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The COVID-19 crisis and Amazonia's indigenous people: Implications for conservation and global health

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ABSTRACT

Ecosystem health and zoonotic diseases are closely interwoven. Even as we grapple with the SARS-Coronavirus-2 pandemic, which may have its origins in wildlife, weakening environmental policies in the Brazilian Amazon are elevating the risk of additional zoonotic spillover events. We examine the links between deforestation and disease emergence in the Amazon, as illustrated by outbreaks of yellow fever virus, Venezuelan equine encephalitis virus, and Oropouche virus. It has been well established that in Brazil, indigenous territories exhibit lower rates of forest conversion and degradation than in areas designated for sustainable use. In this way, Amazonia's indigenous tribes promote public health while sustaining ecosystem services. However, indigenous land rights are under attack due to current policies enabling illegal land grabbing, mining and logging. Further adding to the existential struggle of indigenous tribes, malaria and SARS-Coronavirus-2 are wreaking havoc on these vulnerable populations. There is a critical need for protection of indigenous people's rights and health, as well as a sustained effort to support the study of mechanisms underlying anthropogenic land use change and zoonotic disease risk.

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The origins of the Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2) pandemic appear to lie in nature. Current evidence suggests that the virus may have originated in the horseshoe bat, after which it migrated to an intermediate host, prior to spilling over into the human population (Andersen, Rambaut, Lipkin, Holmes, & Garry, 2020; Lam et al., 2020; Liu, Chen, & Chen, 2019; Zhang, Wu, & Zhang, 2020). This is by no means an isolated event. Not only did two other pathogenic coronaviruses, SARS and MERS, emerge in a similar fashion, but a long list of pathogens has recently emerged or re-emerged into the human population following introduction from wildlife. This list includes diseases that have significantly impacted the public's health in recent years, such as Zika virus, West Nile virus, Ebola virus, *Borrelia burgdorferi* (causative agent of Lyme disease), Yellow Fever virus, malaria, and HIV. Given this trend, it is of paramount importance to identify the drivers of such spillover events. Though the detailed mechanisms underlying spillover are often elusive, in broad terms, these drivers comprise human incursions into wilder-

ness, wildlife trade, and intensification of animal husbandry (Horby, Pfeiffer, & Wertheim, 2014).

In general, tropical humid forests are repositories of the majority of Earth's plant, fungal, animal and microbial species. As a consequence, land cover change in this region threatens biodiversity at the same time as it provides opportunities for the expansion of generalist species that adapt to anthropogenic conditions (Johnson et al., 2020). These generalist species, such as rodents, have been linked to higher probabilities of harboring pathogens shared by humans due to their abundance and proximity to human dwellings (Johnson et al., 2020). Land cover change in tropical forests is of particular concern because it involves the full spectrum of drivers of zoonotic spillovers just mentioned. In the Amazonian case, the specific changes in question involve deforestation, pasture expansion, habitat fragmentation, and forest destruction associated with agricultural fires.

From 2009 to 2019, a global initiative to surveil for zoonotic spillover events and build capacity (PREDICT, funded by the United States Agency for International Development (USAID)) detected nearly 1200 wildlife viruses with the capacity to infect humans (UC-Davis, 2020). Funding for this program was not renewed under President Trump, though due to opposing voices it was granted a six month emergency extension (Cohen, 2020). Following the emergence of SARS-Cov-2, a new program sponsored by USAID

