

No Escape from the Heat: The Cost of Deforestation on Human and Animal Health

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In the mighty, dense rainforests of Indonesia, orangutans swing between trees, pygmy elephants snack on grasses and fruits, and tigers roam the thickets. Or they did. As recently as the 1960s, forests covered about 80% of Indonesia, but in the last six decades, demand for commodities like pulp and palm oil has driven the clearing of these lands, and less than half of the original forestland now remains.

Such widescale deforestation has inflicted devastating impacts on many plant and animal species that once thrived in Indonesia: Balinese and Javan tigers are now extinct, and orangutan populations are dwindling. Since rainforests store billions of tons of carbon, destroying these ecosystems also releases huge amounts of the potent greenhouse gas carbon dioxide into the atmosphere. But that is not all. In 2009, when researchers visited villages in Kalimantan, Indonesia, they stumbled across another deadly consequence of deforestation: the impact of increased heat on human health.

Exposure to prolonged heat undoubtedly takes a toll on many wild animals, prompting them to try to move to cooler zones or microhabitats when possible. But the 2009 findings marked a new phase of interdisciplinary research whereby researchers



Deforestation in Central Kalimantan, Borneo. Photograph: IndoMet in the Heart of Borneo. CC-BY-2.0.

in forestry, climate modeling, public health, and agriculture began to investigate the role of deforestation and rising temperatures on the health of humans and livestock. It is work that has the potential to inform mitigation strategies to address deforestation and climate driven heat stress.

Scientists from The Nature Conservancy (TNC) and other partners had been initially investigating

how rural people interacted with orangutans, interviewing more than 4600 people across nearly 500 villages in Kalimantan, Borneo. One question in their survey asked if there were any health benefits to the forests. More than a third of the villagers replied that the forests kept them cool.

“That really sort of raised our eyebrows,” says Nick Wolff, a climate change scientist at TNC. The response

prompted TNC researchers to compare answers from villagers in forested areas with those from regions where trees had recently been cleared. The scientists found that respondents from deforested regions were the ones who noted the cooling benefits of trees or, more importantly, the lack of cooling now that the trees were gone.

With interest piqued, the TNC scientists teamed up with experts in occupational and public health from Mulawarman University in Indonesia and the University of Washington in the United States to see if there was a scientific basis for the villagers' perceptions. The ensuing research illuminated the previously unrecognized impact of deforestation on regional temperatures, human health, and working conditions in the archipelago.

Having identified how deforestation-related heat stress was negatively affecting physical and mental health in Indonesia—and, consequently, reducing worker productivity—the scientists began to investigate further: Was deforestation driving local temperatures in other countries in the tropics, and, if so, what actions could mitigate the impacts on people and animals in the hot zones?

A pantropical plight

In Indonesia, the TNC-led team interviewed individuals to determine how deforestation and heat stress affected their health. For example, for one study in the Berau region of Kalimantan, healthy adult workers in both forested and deforested areas completed cognitive and memory assessment tests after just 90 minutes of daily physical labor. The participants in deforested settings—where temperatures were up to 10 degrees Celsius (°C) higher—had statistically significant lower scores on both tests.

Scaling up such experiments across the tropics would be logistically challenging, however, so the team took a big-picture approach. They used high-resolution global maps of forest cover change between 2003 and 2018 to determine the extent of deforestation in the tropics and calculated the



Private property showing deforestation on the Guandú Watershed in the state of Rio de Janeiro, Brazil. Photograph: Adriano Gambarini/TNC Collection.

local changes in temperature associated with tree cover loss. The findings proved stark: Across the entire tropics, in the 15-year period, nearly 5 million people suffered from increased heat exposure because of deforestation.

When the same team of scientists looked at how the tropics' maximum annual temperature had changed in deforested regions, they found the change could be as high as 6°C to 8°C. The change "is the equivalent to basically a century of unabated global warming," says Luke Parsons, a climate researcher at Duke University and lead author of the paper published in the journal *One Earth* in December 2021. "That's happening over the course of a decade," he added.

