Cultivating Crisis: Coffee, Smallholder Vulnerability and the Uneven Socio-Material Consequences of the Leaf Rust Epidemic in Jamaica

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Abstract

Since September 2012, the Jamaican coffee industry has been grappling with the coffee leaf rust (CLR) epidemic caused by the fungal pathogen, *Hemileia vastatrix*. The first widespread outbreak affected more than one-third of coffee plants across the island, resulting in millions of dollars in lost revenues for the sector. The emergence and spread of the disease have been linked to a confluence of factors ranging from changing climatic conditions, to impacts from extreme weather events, improper farm management practices, and institutional and market constraints that restrict control measures. In this paper, we use the case of the CLR epidemic to illustrate how its emergence and continued presence in the Jamaican Blue Mountains is inextricably tied to the wider political-economic and ecological conditions under which coffee production takes place and how *H. vastatrix*'s complex pathogenesis makes the disease difficult to control. Drawing on an empirical study comprising household surveys, focus groups, archival research and interviews, we demonstrate how smallholder farmers' ability to manage rust impacts was severely compromised by ecological pressures, resource constraints, bounded knowledge systems as well as market and regulatory limitations.

Keywords: *coffee, materiality, plant diseases, political ecology, smallholders*

Introduction

Just as coffee farmers in the Jamaican Blue Mountains (BMs) were rushing into their fields amidst news of a long-awaited upturn in coffee prices in the fall of 2012, they were thrown into a tailspin as the first signs of a virulent strain of the coffee leaf rust (CLR) disease were detected in coffee fields that had been left unattended from previous harvests. While other strains of the fungus had been observed in Jamaica prior to 2012, past CLR incidences were mostly confined to lower elevations of the BMs and had been primarily controlled through the application of fungicides (CIB 2004, 2008). The 2012 outbreak was indiscriminate with respect to elevation, affecting farming communities in the higher areas of the BMs that were once believed to be too cool for the disease to proliferate. The outbreak followed several years of economic downturn in the Jamaican coffee industry, triggered in part by the 2008 global economic recession that saw many hectares of coffee left unattended as farmers shifted towards other crops or livelihood practices to sustain their households. By the summer of 2013, CLR had affected an estimated 25-30 percent of coffee plants across the BMs and had led to a significant reduction in both the quality and quantity of BM coffee production. Revenues in the coffee sector declined by an estimated US$5.2 million during the 2012–2013 crop year, resulting in a significant reduction in farmers' income over that same period (ICO 2013; BOJ 2015). Since 2012, CLR has been one of, if not the most, significant and sustained environmental problem for coffee production in Jamaica. It has continually affected the livelihoods of the tens of thousands of people who rely on the coffee commodity chain for a living.

The 2012 coffee rust outbreak in Jamaica coincided with several major rust epidemics in Central and South America, including major coffee producing countries like Brazil, Colombia, Ecuador, Guatemala, Honduras and Peru (Avelino et al. 2015). The onset of these epidemics has been linked to a confluence of factors ranging from prevailing weather conditions and improper crop management practices to macro-economic constraints that restricted remedial measures to control the disease (Avelino et al. 2015; Talhinhas et al. 2017). To date, the majority of responses aimed at managing coffee rust have trended towards developing technological solutions ranging from breeding rust resistant coffee cultivars, to chemical control and developing early warning systems. While such measures have generated some success in countries like Colombia, primarily through the rolling out of large-scale programs aimed at replacing susceptible coffee varieties with rust resistant cultivars, Jamaica has adopted an approach based more on disease management rather than a full suppression of the rust pathogen. These country-level differences in disease management efforts thus require close attention to the institutional and political-economic contexts in which CLR unfolds.

In this paper, we draw largely from political ecology scholarship to explore and demonstrate how social and environmental conditions combined to co-produce vulnerability to CLR in the Jamaican BMs. In line with ongoing calls within political ecology to attend more to issues of materiality (see, for example, Paulson, Gezon and Watts 2003; Walker 2005; Turner 2016) we demonstrate the ways coffee leaf rust is mediated through the dynamic, shifting and everyday interactions between BM farmers, their coffee plants, the rust pathogen and the biophysical environment in which coffee production takes place. We show how these interactions are also linked to a range of cross-scalar and coalescing macro-economic (e.g. changes in input costs and the volatility of the coffee export market) and political (e.g. global market reforms, deregulation policies and phytosanitary regulations) exigencies that set the biosocial conditions in which the disease proliferates and is experienced. We show how efforts at curtailing and managing CLR were uneven and illustrate how the very biosocial conditions that gave rise to the disease also exacerbated underlying socio-economic vulnerabilities – particularly among small-scale resource-poor farmers who were generally found to be less equipped to recover from or mitigate the disease's damaging impacts compared to large-scale farmers with greater access to capital.

The article is divided into four main sections. First, we review some of the recent debates and trends in the political ecologies of health literature before exploring the implications of the recent material turn for advancing critical perspectives on disease outcomes. Next, we provide an overview of the life cycle stages and etiology of *H. vastatrix*, followed by a brief description of the conditions in which coffee production takes place within the BMs. We then describe the methodology informing our study, before presenting the key findings of the research. Here we outline the various biophysical and farm-level management factors at play that shape CLR incidence in the BMs and the wider institutional and market mechanisms that reinforce smallholder vulnerability to the disease. We conclude with a discussion highlighting the cross-cutting political-economic and material ways the CLR epidemic can be understood.

Political ecologies of health/disease and implications of the material turn

In the last several decades political ecology has emerged as a dominant geographic subfield for exploring the ways nature gets produced through social processes (Smith 1996; Castree and Braun 2001; Swyngedouw 2004), and how decisions to transform the biophysical environment are often shaped by political and economic forces operating across multiple temporal and spatial scales (see, for example, Zimmerer 2000; Hodgson and Schroeder 2002; Perreault 2003; Peet and Watts 2004; Robbins 2004). This has included a focus on the everyday interactions between people and the biophysical environment, and how these interactions fit within larger, often global or national political-economic contexts. Political ecology scholarship has also explored how uneven power relations usually reinforce inequities in the access, use and management of land-based resources. Tied to this has been an underlying concern for issues of social justice and the political empowerment of marginalized populations within a context of environmental change (Paulson, Gezon and Watts 2003; Peet and Watts 2004).

Recently political ecology has become a key interpretive and explanatory framework for a small but growing body of scholarship that explores how diseases emerge and are experienced differently across a variety of contexts (see, for example, Mayer 2000; King 2010). Piers Blaikie and Tony Bennett's work on the agricultural effects of the Human Immunodeficiency Virus (HIV) and Acquired Immunodeficiency Syndrome (AIDS) in eastern and southern Africa represents one of the subfield's first attempts to explore the ways human health both constrains, and is constrained by, dynamic and shifting human-environment relations (Blaikie and Bennett 1992). Since then, an increasing number of political ecologists have sought to advance questions around uneven health and disease outcomes, with growing interests in examining the ways larger-scale political and economic processes shape how ill-health and diseases are experienced in local settings (see, for example, Sultana 2006; King 2010; Hayes-Conroy and Hayes-Conroy 2013; Senanayake and King 2017; Ferring and Hausermann 2019).

