gwinn et al. 2019). Selection of specific sentinel human and animal populations (blood donors, livestock, vectors, among others) helps to detect the emergence of new infectious diseases and of disease outbreaks, enabling actions to mitigate the spread of such events (Ellwanger et al. 2019).

It is also important to invest in laboratory facilities and in training personnel to identify

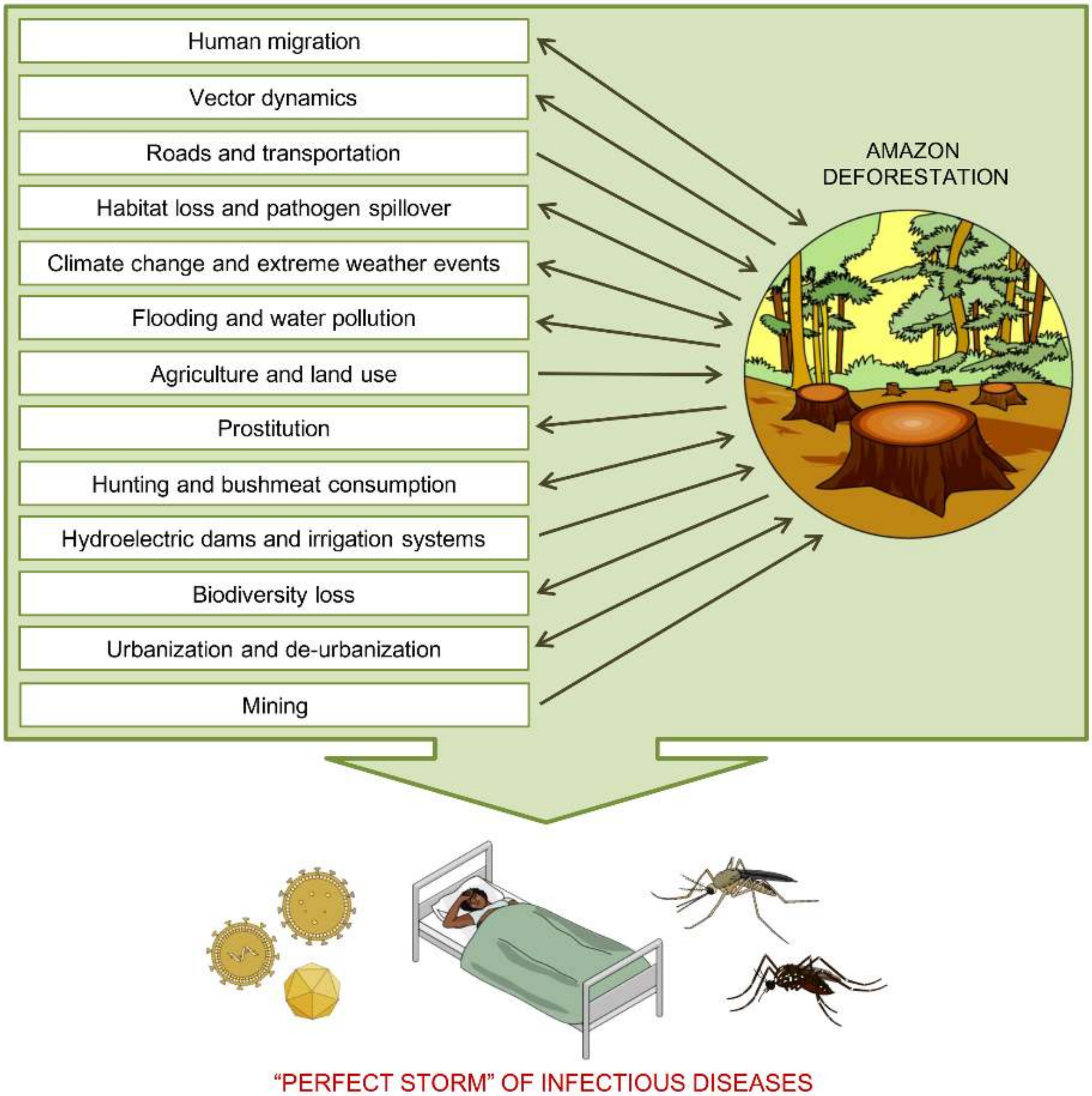

Figure 1. Problems and activities associated with Amazon deforestation and impacts on infectious diseases. The problems and activities associated with the emergence of infectious diseases can result from Amazon deforestation (e.g., floods and water pollution). In other situations, they act as promoters of deforestation (e.g., road construction and mining). Some factors are both consequences and causes of deforestation, as in the case of human migrations and urbanization, as represented by bidirectional arrows. This figure was created using *Mind the Graph* illustrations (available at www.mindthegraph.com).

new pathogens quickly, safely, and effectively. Regarding arboviruses, development of techniques with low cross-reactivity is essential. Outbreak-response networks need to be strengthened and expanded through national and regional surveillance systems. Two actions should be highlighted: vaccine development and vector control. Together with environmental sanitation, these two factors could bring robust advances in the control of infectious diseases in the Amazon forest and in other tropical regions (Barata 1997, Waldman 2001, Lima-Camara 2016, Cardoso & Navarro 2007, Donalisio et al. 2017).

Brazil already has basic infrastructure and technical capacity for prevention and mitigation of infectious diseases. However, for these actions to be effectively applied, the government needs to supply resources to the agencies and to the professionals who are committed to these goals. Civil society should support the work of scientists and health professionals, and demand that the government appropriately allocate resources to agencies responsible for health promotion and environmental surveillance throughout the country, including the training of community health agents (Luna 2002). The vast territorial extent of Brazil is a challenge for epidemiological surveillance. Many activities of great social and environmental impact occur in conditions of geographical isolation or informal processes. Similarly, many public health emergencies occur in hard-to-reach places with little installed capacity for monitoring, prophylaxis, and treatment of diseases resulting from ecological disturbances. Investing in technologies for remote monitoring of environmental impacts and for remote health care can help overcome the challenges of epidemiological surveillance in Brazil.

The civil society needs to be more engaged with environmental issues, and it is the role of scientists and educators to encourage the population to be involved in actions focused on biodiversity preservation. Therefore, scientists must work to popularize science and raise awareness of the importance of preserving Amazon ecosystems from a broad perspective, including human health. Several new ways to promote this approach exist, including the use of mobile apps focused on environmental education, science podcasts, and platforms for promoting individuals' engagement in science tasks (Palumbo et al. 2012, Bagnolini et al. 2017, von Konrat et al. 2018).

In addition to reducing deforestation, it is necessary to recuperate degraded areas. Reforestation, afforestation, and restoration of forest environments help mitigate climate change through carbon sequestration, and social, ecological and economic benefits are obtained through the recovery of degraded forest areas (Bonan 2008, Brancalion et al. 2019, Bustamante et al. 2019, Prevedello et al. 2019). However, the carbon and biodiversity benefits of preventing Amazonian deforestation are much greater than those of forest recovery, both per hectare and per unit cost, making avoiding deforestation the current priority in the Amazon region (Fearnside 2017b).

Any interference in nature has consequences. Increasing forestation and biodiversity may increase the burden of some infectious diseases since this can facilitate the contact of humans with pathogens. In addition, urbanization can have a favorable effect on the control of such diseases, as it provides the population greater access to health services and better sanitation (Bauch et al. 2015, Wood et al. 2017). Therefore, reforestation and actions to preserve biodiversity could have undesirable effects on human health if these actions are not coupled with the implementation of public health infrastructure, especially in cities and new settlements located in forest areas.

Beyond maintaining vegetation cover, it is necessary to limit and regulate human activity in the Amazon forest. Policies and inspection actions focused on the control of deforestation must be strengthened and expanded, limiting artisanal gold digging, industrial mining, agriculture, livestock and logging operations in Amazonia. Forest fires must be controlled more actively. Protected areas and indigenous lands (*terras indígenas*) must be respected. Besides preserving indigenous culture of ethnic groups, demarcation of indigenous lands contributes to the maintenance of forest areas with their original characteristics. Non-governmental organizations need to be recognized as important actors in the control of Amazon deforestation (Barlow et al. 2016, Nogueira et al. 2018, Artaxo 2019, Brito et al. 2019, Carvalho et al. 2019).

The Brazilian National System of Conservation Units (*Sistema Nacional de Unidades de Conservação da Natureza* - SNUC), which was created by law in 2000, establishes the criteria for the creation, implementation and management of protected areas (PAs). The SNUC classifies PAs into two main categories: "strictly protected areas," which have as their primary objective the preservation of biodiversity and therefore can be used only for a few purposes (such as research), and "sustainable-use" PAs, which allow people to live within their borders and harvest forest products sustainably (Brazil 2000, Bauch et al. 2015). Besides contributing to biodiversity preservation, implementation of strictly protected areas has been associated with decreases in the incidence of diseases such as malaria, diarrhea and respiratory infection; sustainable-use PAs, on the other hand, have shown a positive correlation with malaria, probably due to greater exposure of people to mosquitoes (Bauch et al. 2015).

Historically, Brazil has a prominent role in the field of tropical medicine. The country should therefore be a protagonist in controlling deforestation and climate change and their impacts on infectious diseases. Since the country has the largest portion of the Amazon rainforest, Brazil should keep its leading role in health research in Latin America (Lacerda et al. 2019).

ADDITIONAL CONSIDERATIONS

Human pathogens represent only a tiny fraction of the world's parasite diversity (Balloux & van Dorp 2017). It is naive to imagine that infectious diseases can be totally controlled. The human population needs to learn how to live in a balance with pathogens, controlling and managing disease dissemination and taking measures to hinder the emergence of new infections (Bañuls et al. 2013). For example, many infectious diseases are endemic to the Amazon region as a result of the region's natural landscape (Confalonieri 2005). Almost all cases of malaria in Brazil occur in the Amazon region (Lacerda et al. 2019). A huge decrease in the human cases of these diseases would only be feasible through the absence of human contact with the forest, which is unrealistic and not beneficial for humans. Therefore, it is necessary to identify the regions with the highest risk for emerging infections, to invest in diagnostic technologies, and to develop better therapeutics.

Climate change and anthropogenic changes in forest environments can have varied effects on infectious diseases, including decreasing either vector populations or the number of disease cases in some situations, especially regarding malaria (Sanches-Ribas et al. 2012, Gottdenker et al. 2014, Laporta 2019). However, these cases in no way justify neglecting the impacts of deforestation on human health and biodiversity. The few potential "benefits" from climate change will be outweighed by a plethora of hazardous collateral effects. Based on the studies discussed in this article, it is evident that the decrease in the spread of some infectious diseases as a result of deforestation is very small and context-dependent compared to the large effect that deforestation has in promoting the spread of disease vectors and pathogens. Moreover, the Amazon region and other forest areas play multiple essential functions for the balance of life on Earth in ways that are not directly related to infectious diseases.