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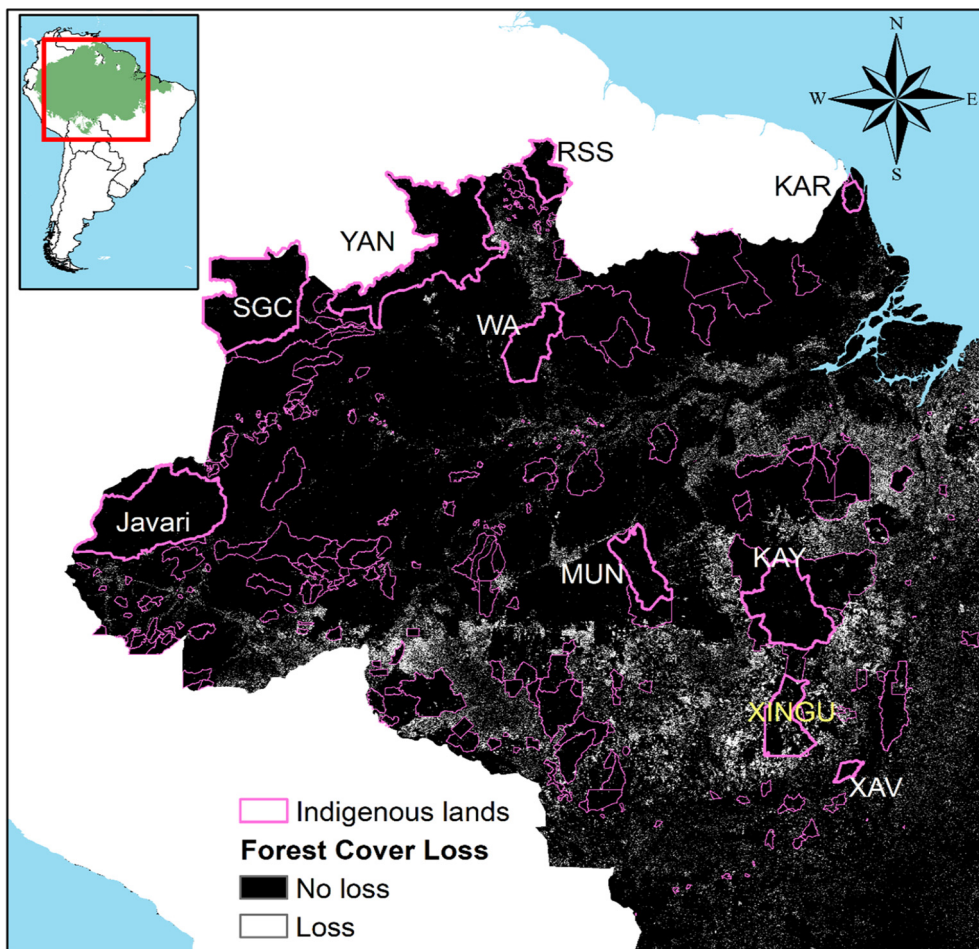


Fig. 1. Indigenous lands and forest cover loss from 2000 to 2017. Indigenous areas have retained more their forest cover in comparison with adjacent non-indigenous areas. The selected indigenous lands are: Javari, Vale do Javari; SGC, São Gabriel da Cachoeira; YAN, The Yanomami’s indigenous land; RSS, Raposa Serra do Sol; KAR, The Karipuna’s indigenous land; WA, The Waimiri-Atoari’s indigenous land; MUN, The Mundukuru’s indigenous land; KAY, The Kayapó’s indigenous land; XINGU, The Xingu indigenous reserve; and XAV, The Xavantes’ indigenous land.

(STOP SPILLOVER) will focus on leveraging the data collected during PREDICT to develop interventions to prevent spillover of key pathogens. This new initiative, however, does not include the Amazon basin (or Latin America), which has long been subject to land cover change in the form of deforestation and presents a significant, zoonotic threat given its myriad of potential pathogens.

Yellow fever (Barrett, 2018), Oropouche (Romero-Alvarez & Escobar, 2018), Venezuelan equine encephalitis (Aguilar et al., 2011; Vittor et al., 2016) and Mayaro (Esposito & Fonseca, 2017) are examples of wildlife diseases that have caused recent human outbreaks in the Amazon basin. These viruses have a jungle (sylvatic) cycle involving forest-dwelling vertebrates and arthropods. Bridge vectors that occupy forest edges and villages can infect humans dwelling in rural and suburban areas. In the case of yellow fever, the urban mosquito *Aedes aegypti* can then cause the virus to become established in a human-mosquito domestic cycle, resulting in explosive epidemics. For example, between 2016 and 2018, South America saw the largest yellow fever virus outbreak in over 80 years (Barrett, 2018). Brazil, the most affected country, had more than 1500 human yellow fever cases, a third of which were fatal, as well as over 4000 nonhuman primate cases (PAHO, 2018).