A number of these studies have started to explore the entangled ways health and disease outcomes are often negotiated in relation to, and in concert with, complex and shifting nature-society dynamics involving multiple and intersecting human and non-human entities (see, for example, Nading 2013; Ferring and Hausermann 2019). Tied to this trend is a growing interest among some scholars in political ecology (and nature-society scholarship more broadly) to foreground the socio-material and health implications of non-human natures in their work. As a result, recent research has shown how the human body both encounters, and is transformed by, a range of non-human entities from hookworms (Lorimer 2017) and mosquitoes (Ferring and Hausermann 2019) to human exposures to biochemical contaminants, environmental toxins and pathogens (Guthman 2014; Wu et al. 2015; Senanayake and King 2017; Barbour and Guthman 2018). Other studies have shown the human health ramifications of land use and ecosystem changes linked to techno-natural shifts in the biophysical environment (e.g. irrigation, mining, dam and road construction). Sokolow et al. (2017) have illustrated, for instance, how increased incidence of human schistosomiasis (a debilitating disease caused by human contact with freshwaters containing larvae shed from infected snail intermediate hosts) in Senegal is linked to dam-associated declines in snail-eating river prawn populations. In sum, these studies demonstrate how changes in the biophysical environment – triggered in part by cross-scalar political-economic forces – can lead to fundamental alterations in human-environment relations that in turn set the conditions in which diseases emerge and spread locally.

We see this as being synergistic with broader calls for human geography to pay greater attention to materiality (e.g. Bakker and Bridge 2006), which includes an acknowledgement of the generative capacities of biophysical systems and processes, or as Turner (2016, 417) puts it, making visible the "active role played by nonhuman life in the unfolding of human-nonhuman relations". For the most part, the growing interest in materiality and the non-human is tied to a more recent *material turn* that is taking place within the social sciences and the humanities. New materialism thus serves as an umbrella term for describing a range of contemporary perspectives that share a theoretical and practical re/turn to matter (Fox and Alldred 2017), which includes more-than-human modes of enquiry that foreground the material and ecological dimensions of everyday life (Whatmore 2009). But as Bakker and Bridge (2006, 6) make clear, these "Appeals to materiality are, of course, not all of a piece; … the plasticity of the term can elide different and even incompatible ontological commitments."

Despite the immense diversity associated with new materialist perspectives, there seems to be a shared interest in decentering the human as the central or sole focus of social inquiry, underpinned by a strong interest in rethinking or outright rejecting conventional ontological distinctions and dualisms such as nature/society or human/non-human (Muller 2015). This is matched by a tendency for some new materialist perspectives (particularly evident in the writings of proponents of actor-network theory and assemblage thinking) to adopt 'flat ontologies' where all entities – humans and non-humans alike – stand on equal ontological footing (Latour 2005), and where agency is seen or theorized as distributed between multiple and overlapping human and non-human entities. In this regard, agency as well as power are neither pre-determined nor assumed to be the sole reserve of humans that can only be exercised through social structures.

Added to this is a general call to recognize the ways that "the 'material' and the 'social' intertwine and interact in all manner of promiscuous combinations" (Thrift 1996, 24), as well as to better foreground and account for the physicality and co-presence of the non-human (Bakker and Bridge 2006) in social theory. Non-human entities are thus conceived of as "more or less accommodating to human designs and may respond to human intentions and actions in ways that are not predictable…" (Turner 2016, 417).

Linked to this material turn is a growing interest in various forms of materialism, including a growing emphasis on foregrounding the spatial and political significance of microbial life forms, particularly the unpredictable ways bacteria, fungi and other microorganisms become implicated in complex human and non-human entanglements (Clark and Hird 2018). This has included emerging interests in human-microbial geographies (e.g. Helmreich 2015; Lorimer 2017), where the microbial is seen as always present and co-constitutive with the human yet possessing the capacity to evade or even resist human control and manipulation. Tied to this is an effort to acknowledge and highlight the limits non-human entities pose to social and political life, including human health and well-being. It follows that material objects and non-human things are not only unpredictable in their vitality and capacity to mobilize and proliferate but can be outright disruptive and resistant to even the most coordinated of human attempts at control and management. As Clark and Hird (2018, 246) argue, "Microorganisms…[and] their effects tend to turn up unexpectedly, their arrival frequently threatens our lives or the lives of creatures [and the things] we value, and they have an uncanny ability to use our own pathways or conveyances with greater efficacy than we ourselves manage." Implicit here is a recognition of the inherent capacity of non-human entities to shape and confine individual and collective human actions, or as Whatmore (2009, 587-588) argues, these disruptions represent "moments of ontological disturbance in which the things on which we rely as unexamined parts of the material fabric of our everyday lives become molten and make their agential force felt".

Not surprisingly, this theorizing of power and agency as distributive (and dehumanized) has been heavily criticized by critical scholars in geography and cognate disciplines for ignoring the uneven political and socio-economic contexts in which these associations take place. Whether conceived of in terms of networks, topological enfoldings or assemblages, new materialist perspectives have been criticized for their general failure to offer an analytic that accounts for the physicality and co-presence of the material world "without surrendering the social to the biological" (Bakker and Bridge 2006, 15). A central concern for critical scholars relates to the ways questions around structural inequality, uneven power dynamics and axes of human difference are rarely reflected in new materialist perspectives (Brenner, Madden and Wachsmuth 2011; Anderson and McFarlane 2011; Saldanha 2012), as well as the tendency for these perspectives to ignore the role and significance of hierarchical power structures in the production and sustenance of social and material differences (Kinkaid 2019). An even more contentious insistence within some new materialist approaches (particularly actor-network theory and assemblage thinking) is the dissolution of the subject/object dichotomy often used in social theory to distinguish the human subject from non-human objects/things. This can result in downplaying humans' distinct ability to make conscious moral decisions about our own and others' actions, rather than being mere prisoners of natural laws and instincts. As Lave (2015, 218) points out, "Insisting on the ontological equivalence of nonhuman entities, such as ocean currents, does not obviously support emancipatory struggles for human beings suffering oppression" – thus making approaches like actor-network theory seemingly incompatible to the emancipatory project that is characteristic of a number of critical geographic perspectives, including political ecology.

Despite these tensions, we find inspiration with approaches that advance an ontological reading of materiality that recognizes the physicality, co-presence, generative capacities and even the unruliness of material nature, while being attentive to the ways socio-material outcomes are partly shaped by wider political-economic structures that set the very conditions in which human-environment relations unfold. In other words, while we see the value in better engaging and foregrounding the material/non-human in social research, we maintain that struggles over material resources and their attendant socio-material outcomes are inherently political and rooted in specific local histories and cultural contexts. Similar arguments have been made by a number of nature-society scholars who have engaged with materiality in varying degrees in their research (see, for example, Bakker and Bridge 2006; Turner 2016; Lorimer 2017).