Parsons also led research looking into how much those higher temperatures translated into intolerable working conditions because of both high heat and humidity. The analysis showed that every day, outdoor workers lost, on average, 30 minutes of safe working conditions. Heat stress particularly affects outdoor workers, and in the rural regions of low- and middle-income countries, a lot of the work is outdoors. There, men often work on farms—tilling, weeding, and harvesting—mining, or doing manual

labor such as building fences around fields, for example. Women and children often also work outdoors, collecting water or firewood.

Wolff, a coauthor of the study, points out that the number was only an average. Many people in the tropics lost more than half an hour of work time daily to excess heat. Many of those surveyed were living in poverty. "People are having to make hard choices such as *Am I putting my health at risk to feed my family?*" Wolff says. "That's not a pleasant choice to make."

The Parsons-led team also examined the states of Mato Grosso and Pará, Brazil, to determine the impacts of deforestation on temperatures and working conditions in tropical areas that had seen large-scale tree loss. These states lost an average of more than 5000 square kilometers of forest each year between 2008 and 2019. These losses accounted for 63% of all deforestation in the Amazon. The team found that in these two states alone, in the 15-year study period, nearly 3000 people had lost more than 2 hours of safe work time each day.

To highlight the role of trees in cooling, Parsons's team analyzed regions in South America where added heat stress was reducing the safe working

hours by 2 hours per day, finding trees cleared in nearly 94% of those areas. “I’m consistently surprised by the ability of intact tropical forests to keep an area relatively cool and how quickly these cooling services disappear when the trees are cut down,” Parsons says.

A killing heat

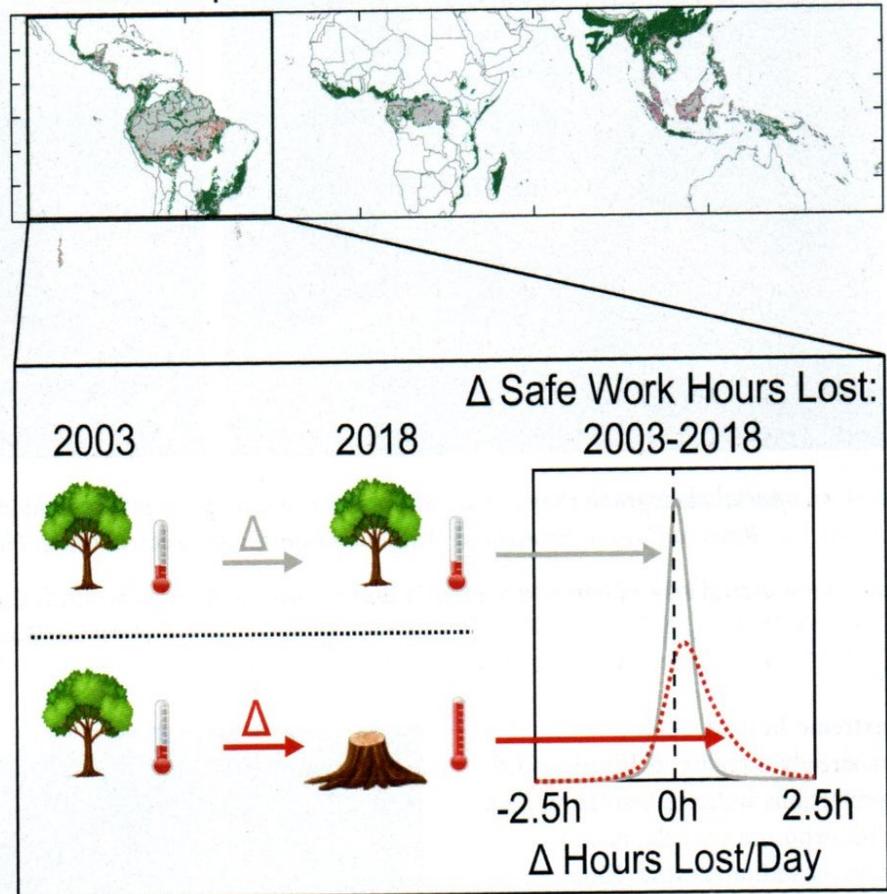
As trees grow and photosynthesize, their roots pull water out of the ground into their leaves, where it evaporates into the air. That means it’s not only cooling shade that trees provide. According to the US Environmental Protection Agency, trees also act like living air conditioners—their “sweating” (transpiration) of cool water vapor can reduce peak summer temperatures by 1°C–5°C.