CONCLUSIONS

The influence of Amazon deforestation on the emergence of infectious diseases is supported by a large amount of consistent data. Deforestation and related human disturbances provide the link between a variety of factors involved in the emergence and spread of the infections. The complex interactions between proposed development projects and the respective burden of diseases in the Amazon region need to be considered.

Prevention and control of infectious diseases in the Amazon region are complex tasks and involve actions to mitigate all of the problems discussed in this article. Therefore, participation of different professionals and institutions is needed, including government agencies, universities, research institutions, non-governmental organizations, schools, and local communities. A One Health perspective should be applied, primarily to identify the factors contributing to the emergence and transmission of infectious diseases. Specific measures can be taken to address each specific problem, but these measures require integrated actions involving different spheres of the society. For example, the government may act with the help of non-governmental organizations to monitor deforestation in the Amazon region. Similarly, public health agencies, schools and scientists should work together to stimulate vaccination and other preventive and health promotion strategies.

Controlling deforestation means preserving biodiversity and protecting human health. Brazil has a great responsibility in this regard as the holder of the largest Amazon territory and must, therefore, actively and constantly ensure its preservation. From a broader perspective, the extent of Brazil's commitment to the preservation of the Amazon region will be reflected in planetary health.

Acknowledgments

We thank the agencies that funded the authors of this article: JHE receives a postdoctoral fellowship from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brazil). BKL receives a masters scholarship from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brazil). VLK and LC receive doctoral scholarships from CAPES (Brazil). JMVV was supported by Labex EpiGenMed, an "Investissements d'avenir" program, ANR-10-LABX-12-01 postdoctoral fellowship (France). JABC, FRS and MRB receive research fellowships from CNPq (Brazil). PMF is funded by CNPq Proc. 311103/2015-4, 429795/2016-5; FAPEAM proc. 708565; INPA PRJ15.125, and Rede Clima (INPE) FINEP Proc. 01.13.0353-00. LLG receives support from the *Fundação de Amparo à Pesquisa do Estado de São Paulo*/São Paulo Research Foundation (FAPESP – proc.n. 2019/12804-3, Brazil) and from CNPq (Brazil) proc.n. 309840/2018-0. SEMA receives financing support from *Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul* (FAPERGS, Brazil).

REFERENCES

ABRAHÃO JS ET AL. 2010. Vaccinia virus infection in monkeys, Brazilian Amazon. Emerg Infect Dis 16: 976-979.

AGUILAR HM, ABAD-FRANCH F, DIAS JCP, JUNQUEIRA ACV & COURA JR. 2007. Chagas disease in the Amazon region. Mem Inst Oswaldo Cruz 102: 47-56.

AGUIRRE AA & TABOR GM. 2008. Global factors driving emerging infectious diseases. Ann NY Acad Sci 1149: 1-3.

ALENCAR AA, BRANDO PM, ASNER GP & PUTZ FE. 2015. Landscape fragmentation, severe drought, and the new Amazon forest fire regime. Ecol Appl 25: 1493-1505.

ALENCAR A, NEPSTAD D & DIAZ MCV. 2006. Forest understory fire in the Brazilian Amazon in ENSO and non-ENSO years: Area burned and committed carbon emissions. Earth Interact 10: 1-17.

ALHO CJR. 2012. The importance of biodiversity to human health: An ecological perspective. Estud Av 26: 151-165.

ALI S ET AL. 2017. Environmental and social change drive the explosive emergence of Zika virus in the Americas. PLoS Negl Trop Dis 11: e0005135.

ALLEN T, MURRAY KA, ZAMBRANA-TORRELIO C, MORSE SS, RONDININI C, DI MARCO M, BREIT N, OLIVAL KJ & DASZAK P. 2017. Global hotspots and correlates of emerging zoonotic diseases. Nat Commun 8: 1124.

ALMEIDA ACG ET AL. 2018. High proportions of asymptomatic and submicroscopic *Plasmodium vivax* infections in a peri-urban area of low transmission in the Brazilian Amazon. Parasit Vectors 11: 194.

ALTIZER S, OSTFELD RS, JOHNSON PTJ, KUTZ S & HARVELL CD. 2013. Climate change and infectious diseases: from evidence to a predictive framework. Science 341: 514-519.

ALVAR J, YACTAYO S & BERN C. 2006. Leishmaniasis and poverty. Trends Parasitol 22: 552-557.

ANA - AGÊNCIA NACIONAL DE ÁGUAS. 2019. Agência Nacional de Águas autoriza utilização do rio Xingu para Belo Monte, 2019. Available at: https://www.ana.gov.br/noticias-antigas/agaancia-nacional-de-aguas-autoriza-utilizaa ssapso.2019-03-15.1595176417. Access on September 23, 2019.

ARTAXO P. 2019. Working together for Amazonia. Science 363: 323.

ASTON EJ, MAYOR P, BOWMAN DD, MOHAMMED HO, LIOTTA JL, KWOK O & DUBEY JP. 2014. Use of filter papers to determine seroprevalence of *Toxoplasma gondii* among hunted ungulates in remote Peruvian Amazon. Int J Parasitol Parasites Wildl 3: 15-19.

BAGNOLINI G, DA COSTA G, GERINO M, ROTH M & CÉCILE T. 2017. Multidisciplinarity for biodiversity management on campus through citizen sciences. In: 2nd Workshop on Smart and Sustainable City (WSSC 2017) in conjunction with 2017 IEEE Smart World Conference. San Francisco, United States. https://doi.org/10.1109/UIC-ATC.2017.8397397.

BAÍA JÚNIOR PC, GUIMARÃES DA & LE PENDU Y. 2010. Non-legalized commerce in game meat in the Brazilian Amazon: a case study. Rev Biol Trop 58: 1079-1088.

BAKER JCA & SPRACKLEN DV. 2019. Climate benefits of intact Amazon forests and the biophysical consequences of disturbance. Front For Glob Change 2: 47.

BALBUS J, CRIMMINS A, GAMBLE JL, EASTERLING DR, KUNKEL KE, SAHA S & SAROFIM MC. 2016. Ch. 1: Introduction: Climate Change and Human Health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, p. 25-42.

BALLOUX F & VAN DORP L. 2017. Q&A: What are pathogens, and what have they done to and for us? BMC Biol 15: 91.

BAÑULS AL, THOMAS F & RENAUD F. 2013. Of parasites and men. Infect Genet Evol 20: 61-70.

BARATA RCB. 1997. O desafio das doenças emergentes e a revalorização da epidemiologia descritiva. Rev Saude Publica 31: 531-537.

BARBER CP, COCHRANE MA, SOUZA JR CM & LAURANCE WF. 2014. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. Biol Conserv 177: 203-209.

BARBIERI AF & CARR DL. 2005. Gender-specific out-migration, deforestation and urbanization in the Ecuadorian Amazon. Glob Planet Change 47: 99-110.

BARCELLOS C, FEITOSA P, DAMACENA GN & ANDREAZZI MA. 2010. Highways and outposts: economic development and health threats in the central Brazilian Amazon region. Int J Health Geogr 9: 30.

BARCELLOS C, MONTEIRO AMV, CORVALÁN C, GURGEL C, CARVALHO MS, ARTAXO P, HACON S & RAGONI V. 2009. Mudanças climáticas e ambientais e as doenças infecciosas: cenários e incertezas para o Brasil. Epidemiol Serv Saude 18: 285-304.

BARCELLOS C, XAVIER D, HACON S, ARTAXO P, GRACIE R, MAGALHÃES M, MATOS V, MONTEIRO AM & FEITOSA P. 2019. Queimadas na Amazônia e seus impactos na saúde: A incidência de doenças respiratórias no sul da Amazônia aumentou significativamente nos últimos meses. 3º Informe técnico do Observatório de Clima e Saúde. Observatório de Clima e Saúde Instituto de Comunicação e Informação Científica e Tecnológica em Saúde (ICICT), Fundação Oswaldo Cruz (Fiocruz). Available at: https://climaesaude.icict.fiocruz.br/sites/climaesaude.icict.fiocruz.br/files/informe_observatorio_queimadas.pdf Accessed on 30 August, 2019.

BARLOW J ET AL. 2016. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature 535: 144-147.

BARONA E, RAMANKUTTY N, HYMAN G & COOMES OT. 2010. The role of pasture and soybean in deforestation of the Brazilian Amazon. Environ Res Lett 5: 024002.

BARROS BCV ET AL. 2018. Rotavirus A in wild and domestic animals from areas with environmental degradation in the Brazilian Amazon. PLoS One 13: e0209005.

BARROZO LV, BENARD G, SILVA MES, BAGAGLI E, MARQUES SA & MENDES RP. 2010. First description of a cluster of acute/subacute paracoccidioidomycosis cases and its association with a climatic anomaly. PLoS Negl Trop Dis 4: e643.

BARTLETT EC, ZAVALETA C, FERNÁNDEZ C, RAZURI H, VILCARROMERO S, VERMUND SH & GOTUZZO E. 2008. Expansion of HIV and syphilis into the Peruvian Amazon: a survey of four communities of an indigenous Amazonian ethnic group. Int J Infect Dis 12: e89-e94.

BARTLOW AW, MANORE C, XU C, KAUFELD KA, DEL VALLE S, ZIEMANN A, FAIRCHILD G & FAIR JM. 2019. Forecasting zoonotic infectious disease response to climate change: Mosquito vectors and a changing environment. Vet Sci 6: 40.

BAUCH SC, BIRKENBACH AM, PATTANAYAK SK & SILLS EO. 2015. Public health impacts of ecosystem change in the Brazilian Amazon. Proc Natl Acad Sci USA 112: 7414-7419.

BECKER BK. 2004. Amazônia: Geopolítica na virada do III milênio. Rio de Janeiro: Garamond.

BECKER DJ, DOWNS CJ & MARTIN LB. 2019. Multi-scale drivers of immunological variation and consequences for infectious disease dynamics. Integr Comp Biol: icz138.

BENZAKEN AS, SABIDÓ M, BRITO I, BERMÚDEZ XPD, BENZAKEN NS, GALBÁN E, PEELING RW & MABEY D. 2017. HIV and syphilis in the context of community vulnerability among indigenous people in the Brazilian Amazon. Int J Equity Health 16: 92.

BIESKI IGC ET AL. 2015. Ethnobotanical study of medicinal plants by population of Valley of Juruena Region, Legal Amazon, Mato Grosso, Brazil. J Ethnopharmacol 173: 383-423.

BLUM AJ & HOTEZ PJ. 2018. Global "worming": Climate change and its projected general impact on human helminth infections. PLoS Negl Trop Dis 12: e0006370.

BONAN GB. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320: 1444-1449.

BONATO L, FIGUEIREDO MAP, GONÇALVES LR, MACHADO RZ & ANDRÉ MR. 2015. Occurrence and molecular characterization of *Bartonella* spp. and hemoplasmas in neotropical primates from Brazilian Amazon. Comp Immunol Microbiol Infect Dis 42: 15-20.