We contend that political ecology is well positioned to take up questions of materiality while being attentive to the uneven and power-laden ways diseases emerge and are managed in different local settings. This should come as no surprise, given the subfield's longstanding (though, arguably, under-explored) concern with the biophysical world (*cf.* Lave 2015). This also aligns well with some political-ecological approaches that refuse to place "political processes outside of, or even adjacent to, the domain of the material," but rather as an inextricable dimension of it (cf. Paulson, Gezon and Watts 2003, 209). These approaches have sought to establish relationships among people, practices and biophysical phenomena, while situating these relationships within larger historical and ecological processes. A few nature-society scholars are already engaging with non-human natures in a number of critical and innovative ways, drawing attention to the transformative capacities of a range of non-human entities within differing health contexts. Several of these studies have drawn explicitly on political ecology as a framework for advancing relational understandings of health and disease outcomes. Lorimer (2017, 555) for instance, draws on both more-than-human and political ecology scholarship to show how disease associated with hookworms arise from particular socio-ecological situations that often "map on to historical and contemporary geographies of colonialism, development, trade, property and urbanization…." Likewise, Ferring and Hauserman (2019) adopt a cumulative vulnerability approach to illustrate the uneven community health implications of small-scale gold mining by examining the ways socio-structural conditions (e.g. food insecurity, gender dynamics), land use change (e.g. abandoned water-logged pits), and materiality (e.g. the transformative capacities of mercury and the malaria-causing parasite, *Plasmodium falciparum*, to breakdown the human immune system) combine to increase local malaria incidence in central Ghana. They conclude that "Increased malaria incidence thus emerges from relations and coconstitutions between bodies in increasingly pathogenic mining landscapes wherein mutable, internal biologies are inextricably linked to the global in *more-than-human political ecologies of health*" (Ferring and Hausermann 2019: 1086-87; emphasis is ours).

This study builds on recent advances in political ecology that have emphasized the role of political-economic processes in shaping health outcomes by demonstrating the ways diseases emerge partly from biosocial processes that shape the exposure and spread of pathogens. Studies in political ecology also illustrate the importance of biophysical processes in creating the conditions that influence the spread of infectious diseases or exposure to non-communicable disease pathogens (see, for example, King 2010). Underlying these studies is a deepening concern for understanding the capacity of pathogenic agents to transform the interactions between social and environmental systems on the one hand, and how these systems in turn combine to shape health and disease outcomes on the other. To date, the vast majority of political ecology scholarship on the relational dimensions of health and disease has focused on the implications for human health outcomes (see, for example, Guthman and Mansfield 2012; Guthman 2014; Lorimer 2017; Senanayake and King 2017). A topic less frequently discussed is non-human diseases and the attendant ways these diseases are equally co-constitutive of underlying political-economic structures and the inextricable linkages between humans and the biophysical environment. This paper thus fills another important empirical gap in the political ecology of health literature through exploring the ways this specific plant disease both shapes, and is shaped by, struggles over economic and land-based resources.

***Hemileia vastatrix*: Life Cycle and Etiology**

CLR is regarded as the most destructive coffee disease in the world, dating back to the late 1800s (McCook 2006; Luaces et al. 2010), and it is the only major coffee disease with worldwide distribution (Avelino et al. 2018). CLR is caused by the fungus Hemileia vastatrix, an obligate parasite that requires a host—coffee—to survive and reproduce (Avelino, Willocquet and Savary 2004). While CLR infections seldom kills the host plant, severe infections often result in significantly reduced yield in subsequent years (Talhinhas et al. 2017).

The fungus begins its life cycle as a microscopic spore (produced from the brownish/reddish rust-like pustules formed on the underside of the coffee leaf) and is transmitted when these spores disperse from one part of the plant to another, or to a new, uninfected plant. Deposited spores will germinate and infect the leaf during favorable weather conditions (De Jong et al.

1987). Spores attach themselves to the leaf surface using the spines on their rough side. Once the spore attaches itself, it penetrates the leaf through the stomata and then moves on to colonize the leaf to extract nutrients (Arneson 2000; Kolmer, Ordonez and Groth 2009). Once the spores begin germinating, the entire infection process is usually completed within 1-2 days, provided there is a continuous presence of moisture and the temperature ranges between 15 and 30 degrees Celsius (Nutman, Roberts and Clarke 1963). After infection, the fungus will grow and produce new spores in about three to four weeks (Zambolim et al. 2016). One rust lesion can produce 4-6 spore crops in as short as three months, producing and releasing up to 400,000 spores to repeat the process. The time needed for germination, infection, and the production of new spores, and the extent of the infection are largely determined by weather conditions, particularly temperature, moisture and wind (Rayner 1961; Nutman, Roberts and Clarke 1963; Avelino, Willocquet and Savary 2004). As illustrated in Figure 1 and further outlined in Table 1, each of these variables affect CLR at different stages in its life cycle.

[Insert Figure 1 around here]

[Insert Table 1 around here]

The *H. vastatrix* pathogen is regarded as highly proficient and suited for warm moist tropical environments, where almost all of the world's coffee cultivation takes place. Added to this, *H. vastatrix's* complex pathogenesis makes it difficult to detect CLR in the early stages of its life cycle and becomes extremely difficult to curtail in its later stages (Talhinhas et al. 2017). The first macroscopic signs of infection are small pale-yellow spots formed on the upper surfaces of coffee leaves, which gradually increase in diameter, forming masses of yellow-orange powdery spores on the undersides (Figure 2). The spores tend to be concentrated toward the margins of the leaves where dew and raindrops collect (Arneson 2000). Over time, the area surrounding the lesions typically becomes discolored as the fungus inhibits production of chlorophyll. This in turn impedes photosynthesis in the infected leaf, depriving it of nutrients and causing it to drop from the plant prematurely. The loss of leaves can hinder branch growth and decrease crop yield, most acutely during the season following infection (Avelino, Willocquet and Savary 2004). The damage caused to the leaf during the infection process is also dependent on plant health (Rayner 1961; Bock 1962; Brown et al. 1995) and if left untreated, a fully infected plant could die in a matter of weeks under extreme conditions. This poses several farm-level management challenges to farmers, including difficulty in detecting the disease in its early stages and a high resource demand to manage infected trees once the disease reaches an advanced stage. It is instructive to point out that the formation of lesions and spore development can occur several weeks after infection, depending on prevailing weather conditions (Brown et al. 1995; Arneson 2000).

[Insert Figure 2 around here]

To date, most of the efforts aimed at minimizing the impacts of future CLR outbreaks at the global level have led to research on new rust resistant coffee varieties – in line with conventional crop scientific knowledge and praxis (*cf.* Francl 2001) – and the rolling out of large-scale programs aimed at replacing susceptible varieties with rust resistant cultivars (Arneson 2000; Avelino et al. 2015). Capacity-building efforts (including the development of early warning systems and the provision of tailored climate information services) aimed at enabling better management of the disease have also been implemented (e.g. Avelino et al. 2015; Zambolim 2016).

Studies have however shown that these efforts have reaped mixed results so far. Even in instances where there is a large-scale shift towards the cultivation of rust-resistant coffee varieties, research is suggesting that the risk posed by the leaf rust disease is never totally eradicated. Despite some fairly significant breakthroughs in CLR disease resistance breeding over the years, including the successful deployment of resistant strains into commercial cultivars, studies have shown that plants that come in constant contact with the rust pathogen usually lose their resistance to the rust over time – a case that recently played out with the Lempira variety (Hughes 2013; WCR 2017). This speaks to *H. vastatrix*'s ability to mutate and reproduce itself even in instances of targeted and well-coordinated human interventions. In fact, coffee rust has been found to be highly adaptable and has demonstrated a remarkable ability to evolve in response to the selection pressures exerted by the periodic introduction of new resistant coffee genotypes. Talhinhas (2017, 1045) goes as far as to describe this as a "dynamic host–pathogen co-evolutionary arms race, in which [as] short-term selection of pathogen strains with fitness advantages is promoted, new pathotypes with increased virulence have been continuously appearing".