Oropouche, Mayaro, and Venezuelan equine encephalitis viruses have also increased in frequency and geographic range. Tome’s spiny rat (*Proechimys semispinosus*), known to harbor Venezuelan equine encephalitis virus, is widely found in tropical forests in the Americas and readily occupies disturbed forest and

forest fragments (Adler, Tomblin, & Lambert, 1998; Lambert & Adler, 2000; Vittor et al., 2016). Another rodent species that may play a role in viral transmission in Panama, the short-tailed cane mouse (*Zygodontomys brevicauda*), prefers habitat on the edge of forest and abutting cattle pasture (Passos Cordeiro & Oliveira, 2005). As deforestation in this region progresses, these two rodents occupy different ecological niches, ranging from intact forest, forest fragments, cattle pastures, and the regrowth that arises when fields lie fallow. Furthermore, the mosquito vectors also occupy this spectrum of habitats (Loaiza et al., 2017). Thus, these versatile hosts and vectors bring the virus in close proximity to humans and their livestock.

The risk of zoonoses emerging from the Amazon is especially alarming considering weakening environmental governance in Brazil. Together with climate change, this has contributed to an alarming rise in uncontrolled wildfires, commodity-driven forest conversion, and degradation (Brando et al., 2020). Between 2018 and 2019, deforestation in the Brazilian Amazon increased by 34% (PRODES, 2020), after having experienced a long period of relatively low levels of forest clearing. That land cover changes precipitate zoonotic spillovers is of serious concern for the South American continent, given the Amazonian deforestation that has occurred to date, and what lies ahead in the near future. This is because of a program of large-scale infrastructure development, the Initiative for the Integration of the Regional Infrastructure of South America, or IIRSA. This program, which began in 2001 under