BONAUDO T, LE PENDU Y, FAURE JF & QUANZ D. 2005. The effects of deforestation on wildlife along the transamazon highway. Eur J Wildl Res 51: 199-206.

BRAGA WSM ET AL. 2009. Prevalence of hepatitis A virus infection: the paradoxical example of isolated communities in the western Brazilian Amazon region. Rev Soc Bras Med Trop 42: 277-281.

BRAGAGNOLO C ET AL. 2019. Hunting in Brazil: What are the options? Perspect Ecol Conser 17: 71-79.

BRANCALION PHS ET AL. 2019. Global restoration opportunities in tropical rainforest landscapes. Sci Adv 5: eaav3223.

BRAZIL. 2000. Presidência da República, Casa Civil, Subchefia para Assuntos Jurídicos. 2000. Lei No 9.985, de 18 de julho de 2000. Available at: http://www.planalto.gov.br/ccivil_03/LEIS/L9985.htm Acessed on October 9, 2019.

BRAZIL. 2018. Ministério da Saúde, Secretaria de Vigilância em Saúde, Departamento de Vigilância, Prevenção e Controle das Infecções Sexualmente Transmissíveis, do HIV/Aids e das Hepatites Virais. 2018. Boletim Epidemiológico - HIV Aids 2018. vol 49. Brasília, Ministério da Saúde. 72 p.

BRIERLEY CK, SUAREZ N, ARORA G & GRAHAM D. 2014. Healthcare access and health beliefs of the indigenous peoples in remote Amazonian Peru. Am J Trop Med Hyg 90: 180-183.

BRITO B, BARRETO P, BRANDÃO JR A, BAIMA S & GOMES PH. 2019. Stimulus for land grabbing and deforestation in the Brazilian Amazon. Environ Res Lett 14: 064018.

BRITO MTFM, AARÃO TLS & PINTO DS. 2018. Seroepidemiology of arbovirus in communities living under the influence of the lake of a hydroelectric dam in Brazil. Cad Saude Colet 26: 1-6.

BURKETT-CADENA ND & VITTOR AY. 2018. Deforestation and vector-borne disease: Forest conversion favors important mosquito vectors of human pathogens. Basic Appl Ecol 26: 101-110.

BUSTAMANTE MMC ET AL. 2019. Ecological restoration as a strategy for mitigating and adapting to climate change: lessons and challenges from Brazil. Mitig Adapt Strateg Glob Change 24: 1249-1270.

CARDOSO BA, FONSECA FO, MORAES NETO AHA, MARTINS ACGS, OLIVEIRA NVDS, LIMA LNGC, DIAS GADS & SAAD MHF. 2017. Environmental aspects related to tuberculosis and intestinal parasites in a low-income community of the Brazilian Amazon. Rev Inst Med Trop Sao Paulo 59: e57.

CARDOSO JC ET AL. 2010. Yellow fever virus in *Haemagogus leucocelaenus* and *Aedes serratus* mosquitoes, southern Brazil, 2008. Emerg Infect Dis 16: 1918-1924.

CARDOSO TAO & NAVARRO MBMA. 2007. Emerging and reemerging diseases in Brazil: data of a recent history of risks and uncertainties. Braz J Infect Dis 11: 430-434.

CARVALHO BM, RANGEL EF, READY PD & VALE MM. 2015. Ecological niche modelling predicts southward expansion of *Lutzomyia (Nyssomyia) flaviscutellata* (Diptera: Psychodidae: Phlebotominae), vector of *Leishmania*

(Leishmania) amazonensis in South America, under climate change. PLoS One 10: e0143282.

CARVALHO WD, MUSTIN K, HILÁRIO RR, VASCONCELOS IM, EILERS V & FEARNSIDE PM. 2019. Deforestation control in the Brazilian Amazon: A conservation struggle being lost as agreements and regulations are subverted and bypassed. Perspect Ecol Conser 17: 122-130.

CARVALHO-COSTA FA ET AL. 2009. Pseudoparasitism by *Calodium hepaticum* (syn. *Capillaria hepatica*; *Hepaticola hepatica*) in the Negro River, Brazilian Amazon. Trans R Soc Trop Med Hyg 103: 1071-1073.

CARVALHO-COSTA FA, TEDESQUI VL, MONTEIRO MJN & BÓIA MN. 2012. Outbreaks of attacks by hematophagous bats in isolated riverine communities in the Brazilian Amazon: a challenge to rabies control. Zoonoses Public Health. 59: 272-277.

CASADEVALL A, KONTOYIANNIS DP & ROBERT V. 2019. On the emergence of *Candida auris*: climate change, azoles, swamps, and birds. MBio 10: e01397-19.

CASTELLI F & SULIS G. 2017. Migration and infectious diseases. Clin Microbiol Infect 23: 283-289.

CAVALCANTE NDS, LIMA HRR, TABOSA DF, BARBOSA EDSS, COSTA NPDS, COSTA LMD, FRADE PCR, MARTINS LC, SILVA-OLIVEIRA GC & OLIVEIRA-FILHO AB. 2019. Syphilis in female sex workers: an epidemiological study of the highway system of the state of Pará, northern Brazil. Rev Soc Bras Med Trop 52: e20180064.

CDC - CENTERS FOR DISEASE CONTROL AND PREVENTION. 2015. The Panama Canal. Available at: https://www.cdc.gov/malaria/about/history/panama_canal.html Accessed on: October 7, 2019.

CHAGAS ATA, COSTA MA, MARTINS APV, RESENDE LC & KALAPOTHAKIS E. 2015. Illegal hunting and fishing in Brazil: a study based on data provided by environmental military police. Nat Conserv 13: 183-189.

CHECKLEY W, EPSTEIN LD, GILMAN RH, FIGUEROA D, CAMA RI, PATZ JA & BLACK RE. 2000. Effect of *El Niño* and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. Lancet 355: 442-450.

COHN AS, BHATTARAI N, CAMPOLO J, CROMPTON O, DRALLE D, DUNCAN J & THOMPSON S. 2019. Forest loss in Brazil increases maximum temperatures within 50km. Environ Res Lett 14: 084047.

CONFALONIERI U. 2000. Environmental change and human health in the Brazilian Amazon. Global Change & Human Health 1: 174-183.

CONFALONIERI UEC. 2005. Saúde na Amazônia: um modelo conceitual para a análise de paisagens e doenças. Estud Av 19: 221-236.

CONFALONIERI UEC, MARGONARI C & QUINTÃO AF. 2014. Environmental change and the dynamics of parasitic diseases in the Amazon. Acta Trop 129: 33-41.

CONFALONIERI UEC, MARINHO DP & RODRIGUEZ RE. 2009. Public health vulnerability to climate change in Brazil. Clim Res 40: 175-186.

CONSTENLA DO, LINHARES AC, RHEINGANS RD, ANTIL LR, WALDMAN EA & DA SILVA LJ. 2008. Economic impact of a rotavirus vaccine in Brazil. J Health Popul Nutr 26: 388-396.

COSTA F, CARVALHO-PEREIRA T, BEGON M, RILEY L & CHILDS J. 2017. Zoonotic and vector-borne diseases in urban slums: opportunities for intervention. Trends Parasitol 33: 660-662.

COSTA KMM, ALMEIDA WAF, MAGALHÃES IB, MONTOYA R, MOURA MS & LACERDA MVG. 2010. Malária em Cruzeiro do Sul (Amazônia Ocidental brasileira): análise da série histórica de 1998 a 2008. Rev Panam Salud Publica 28: 353-360.

COSTA LM, RAIOL NC, LISBOA BLA, FRADE PCR, BLANDTT LDS, SILVA-OLIVEIRA GC, MACHADO LFA, MARTINS LC & OLIVEIRA-FILHO AB. 2019. Prevalence and risk factors for Human Immunodeficiency Virus infection among female sex workers: distinct offers of sexual services in a municipality of the Brazilian Amazon. AIDS Res Hum Retroviruses 35: 826-832.

COURA JR, JUNQUEIRA ACV, FERNANDES O, VALENTE SAS & MILES MA. 2002. Emerging Chagas disease in Amazonian Brazil. Trends Parasitol 18: 171-176.

DANTAS-TORRES F. 2008. Bats and their role in human rabies epidemiology in the Americas. J Venom Anim Toxins incl Trop Dis 14: 193-202.

DA ROSA EST AL. 2006. Bat-transmitted human rabies outbreaks, Brazilian Amazon. Emerg Infect Dis 12: 1197-1202.

DA SILVA MB ET AL. 2018. Evidence of zoonotic leprosy in Pará, Brazilian Amazon, and risks associated with human contact or consumption of armadillos. PLoS Negl Trop Dis 12: e0006532.

DASZAK P, CUNNINGHAM AA & HYATT AD. 2001. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Trop 78: 103-116.

DE ANDRADE FAG, GOMES MN, UIEDA W, BEGOT AL, RAMOS OS & FERNANDES MEB. 2016. Geographical analysis for detecting high-risk areas for bovine/human rabies transmitted by the common hematophagous bat in the Amazon region, Brazil. PLoS ONE 11: e0157332.

DE OLIVEIRA ALVES N ET AL. 2017. Biomass burning in the Amazon region causes DNA damage and cell death in human lung cells. Sci Rep 7: 10937.

DE OLIVEIRA GALVÃO MF, DE OLIVEIRA ALVES N, FERREIRA PA, CAUMO S, DE CASTRO VASCONCELLOS P, ARTAXO P, DE SOUZA HACON S, ROUBICEK DA & BATISTUZZO DE MEDEIROS SR. 2018. Biomass burning particles in the Brazilian Amazon region: Mutagenic effects of nitro and oxy-PAHs and assessment of health risks. Environ Pollut 233: 960-970.

DESJEUX P. 2004. Leishmaniasis: current situation and new perspectives. Comp Immunol Microbiol Infect Dis 27: 305-318.

DESTOUMIEUX-GARZÓN D ET AL. 2018. The One Health concept: 10 years old and a long road ahead. Front Vet Sci 5: 14.

DONALISIO MR, FREITAS ARR & VON ZUBEN APB. 2017. Arboviruses emerging in Brazil: challenges for clinic and implications for public health. Rev Saude Publica 51: 30.

DORNAS FP, RODRIGUES FP, BORATTO PVM, SILVA LCF, FERREIRA PCP, BONJARDIM CA, TRINDADE GS, KROON EG, LA SCOLA B & ABRAHÃO JS. 2014. Mimivirus circulation among wild and domestic mammals, Amazon Region, Brazil. Emerg Infect Dis 20: 469-472.

DO VALLE ACF, MARQUES DE MACEDO P, ALMEIDA-PAES R, ROMÃO AR, LAZÉRA MDS & WANKE B. 2017. Paracoccidioidomycosis after highway construction, Rio de Janeiro, Brazil. Emerg Infect Dis 23: 1917-1919.