The Jamaican Blue Mountain Context

Coffee was first introduced to Jamaica in 1728 from either Martinique or Haiti. Within a century, one-third of the world's coffee supply was being grown in the Blue Mountains. After emancipation of the British West Indies in 1838, production fell by almost three-quarters, and many large plantation owners sold their landholdings (Mighty 2016). Independent farmers then began to purchase, rent or squat on small, fragmented parcels of land (Barker and McGregor 1988). Jamaica's last census of coffee farmers, in 2004, found 7,032 registered farmers in the BM (CIB 2014), although the current number of registered farmers is likely only half that (in-person conversation with Acting Director General of JACRA, June 15, 2018). The great majority of BM coffee farmers cultivate plots less than 5 acres. And although these smallholders own about 80 percent of BM farmland, they produce only about 20 percent of the BM coffee exported. The large coffee estates produce the rest.

In 1948, Jamaica's Coffee Industry Board (CIB) was set up to buy, clean, grade and export coffee in order to assure a uniform quality product. As the principal purchaser of coffee, the CIB set one price for all BM coffee farmers, giving them the majority of the export price. The CIB's network of farmers' cooperatives was instrumental in the industry's nearly twentyfold increase in production in CIB's first two decades. Cooperative members also received extension support and access to low-interest loans (CIB 1954, 1980). This arrangement began to change as a result of the global recession of the late 1970s that exacerbated Jamaica's high interest rates, inflation and unemployment. In order to address these hardships, the government accepted an International Monetary Fund loan (Schipke 2001). As part of the required structural adjustment reforms, the Coffee Industry Deregulation Policy was instituted in 1983, with the goal of increasing foreign exchange earnings (CIB 1983). The Policy allowed select processors to buy directly from the growers, bypassing the cooperative system. Deregulation thus ended CIB's three-decade role as the sole buyer and exporter of the country's coffee crop and brought about the rise of the large processing companies. At the same time, because the government no longer guaranteed a minimum farmgate price, the farmer's share of the export price declined from 75 to 50 percent through the 1960s and 1970s to less than 25 percent today (CIB 1964, 1976).

In 2018, the CIB was restructured into the broader Jamaica Agricultural Commodities Regulatory Authority. One of JACRA's remaining responsibilities is to inspect all BM coffee exported and maintain its Blue Mountain ® trademark and geographical indication. Only coffee grown in the parishes of Saint Andrew, Saint Thomas, Portland and Saint Mary can be labelled Blue Mountain, where most of the island's highest quality coffees are cultivated at elevations between 900 and 1700 meters, where cooler temperatures allow berries to mature slowly and produce the complex flavor profiles that characterize the high-end Jamaican BM brand (Mighty 2015). For the most part, coffee plants are either cultivated in open fields or shade grown on steep hillsides.

Japan has purchased the majority of BM coffee for over fifty years. Japan's share of exports increased from about 80 percent in the late 1960s to almost 100 percent in the late 1970s (CIB 1967, 1977). A large part of the Jamaican BM brand's popularity in the Japanese market is presumably linked to its rare and distinctive flavor profile which is partly tied to the cultivation of high-quality specialty Arabica coffee. However, the global recession that began in 2008 set off a decline in Japan's purchases. In the 2009-2010 agricultural year, Jamaica's exports of BM coffee to Japan fell by 49.6 percent. This resulted in a total reduction in BM coffee revenue from US$35.8 million to US$20.13 million, though the price per weight rose slightly (CIB 2010). In 2011, Japan's share of BM coffee exports fell below 70 percent, where it has approximately remained today. The relatively high price of BM coffee is matched by its high volatility, which is in part caused by the industry's continuing reliance on Japan as a majority purchaser. Japan's inconsistent demand results in large year-by-year farmgate price fluctuations, which has been exacerbated by the inability of BM exporters to negotiate contracts with Japanese buyers since at least 2015 (in-person conversation with BM coffee exporter, July 12, 2018).

The steep hillsides of the BMs make it extremely difficult to mechanize farms, which means most estates are rain-fed and beans have to be hand-picked and manually sorted before processing. The industry is susceptible to a wide range of environmental shocks, including droughts, hurricanes, wildfires, and various plant pests and diseases. Though the sector has been plagued with numerous economic and environmental challenges, the 2012-2013 CLR outbreak has been one of the worst ecological shocks to have impacted the Jamaican coffee industry in recent years. It affected nearly every household we surveyed, regardless of elevation, micro-climate, or community. Not only did the epidemic result in a significant loss of revenue, but it emerged as the industry was rebounding from multiple years of declining production due in part to the global economic recession (Guido et. al. 2020). Since its initial outbreak, CLR has persisted despite significant efforts by Jamaican coffee industry stakeholders to curb the spread of the disease.

Methodology

This article draws on fieldwork conducted in Jamaica between 2014 and 2016 as part of a transdisciplinary project addressing climate risk management among smallholder farmers

(Guido et al. 2018; Guido et al. 2019; Knudson and Guido 2019). Drawing on a mixed-methods research design, involving focus group discussions, household surveys, stakeholder interviews and archival research, this research has explored the cross-scalar and dynamic ways the coffee rust disease was experienced and managed. The methods chosen were based on the configuration of the BM coffee chain, which involves a variety of actors, both institutional (JACRA, Coffee Growers Association, Jamaica Agricultural Society) and market (coffee processors, roasters, exporters), and the relatively large number of smallholder farmers located at various elevations across the BMs. Our fieldwork coincided with a period of multiple stressors for BM coffee farmers, including the first severe outbreak of CLR on the island in 2012–2013 and several dry spells and bush fires in the years leading up to our fieldwork that caused extensive and catastrophic damages throughout the study region.

Following several visits to the BMs and consultations with key stakeholders in the Jamaican coffee industry in 2015, the research team conducted 12 focus group discussions (FGDs) in major coffee-producing communities in the three parishes of St. Thomas, St. Andrew, and Portland (Figure 3). The communities selected for the FGDs were drawn across a wide elevation range to reflect differences in coffee quality, crop phenology, growing cycles and farm-level management practices. Coffee was also the primary livelihood activity in each of the communities selected, with 73 percent of the farmers surveyed reporting cultivating on plots less than 5 acres.

[Insert Figure 3 around here]

Participation in the individual FGDs ranged from 6 to 19 persons, involving a total of 143 farmers, approximately 33 percent of whom were women. The FGDs generally lasted from 1–2 hours on average, and were facilitated, at times, in local patois. The sessions covered a wide range of topics including farming history, management practices, challenges, and coping strategies. After each session, team members discussed the notes to identify common themes and addressed issues that surfaced during discussions. We also performed a series of content analyses on the notes collected, building a common set of themes from all discussions.

The qualitative information collected from the FGDs was further supplemented with information retrieved from interviews and historical data gathered through archival research. We conducted 26 semi-structured interviews in Spring 2016. These interviews were conducted with key players in the coffee industry, including the management team of JACRA, coffee and extension officers, coffee buyers and a number of large-scale farmers. We later transcribed interviews and analyzed in conjunction with the FGD notes to identify key themes emerging from the study. Additionally, archival research of all JACRA (or CIB before 2018) annual reports dating back to 1953 was done in order to capture the institutional and historical context.