Conversely, the removal of trees can increase surrounding temperatures significantly, and human health quickly suffers. “The human body is super sensitive to heat,” says Camilo Mora, a professor in the Department of Geography and Environment at the University of Hawaii at Manoa. In 2017, he authored “Twenty-Seven Ways a Heat Wave Can Kill You” in the journal *Circulation*.

Heat stress is particularly concerning in the tropics, because the region’s high humidity prevents sweat from evaporating and cooling the body. The tropics also lack a stark contrast between daytime and nighttime temperatures. So when hot days pair with hot nights, there’s a cumulative strain on the body, especially the heart, says Kristie Ebi, a professor of environmental, occupational, and global health at the University of Washington. Overall, cardiovascular disease causes approximately half of all excessive deaths due to heat waves, Ebi says.

Heat stress affects the body’s vital organs, including the kidneys. An international team of scientists from the Multi-Country Multi-City Collaborative Research Network coordinated by a research team at the London School of Hygiene and Tropical Medicine recently investigated the effects of rising temperatures on kidney function in Brazil. In

Global tropical forest and forest loss 2003-2018



In regions of tree loss, temperatures have risen significantly between 2003 and 2018 in the tropics. These temperature rises correspond to an increase in heat exposure for 4.9 million people and a reduction in the available safe working hours each day. Photograph: Originally published in One Earth: [https://www.cell.com/one-earth/pdfExtended/S2590-3322\(21\)00664-3](https://www.cell.com/one-earth/pdfExtended/S2590-3322(21)00664-3), CC BY-NC-ND 4.0. Reprinted with permission from Parsons and colleagues (2021).

this country, temperatures have risen sharply because of both climate change and deforestation.

The researchers analyzed the hospital admission data on kidney disease from 1816 cities in Brazil between 2000 and 2015 and compared the data with regional temperature increases during the same period. They found that for every degree Celsius increase in daily mean temperatures, the risk of hospitalization due to kidney diseases increased by nearly 1% in the following week. The team’s analysis determined that 7.4% of the almost 3 million hospitalizations for kidney disease were attributable to temperature increases, equating to an extra 202,093 hospitalizations over the 15 years. The study was published in *The Lancet Regional Health—Americas* in February 2022.

The study also showed that the highest percentage of hospital visits occurred in the country’s hottest regions. “We have this considerable burden of disease associated with changes in temperature, which is worrying because especially in the central, eastern, central-western, and northern regions [of Brazil], the deforestation is increasing,” says study coauthor Paulo Hilario Nascimento Saldiva, a pathologist at the University of São Paulo’s medical school.

When a team of Brazilian researchers investigated the combined impacts of deforestation and climate change in Brazil, they found that, under a high emissions scenario, severe heat stress could affect 11 million people in the country by 2100, including 5 million outdoor workers. “The loss of ‘workability’ as a result of exposure to



Aerial photograph shows clear cutting of forest hilltops on private inholding land within the Nature Conservancy's Reserva Costera Valdiviana (Valdivian Coastal Reserve), in Chile. Photograph: Mark Godfrey/TNC Collection.

Aerial view of part of a mountain that has been deforested for cattle farming near the town of Plato, Magdalena, Colombia. Photograph: Juan Arredondo/TNC Collection.

extreme heat in outdoor workplaces is already a reality in Brazil, and the projections indicate increasing high-risk exposure over the next decades,” says coauthor Beatriz Fátima Alves de Oliveira of the National School of Public Health in Piauí, Brazil. The team published their findings in *Communications Earth and Environment* in October 2021.

Wolff and Parsons are concerned about the cascading impacts of climate change and deforestation on rural populations in the tropics. With about 1°C of global warming over the last century, many low-lying areas in the tropics are already warm and humid enough to create uncomfortable or unsafe working conditions, particularly in the afternoon.

Steadily rising temperatures don't just gradually diminish the hours in the day when it is safe to work, Wolff says. Instead, he explains, there is a “tipping point,” a temperature above which people won't be able to work at all.