DUARTE JL & GIATTI LL. 2019. Leptospirosis incidence in a state capital in the Western Brazilian Amazon and its relationship with climate and environmental variability, 2008-2013. Epidemiol Serv Saude 28: e2017224.

DUARTE JL, DIAZ-QUIJANO FA, BATISTA AC & GIATTI LL. 2019a. Climatic variables associated with dengue incidence in a city of the Western Brazilian Amazon region. Rev Soc Bras Med Trop 52: e20180429.

DUARTE JL, DIAZ-QUIJANO FA, BATISTA AC, DUARTE AF, MELCHIOR LAK & GIATTI LL. 2019b. Climate variability and hospitalizations due to infectious diarrheal diseases in a municipality of the Western Brazilian Amazon Region. Cien Saude Colet 24: 2959-2970.

EBI KL, KOVATS RS & MENNE B. 2006. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. Environ Health Perspect 114: 1930-1934.

EISENBERG JNS ET AL. 2006. Environmental change and infectious disease: how new roads affect the transmission of diarrheal pathogens in rural Ecuador. Proc Natl Acad Sci USA 103: 19460-19465.

ELLWANGER JH & CHIES JAB. 2016. Emergent diseases in emergent countries: we must study viral ecology to prevent new epidemics. Braz J Infect Dis 20: 403-404.

ELLWANGER JH & CHIES JAB. 2018a. Zoonotic spillover and emerging viral diseases - time to intensify zoonoses surveillance in Brazil. Braz J Infect Dis 22: 76-78.

ELLWANGER JH & CHIES JAB. 2018b. Wind: a neglected factor in the spread of infectious diseases. Lancet Planet Health 2: e475.

ELLWANGER JH & CHIES JAB. 2019. The triad “dogs, conservation and zoonotic diseases” – An old and still neglected problem in Brazil. Perspect Ecol Conser 17: 157-161.

ELLWANGER JH, KAMINSKI VL & CHIES JAB. 2017. How to detect new viral outbreaks or epidemics? We need to survey the circulation of viruses in humans and other animals using fast, sensible, cheap, and broad-spectrum methodologies. Braz J Infect Dis 21: 211-212.

ELLWANGER JH, KAMINSKI VL & CHIES JAB. 2019. Emerging infectious disease prevention: Where should we invest our resources and efforts? J Infect Public Health 12: 313-316.

ENDO N & ELTAHIR EAB. 2018a. Modelling and observing the role of wind in *Anopheles* population dynamics around a reservoir. Malar J 17: 48.

ENDO N & ELTAHIR EAB. 2018b. Prevention of malaria transmission around reservoirs: an observational and modelling study on the effect of wind direction and village location. Lancet Planet Health 2: e406-e413.

EPSTEIN PR. 2001. Climate change and emerging infectious diseases. Microbes Infect 3: 747-754.

ESCOBAR H. 2019. Amazon fires clearly linked to deforestation, scientists say. Science 365: 853.

ESKEW EA & OLIVAL KJ. 2018. De-urbanization and zoonotic disease risk. Ecohealth 15: 707-712.

EVE E, ARGUELLES FA & FEARNSIDE PM. 2000. How well does Brazil’s environmental law work in practice? Environmental impact assessment and the case of the Itapiranga private sustainable logging plan. Environ Manage 26: 251-267.

FARIA NR ET AL 2014. The early spread and epidemic ignition of HIV-1 in human populations. Science 346: 56-61.

FARIKOSKI IO, MEDEIROS LS, CARVALHO YK, ASHFORD DA, FIGUEIREDO EES, FERNANDES DVGS, SILVA PJB & RIBEIRO VMF. 2019. The urban and rural capybaras (*Hydrochoerus hydrochaeris*) as reservoir of *Salmonella* in the western Amazon, Brazil. Pesq Vet Bras 39: 66-69.

FAVORETTO SR ET AL. 2019. Zika virus in peridomestic neotropical primates, northeast Brazil. Ecohealth 16: 61-69.

FEARNSIDE PM. 1986. Human Carrying Capacity of the Brazilian Rainforest. New York, USA: Columbia University Press. 293 p.

FEARNSIDE PM. 1999. Social impacts of Brazil's Tucuruí Dam. Environ Manage 24: 483-495.

FEARNSIDE PM. 2008. The roles and movements of actors in the deforestation of Brazilian Amazonia. Ecol Soc 13: 23.

FEARNSIDE PM. 2015. Hidrelétricas na Amazônia: impactos ambientais e sociais na tomada de decisões sobre grandes obras, v. 1. Manaus: Editora do INPA, 296 p.

FEARNSIDE PM. 2017a. Planned disinformation: the example of the Belo Monte Dam as a source of greenhouse gases, p. 125-142. In: Issberner L-R & Lena P (Eds), Brazil in the Anthropocene: Conflicts between Predatory Development and Environmental Policies. New York, USA: Routledge, 368 p.

FEARNSIDE PM. 2017b. Deforestation of the Brazilian Amazon. In: Shugart H (Ed), Oxford Research Encyclopedia of Environmental Science. New York, USA: Oxford University Press. https://doi.org/10.1093/acrefore/9780199389414.013.102.

FEARNSIDE PM. 2019. Brazilian Amazon deforestation surge is real despite Bolsonaro's denial (commentary). Mongabay, July 29, 2019. Available at: https://news.mongabay.com/2019/07/brazilian-amazon-deforestation-surge-is-real-despite-bolsonaros-denial-commentary/.

FERNANDES J ET AL. 2018. Xapuri virus, a novel mammarenavirus: natural reassortment and increased diversity between New World viruses. Emerg Microbes Infect 7: 120.

FERNANDES MEB, DA COSTA LJC, DE ANDRADE FAG & SILVA LP. 2013. Rabies in humans and non-human in the state of Pará, Brazilian Amazon. Braz J Infect Dis 17: 251-253.

FERRANTE L & FEARNSIDE PM. 2019. Brazil's new president and "ruralists" threaten Amazonia's environment, traditional peoples and the global climate. Environ Conserv 46: 261-263.

FLAHAULT A, DE CASTANEDA RR & BOLON I. 2016. Climate change and infectious diseases. Public Health Rev 37: 21.

FOLEY JA ET AL. 2005. Global consequences of land use. Science 309: 570-574.

FRANCO FILHO LC, BARATA RR, CARDOSO JF, MASSAFRA JMV, LEMOS PDS, CASSEB LMN, CRUZ ACR & NUNES MRT. 2019. Metagenomic analysis of samples from three bat species collected in the Amazon rain forest. Microbiol Resour Announc 8: e01422-18.

FREIRE LM, LIMA JS & SILVA EV. 2018. Belo Monte: fatos e impactos envolvidos na implantação da usina hidrelétrica na região Amazônica Paraense. Soc Nat 30: 18-41.

FREITAS CM DE & GIATTI LL. 2009. Indicadores de sustentabilidade ambiental e de saúde na Amazônia Legal, Brasil. Cad Saúde Pública 25: 1251-1266.

GARCIA RA, SOARES-FILHO BS & SAWYER DO. 2007. Socioeconomic dimensions, migration, and deforestation: An integrated model of territorial organization for the Brazilian Amazon. Ecol Indic 7: 719-730.

GARDA AA, DA SILVA JMC & BAIÃO PC. 2010. Biodiversity conservation and sustainable development in the Amazon. Syst Biodivers 8: 169-175.

GARDY JL & LOMAN NJ. 2018. Towards a genomics-informed, real-time, global pathogen surveillance system. Nat Rev Genet 19: 9-20.

GEOGHEGAN JL, SENIOR AM, DI GIALLONARDO F & HOLMES EC. 2016. Virological factors that increase the transmissibility of emerging human viruses. Proc Natl Acad Sci USA 113: 4170-4175.

GIATTI LL & CUTOLO SA. 2012. Acesso à água para consumo humano e aspectos de saúde pública na Amazônia Legal. Ambient Soc 15: 93-109.

GIATTI LL. 2007. Reflexões sobre água de abastecimento e saúde pública: um estudo de caso na Amazônia brasileira. Saude Soc 16: 134-144.

GIL LH, TADA MS, KATSURAGAWA TH, RIBOLLA PEM & SILVA LHP. 2007. Urban and suburban malaria in Rondônia (Brazilian Western Amazon) II. Perennial transmissions with high anopheline densities are associated with human environmental changes. Mem Inst Oswaldo Cruz 102: 271-276.

GILBERT AT, PETERSEN BW, RECUENCO S, NIEZGODA M, GÓMEZ J, LAGUNA-TORRES VA & RUPPRECHT C. 2012. Evidence of rabies virus exposure among humans in the Peruvian Amazon. Am J Trop Med Hyg 87: 206-215.

GITHEKO AK, LINDSAY SW, CONFALONIERI UE & PATZ JA. 2000. Climate change and vector-borne diseases: a regional analysis. Bull World Health Organ 78: 1136-1147.

GOLDANI LZ. 2017. Yellow fever outbreak in Brazil, 2017. Braz J Infect Dis 21: 123-124.

GOMES RKS, PEREIRA LCC, RIBEIRO CMM & DA COSTA RM. 2009. Dinâmica socioambiental em uma comunidade pesqueira Amazônica, PA-Brasil. Revista de Gestão Costeira Integrada 9: 101-111.

GONÇALVES AQ, JUNQUEIRA ACV, ABELLANA R, BARRIO PC, TERRAZAS WCM, SODRÉ FC, BÓIA MN & ASCASO C. 2016. Prevalence of intestinal parasites and risk factors for specific and multiple helminth infections in a remote city of the Brazilian Amazon. Rev Soc Bras Med Trop 49: 119-124.

GORAYEB A, LOMBARDO MA & PEREIRA LCC. 2009. Condições ambientais em áreas urbanas da bacia hidrográfica do Rio Caeté Amazônia oriental - Brasil. Revista da Gestão Costeira Integrada 9: 59-70.

GOTTDENKER NL, CALZADA JE, SALDAÑA A & CARROLL CR. 2011. Association of anthropogenic land use change and increased abundance of the Chagas disease vector *Rhodnius pallescens* in a rural landscape of Panama. Am J Trop Med Hyg 84: 70-77.

GOTTDENKER NL, STREICKER DG, FAUST CL & CARROLL CR. 2014. Anthropogenic land use change and infectious diseases: a review of the evidence. Ecohealth 11: 619-632.

GOVEIA CO, SOUZA E GUIMARÃES RJP, NUNES MRT, DIAS IHL & ENK MJ. 2019. Schistosomiasis Mansoni in the Amazon Region: malacological surveys of intermediate hosts for the identification of disease transmission areas in Belém, Pará, Brazil. JPP 7: 51-60.

GRACIE R, BARCELLOS C, MAGALHÃES M, SOUZA-SANTOS R & BARROCAS PR. 2014. Geographical scale effects on the analysis of leptospirosis determinants. Int J Environ Res Public Health 11: 10366-10383.