We also conducted 434 household surveys in the summer of 2016 spanning 20 farming communities cutting across all of the main areas of coffee production in the BM. Similar to the FGDs, the communities chosen for the household surveys spanned nearly the full elevational range of the BMs (approximately 50 masl to 1250 masl), and were distributed across the three main parishes comprising the BM region (cf. Figure 3). We selected communities that had a population of at least 100 households and where coffee was the main livelihood activity.

Approximately 84 percent of the respondents stated that at least half their household income was generated from coffee. Roughly 23 percent of our sampled population were female farmers. The median age of the entire sample was 53 years, while the median farm size was about 2.75 acres.

The household surveys followed a random data collection protocol. In each community, we targeted approximately 10 percent of the houses. Because the communities lacked base maps and formal political boundaries, we used Google Earth imagery to first identify all dwellings close to the community center and then randomly chose 10 percent of those structures. This method proved accurate at identifying residences. However, in the cases where a dwelling was abandoned or not a residence, the enumerator went to the nearest home. The surveys covered a variety of topics including information on household characteristics, livelihood activities, farm management practices, social networks and farmer perceptions of risks and impacts. From the survey, we were able to compile descriptive statistics of key household variables and explore associations between coffee yields and losses with a number of different explanatory variables captured in the dataset.

Socio-Material Drivers and Outcomes of the Coffee Rust Epidemic

By the time we started our fieldwork in 2015, the coffee leaf rust had impacted the entire BM region. Since the initial outbreak in 2012, the disease had spread rapidly, the effects of which could be easily seen in every community we visited. Farmers were asked in our household surveys to report their losses to CLR over a three-year span, starting from the 2012/2013 crop year (Figure 4). The results show that the problem had worsened by the time of our survey, with around 71 percent of the farmers reporting CLR related losses for the 2014/2015 crop year compared to 50 percent in 2012/2013. Although our data collection focused on the smallholder farmers in the BM, as we described in the previous section, we can provide here a brief contrast in response and outcomes with the larger farms, based on conversations with their owners. We found that whereas the majority of smallholders struggled to manage the CLR outbreak, especially as coffee losses reduced spending on labor and inputs, large-scale farmers, who had access to more capital, confronted CLR as a disease that increased operating costs but did not lead to significant crop loss.

[Insert Figure 4 around here]

We contend that the reasons for CLR's continued persistence in the Jamaican BMs can be understood in largely political ecological terms, and thus co-constitutive of the wider political, economic and biophysical environment in which BM coffee production takes place. In the remainder of this section, we provide a synthesis of our main research findings. We illustrate the ways smallholders' vulnerability to CLR is co-constitutive of everyday human-plant-microbial interactions that are often situated within larger cross-scalar contexts of political- economic (global economic recession, unstable commodity prices, market restrictions and so on) and environmental change. We outline and explain the multiple and cross-cutting farm-level, ecological and institutional conditions driving CLR incidence in the Jamaican BMs, while considering how these in turn link into underlying structural forces that have limited smallholders' capacity to manage the rust outbreak.

Farm-level Practices as Bounded

There is currently no cure for coffee leaf rust. It is likely that CLR has co-existed with wild Arabica coffee even before it was first reported in the 1870s (McCook 2019). As coffee became a global commodity and agricultural practices changed, the rust evolved as well. The first epidemic struck Ceylon (now the Democratic Socialist Republic of Sri Lanka) in the 1870s, and ever since coffee farmers worldwide have attempted to live with the fungus with various degrees of success (McCook 2019). Farmers address the disease in two main ways: replacing susceptible coffee varieties with resistant ones (e.g. Avelino et al. 2015) and implementing management practices that are meant to minimize the disease burden such as the application of chemical fungicides, plant nutrition, shade management and pruning (Avelino, Willocquet and Savary 2004). The goals of farm-level management techniques are to make the environmental conditions both less favorable for CLR while also boosting the natural defenses of the coffee plant by increasing its health. While there is some evidence that biological agents such as ants or naturally co-evolved fungal enemies of the rust could help limit CLR (Barreto, Colman and Evans 2015; McCook and Vandermeer 2015; Vandermeer, Perfecto and Liere 2009), these biocontrol methods are still in their early stages of development and are not widely promoted as control measures.

As noted previously, Jamaica's response to the coffee rust epidemic has so far centered on curtailing the disease through the promotion of a range of farm-level management practices rather than replacing susceptible coffee varieties. Addressing the disease at the farm level has largely entailed a combination of farm management techniques aimed at minimizing rust impact and chemical control. In this domain, the BM farmers' limited knowledge and experiences with CLR and their low resource endowments likely determined CLR's initial outbreak and its subsequent spread. The key to prevent a CLR epidemic is knowledge of its etiology, including an ability to identify early signs of the disease that enable a timely response. Yet many of the farmers we surveyed indicated that at the time of the initial outbreak they were unaware of the disease and how it was transmitted. As mentioned earlier, even though CLR has been in Jamaica since at least the mid 1980s, the disease was largely confined to lower elevations of the BMs, which meant many of the farmers we surveyed had never encountered the disease prior to 2012. The lack of awareness meant that farmers missed crucial early warning signs to respond, even if they had been in a position to do so. The fact that in each of the first three years of the epidemic the damage to BM coffee from the rust increased in amount and severity demonstrates that the farm-level management practices that were being employed were insufficient in containing the disease (Figure 3).

Farmers may also have unwittingly aided in CLR's transmission from plant to plant, farm to farm, and even across the BMs by acting as the spore-vectors. In other areas, CLR has been spread by farmers and laborers as spores hitch on clothing (Kushalappa and Eskes 1989). Past research also has shown that CLR incidence is greater close to foot paths and residences than in less traveled areas, and new outbreaks may increase during and after harvests when people tend to come into contact with coffee plants more frequently (see, for example, Waller 1982). In the BM, the root cause of the 2012 epidemic is not known, but one hypothesis for its initial spread is through the movement of farmers and laborers within and between farms.

Beyond farmers' limited knowledge, many farmers did not possess the requisite tools and resources to treat infected plants (Table 2), which also contributed to the widespread CLR incidence, severity, and losses (Figure 3). CLR affects the underside of coffee leaves, requiring not only the knowledge that this is where the rust takes root but also tools to effectively coat the underside of leaves should fungicide applications be used. While mechanical sprayers were generally regarded as being more effective in applying fungicides compared to hand pumps, only 15 percent of the farmers surveyed indicated owning a mechanical sprayer, whereas just over one-half owned a hand pump. In related research, Guido et al. (2020) found that the damage caused by CLR to coffee was significantly associated with the use of agriculture inputs. Higher usages of fertilizers and fungicides and more farming tools including mist blowers were correlated with less coffee losses. While JACRA and its extension agents advised applying fertilizer 4-5 times per year, the vast majority of coffee farmers were unable to achieve this level of input use. In contrast, many farmers spoke about having reduced their crop care in the years leading up to the 2012 outbreak due to the downturn in coffee prices, triggered largely by the 2008 global economic recession. Moreover, Table 2 shows how little access BM farmers had to basic farming equipment, inputs such as fungicides, and resources such as labor and agricultural credit.

