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Impacts of tropical deforestation on local temperature and human well-being perceptions

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ABSTRACT

The combined effects of changes in climate and land cover expose millions of people to an increased likelihood of heat illness. Impacts of heat stress on health have primarily been quantified for urban environments, particularly in developed countries. Far less is known in other settings, including the effects of ongoing tropical deforestation on local temperature and its consequences for people living in these rapidly changing landscapes. Here, we explore links between deforestation and self-reported human health and well-being in the tropical landscapes of Borneo. We use extensive social surveys from nearly 500 villages throughout Kalimantan (Indonesian Borneo) that asked whether forests were important for health, and why. The most frequent answer viewed forests as important for maintaining cool local temperatures (volunteered by 28% of 4634 respondents). Using boosted regression tree analysis incorporating spatial metrics of deforestation and temperature, we found that villagers were more likely to report this cooling effect if they were from villages with higher or more variable temperatures, and in recently deforested or fragmented landscapes. Our results highlight the role of forests in regulating the local climate. This ecosystem service is highly threatened, and yet increasingly vital for avoiding heat illness and enabling adaptation to global climate change.

1. Introduction

Much has been written about how climate and environmental change are linked to extreme heat events, but these events represent just one pathway by which people can experience or be at risk of heat illness. An important yet underexplored area is how such changes operate at local scales and how they affect incidence and risk of heat illness via less extreme events. For instance, rural communities may be exposed to higher temperatures due to deforestation. Forests can remain much cooler than deforested landscapes due to shade and the role of evaporation and transpiration in reducing sensible heat (Bright et al., 2017; Ellison et al., 2017). Loss of shade alone can increase the heat index, the temperature one feels when air temperature and humidity are combined, by over 9 °C (NOAA, 2017). While these impacts may fall below the threshold of an extreme heat event, small increases in heat index may lead to subtle, indirect effects on health and well-being. For example, people will self-manage the amount of time they are exposed to heat, known as autonomous adaptation, such that the largest negative impacts may be economic costs associated with decreased productivity (Malik et al., 2010). Productivity loss may also occur from both cognitive and physical impairment, as heat exposure has been found to decrease working memory and executive function (McMorris et al., 2006), increase error in tasks (Froom et al., 1993), and increase fatigue (Gaoua et al., 2011). Temperature increases often also affect crop yields directly (Schlenker and Lobell, 2010; Schlenker and Roberts, 2009), with consequences for food security and human health. Despite the significant potential impacts of increasing temperatures from deforestation and climate change, we know very little about whether communities in and around forests are losing critical cooling services from forests, and whether they believe their health and well-being is being impacted by these changes.

To date, most research on climate change and the impact of increasing temperatures on communities has focused on the effects of extreme heat events on vulnerable populations. This body of work has found extreme heat events impact virtually every country in the world, with recent increases in frequency, severity and duration due to

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anthropogenic forcing (Hansen et al., 2012; Mora et al., 2017; Zwiers et al., 2010). Since the 1960s the annual global land area impacted by extreme hot summers has increased by nearly two orders of magnitude, from ~0.1% to 10% (Hansen et al., 2012). It is well established that these climate temperature signals are exacerbated by urbanization, agricultural expansion and deforestation (Kalnay and Cai, 2003), and tree planting has become an important strategy for mitigating heat island effects in many of the world's cities and towns (Bowler et al., 2010; Luber and McGeehin, 2008). While the effects of extreme heat events are global, studies quantifying their human consequences have focused on developed, higher-latitude countries primarily due to health data availability (Kjellstrom et al., 2009a; Zivin and Shrader, 2016). These results highlight the significance of heat illness, for example, in the US and Australia, where extreme heat events are now responsible for more deaths annually than all other natural hazards combined (Coates et al., 2014; Luber and McGeehin, 2008). The human impacts in less developed, low-latitude, countries may be much greater (Kjellstrom et al., 2009a), and projections suggest this discrepancy will grow even more severe (Mueller et al., 2016). Low-latitude regions are projected to experience more frequent heat extremes, and sooner, than mid-to-high latitude regions due to latitudinal differences in natural temperature variability (Harrington et al., 2016) and because current climatic conditions in many low-latitude regions already approach human thermoregulatory thresholds (Mora et al., 2017). This difference in exposure to extreme heat events between wealthy and poor regions will likely be amplified by differences in adaptive capacity (e.g. diversity of employment options, access to electricity and social services) and sensitivity (e.g. compromised health due to exposure to disease), possibly resulting in an even larger disparity in vulnerability (St. Louis and Hess, 2008; Whitmee et al., 2015) than differences in exposure alone would predict.