GREGIANINI TS, RANIERI T, FAVRETO C, NUNES ZMA, TUMIOTO GIANNINI GL, SANBERG ND, DA ROSA MTM & DA VEIGA ABG. 2017. Emerging arboviruses in Rio Grande do Sul, Brazil: Chikungunya and Zika outbreaks, 2014-2016. Rev Med Virol 27: e1943.

GRILLET ME ET AL. 2019. Venezuela's humanitarian crisis, resurgence of vector-borne diseases, and implications for spillover in the region. Lancet Infect Dis 19: e149-e161.

GRISOTTI M. 2016. The challenges of health care in relation to the Belo Monte Dam context. Ambiente & Sociedade 19: 287-304.

GUIMARÃES RM, VALENTE BC, FARIA PA, STEPHANELLI LL, CHAIBLICH JV & ARJONA FBS. 2016. Deforestation and malaria incidence in the legal Amazon Region between 1996 and 2012. Cad Saúde Colet 24: 3-8.

GU W, MILLER S & CHIU CY. 2019. Clinical metagenomic next-generation sequencing for pathogen detection. Annu Rev Pathol 14: 319-338.

GULACHENSKI A, GHERSI BM, LESEN AE & BLUM MJ. 2016. Abandonment, ecological assembly and public health risks in counter-urbanizing cities. Sustainability 8: 491.

GWINN M, MACCANNELL D & ARMSTRONG GL. 2019. Next-generation sequencing of infectious pathogens. J Amer Med Assoc 321: 893-894.

HACON SS, DE OLIVEIRA BFA & SILVEIRA I. 2018. A review of the health sector impacts of 4 °c or more temperature rise. In: Climate Change Risks in Brazil. Springer, Amsterdam, the Netherlands, p. 67-129.

HAGEN F ET AL. 2013. Ancient dispersal of the human fungal pathogen *Cryptococcus gattii* from the Amazon rainforest. PLOS ONE 8: e71148.

HALES S, DE WET N, MAINDONALD J & WOODWARD A. 2002. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. Lancet 360: 830-834.

HALLIDAY JEB, ALLAN KJ, EKWEM D, CLEAVELAND S, KAZWALA RR & CRUMP JA. 2015. Endemic zoonoses in the tropics: a public health problem hiding in plain sight. Vet Rec 176: 220-225.

HENDRIX CS & SALEHYAN I. 2012. Climate change, rainfall, and social conflict in Africa. J Peace Res 49: 35-50.

HERNANDEZ AD, POOLE A & CATTADORI IM. 2013. Climate changes influence free-living stages of soil-transmitted parasites of European rabbits. Glob Chang Biol 19: 1028-1042.

HOTEZ PJ, BOTTAZZI ME, FRANCO-PAREDES C, AULT SK & PERIAGO MR. 2008. The neglected tropical diseases of Latin America and the Caribbean: a review of disease burden and distribution and a roadmap for control and elimination. PLoS Negl Trop Dis 2: e300.

HUBER M & KNUTTI R. 2012. Anthropogenic and natural warming inferred from changes in Earth's energy balance. Nat Geosci 5: 31-36.

HUESTIS DL ET L. 2019. Windborne long-distance migration of malaria mosquitoes in the Sahel. Nature 574: 404–408.

IPCC - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2013. Annex I: Atlas of Global and Regional Climate Projections. In: Van Oldenborgh GJ, Collins M, Arblaster J, Christensen JH, Marotzke J, Power SB, Rummukainen M & Zhou T

(Eds), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V & Midgley PM (Eds), Cambridge University Press, Cambridge, UK, p. 1311-1393.

INPE - INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. 2019. Projeto PRODES: Monitoramento da Floresta Amazônica Brasileira por Satélite. http://www.obt.inpe.br/prodes/.

JOHANSEN IC & DO CARMO RL. 2012. Dengue e falta de infraestrutura urbana na Amazônia brasileira: o caso de Altamira (PA). Novos Cadernos NAEA 15: 179-208.

JOHNSON CK ET AL. 2015. Spillover and pandemic properties of zoonotic viruses with high host plasticity. Sci Rep 5: 14830.

JONES BA ET AL. 2013. Zoonosis emergence linked to agricultural intensification and environmental change. Proc Natl Acad Sci USA 110: 8399-8404.

JONES KE, PATEL NG, LEVY MA, STOREYGARD A, BALK D, GITTLEMAN JL & DASZAK P. 2008. Global trends in emerging infectious diseases. Nature 451: 990-993.

KATSURAGAWA TH, GIL LHS, TADA MS & SILVA LHP. 2008. Endemic and epidemic diseases in Amazonia: Malaria and other emerging diseases in riverine areas of the Madeira River. A school case. Estud Av 22:111-141.

KEESING F ET AL. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature 468: 647-652.

KHAN MD, THI VU HH, LAI QT & AHN JW. 2019. Aggravation of human diseases and climate change nexus. Int J Environ Res Public Health 16: 2799.

KHANNA J, MEDVIGY D, FUEGLISTALER S & WALKO R. 2017. Regional dry-season climate changes due to three decades of Amazonian deforestation. Nat Clim Change 7: 200-204.

KLITTING R, GOULD EA, PAUPY C & DE LAMBALLERIE X. 2018. What does the future hold for yellow fever virus? (I). Genes (Basel) 9: e291.

KOVATS S ET AL. 2003. Methods of assessing human health vulnerability and public health adaptation to climate change. Copenhagen, Regional Office for Europe (EURO) - World Health Organization, 112 p.

KRAEMER MUG ET AL. 2019. Past and future spread of the arbovirus vectors *Aedes aegypti* and *Aedes albopictus*. Nat Microbiol 4: 854-863.

KRUSE H, KIRKEMO AM & HANDELAND K. 2004. Wildlife as source of zoonotic infections. Emerg Infect Dis 10: 2067-2072.

LACERDA MVG, VAL FFA & MONTEIRO WM. 2019. Dilemma in the Brazilian tropical medicine: 'Is speed more important than direction?' An Acad Bras Cienc 91: e20190132.

LAGARDE E ET AL. 2003. Mobility and the spread of human immunodeficiency virus into rural areas of West Africa. Int J Epidemiol 32: 744-752.

LAPORTA GZ. 2019. Amazonian rainforest loss and declining malaria burden in Brazil. Lancet Planet Health 3: e4-e5.

LATRUBESSE EM ET AL. 2017. Damming the rivers of the Amazon basin. Nature 546: 363-369.

LAURANCE WF, GOOSEM M & LAURANCE SGW. 2009. Impacts of roads and linear clearings on tropical forests. Trends Ecol Evol 24: 659-669.

LEE K & BRUMME ZL. 2013. Operationalizing the One Health approach: the global governance challenges. Health Policy Planning 28: 778-785.

LEITE-FILHO AT, PONTES VYS & COSTA MH. 2019. Effects of deforestation on the onset of the rainy season and the duration of dry spells in southern Amazonia. J Geophys Res Atmos 124: 5268-5281.

LEROY EM, EPELBOIN A, MONDONGE V, POURRUT X, GONZALEZ JP, MUYEMBE-TAMFUM JJ & FORMENTY P. 2009. Human Ebola outbreak resulting from direct exposure to fruit bats in Luebo, Democratic Republic of Congo, 2007. Vector Borne Zoonotic Dis 9: 723-728.

LETCHER TM. 2019. Why do we have global warming? In: Managing Global Warming: An Interface of Technology and Human Issues, Elsevier, p. 3-15.

LEVITUS S, ANTONOV JI, WANG J, DELWORTH TL, DIXON KW & BROCCOLI AJ. 2001. Anthropogenic warming of Earth's climate system. Science 292: 267-270.

LI Y, KAMARA F, ZHOU G, PUTHIYAKUNNON S, LI C, LIU Y, ZHOU Y, YAO L, YAN G & CHEN XG. 2014. Urbanization increases *Aedes albopictus* larval habitats and accelerates mosquito development and survivorship. PLoS Negl Trop Dis 8: e3301.

LIANG L & GONG P. 2017. Climate change and human infectious diseases: A synthesis of research findings from global and spatio-temporal perspectives. Environ Int 103: 99-108.

LIMA-CAMARA TN. 2016. Emerging arboviruses and public health challenges in Brazil. Rev Saude Publica 50: 36.

LOCKHART SR ET AL. 2017. Simultaneous emergence of multidrug-resistant *Candida auris* on 3 continents confirmed by whole-genome sequencing and epidemiological analyses. Clin Infect Dis 64: 134-140.

LOPES TMR, VENTURA AMRS, SOUZA E GUIMARÃES RJP & GUIMARÃES LHR. 2019. Situação epidemiológica da malária em uma região de Garimpo, na região da Amazônia brasileira, no período de 2011 a 2015. REAS 25: e759.

LORENZ C, AZEVEDO TS, VIRGINIO F, AGUIAR BS, CHIARAVALLOTI-NETO F & SUESDEK L. 2017. Impact of environmental factors on neglected emerging arboviral diseases. PLoS Negl Trop Dis 11: e0005959.

LOVEJOY TE & NOBRE C. 2018. Amazon tipping point. Sci Adv 4: eaat2340.

LUNA EJA. 2002. A emergência das doenças emergentes e as doenças infecciosas emergentes e reemergentes no Brasil. Rev Bras Epidemiol 5: 229-243.

MA W & JIANG B. 2019. Health impacts due to major climate and weather extremes. In: Ambient Temperature and Health in China. Singapore, Springer, p. 59-73.

MACDONALD AJ & MORDECAI EA. 2019. Amazon deforestation drives malaria transmission, and malaria burden reduces forest clearing. Proc Natl Acad Sci USA 44: 22212-22218.

MACHADO CJS, MIAGOSTOVICH MP, LEITE JPG & VILANI RM. 2013. Promoção da relação saúde–saneamento–cidade por meio da Virologia Ambiental. RIL 50: 321-345.

MACHOVINA B, FEELEY KJ & RIPPLE WJ. 2015. Biodiversity conservation: The key is reducing meat consumption. Sci Total Environ 536: 419-431.

MACIEL FB, SCHWEICKARDT JC, MACIEL JB & COSTA ICNP. 2019. Development policy, the environment and health in the Amazon: an analysis of the Tapajós region. Rev Bras Estud Urbanos Reg 21: 155-172.

MACKENSTEDT U, JENKINS D & ROMIG T. 2015. The role of wildlife in the transmission of parasitic zoonoses in peri-urban and urban areas. Int J Parasitol Parasites Wildl 4: 71-79.

MAGNUSSON WE. 2019. Biodiversity: the chasm between what we know and we need to know. An Acad Bras Cienc 91: e20190079.

MALHI Y, ROBERTS JT, BETTS RA, KILLEEN TJ, LI W & NOBRE CA. 2008. Climate change, deforestation, and the fate of the Amazon. Science 319: 169-172.