[Insert Table 2 around here]

The inability of many farmers to access capital also resulted in a positive feedback loop where reduced plant care had severe implications for future CLR outbreaks. Studies have shown that plant nutrition is vital for controlling the rust disease (Avelino, Willocquet and Savary 2004;

Talhinhas 2017). In general, healthy plants are believed to fair better when exposed to the rust pathogen – a fact many farmers were seemingly aware of. One farmer stated "If we treat our body well then we can fight against a disease and build up certain resistance. Same with coffee. If we fertilize on a regular basis then the coffee will be able to stand against the disease" (male farmer, Penlyne Castle FGD, July 2015). Yet many farmers were either unable to take the requisite measures needed to boost plant health or opted not to do anything. The high costs of inputs and labor were singled out by several farmers during interviews and focus groups as major constraints to following the farm management practices prescribed by JACRA. In other instances, farmers simply left their plots unattended in hopes of salvaging whatever yield they could harvest from infected trees. During several of the focus group discussions, farmers highlighted the benefits of stumping (cutting back) trees as a strategy to get rid of infected leaves and curb the spread of spores once the disease is detected on a farm. However, since this would prevent the tree from bearing as much fruit until full regrowth several years later, a number of the farmers expressed reluctance to cut back trees (especially in the absence of a state compensation scheme), preferring instead to reap the few berries that remained on the trees.

Ecological Pressures

In addition to farm-level practices, several biophysical factors contributed to the rust's severity and spread. Following the 2012 CLR outbreak, Jamaica experienced several periods of intense drought and several sections of the BMs were impacted by wildfires. These events took place around the same time when farmers were trying to recover from the rust outbreak, and further disrupted farmers' ability to invest in the requisite remedial measures to combat the disease. Droughts were found to be particularly damaging to coffee farms, resulting in reduced coffee yields and lowered income for farmers. A few of the farmers also pointed out that under drought conditions, fertilization becomes less effective – and in some instances, can damage the root system of coffee plants: "When you apply the fertilizer and the rain doesn't come, it's just like applying heat to the coffee" (female farmer, Woodford, September 2015). Under these conditions, coffee plants were believed to be more susceptible to CLR infestation and had a greater likelihood of dying.

Our fieldwork also indicated that the materiality of the coffee plant itself played an important role in shaping CLR incidence. Farmers indicated that the *Coffea arabica* Typica variety was more susceptible to CLR than the less favored Robusta or hybrid varieties (WCR 2018). This is supported by the scientific literature that has pointed to a generally higher susceptibility of Arabica varieties to most of the recognizable strains of the rust pathogen. This has seen a continued preoccupation for breeding for genetic resistance against CLR among a wide range of Arabica coffee (see, for example, Hindorf and Omondi 2011). Studies have also found that the Typica variety is resource intensive and less suited for small-scale cultivation (WCR 2018). Again, this has significant implications for CLR incidence since nutrient deficient plants are generally found to be more susceptible to the rust pathogen.

While the adaptive evolution of *H. vastatrix* was not apparent in our case study, it does point to the enormous challenges this disease presents for the future viability of the flagship Jamaican BM coffee brand. More importantly, *H. vastatrix*'s demonstrable capacity to break down rust resistance with "relative ease" (Talhinas 2017) poses a threat for hybrid and Robusta varieties as well (of which the latter has so far reportedly demonstrated a higher resistance to the rust), which may also lose their tolerance over time. This has wide-ranging future implications for the BM coffee industry, not least being the constant risk of future CLR outbreaks given the adaptive and reproductive capabilities of the rust pathogen.

In addition to varietal differences, the phenotypic characteristics of the coffee plant itself, including its shrub-like morphology, fruiting pattern and biochemical properties, complicates the kind of management practices that farmers can employ to curtail the disease at various points throughout the growing cycle. For instance, the thick foliage, fruiting cycle and the sensitive root system of the coffee plant, place a limit on the timing and application of fungicides and other inputs vital to maintaining individual plants' health and resistance to the rust disease. Other characteristics such as stomatal density and canopy architecture have been identified as significant factors in determining CLR incidence and severity (Cressey 2013; Talhinhas et al. 2017). Stomatal density for instance, affects the rust pathogen's ability to penetrate the leaf; if the density of stomata on the underside of leaves is high, then there are more areas where the fungus can penetrate into the leaf and form lesions that produce spores (Silva et al. 1998; Avelino, Willocquet and Savary 2004).

Studies have also shown that CLR incidence tends to increase with fruit load (Avelino et al. 2006, 2015) which can have a devastating impact on farm productivity and income. This can prove particularly challenging for smallholder farmers who might not be in a position to recover from a failed crop season due to their limited resource base. Because coffee is a long-term crop, farmers are not just able to replace infected plants with new ones. Depending on the variety, it takes approximately 3-4 years for a newly planted coffee plant to bear fruit. As such, removing a mature coffee tree from the field was seen as a last resort for most farmers.

CLR incidence and life cycle are also influenced by other microbial agents. Coffee trees that are affected by other plant diseases and pests were found to be more susceptible to CLR. As aforementioned, the overall health of a coffee plant was found to be a major determining factor for CLR susceptibility (Avelino et al. 2015). Plant health outcomes, of course, are largely determined by differences in individual farmers' resource endowments and management practices, creating a dynamic and complex environment in which CLR proliferates. As one farmer pointed out, "The people…who can afford to buy the manure and fertilizer and feed them [sic] farm, the disease doesn't affect them that much" (male farmer, Settlement FGD, August 2015).

Institutional and Market Constraints

Finally, we argue that CLR's emergence and spread in the BMs also have to do with the way the coffee sector is organized and the wider market constraints shaping farm-level practices. The heavy reliance on the high-end Japanese market and the insistence on growing the Typica variety meant farmers had very little options available to cultivate other coffee varieties. The Jamaica coffee industry's policies also prevent farmers from applying fungicides to treat infected plants before harvesting due to the strict phytosanitary regulations enforced by Japanese importers. This had different implications for farmers depending on the elevation at which their farms were situated. Our field results showed that due to elevation and micro-climatic differences, the apex of CLR infection aligns with the harvesting period for farms at higher elevations in the BMs, causing differential impacts among BM growers according to distinct differences in bearing cycles.

Our fieldwork found that one of the biggest contributing factors to the CLR outbreak could be traced back to the downturn in the Japanese coffee export market triggered by the 2008 global economic recession (see also, Guido et al. 2019, 2020). Farmers singled out 2008 as a period of severe economic stress. The recession set off a decline in the price farmers received for their coffee berries that ultimately plummeted to the lowest levels in many farmers' memories. This, in turn, reduced their income which further impacted their ability to care for their coffee plants. Data on Jamaica's coffee production and exports corroborate the recollections of farmers. As prices fell, there was a commensurate increase in the costs of fertilizers and other agro-chemicals which compounded the economic burden of farmers, with smallholder farmers being hit the hardest. This is supported by other studies that have shown how fluctuations in the price of coffee normally influence crop management and care, which in turn influence rust incidence and severity (Talhinhas et al. 2017).

BM farmers' exposure to the price volatility of the Japanese export market was exacerbated by decades of structural adjustment that dismantled government support for the industry. Smallholders suffered through not only the deregulation of price support in the 1980s, but also the widespread closure of coffee cooperatives in the 1990s, and a reduction of extension personnel so severe in the 2000s that JACRA "converted its Extension Department into Advisory Services reflecting the reality that it could no longer provide Extension support as classically defined to Coffee Growers" (CIB 1999-2004: 6).