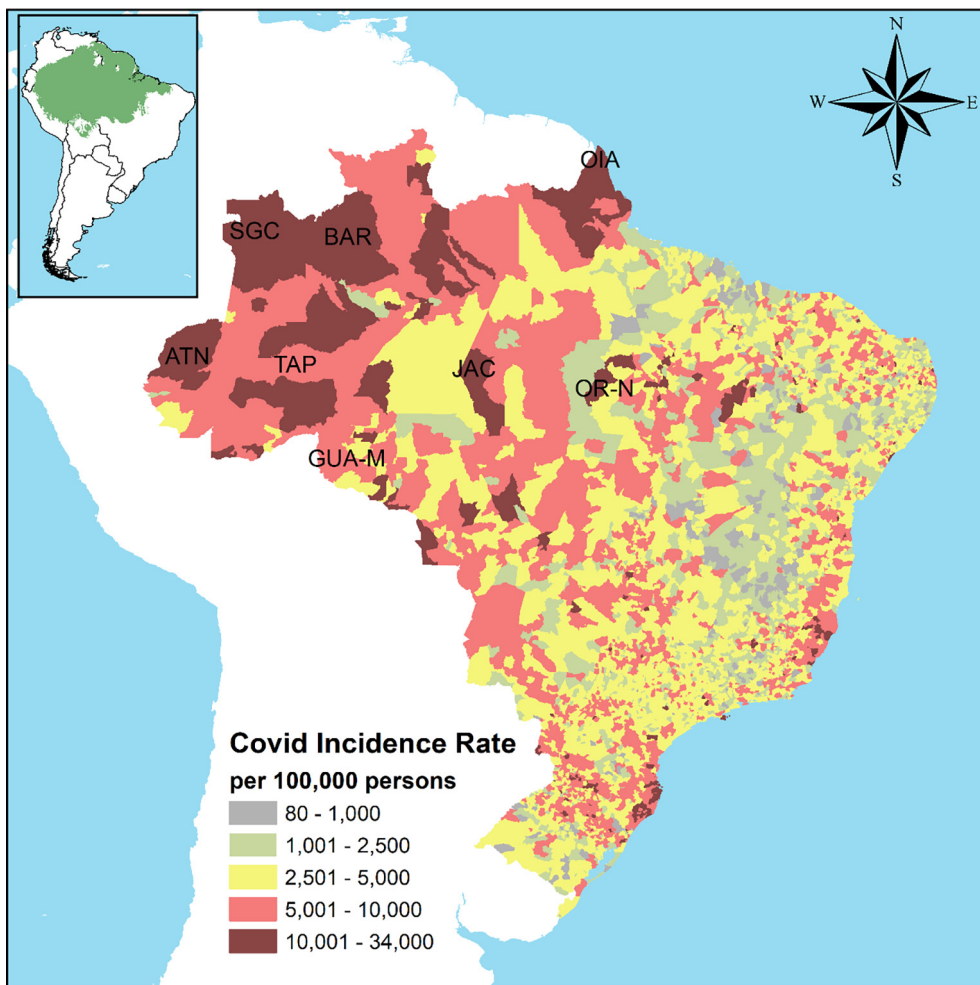


Fig. 2. Incidence rate (number of cases/100,000 persons) of SARS-CoV-2 per municipality, Brazil, February 26, 2020–February 23, 2021. Incidence rate in selected municipalities with indigenous territories and populations: SGC, São Gabriel da Cachoeira = 6189; BAR, Barcelos = 4403; OIA, Oiapoque = 5757; OR-N, Ourilândia do Norte = 4029; JAC, Jacareacanga = 4842; GUA-M, Guajara-Mirim = 3040; TAP, Tapauá = 4552; ATN, Atalaia do Norte = 2836.

the auspices of Brazilian President Henrique Cardoso, promises to connect the entire continent with rail lines, waterways, and highway. It also envisions transforming Amazonia into a transportation hub and a continental source of hydropower. IIRSA, which far exceeds the infrastructure program that opened Amazonia in the 1960s and 1970s, is likely to unleash a new wave of deforestation into parts of the Basin that have so far remained intact (Walker et al., 2019). As conversion pressures mount on the region’s tropical forests, the continent may become ever more prone to zoonotic spillover events.

Given the apparent link between deforestation and zoonotic spillovers, forest conservation provides -- in addition to its environmental benefits -- an important public health intervention. In the case of Brazil, and the Amazon in particular, this is particularly relevant given the amount of forest found in both federal and state systems of protected areas. In fact, ~40% of the Basin has a protective status of some sort, including indigenous reserves established pursuant to ratification of the Federal Constitution of 1988 (FC/88). The new constitution strengthened indigenous rights and greatly facilitated the declaration of indigenous reserves, which presently account for about half of all Amazonia’s protected areas. This represents 21% of the entire Brazilian Amazon (Le Tourneau, 2015). FC/88, in providing a constitutional basis for indigenous homelands, expressed an expectation of environmental stewardship on part of those who would occupy the newly formed reserves. The

expectation has been fulfilled, in that Amazonia’s indigenous territories exhibit lower rates of forest conversion and degradation than other conservation areas, such as national parks, forests, and settlements permitting only low intensity forest extraction. The conservation record of Amazonia’s indigenous population proves its ability to promote and protect public health while sustaining ecosystem services (Baragwanath & Bayi, 2020; Nolte, Agrawal, Silvius, & Soares, 2013; Walker et al., 2020). Here we map indigenous territories in relation to the retention of forest cover (Fig. 1) (FUNAI, 2020; Hansen et al., 2013). The selected indigenous areas in Figure 1 show that 90% (9 out of 10) retained forest cover between 2000 and 2017.

The protection of indigenous rights has often proved difficult, and there is a substantial record of incursions into indigenous territories (Le Tourneau, 2015). That said, the situation is worsening in the current political climate of Brazil. President Bolsonaro, in particular, has expressed hostility to indigenous peoples, and has effectively ended the declaration of new indigenous territories. This has given a green light to economic interests desirous of exploiting Amazonia’s vast resource wealth. The implication is that lands that had not achieved the official registration prior to the Bolsonaro administration will never do so, which effectively opens the door to the abuse of territorial rights. The political atmosphere in Brazil today has amplified the threats to indigenous peoples posed by aggressive outsiders. That a number of their homelands