Another factor hitting farmers in the tropics is that rising temperatures are harmful to livestock. When researchers investigated the number of extreme heat stress days for cattle, sheep, goats, poultry, and pigs under different greenhouse gas emission scenarios, they found that, by



The hillsides deforested for agriculture and livestock in Extrema, Brazil. The Nature Conservancy's Atlantic Forest program began a Water Producer Program in this area to compensate landowners who protect and reforest riparian areas on their property. Photograph: Adriano Gambarini/TNC Collection.

the end of the century, extreme heat stress risk is projected to increase for all livestock species in the tropics. “Production is already compromised in some places to some extent by the heat stress that is already going on,” says Philip Thornton, formerly at the International Livestock Research Institute and lead author of the paper

published in August 2021 in *Global Change Biology*.

As the number of hot days increases, domestic animals eat less, show signs of stress, and can compete for shade and water. “They can get extremely uncomfortable, and some of their behavior and their movements will reflect that,” Thornton says.



Cow lying down. Livestock and farming near Chiana, Kassena Nankana District, Ghana. Photograph: Photo by Axel Fassio/CIFOR.

Cattle grazing near maize field, Nigeria. From year 2000 to 2005, Nigeria had the highest rate of deforestation in the world at 55.7% according to the Food and Agriculture Organisation of the United Nations. Photograph: C. de Bode/CGIAR. Attribution-NonCommercial-ShareAlike 2.0 Generic (CC BY-NC-SA 2.0).

Over time, such stress leads to lower fertility, greater disease susceptibility, and reduced productivity for farms. Extended periods of extreme heat stress increase livestock's risk of mortality, Thornton says.

Mitigation measures

The toll on livestock is already leading to investigations into mitigation strategies that farmers can implement. In some countries, scientists are researching the possibility of breeding more heat stress-tolerant livestock varieties. In other nations, farmers are simply keeping different animals. For example, in southern Ethiopia and northern Kenya, some farmers are switching from raising cattle to camels, which are more heat resistant. "But species switching isn't always going to be possible," Thornton says.

Moving animals at high risk of extreme heat stress is also another possible strategy, but it's one that relies heavily on context. A new location needs to have an adequate food and water supply, and the costs of production need to be reasonable. These same factors can make species switching impractical in certain scenarios.

The simplest strategy is providing shade for animals in the form of sheds or trees. More complex strategies

involve installing electric fans in sheds or different ventilation and cooling systems, but such schemes increase production costs substantially and may be prohibitive for many farmers in the tropics. Moving animals to higher ground may also help, but that's often not an option. "For livestock keepers who have few assets, they don't have the wherewithal to take on interventions that are going to cost them lots of money," Thornton says.

There are limits as to what is going to be feasible in terms of mitigation and adaptation in many farming systems, Thornton says. But currently, there's a lack of data detailing what those limits are and the costs and benefits of different adaptation strategies. "We just don't really know enough to be able to advise what are the most effective actions that should be taken," Thornton says. "And then how can you make rational decisions based on incomplete or nonexistent data? It's a real worry."

For humans, the picture appears a little clearer. Ebi notes many possible actions for reducing heat stress for heat-exposed outdoor workers. Managers can provide cooling areas for breaks to bring worker core temperatures down to normal and ensure that the laborers drink plenty of water.

"We know that heat stress in outdoor workers is preventable, and the more that we communicate about this, the more people understand the actions that need to be taken," Ebi says.

Doing so can rely on regulated work conditions, however. In Brazil, the activities related to deforestation, such as forest fires, increased agriculture, and mining, are fueling new work opportunities, which lack established regulations to protect worker health. And the additional heat stress from tree burning or cutting exacerbates the existing vulnerabilities and inequities for people in deforested regions. Consequently, it is essential to improve labor conditions by reviewing working hours and clothing and monitoring workers' health, Oliveira says. "It will be urgent to continuously review the public policies and labor regulations for providing safe workplaces," she says.

A nature-based prescription

One obvious strategy could potentially prove viable and effective for reducing heat stress impacts on both outdoor workers and livestock in deforested areas: planting trees. "If you remove the trees, you take the cooling services away, but if you can replant some trees, you might get some of that cooling

back,” Parsons says. “And it could help mitigate the local impacts of global warming.”