Concluding Remarks

In this paper, we use the example of the coffee leaf rust to illustrate how vulnerability to the disease is shaped in part by the multiple and intersecting political-economic and ecological forces under which coffee is produced, regulated and traded. We demonstrate that the impacts resulting from CLR were unevenly felt among farmers in the Jamaican BMs, with small resource-poor farmers displaying a disproportionately higher vulnerability to the plant disease. At a minimum, farmers who produced less coffee, earned less income from its sales and generally had less resources to invest in their farms. At an extreme, some farmers have abandoned coffee farming altogether as the costs of maintaining infected coffee plants have become prohibitive. In general, smallholders' limited access to resources (e.g. fungicide, fertilizer and labor) played an important role in restricting the response pathways available to a significant portion of BM coffee farmers.

Our case study also illustrates the importance of considering materiality in the analysis of the coffee rust epidemic. Varietal differences as well as the phenology of the coffee plant played an important role in facilitating or curbing the development and circulation of the disease agent. For instance, the generally higher susceptibility of the Arabica variety to this recent strain of the coffee rust pathogen featured highly in our study. Phenotypic characteristics of the coffee plant (e.g. fruiting pattern and its shrub-like morphology) also placed a limitation on the kinds of farm-level management practices that were possible to curb the spread of the disease. Additionally, *H. vastatrix's* complex pathogenesis makes the disease difficult to control. This was clearly evident in the Jamaican BMs where complex host-pathogen-environmental interactions, as well as the dynamic and unpredictable ways these interactions unfolded across space and time, compromised efforts aimed at containing the disease. Added to this is the nature of BM coffee production itself which entails close interactions between humans and coffee plants because most farms are located on steep hillslopes that are unsuitable for mechanized harvesting techniques.

Yet, the varied, cross-scalar and uneven ways *H. vastatrix* maps onto, and is mediated through, everyday human-plant-microbial interactions are partly conditioned by wider political-economic forces. The clear preference for a specific *Coffea arabica* variety, the heavy reliance on the Japanese export market and the strict phytosanitary restrictions caused BM coffee farmers to adhere to conditions that accentuated their exposure and vulnerability to CLR. The fact that local farmers became aware of the Typica variety's higher susceptibility to the leaf rust disease but were unable to shift towards varieties that were deemed more tolerant, demonstrates the underlying power structures that both shape and limit farm-level decisions and livelihood practices. Also, the fact that coffee is a perennial crop makes it difficult for farmers to switch towards other crops, and the comparatively higher price the commodity fetches provides adequate incentive for smallholder farmers to prioritize coffee over low-end cash crops.

In sum, the economic consequences for smallholder farmers are enormous. This is not to say that farmers were passive agents and were unaware of most of the structural limitations they faced. However, the vast majority of smallholder farmers we spoke with explained that their ability to cope with the rust impacts was compromised by resource constraints and bounded knowledge systems. In the latter case, we see where the uncertainties surrounding the material and temporal properties of the CLR disease impacted many farmers' ability to curtail its spread.

This also had a lot to do with the highly regulated and highly volatile BM coffee commodity chain that, more often than not, placed smallholders in a precarious and disadvantaged position. When combined, these intersecting socio-economic and political factors served to reinforce pre-existing subjectivities that further conditioned smallholder farmers' vulnerability to CLR's damaging impacts.

In closing, we argue that none of these factors can be assessed independently but must be viewed in relation to each other. As Bennett (2004, 365) points out "humans are always in composition with nonhumanity, never outside of a sticky web of connections or an ecology". At the same time, it is hard to conceive of any non-human entity that is not bound up or influenced by some kind of human or social system. We contend that in order to arrive at a better understanding of smallholder vulnerability to CLR, close attention has to be paid to both its socio-material and political-economic dimensions. In the former case, we foreground the ways the disease maps onto, shapes and is itself mediated by complex human-plant-microbial interactions. In the latter, we contend that it is the uneven ways the coffee commodity chain is structured that partly condition those smallholder vulnerabilities (and the attendant subjectivities) in the first place.

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Table Captions

Table 1: CLR Life Cycle and Major Biophysical Variables that Influence Each Stage

Table 2: Distribution of Assets Among BM Farmers.

Figure Captions

Figure 1: Influences of Climate and Weather Variables on the CLR Life Cycle

Figure 2: Image of a coffee leaf infected with coffee leaf rust (yellow spores located on the underside of the leaf). Photo credit: Zack Guido.

Figure 3: The approximate community locations of household survey and focus groups within the Blue Mountain (BM) coffee farming zone. The number of surveys, along with approximate elevation of the community, is also shown.

Figure 4: Farmers' Self-Reported Estimations of CLR losses, 2012-2015

Table 1: CLR Life Cycle and Major Biophysical Variables that Influence Each Stage

Life Cycle	***Description***	***Abiotic Variables***			***Biotic Variables***
		Temperature	***Moisture***	***Wind***	
Development of new spores	Brownish/reddish rust-like pustules form on the underside of coffee leaf	New spores normally develop when temperatures range from 15-30C	Leaf wetness and humidity can influence spore production	No significant influence	Stomatal density; canopy structure and foliage
Spore dispersal and deposition	Spores disperse from one part of an infected plant to another or to a new plant	No significant influence	Rainfall can dislodge and disperse spores (usually over short distances)	Winds can transport spores over short and far distances	Leaf size
Germination and appressorium formation	Spores germinate to produce one or more germ tubes (appressoria) that is used to enter the leaf through the stomata	Germination influenced by variations in diurnal temperature; as average minimum temperature increases, both the incidence and severity of CLR increases CLR incidence normally vary by elevation (low incidence associated with higher elevations due to cooler micro-climatic conditions)	Spore germination increases with humidity Prolonged leaf wetness affects germination (though in the absence of water dry spores can survive on leaves up to six weeks) Early onset of rainy season	No significant influence	Stomatal density; canopy structure and foliage Plant health
Colonization and infection	At this stage, the spore has penetrated the leaf through it stomata. Nutrients are being extracted and the fungus starts to reproduce itself.	Infection usually takes place when temperature ranges between 15-30C Infection rates also increase as average minimum temperature increase	Infection rate increases with humidity Prolonged leaf wetness affects germination; infection process can be completed in within 24-48 hours under optimal conditions provided there is continuous presence of leaf moisture Early onset of rainy season can affect infection rates as well	No significant influence	Fruit load; stomatal density; canopy structure and foliage Plant health

Table 2: Distribution of Assets Among BM Farmers.