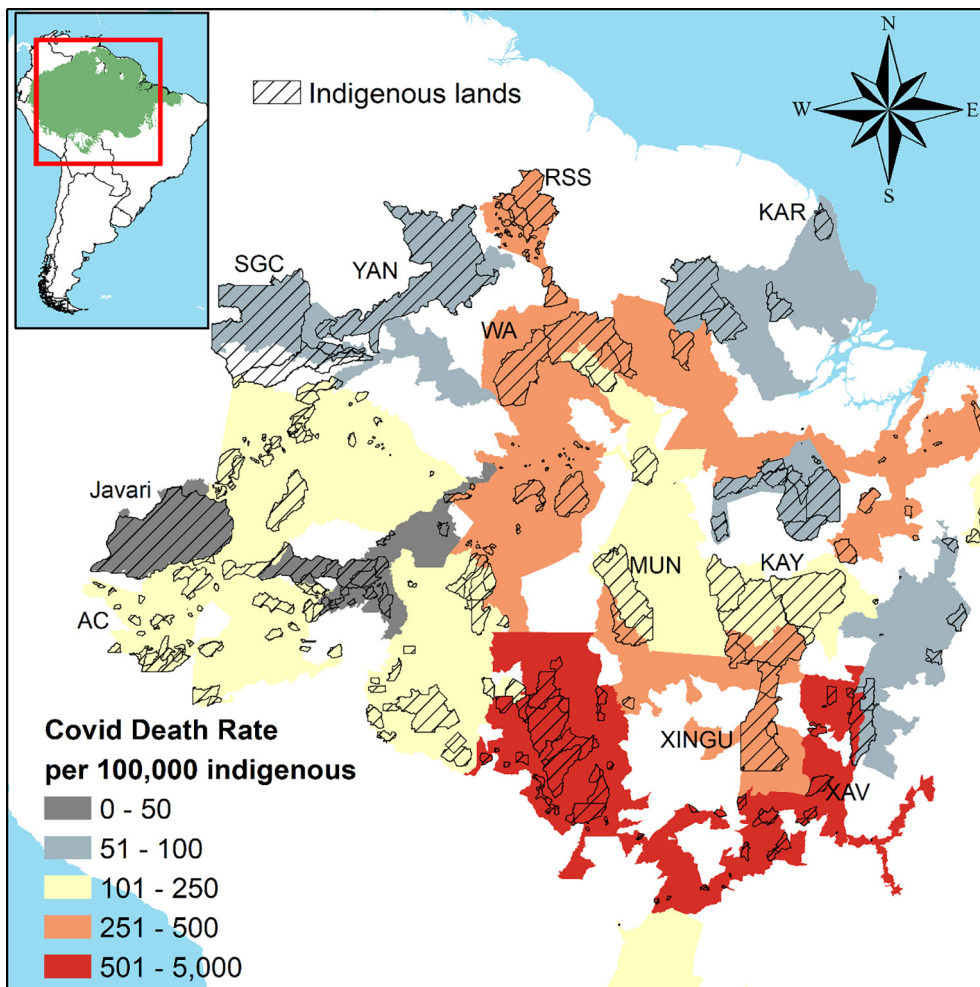


Fig. 3. COVID death rate (Saude) (confirmed deaths/100,000 indigenous persons). Indigenous population size for each DSEI was obtained from IBGE 2010 Census (IBGE), and DSEI locations were obtained from (FUNAI, 2020). The selected indigenous lands are: AC, Acre State indigenous lands; Javari, Vale do Javari; SGC, São Gabriel da Cachoeira; YAN, The Yanomami’s indigenous land; RSS, Raposa Serra do Sol; KAR, The Karipuna’s indigenous land; WA, The Waimiri-Atroari’s indigenous land; MUN, The Munduruku’s indigenous land; KAY, The Kayapó’s indigenous land; XINGU, The Xingu indigenous reserve; and XAV, The Xavantes’ indigenous land.

contain significant stores of valuable minerals only aggravates the situation. For example, the Munduruku Reserve located in Fig. 1 may hold the world’s largest gold reserve, and in 2018 an exploratory license was granted to the corporation, Vale S.A., one of the world’s largest producers of iron ore and nickel, and a leader in mining technology (Walker et al., 2019). Conflicts between economic interests and indigenous rights, long endemic to the region, have intensified, and fatalities are on the rise, especially involving indigenous leadership (Walker, 2020). Recently, new modifications to Brazil’s indigenous land policy were instituted that would facilitate the takeover of unregistered indigenous lands by commercial interests (Torres & Branford, 2020).