When it comes to replanting trees, strategies range from letting the forest grow back on its own to planting giant swaths of native trees to simply setting a small number of trees around the border of a farm field to protect crops from wind and soil erosion. “There’s no universal best strategy for restoring tree cover. It’s going to be what is the most appropriate method for the people that live in that community,” says Susan Cook-Patton, a forest restoration scientist at TNC.

Yuta Masuda, a sustainable development and behavioral scientist at TNC, was one of the original group of scientists who surveyed the villagers’ perceptions of deforestation in Borneo in 2018. Three years later, he led a study to explore the cooling potential of planting different densities of trees in pasture lands in Latin America and Africa.

In their first study in this solutions space, the researchers found that trees in pasturelands can offer substantial cooling benefits. In Africa, even adding a few trees, to levels that are equivalent to the median amount across the whole biome (taking into account both natural and unforested areas) would provide an average cooling benefit of more than 1°C. Such vegetation could also counteract a significant fraction of the local projected warming by 2050. The team published their findings in the journal *Nature Communications* in February 2022.

The scientists hope these studies will provide the first steps toward investigating nature-based solutions to address global climate change and local environmental conditions. Nature-based solutions certainly aren’t the “be all and end all” when it comes to tackling climate change, Masuda says. Careful and rigorous research is imperative in assessing their effectiveness and viability for resource-poor farmers. “Nature-based solutions are just one part of a broader strategy,” he says, “and these



Healthy forest in Berau, Kalimantan, Borneo. Photograph: Yuta Masuda/The Nature Conservancy.



A cow grazes in a cleared area of the Ecuadorian Amazon. Photograph: Luke Parsons.

require local community involvement and buy-in, which makes them more challenging.”

Ultimately, through such studies, Masuda says their team would like to produce a menu of policy options for local partners, communities, and governments. The options would present alternative scenarios for land use planning such as different

densities of silvopastures—areas that intentionally integrate trees, and pasture and forage crop for raising livestock—that would have clear benefits for local populations. Then, policymakers could make decisions that contribute to climate mitigation goals but also consider objectives around local resilience and well-being, he says.

The new studies provide critical pieces of evidence to inform communities and authorities and hopefully inspire them to join the quest for solutions, Masuda says. "Ultimately, the aim is to identify how different land-use changes can advance not just climate change and biodiversity goals but other, local-scale goals," he says. As for the potential of silvopastures to mitigate the heat stress impacts of deforestation, Masuda says, "I'm cautiously optimistic."

Highlighting the costs

Despite the dire findings on the impacts of deforestation on safe working conditions, Parsons hopes that his team's study will help international, federal, and regional governments and local communities better comprehend the costs of clearing forests. It is research he also hopes will increase incentives for tackling climate change. "Any efforts to limit climate change will help minimize impacts for some of the most vulnerable people who have the least capacity to adapt to climate change," Parsons says.

The team's research has also demonstrated some of the economic costs

of heat stress. In a study published in November 2021 in *Environmental Research Letters*, the scientists showed that humid heat is associated with 650 billion hours of annual lost labor—the equivalent of 148 million people losing their full-time jobs. The team estimated that some countries were losing more than 10% of their gross domestic product and that relatively small changes in climate, as little as half a degree Celsius, can have large impacts on the economy.

Such estimates don't even begin to consider the costs associated with reduced productivity of crops or livestock, the increased costs of health care, or the economics of mitigation strategies—all factors that will significantly affect regional economies. Although the scientists hope that their research on the heat stress impacts of deforestation provides even more reasons to curb climate change and deforestation on a global scale, they also hope it offers incentives to reconsider tree clearing on a regional or local scale. "Deforestation is not only a problem for global climate change but also a local problem for the health and

safety of people living and working in and around the forest," Parsons says. "This work provides a clear incentive for local populations to maintain intact local forests."

The findings of the Brazilian study on deforestation and heat stress highlight the importance of protecting the forests on both a regional and local scale. The delicate biogeochemical balances that exist in a tropical rainforest are essential for the habitability of Earth, says coauthor Paulo Nobre of the National Institute for Space Research in São Paulo, Brazil. The cooling effects of forests in making our planet habitable have been underappreciated and undervalued. "There must be a change in the way forests are perceived, both locally and globally," Nobre says. "The ethical, cultural, biological, and spiritual values entrusted in a forest and its peoples cannot be measured by its weight in carbon alone."

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