Variable	**Description**	**n**	**Mean (SD)**	**%**
Fertilizer	Number of fertilizer applications per household	382	2.1 (1.3)	
Fungicides	Percent of households who applied at least one fungicide application	424		41
Labor	Percent of households who hired labor	424		52
Savings	Percent of households who had savings	399		63
Loans	Percent of households who accessed loans	417		<1
Irrigation system	Percent of households who used irrigation on at least a portion of their crops	418		11
Mechanical sprayer	Percent of households who own a mechanical sprayer to apply fungicides	433		15
Hand sprayer	Percent of households who own a hand sprayer to apply fungicides	433		52
Pruning Saw	Percent of households who own a pruning saw	433		43

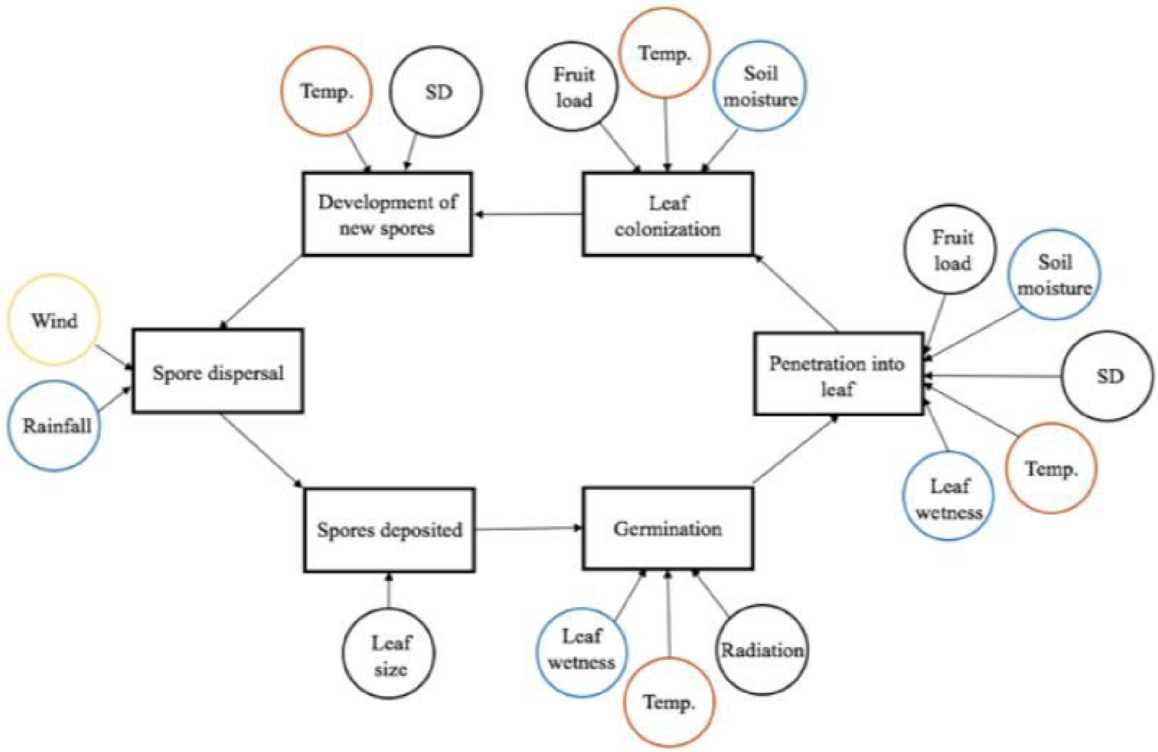


Figure 1: Influences of Climate and Weather Variables on the CLR Life Cycle

Figure 2: Image of a coffee leaf infected with coffee leaf rust (yellow spores located on the underside of the leaf). Photo credit: Zack Guido.

144x318mm (300 x 300 DPI)

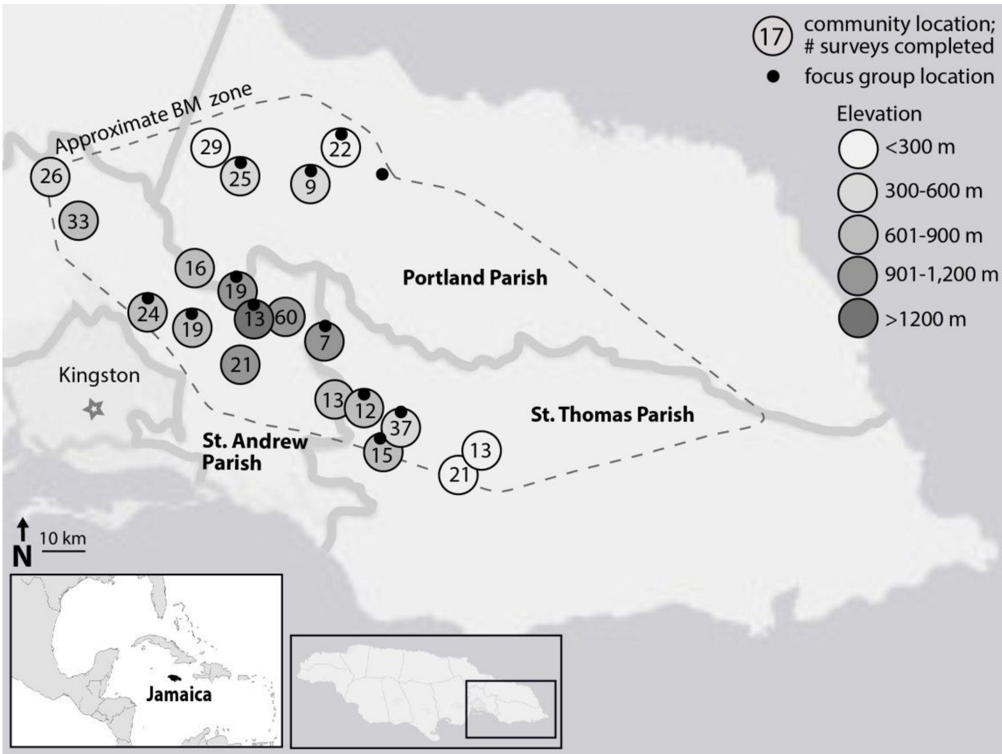
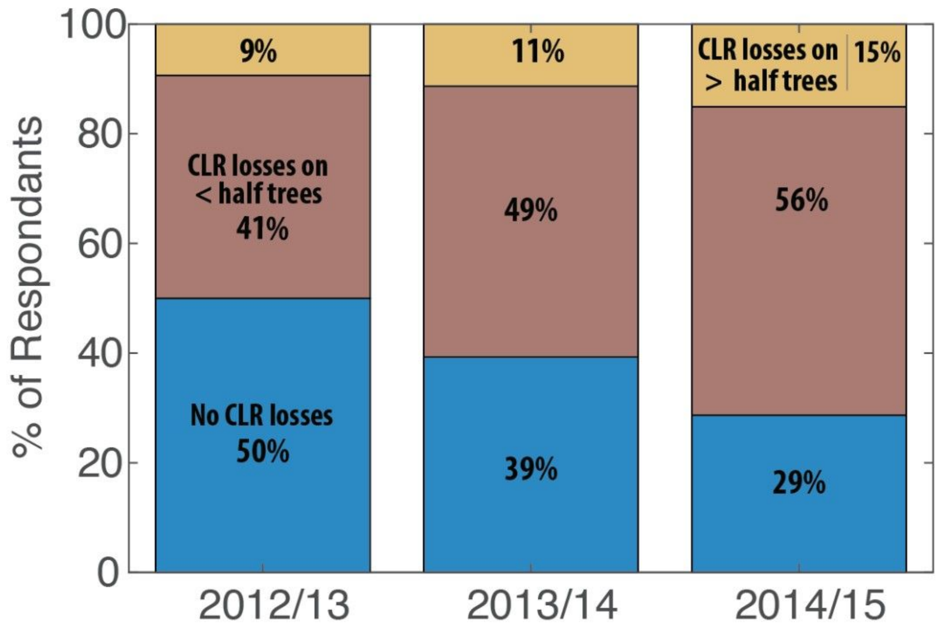


Figure 3. The approximate community locations of household survey and focus groups within the Blue Mountain (BM) coffee farming zone. The number of surveys, along with approximate elevation of the community, is also shown

90x143mm (300 x 300 DPI)



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