Further adding to the existential struggle of indigenous tribes, SARS-CoV-2 is wreaking havoc on numerous indigenous tribes (Missionario, 2020). They have been bereft of public health services, and their remote settlements are far removed from health posts and hospitals. As of March 10th, 2021, 44,461 cases with 594 deaths have occurred amongst indigenous people in the Brazilian Amazon (Saude, 2021a, Saude, 2021b). These cases and deaths, surely an undercount since they do not consider impacts on isolated tribes, are distributed in the each of the 34 Indigenous Health Districts (Distrito Sanitário Especial Indígena, DSEI) in Brazil. We mapped the SARS-CoV-2 incidence rates by municipality in Fig. 2, which demonstrates surprisingly high rates in municipalities

(Brasil.io, 2020). Using a different dataset to specifically map SARS-CoV-2 deaths amongst indigenous people in Brazil (Saude), we show in Fig. 3 that most tribes have deaths rates exceeding 50 deaths per 100,000 indigenous people (IBGE; Saude). Some of the affected areas are very remote, suggesting that illegal mining and other external incursions could be the source of introductions. To better illustrate this, illegal mining routes and major rivers are mapped in Fig. 4 (Socioambiental).

Forest land invasion for illegal mining and logging is associated with high deforestation rates and can disseminate infectious diseases to hard-to-reach indigenous tribes (Quijano Vallejos, Veit, Tipula, & Reyta, 2020). Specifically, these activities could provide transmission modes for the introduction of SARS-CoV-2 to Amazonia’s tribal peoples (Fig. 3, Fig. 4). Analogously, falciparum malaria, a disease once restricted to rural settlements in the Amazon basin between 1970 and 1990, has been reported in several indigenous territories. The Yanomami reservation, the country’s largest located on the border with Venezuela, has a high incidence of malaria (Grillet et al., 2021). Herein, we mapped a higher 2020 malaria incidence concomitantly associated with indigenous territories in the Amazon basin (Fig. 5, (Saude)). This association is likely the result of miners, loggers, poachers, drug traffickers, land grabbers, and others who can be vectors of transmission. SARS-CoV-2 could hasten the decline of tribes whose immune systems