MARENGO JA & ESPINOZA JC. 2016. Extreme seasonal droughts and floods in Amazonia: causes, trends and impacts. Int J Climatol 36: 1033-1050.

MARQUES-DA-SILVA SH, RODRIGUES AM, DE HOOG GS, SILVEIRA-GOMES F & CAMARGO ZP. 2012. Occurrence of *Paracoccidioides lutzii* in the Amazon region: description of two cases. Am J Trop Med Hyg 87: 710-714.

MARTINS M, LACERDA MVG, MONTEIRO WM, MOURA MA, SANTOS ECS, SARACENI V & SARAIVA MGG. 2015. Progression of the load of waterborne and intestinal parasitic diseases in the State of Amazonas. Rev Soc Bras Med Trop 48 Suppl 1: 42-54.

MAYSTADT JF & ECKER O. 2014. Extreme weather and civil war: does drought fuel conflict in Somalia through livestock price shocks? Amer J Agr Econ 96: 1157-1182.

MEDEIROS DBA & VASCONCELOS PFC. 2019. Is the brazilian diverse environment is a crib for the emergence and maintenance of exotic arboviruses? An Acad Bras Cienc 91: e20190407.

MENDES A, GALVÃO P, DE SOUZA J, DA SILVA I & CARNEIRO RN. 2019. Relations of the groundwater quality and disorderly occupation in an Amazon low-income neighborhood developed over a former dump area, Santarém/PA, Brazil. Environ Dev Sustain 21: 353-368.

MENDES WS ET AL. 2009. An outbreak of bat-transmitted human rabies in a village in the Brazilian Amazon. Rev Saude Publica 43: 1075-1077.

MENESES CAR ET AL. 2019. Molecular characterisation of the emerging measles virus from Roraima state, Brazil, 2018. Mem Inst Oswaldo Cruz 114: e180545.

METCALF CJE, WALTER KS, WESOLOWSKI A, BUCKEE CO, SHEVLIAKOVA E, TATEM AJ, BOOS WR, WEINBERGER DM & PITZER VE. 2017. Identifying climate drivers of infectious disease dynamics: recent advances and challenges ahead. Proc Biol Sci B 284: 20170901.

METZGER JP ET AL. 2019. Why Brazil needs its Legal Reserves. Perspect Ecol Conser 17: 91-103.

MIDEGA JT ET AL. 2012. Wind direction and proximity to larval sites determines malaria risk in Kilifi District in Kenya. Nat Commun 3: 674.

MILNER-GULLAND EJ, BENNETT EL & THE SCB 2002 ANNUAL MEETING WILD MEAT GROUP. 2003. Wild meat: the bigger picture. Trends Ecol Evol 18: 351-357.

MIRZA MMQ. 2003. Climate change and extreme weather events: can developing countries adapt? Clim Policy 3: 233-248.

MORAES LLC, FREITAS JL, MATOS FILHO JR, SILVA RBL, BORGES CHA & SANTOS AC. 2019. Ethno-knowledge of medicinal plants in a community in the eastern Amazon. Rev de Ciências Agrárias 42: 565-573.

MORDECAI EA ET AL. 2019. Thermal biology of mosquito-borne disease. Ecol Lett 22: 1690-1708.

MORENS DM, FOLKERS GK & FAUCI AS. 2004. The challenge of emerging and re-emerging infectious diseases. Nature 430: 242-249.

MORSE SS. 1995. Factors in the emergence of infectious diseases. Emerg Infect Dis 1: 7-15.

MOSNIER E ET AL. 2018. Spatial dynamics and epidemiology for AIDS in remote areas in French Guiana. AIDS Care 31: 498-504.

NAING C, REID SA, AYE SN, HTET NH & AMBU S. 2019. Risk factors for human leptospirosis following flooding: A meta-analysis of observational studies. PLOS ONE 14: e0217643.

NAVA A, SHIMABUKURO JS, CHMURA AA & LUZ SLB. 2017. The impact of global environmental changes on infectious disease emergence with a focus on risks for Brazil. ILAR J 58: 393-400.

NEIDERUD CJ. 2015. How urbanization affects the epidemiology of emerging infectious diseases. Infect Ecol Epidemiol 5: 27060.

NEPSTAD DC, STICKLER CM, FILHO BS & MERRY F. 2008. Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. Philos Trans R Soc Lond B Biol Sci 363: 1737-1746.

NETO PLF ET AL. 2019. Syphilis among newly diagnosed therapy-naive HIV patients in Belém, Pará, Amazon region of Brazil. AIDS Res Hum Retroviruses 35: 511-512.

NICHOL ST, ARIKAWA J & KAWAOKA Y. 2000. Emerging viral diseases. Proc Natl Acad Sci USA 97: 12411-1242.

NOGUEIRA EM, YANAI AM, DE VASCONCELOS SS, GRAÇA PMLA & FEARNSIDE PM. 2018. Brazil's Amazonian protected areas as a bulwark against regional climate change. Reg Environ Change 18: 573-579.

OLIVAL KJ, HOSSEINI PR, ZAMBRANA-TORRELIO C, ROSS N, BOGICH TL & DASZAK P. 2017. Host and viral traits predict zoonotic spillover from mammals. Nature 546: 646-650.

OLIVEIRA-FERREIRA J, LACERDA MV, BRASIL P, LADISLAU JLB, TAUIL PL & DANIEL-RIBEIRO CT. 2010. Malaria in Brazil: an overview. Malar J 9: 115.

OLSON SH, GANGNON R, ELGUERO E, DURIEUX L, GUÉGAN JF, FOLEY JA & PATZ JA. 2009. Links between climate, malaria, and wetlands in the Amazon Basin. Emerg Infect Dis 15: 659-662.

OMETTO JP, AGUIAR APD & MARTINELLI LA. 2011. Amazon deforestation in Brazil: effects, drivers and challenges. Carbon Manag 2: 575-585.

ORELLANA ER, ALVA IE, CÁRCAMO CP & GARCÍA PJ. 2013. Structural factors that increase HIV/STI vulnerability among indigenous people in the Peruvian Amazon. Qual Health Res 23: 1240-1250.

PALUMBO M, JOHNSON SA, MUNDIM FM, LAU A, WOLF AC, ARUNACHALAM S, GONZALEZ O, ULRICH JL, WASHUTA A & BRUNA EM. 2012. Harnessing smartphones for ecological education, research, and outreach. Bull Ecol Soc Am 93: 390-939.

PANIZ-MONDOLFI AE ET AL. 2019. Resurgence of vaccine-preventable diseases in Venezuela as a regional public health threat in the Americas. Emerg Infect Dis 25: 625-632.

PANTOJA-LIMA J, ARIDE PHR, DE OLIVEIRA AT, FÉLIX-SILVA D, PEZZUTI JCB & REBÊLO GH. 2014. Chain of commercialization of *Podocnemis* spp. turtles (Testudines: Podocnemididae) in the Purus River, Amazon basin, Brazil: current status and perspectives. J Ethnobiol Ethnomed 10: 8.

PARRIAULT MC, VAN MELLE A, BASURKO C, GAUBERT-MARECHAL E, MACENA RHM, ROGIER S, KERR LRFS & NACHER M. 2015. HIV-testing among female sex workers on the border between Brazil and French Guiana: the need for targeted interventions. Cad Saude Publica 31: 1615-1622.

PALATNIK-DE-SOUSA CB & DAY MJ. 2011. One Health: the global challenge of epidemic and endemic leishmaniasis. Parasit Vectors 4: 197.

PATZ JA ET AL. 2004. Unhealthy landscapes: Policy recommendations on land use change and infectious disease emergence. Environ Health Perspect 112: 1092-1098.

PATZ JA, GRACZYK TK, GELLER N & VITTOR AY. 2000. Effects of environmental change on emerging parasitic diseases. Int J Parasitol 30: 1395-1405.

PEREIRA EJAL, FERREIRA PJS, RIBEIRO LCS, CARVALHO TS & PEREIRA HBB. 2019. Policy in Brazil (2016–2019) threaten conservation of the Amazon rainforest. Environ Sci Policy 100: 8-12.

PERES CA, GARDNER TA, BARLOW J, ZUANON J, MICHALSKI F, LEES AC, VIEIRA ICG, MOREIRA FMS & FEELEY KJ. 2010. Biodiversity conservation in human-modified Amazonian forest landscapes. Biol Conserv 143: 2314-2327.

PÉRES WE, RUSSO A & NUNES B. 2019. The association between hydro-meteorological events and leptospirosis hospitalizations in Santa Catarina, Brazil. Water 11: 1052.

PERNET O ET AL. 2014. Evidence for henipavirus spillover into human populations in Africa. Nat Commun 5: 5342.

PETERSON AT ET AL. 2017. Influences of climate change on the potential distribution of *Lutzomyia longipalpis* sensu lato (Psychodidae: Phlebotominae). Int J Parasitol 47: 667-674.

PIGNATTI MG. 2004. Saúde e ambiente: as doenças emergentes no Brasil. Ambient Soc 7: 133-147.

PINHEIRO FP, BENSABATH G, ANDRADE AHP, LINS ZC, FRAIHA H, TANG AT, LAINSON R, SHAW JJ & AZEVEDO MC. 1974. Infectious diseases along Brazil's Trans-Amazon highway: surveillance and research. Bull Pan Am Health Organ 8: 111-122.

PLOWRIGHT RK, PARRISH CR, MCCALLUM H, HUDSON PJ, KO AI, GRAHAM AL & LLOYD-SMITH JO. 2017. Pathways to zoonotic spillover. Nat Rev Microbiol 15: 502-510.

PONGSIRI MJ, ROMAN J, EZENWA WO, GOLDBERG TL, KOREN HS, NEWBOLD SC, OSTFELD RS, PATTANAYAK SK & SALKELD DJ. 2009. Biodiversity loss affects global disease ecology. BioScience 59: 945-954.

POWELL JL. 2015. Climate scientists virtually unanimous: anthropogenic global warming is true. Bull Sci Technol Soc 35: 121-124.

PRADO T & MIAGOSTOVICH MP. 2014. Virologia ambiental e saneamento no Brasil: uma revisão narrativa. Cad Saude Publica 30: 1367-1378.

PREVEDELLO JA, WINCK GR, WEBER MM, NICHOLS E & SINERVO B. 2019. Impacts of forestation and deforestation on local temperature across the globe. PLoS One 14: e0213368.

RAO VB, MANEESHA K, SRAVYA P, FRANCHITO SH, DASARI H & GAN MA. 2019. Future increase in extreme El Nino events under greenhouse warming increases Zika virus incidence in South America. NPJ Clim Atmos Sci 2: 4.

REUVENY R. 2007. Climate change-induced migration and violent conflict. Political Geogr 26: 656-673.

REZENDE IM ET AL. 2018. Persistence of Yellow fever virus outside the Amazon Basin, causing epidemics in Southeast Brazil, from 2016 to 2018. PLoS Negl Trop Dis 12: e0006538.