The effects of increasing temperatures are not limited to human health. Recent estimates suggest increased heat-related illness over the last few decades has already reduced current global labor capacity to 90%, with projected declines to 80% by 2050 (Dunne et al., 2013). These projected impacts are spatially variable (Heal and Park, 2016), with hot and humid low-latitude locations predicted to reach temperature thresholds that severely affect labor capacity decades earlier than higher latitudes. Some climate change research suggests the alarming possibility that lower latitude areas may eventually become functionally uninhabitable due to physiological limits of human adaptability to projected heat stress (Mora et al., 2017; Sherwood and Huber, 2010). Over shorter time frames, hot and humid locations such as Southeast Asia, Central America and the Caribbean could see labor capacity reduced by 11–27% due to climate change-driven increases in heat stress (Kjellstrom et al., 2009b).

The existing body of work on extreme heat events that focuses mainly on wealthier, higher-latitude countries underscores the difficulty of studying the more nuanced effects of slowly increasing ambient temperatures on human health and well-being in low-latitude, economically developing countries. These countries tend to be data poor where reliable, continuous data on human health and well-being, local temperatures, and environmental change are scarce (Kjellstrom et al., 2009b). This is especially the case in rural settings where the effects of environmental change may be most acute. Even in wealthier countries, studies have rarely linked how local environmental change, such as deforestation, affect healthy, working populations who are likely the first to experience impacts of these changes. Instead, studies have largely focused on the health impacts on vulnerable populations, or have simulated or inferred impacts of increasing temperatures of healthy populations by examining outcomes such as labor supply and productivity (Hanna et al., 2011; Zander et al., 2015; Zivin and Neidell, 2014) at national or firm-level (Dell et al., 2014; Heal and Park, 2016). In frontier areas where environmental change is driven by land use pressures (e.g. deforestation or population growth), there is little understanding of how the loss of ecosystem services provided by local environments (e.g. cooling services provided by forests (Ellison et al., 2017)) may exacerbate the effects of climate change driven warming and its associated impacts. We fill a critical gap in the literature on environmental change and heat illness risk in a low-latitude country by analyzing data on perceived effects of deforestation on the local thermal environments and its effects on human health and well-being from 500 villages in Kalimantan, Indonesia.

Perception data provide a valid measure for evaluating effects of changes in thermal environments driven by environmental change on human health for several reasons. First, research has demonstrated that perceptions correspond with patterns of observed temperature change from objective measurements (Howe et al., 2013). In regions with a paucity of objective data (e.g. from weather stations), perceptions can provide fine-grained information on local temperature change not otherwise available (Reyes-García et al., 2016). Critically, perceptions often go beyond changes in climate, offering nuanced insight into how these changes impact physical, biological and socioeconomic systems (Hartter et al., 2012; Petheram et al., 2010; Reyes-García et al., 2016; Sánchez-Cortés and Chavero, 2011). Therefore, perception data have a rich history of being used to evaluate risks and changes in human well-being, the environment, and other topics (Bennett, 2016; Jabeen and Johnson, 2013; Meijaard et al., 2013; Renn and Graham, 2005). Perception data also play a critical role in evaluating thermal comfort and environmental conditions and their associated risks on occupational health. Thus, perception data are recognized by the International Organization for Standardization (ISO) which helps set international voluntary standards on occupational health parameters. Indeed, ISO 7730 sets standards around measuring and evaluating thermal comfort, and ISO 10551 discusses the validity of subjective judgements of thermal environments. An important first step for evaluating risk of heat illness driven by local environmental change is to measure perceived changes and risks (Balakrishnan et al., 2010; Jabeen and Johnson, 2013).

Quantitative evidence of health impacts from non-extreme heat events is still sparse. However, recent interview surveys in Kalimantan revealed widespread perceptions that temperature regulation by forests is important for human health (Meijaard et al., 2013). Here, we build on this analysis by examining the relationship of these responses with temperature and land-use patterns, as well as rates of deforestation. Our aim is to determine whether local environmental and landscape characteristics drive perceptions of temperature regulation services from intact forests. We believe quantifying relationships between environmental change and perceived risk is important for understanding the level of heat illness risk a community faces, and the drivers of work patterns, heat exposure, and other adaptation strategies. Borneo is at the epicenter of global deforestation and a region particularly vulnerable to climate change impacts (Struebig et al., 2015; Verbesselt et al., 2016). Our expansive dataset on local perceptions of ecosystem services provides a unique opportunity to explore the intersection of environmental change and human well-being and health. We place these results in the context of projected warming trends for Borneo, highlighting the potential of healthy forests for mitigating heat illness.

2. Methods

This study was motivated by the results of Abram et al. (2014) which presented a descriptive analysis of land use change and ecosystem services among forest communities throughout Borneo. Specifically, we were intrigued by the authors' finding that 35% of surveyed villagers responded that cooling services were an important health provision of forests and that these perceptions were generally related to land-use change (e.g. deforestation). A logical next step was to unpack the deforestation-related drivers of these perceptions in more detail, as a growing body of work points to cooling services provided by forests (Ellison et al., 2017; McAlpine et al., 2018; Scott et al., 2018). Yet little is known about how land use change – specifically, deforestation – affects people through increasing local temperatures, and whether and