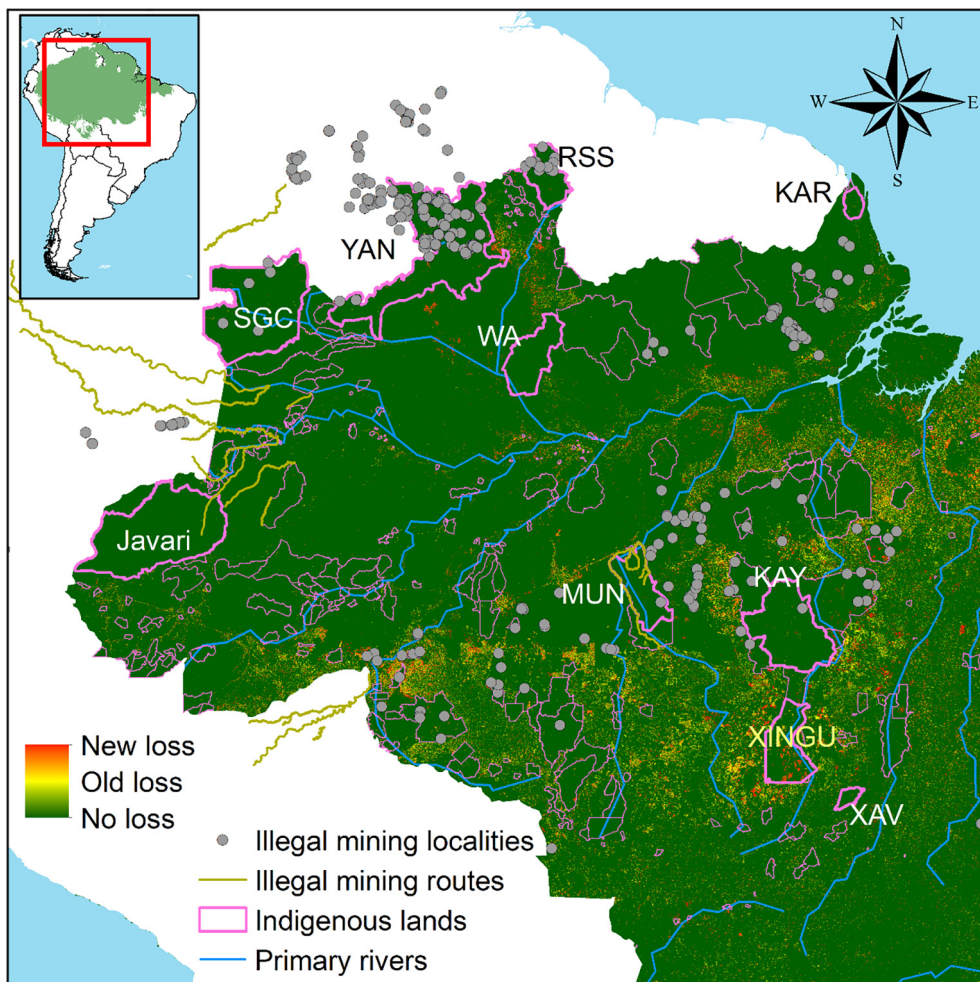


Fig. 4. Possible routes of COVID19 dissemination: rivers, recent deforestation, and illegal mining (Socioambiental).

often are already weakened by other comorbidities (Vega, Orellana, Oliveira, Hacon, & Basta, 2018; Verhagen et al., 2013) – including malaria, malnutrition and mercury poisoning, and thus contribute to a vicious cycle leading to Amazonian tropical rainforest collapse as its indigenous population is decimated.

The SARS-CoV-2 pandemic has intensified focus on zoonoses and the drivers of viral emergence events. The radical alteration of tropical forests following deforestation, coupled with the arrival of the loggers, miners, and ranchers who induce it, possibly facilitates host jumps, alters transmission dynamics, and enhances interactions between humans and wildlife. Our inadequate understanding of the exact mechanisms underlying these drivers needs to be addressed with increased funding for interdisciplinary collaborations aimed at rigorously studying these links. Along with USAID’s STOP SPILLOVER initiative, the launch of the PREZODE (Preventing Zoonotic Diseases Emergence) program at the One Planet Summit for Biodiversity 2021 is an encouraging step in this direction (FAO, 2021). Led by France and with the support of international organizations including WHO, OIE, FAO, UNEP, the World Bank, and the European Commission, PREZODE will map, assess, and mitigate the risks of zoonotic disease emergence while strengthening biodiversity (CIRAD, 2021).

However, additional measures to directly address Amazonia’s accelerating deforestation rate, the rapid erosion of indigenous territories, and the devastation of indigenous peoples from SARS-CoV-2 are needed with immediacy. At this perilous moment, it is tragic that Brazil has chosen to reverse the consolidation of indigenous rights that began with the Federal Constitution of 1988. The

nation’s environmental and indigenous policies are well conceived and have proven effective, but they are of little value in a political environment dominated by President Bolsonaro and the so-called *ruralista* bloc in the Brazilian Congress. The implication is that efforts to mitigate the epidemiological, ecological and cultural crisis now mounting in Brazil will probably have to originate from beyond its borders, at least in the short run. This raises the difficult issue of national sovereignty. Clearly, no nation on earth wishes to be told what to do, but there are exigent circumstances such as those now before us. The Inter-American court of Human Rights, founded in 1979, has adjudicated territorial conflicts in favor of indigenous peoples and so offers a potential avenue (Correia, 2018). In addition, indigenous resistance has also proven effective as, for example, in the Tapajós Valley. Here, in 2016, the Mundurucu People managed to stop a major infrastructure project with support from local offices of the Federal Judiciary and non-governmental organizations. This single feat conserved 492,000 km², the extent of the watershed, or ~7% of the entire basin (Walker et al., 2019).

Green supply chains have been advanced as one way the global community can exert some influence on deforestation activities across international borders. Evidence that they actually result in decreased deforestation is limited (Newton, Agrawal, & Wollenberg, 2013). A recent study suggests that the 2006 Amazon Soy Moratorium has been effective, crediting this policy, along with buy-in from the largest soy purchasers and effective governance, with preventing 18,000 +/- 9000 km² of deforestation (Heilmayr, Rausch, Munger, & Gibbs, 2020). However, other studies