RIDDE V, BENMARHNIA T, BONNET E, BOTTGER C, CLOOS P, DAGENAIS C, DE ALLEGRI M, NEBOT A, QUEUILLE L & SARKER M. 2019. Climate change, migration and health systems resilience: Need for interdisciplinary research. F1000Research 8: 22.

RODRIGUES MT, HENZEL A, STAGGEMEIER R, DE QUEVEDO DM, RIGOTTO C, HEINZELMANN L, DO NASCIMENTO CA & SPILKI FR. 2015. Human adenovirus spread, rainfalls, and the occurrence of gastroenteritis cases in a Brazilian basin. Environ Monit Assess 187: 720.

ROTUREAU B, JOUBERT M, CLYTI E, DJOSSOU F & CARME B. 2006. Leishmaniasis among gold miners, French Guiana. Emerg Infect Dis 12: 1169-1170.

SAKKAS H, BOZIDIS P, FRANKS A & PAPADOPOULOU C. 2018. Oropouche fever: a review. Viruses 10: E175.

SAMUEL GH, ADELMAN ZN & MYLES KM. 2016. Temperature-dependent effects on the replication and transmission of arthropod-borne viruses in their insect hosts. Curr Opin Insect Sci 16: 108-113.

SANCHEZ JF, CARNERO AM, RIVERA E, ROSALES LA, BALDEVIANO GC, ASENCIOS JL, EDGEL KA, VINETZ JM & LESCANO AG. 2017. Unstable malaria transmission in the southern Peruvian Amazon and its association with gold mining, Madre de Dios, 2001-2012. Am J Trop Med Hyg 96: 304-311.

SANCHEZ-RIBAS J, PARRA-HENAO G & GUIMARÃES AÉ. 2012. Impact of dams and irrigation schemes in Anopheline (Diptera: Culicidae) bionomics and malaria epidemiology. Rev Inst Med Trop Sao Paulo 54: 179-191.

SANTOS VRC, MEIS J, SAVINO W, ANDRADE JAA, VIEIRA JRS, COURA JR & JUNQUEIRA ACV. 2018. Acute Chagas disease in the state of Pará, Amazon Region: is it increasing? Mem Inst Oswaldo Cruz 113: e170298.

SCHEFFRAN J, BRZOSKA M, KOMINEK J, LINK PM & SCHILLING J. 2012. Climate change and violent conflict. Science 336: 869-871.

SCHNEIDER MC, ARON J, SANTOS-BURGOA C, UIEDA W & RUIZ-VELAZCO S. 2001. Common vampire bat attacks on humans in a village of the Amazon region of Brazil. Cad Saúde Pública 17: 1531-1536.

SCHULER-FACCINI L ET AL. 2016. Possible association between Zika virus infection and microcephaly - Brazil, 2015. MMWR Morb Mortal Wkly Rep 65: 59-62.

SEGURADO AC, CASSENOTE AJ & LUNA EA. 2016. Saúde nas metrópoles - Doenças infecciosas. Estud Av 30: 29-49.

SENA A, CORVALAN C & EBI K. 2014. Climate change, extreme weather and climate events, and health impacts. In: Global Environmental Change. Handbook of Global Environmental Pollution, v. 1, Springer, Dordrecht, the Netherlands, p. 605-613.

SEO M, CHAI JY, KIM MJ, SHIM SY, KI HC & SHIN DH. 2016. Detection trend of helminth eggs in the strata soil samples from ancient historic places of Korea. Korean J Parasitol 54: 555-563.

SEYMOUR F & HARRIS NL. 2019. Reducing tropical deforestation. Science 365: 756-757.

SHUKLA J, NOBRE C & SELLERS P. 1990. Amazon deforestation and climate change. Science 247: 1322-1325.

SHUMAN EK. 2010. Global climate change and infectious diseases. N Engl J Med 362: 1061-1063.

SILVA FB ET AL. 2019. Climate drivers of hospitalizations for mycoses in Brazil. Sci Rep 9: 6902.

SILVA H. 2006. A saúde humana e a Amazônia no século XXI: reflexões sobre os objetivos do milênio. Novos Cadernos NAEA 9: 77-94.

SMITH NJH. 1982. Rainforest Corridors: The Transamazon Colonization Scheme. University of California Press, Berkeley, California, U.S.A, 248 p.

SOARES HS, BARBIERI ARM, MARTINS TF, MINERVINO AHH, DE LIMA JTR, MARCILI A, GENNARI SM & LABRUNA MB. 2015. Ticks and rickettsial infection in the wildlife of two regions of the Brazilian Amazon. Exp Appl Acarol 65: 125-140.

SONTER LJ, HERRERA D, BARRETT DJ, GALFORD GL, MORAN CJ & SOARES-FILHO BS. 2017. Mining drives extensive deforestation in the Brazilian Amazon. Nat Commun 8: 1013.

SORRIBAS MV, PAIVA RCD, MELACK JM, BRAVO JM, JONES C, CARVALHO L, BEIGHLEY E, FORSBERG B & COSTA MH. 2016. Projections of climate change effects on discharge and inundation in the Amazon basin. Clim Change 136: 555-570.

SOUSA JÚNIOR AS, PALÁCIOS VRCM, MIRANDA CS, COSTA RJF, CATETE CP, CHAGASTELES EJ, PEREIRA ALRR & GONÇALVES NV. 2017. Space-temporal analysis of Chagas disease and its environmental and demographic risk factors in the municipality of Barcarena, Pará, Brazil. Rev Bras Epidemiol 20: 742-755.

SOUTHWORTH J, MARSIK M, QIU Y, PERZ S, CUMMING G, STEVENS F, ROCHA K, DUCHELLE A & BARNES G. 2011. Roads as drivers of change: trajectories across the tri-national frontier in MAP, the southwestern Amazon. Remote Sens 3: 1047-1066.

SOUTO WMS, LIMA RN & SOUSA BFCF. 2019. Illegal bushmeat hunting and trade dynamics in a major road-hub region of the Brazilian Mid North. Indian J Tradit Know 18: 402-411.

SOUZA EA, SILVA-NUNES M, MALAFRONTE RS, MUNIZ PT, CARDOSO MA & FERREIRA MU. 2007. Prevalence and spatial distribution of intestinal parasitic infections in a rural Amazonian settlement, Acre State, Brazil. Cad Saude Publica 23: 427-434.

SOUZA PF, XAVIER DR, SUAREZ MUTIS MC, DA MOTA JC, PEITER PC, DE MATOS VP, MAGALHÃES MAFM & BARCELLOS C. 2019. Spatial spread of malaria and economic frontier expansion in the Brazilian Amazon. PLoS One 14: e0217615.

SPILKI FR. 2015. Crise hídrica, saúde e parâmetros de qualidade microbiológica da água no Brasil. Revista USP 106: 71-78.

STAGGEMEIER R, ALMEIDA SEM & SPILKI FR. 2011. Methods of virus detection in soils and sediments. Virus Rev Res 16: 16-22.

STERN AM & MARKEL H. 2004. International efforts to control infectious diseases, 1851 to the present. J Amer Med Assoc 292: 1474-1479.

STOY PC. 2018. Deforestation intensifies hot days. Nat Clim Change 8: 366-368.

SUFFREDINI IB, SADER HS, GONÇALVES AG, REIS AO, GALES AC, VARELLA AD & YOUNES RN. 2004. Screening of antibacterial extracts from plants native to the Brazilian Amazon Rain Forest and Atlantic Forest. Braz J Med Biol Res 37: 379-384.

TADA MS, MARQUES RP, MESQUITA E, DALLA MARTHA RC, RODRIGUES JA, COSTA JDN, PEPELASCOV RR, KATSURAGAWA TH & PEREIRA-DA-SILVA LH. 2007. Urban malaria in the Brazilian Western Amazon Region I: high prevalence of asymptomatic carriers in an urban riverside district is associated with a high level of clinical malaria. Mem Inst Oswaldo Cruz 102: 263-269.

TAKKEN W, VILARINHOS PTR, SCHNEIDER P & SANTOS F. 2005. Effects of environmental change on malaria in the Amazon region of Brazil. In: Takken W, Martens P & Bogers RJ (Eds), Environmental Change and Malaria Risk: Global and Local Implications. Springer Netherlands, 2005. p. 113-123.

TATEM AJ, ROGERS DJ & HAY SI. 2006. Global transport networks and infectious disease spread. Adv Parasitol 62: 293-343.

TAUIL PL. 2006. Perspectives of vector borne diseases control in Brazil. Rev Soc Bras Med Trop 39: 275-277.

TAYLOR LH, LATHAM SM & WOOLHOUSE MEJ. 2001. Risk factors for human disease emergence. Phil Trans R Soc Lond B 356: 983-989.

TERÇAS-TRETTEL ACP ET AL. 2019. Malaria and hantavirus pulmonary syndrome in gold mining in the Amazon region, Brazil. Int J Environ Res Public Health 16: E1852.

TESLA B, DEMAKOVSKY LR, MORDECAI EA, RYAN SJ, BONDS MH, NGONGHALA CN, BRINDLEY MA & MURDOCK CC. 2018. Temperature drives Zika virus transmission: evidence from empirical and mathematical models. Proc Biol Sci 285: 20180795.

TIAN H ET AL. 2018. Urbanization prolongs hantavirus epidemics in cities. Proc Natl Acad Sci USA 115: 4707-4712.

TUCKER LIMA JM, VITTOR A, RIFAI S & VALLE D. 2017. Does deforestation promote or inhibit malaria transmission in the Amazon? A systematic literature review and critical appraisal of current evidence. Philos Trans R Soc Lond B Biol Sci 372: 20160125.

TUNDISI JG, GOLDEMBERG J, MATSUMURA-TUNDISI T & SARAIVA ACF. 2014. How many more dams in the Amazon? Energy Policy 74: 703-708.

UHART M ET AL. 2013. A 'One Health' approach to predict emerging zoonoses in the Amazon. In: Saúde Silvestre e Humana: Experiências e Perspectivas. Rio de Janeiro, FIOCRUZ, p. 65-73.

VALLI M & BOLZANI VS. 2019. Natural products: perspectives and challenges for use of Brazilian plant species in the bioeconomy. An Acad Bras Cienc 91: e20190208.

VAN VLIET N, QUICENO-MESA MP, CRUZ-ANTIA D, DE AQUINO LLN, MORENO J & NASI R. 2014. The uncovered volumes of bushmeat commercialized in the Amazonian trifrontier between Colombia, Peru & Brazil. Ethnobio Conserv 3: 7.

VARGA I VAN D. 2007. Fronteiras da urbanidade sanitária: sobre o controle da malária. Saúde Soc 16: 28-44.

VARGAS A, ROMANO APM & MERCHÁN-HAMANN E. 2019. Human rabies in Brazil: a descriptive study, 2000-2017. Epidemiol Serv Saude 28: e2018275.