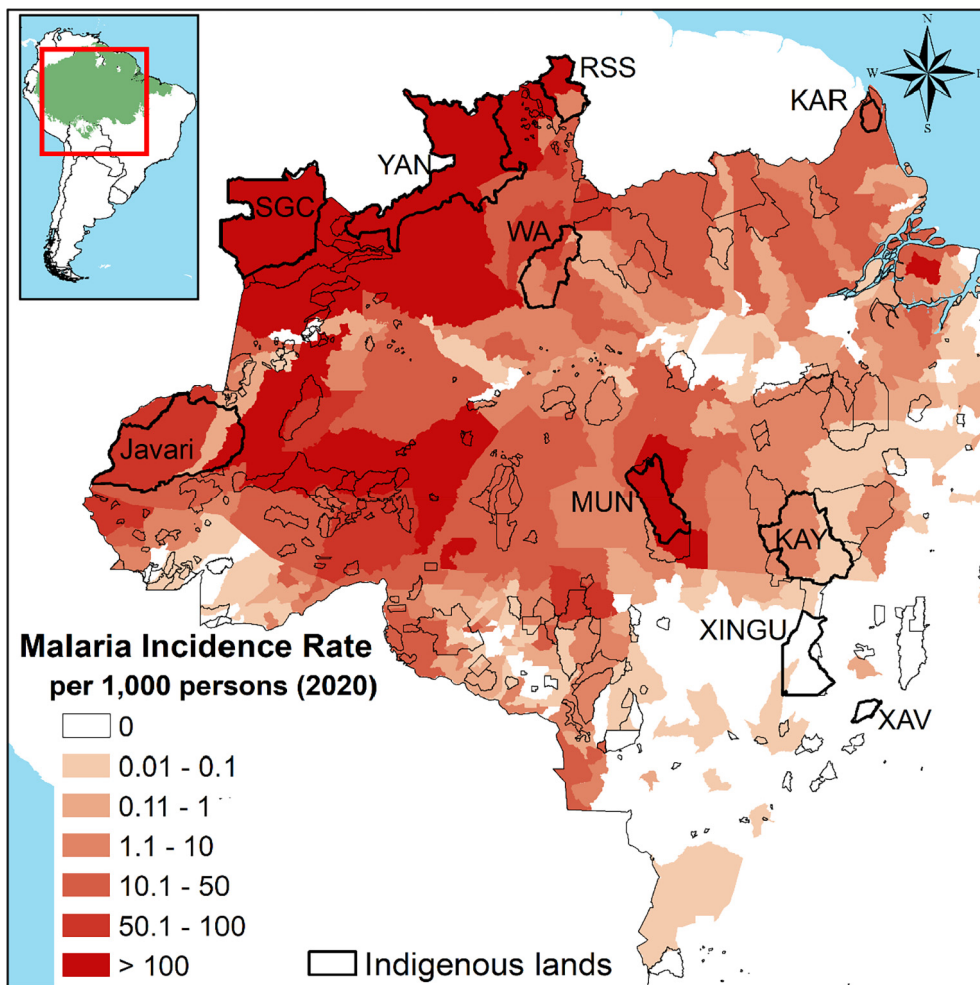


Fig. 5. Confirmed 2020 malaria cases per 1000 persons based on data from Ministry of Health (Sivep-Malaria) [57].

have shown that the moratorium has had minimal to no effect due to indirect land use change, whereby soybean fields cleared on old pastures – as per the moratorium agreement – nevertheless push ranchers into primary forest, transmitting deforestation impulses beyond the extensive margin of agriculture (Arima, Richards, Walker, & Caldas, 2011; Richards, Walker, & Arirna, 2014; Walker, 2011, 2014). Such “leakages” call into question the efficacy of supply chain interventions, which is probably a moot point, given waning political commitment from the Bolsonaro government (Carvalho et al., 2019; Heilmayr et al., 2020).

The global community has grown increasingly concerned with the possibility of a tipping point transgression, whereby deforestation and climate change would push the Amazonian forest into a different state, perhaps a tropical savanna or some new type of degraded ecosystem. Concerns have largely focused on biodiversity and carbon sequestration. If the forest disappears, biodiversity is lost together with its ability to trap carbon. We suggest that the potential for zoonotic spillover adds appreciatively to this looming disaster, and enforcement of indigenous territorial rights may hold the key to forest conservation and reduction of zoonotic emergence risk.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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