VASCONCELOS PFC, TRAVASSOS DA ROSA APA, RODRIGUES SG, TRAVASSOS DA ROSA ES, DÉGALLIER N & TRAVASSOS DA ROSA JFS. 2001. Inadequate management of natural ecosystem in the Brazilian Amazon region results in the emergence and reemergence of arboviruses. Cad Saude Publica 17: 155-164.

VIANA ALD'A ET AL. 2007. Sistema de saúde universal e território: desafios de uma política regional para a Amazônia Legal. Cad Saude Publica 23: S117-S131.

VIANA RL, DE FREITAS CM & GIATTI LL. 2016. Environmental health and development in legal amazon: socio-economic, environmental and sanitary indicators, challenges and perspectives. Saude Soc 25: 233-246.

VIEIRA CB, DE ABREU CORRÊA A, DE JESUS MS, LUZ SLB, WYN-JONES P, KAY D, VARGHA M & MIAGOSTOVICH MP. 2016. Viruses surveillance under different season scenarios of the Negro river Basin, Amazonia, Brazil. Food Environ Virol 8: 57-69.

VIEIRA CB, DE ABREU CORRÊA A, DE JESUS MS, LUZ SLB, WYN-JONES P, KAY D, ROCHA MS & MIAGOSTOVICH MP. 2017. The impact of the extreme Amazonian flood season on the incidence of viral gastroenteritis cases. Food Environ Virol 9: 195-207.

VITTOR AY, GILMAN RH, TIELSCH J, GLASS G, SHIELDS T, LOZANO WS, PINEDO-CANCINO V & PATZ JA. 2006. The effect of deforestation on the human-biting rate of *Anopheles darlingi*, the primary vector of Falciparum malaria in the Peruvian Amazon. Am J Trop Med Hyg 74: 3-11.

VLAHOV D, GALEA S & FREUDENBERG N. 2005. Toward an urban health advantage. J Public Health Manag Pract 11: 256-258.

VON KONRAT M ET AL. 2018. Using citizen science to bridge taxonomic discovery with education and outreach. Appl Plant Sci 6: e1023.

WALDMAN E. 2001. Doenças infecciosas emergentes e reemergentes. Revista USP 51: 128-137.

WALKER JW, HAN BA, OTT IM & DRAKE JM. 2018. Transmissibility of emerging viral zoonoses. PLOS ONE 13: e0206926.

WATTS N ET AL. 2015. Health and climate change: policy responses to protect public health. Lancet 386: 1861-1914.

WATTS N ET AL. 2018. The *Lancet* Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. Lancet 391: 581-630.

WEAVER HJ, HAWDON JM & HOBERG EP. 2010. Soil-transmitted helminthiases: implications of climate change and human behavior. Trends Parasitol 26: 574-581.

WEISS RA & MCMICHAEL AJ. 2004. Social and environmental risk factors in the emergence of infectious diseases. Nat Med 10: S70-S76.

WERTH D & AVISSAR R. 2002. The local and global effects of Amazon deforestation. J Geophys Res Atmos 107: LBA55-1-LBA55-8.

WEST TAP, BÖRNER J & FEARNSIDE PM. 2019. Climatic benefits from the 2006–2017 avoided deforestation in Amazonian Brazil. Front Forests Glob Change 2: 52.

WHITEMAN CW, MATUSHIMA ER, CONFALONIERI UEC, PALHA MDC, DA SILVA ASL & MONTEIRO VC. 2007. Human and domestic animal populations as a potential threat to wild carnivore conservation in a fragmented landscape from the Eastern Brazilian Amazon. Biol Conserv 138: 290-296.

WILCOX BA & ELLIS B. 2006. Forests and emerging infectious diseases of humans. Unasylva 57: 11-18.

WILKINSON DA, MARSHALL JC, FRENCH NP & HAYMAN DTS. 2018. Habitat fragmentation, biodiversity loss and the risk of novel infectious disease emergence. J R Soc Interface 15: 20180403.

WOLFARTH-COUTO B, SILVA RAD & FILIZOLA N. 2019. Variability in malaria cases and the association with rainfall and rivers water levels in Amazonas State, Brazil. Cad Saude Pública 35: e00020218.

WOLFE ND ET AL. 2004. Naturally acquired simian retrovirus infections in central African hunters. Lancet 363: 932-937.

WOLFE ND ET AL. 2005b. Emergence of unique primate T-lymphotropic viruses among central African bushmeat hunters. Proc Natl Acad Sci USA 102: 7994-7999.

WOLFE ND, DASZAK P, KILPATRICK AM & BURKE DS. 2005a. Bushmeat hunting, deforestation, and prediction of zoonoses emergence. Emerg Infect Dis 11: 1822-1827.

WOOD CL, MCINTURFF A, YOUNG HS, KIM D & LAFFERTY KD. 2017. Human infectious disease burdens decrease with urbanization but not with biodiversity. Philos Trans R Soc Lond B Biol Sci 372: 20160122.

WU X, LU Y, ZHOU S, CHEN L & XU B. 2016. Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. Environ Int 86: 14-23.

ZAHOULI JBZ, KOUDOU BG, MÜLLER P, MALONE D, TANO Y & UTZINGER J. 2017. Urbanization is a main driver for the larval ecology of *Aedes* mosquitoes in arbovirus-endemic settings in south-eastern Côte d'Ivoire. PLoS Negl Trop Dis 11: e0005751.

ZANELLA JRC. 2016. Zoonoses emergentes e reemergentes e sua importância para saúde e produção animal. Pesq Agropec Bras 51: 510-519.

ZAVALETA C, FERNÁNDEZ C, KONDA K, VALDERRAMA Y, VERMUND SH & GOTUZZO E. 2007. High prevalence of HIV and syphilis in a remote native community of the Peruvian Amazon. Am J Trop Med Hyg 76: 703-705.

How to cite

ELLWANGER JH ET AL. 2020. Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health. An Acad Bras Cienc 92: e20191375. DOI 10.1590/0001-3765202020191375.

Manuscript received on November 8, 2019;
accepted for publication on February 17, 2020

JOEL HENRIQUE ELLWANGER[1]
https://orcid.org/0000-0002-1040-2738

BRUNA KULMANN-LEAL[1]
https://orcid.org/0000-0002-4959-4087

VALÉRIA L. KAMINSKI[1]
https://orcid.org/0000-0002-2731-0653

JACQUELINE MARÍA VALVERDE-VILLEGAS[2]
https://orcid.org/0000-0001-9446-3521

ANA BEATRIZ G. DA VEIGA[3]
https://orcid.org/0000-0003-1462-5506

FERNANDO R. SPILKI[4]
https://orcid.org/0000-0001-5804-7045

PHILIP M. FEARNSIDE[5]
https://orcid.org/0000-0003-3672-9082

LÍLIAN CAESAR[6]
https://orcid.org/0000-0002-9527-9125

LEANDRO LUIZ GIATTI[7]
https://orcid.org/0000-0003-1154-6503

GABRIEL L. WALLAU[8]
https://orcid.org/0000-0002-1419-5713

SABRINA E.M. ALMEIDA[4,9]
https://orcid.org/0000-0003-3599-8520

MAURO R. BORBA[10]
https://orcid.org/0000-0003-0336-5040

VANUSA P. DA HORA[11]
https://orcid.org/0000-0001-9602-9876

JOSÉ ARTUR B. CHIES[1]
https://orcid.org/0000-0001-7025-0660

[1]Universidade Federal do Rio Grande do Sul/UFRGS, Laboratório de Imunobiologia e Imunogenética, Programa de Pós-Graduação em Genética e Biologia Molecular (PPGBM), Departamento de Genética, Campus do Vale, Avenida Bento Gonçalves, 9500, Bairro Agronomia, 91501-970 Porto Alegre, RS, Brazil

[2]University of Montpellier, Pathogenesis and Control of Chronic Infections (PCCI), Research Unit 1058, Institut National de la Santé et de la Recherche Médicale (INSERM), Établissement Français du Sang, 60 Rue de Navacelles, 34394, Montpellier Cedex 5, Montpellier, France

[3]Universidade Federal de Ciências da Saúde de Porto Alegre/UFCSPA, Rua Sarmento Leite, 245, Centro Histórico, 90050-170 Porto Alegre, RS, Brazil

[4]Universidade Feevale, Laboratório de Saúde Única, Mestrado Acadêmico em Virologia, Instituto de Ciências da Saúde, Rodovia ERS-239, 2755, Bairro Vila Nova, 93525-075 Novo Hamburgo, RS, Brazil

[5]Instituto Nacional de Pesquisas da Amazônia/INPA, Avenida André Araújo, 2936, Aleixo, 69067-375 Manaus, AM, Brazil

[6]Universidade Federal do Rio Grande do Sul/UFRGS, Laboratório de Genômica Evolutiva e Parasitismo,

Programa de Pós-Graduação em Genética e Biologia Molecular (PPGBM), Departamento de Genética, Campus do Vale, Avenida Bento Gonçalves, 9500, Bairro Agronomia, 91501-970 Porto Alegre, RS, Brazil

[7]Universidade de São Paulo/USP, Faculdade de Saúde Pública, Avenida Dr. Arnaldo, 715, Cerqueira César, 01246-904 São Paulo, SP, Brazil

[8]Fundação Oswaldo Cruz/FIOCRUZ, Departamento de Entomologia, Instituto Aggeu Magalhaes, Avenida Professor Moraes Rego, s/n, Cidade Universitária, 50740-465 Recife, PE, Brazil

[9]Universidade Feevale, Laboratório de Genética e Biologia Molecular, Programa de Pós-Graduação em Qualidade Ambiental, Instituto de Ciências da Saúde, Rodovia ERS-239, 2755, Bairro Vila Nova, 93525-075 Novo Hamburgo, RS, Brazil

[10]Universidade Federal do Rio Grande do Sul/UFRGS, Saúde Unificada, Departamento de Medicina Veterinária Preventiva, Faculdade de Veterinária, Avenida Bento Gonçalves, 9090, Bairro Agronomia, 91540-000 Porto Alegre, RS, Brazil

[11]Universidade Federal do Rio Grande/FURG, Laboratório de Biologia Molecular, Programa de Pós-Graduação em Ciências da Saúde, Faculdade de Medicina, Rua Visconde de Paranaguá, 102, Centro, 96203-900 Rio Grande, RS, Brazil

Correspondence to: **Joel Henrique Ellwanger**
E-mail: joel.ellwanger@gmail.com

Author contributions

JHE wrote the initial version of the article. BKL revised the content of the initial version of the article. JHE, BKL, VLK, JMVV, ABGV, FRS, PMF, LC, LLG, GLW, SEMA, MRB, VPH and JABC contributed with opinions on the content of the article and writing the text. JHE and JABC coordinated the work, revised and edited the text. All authors approved the final version of the article.