Parasites and Plantations: Disease, Environment and Society in efforts to induce Extinction of Hookworm in Jamaica, 1919-1936

J.D. Roberts,[a,b*] L.L. Waddington,[b] R.J. Quinnell,[a] G. Huggan,[c] Alison Dunn.[a]

[a] School of Biology, University of Leeds, Leeds, LS2 9JT

[b] School of History, University of Leeds

[c] School of English, University of Leeds

*Corresponding author: j.d.roberts@leeds.ac.uk

Author contributions

Conceptualisation: JDR, AMD, LW, GH and RJQ; Statistical design: JDR, RJQ, and AMD; Archival research, data collection and curation: JDR; Investigation: JDR, AMD, LW, GH and RJQ; Writing – original draft: JDR; Writing – reviewing, critiquing, and editing: JDR, AMD; LW, RJQ and GH.

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Impact Statement

This paper examines an underappreciated form of extinction: an attempt to induce the extinction of a parasite. By doing so, it historicises extinction, demonstrating that anthropogenic extinctions are driven by specific social, economic and ecological configurations, not by any one single 'humanity'. It further adopts a novel interdisciplinary method, extending both epidemiology and medical history, thereby bridging both and bringing two very different approaches into dialogue. This approach aims to speak to both disciplines and thereby have some impact on both fields. It demonstrates that

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diseases are influenced by a complex combination of social, environmental and individual factors, something always worth highlighting in a world where social medicine is now only remembered by historians and biomedicine is individualised to the point where its futuristic dream is ‘personalised medicine’. Finally, it extends historical understanding, by elaborating on the medical landscape of an understudied period in Jamaican history: the period between the 1865 Morant Bay Rebellion and the 1938 Labour Rebellions.

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Abstract

Studies of extinction typically focus on unintended losses of biodiversity and culture. This paper, however, examines an attempt to induce extinction of a parasite: human hookworm (*Necator americanus* & *Ancylostoma duodenale*). Our interdisciplinary approach integrates medical history and epidemiology using records created by the Jamaica Hookworm Commission of 1919-1936. We show that the attempt to induce the extinction of hookworm was driven by its perceived effect on labour productivity and consequent status as an ideological and an economic threat. We use spatial epidemiology to describe the relationships between parasite, environment and the working conditions of plantation labourers. Using data from 330 locations across Jamaica in which 169,380 individuals were tested for hookworm infection we show that the prevalence of hookworm infection was higher in districts surrounding plantations. Prevalence decreased with the temperature of the coldest month, increased with the amount of rainfall in the driest month, and increased with vegetation quantity (normalized difference vegetation index). Worm burden (and thus pathology) varied greatly between individuals, even those living together; hookworm infection varied between environments, socioeconomic conditions and individuals. Nevertheless, the conditions of labour shaped the distribution of hookworm. Plantations both spread and problematised hookworm, driving efforts to bring it to extinction.

Introduction: Induced Extinction

While biology defines extinction as a single event, it is now commonly held in extinction studies that extinction is more of an ongoing process of unknotting webs, as ecological, cultural and emotional entanglements fall apart; even after the last individual of a species has died, memorialisation recapitulates extinction, and extinct species live on as ghosts in the ecological and cultural spaces they once inhabited (Dooren 2014; Heise 2016; Jørgensen 2017; McCorristine and Adams 2019; Rose et al. 2017). Extinction, therefore, has no end. But where does extinction begin?

Most studies of extinction focus on unintended losses of species, biodiversity and cultures. This paper, however, offers an interdisciplinary perspective on an attempt to induce the extinction of a parasite: human hookworm. It aims firstly to elucidate a socioeconomic driver of extinction – the perceived effects of hookworm on labour productivity within a plantation system – using discursive historical analysis. Secondly, the interactions of the socioeconomic/socioecological institution of the plantation with environmental factors in shaping the prevalence of hookworm are explored through spatial epidemiology. Finally, this paper turns to the worm burden, the number of hookworms within individuals, in order to comment upon how far socioecological conditions can be said to determine the pathology of hookworm disease.

These will be studied through the records created by the Jamaica Hookworm Commission (JHC) of 1919-1936. The JHC was launched in 1919 (Jones 2013) as a cooperative endeavour between the colonial government and the Rockefeller Foundation (RF), which viewed hookworm as a convenient 'wedge' to induce foreign governments to build up public health systems (Birn and Solórzano 1999; Farley 2004). The RF was founded by Standard Oil baron John D. Rockefeller and absorbed his business-minded outlook; it aimed to cheaply build up public health systems, and believed that hookworm eradication campaigns part-funded by local governments offered good returns in public health for a relatively small investment (Ettling 1981; Farley 2004). Initially headed by Powell Gardener, the JHC was soon taken over by fellow RF doctor Benjamin Earl Washburn.[1] It was absorbed by the colonial government in 1933, but continued until 1936, when the 'hookworm units' were reconfigured as 'mobile health units' focussing mainly on yaws (*Treponema pallidum pertenue* infection).[2]

Jamaica in 1919 was the largest of the British West Indies, and remained a regional centre, but was neglected by the imperial government (Jones 2013). Following emancipation and the end of slavery in 1838, and more importantly the ending of British tariff protections for West Indian sugar in 1846, the sugar industry which had made Jamaica's planter classes rich crashed (Bryan 2000). As the imperial

[1] UK National Archives, Kew [NA], CO/141/82 'Government Notices' *Jamaica Gazette,* 42:10 (1919).
[2] Jamaica Archives, Spanish Town [JA] IB/5/77/254 'Hookworm + Malaria Commissions – taking over by Government' (1933); University of the West Indies Medical Library, Mona [UWI] 'Medical Department: Report for the year ended 31st December, 1936' (1936).

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government focused on India and Africa, Jamaica became a backwater colony, receiving no financial aid and few medical doctors from Britain (Heuring 2011). Kingston constituted the only major city, but several smaller towns were scattered around the island (Moore and Johnson 2011). Despite the decline of the sugar industry many plantations remained, growing cash crops such as sugar, bananas and coffee, and employing day-labour as well as indentured labourers from India (Bryan 2000; Shepherd 1994). Much of the population consisted of 'small settlers': subsistence farmers who had established their own smallholdings after emancipation (Moore and Johnson 2011). The urban poor crowded into subdivided houses and communal yards, while the urban middle class possessed significant political influence (Moore and Johnson 2011) which they used to influence health efforts according to their social and political goals (Heuring 2011). Access to biomedicine was limited, and many relied on a rich tradition of folk medicine (Jones 2013; Payne-Jackson and Alleyne 2004).

Hookworm disease is caused by parasitic nematodes of the family Ancylostomatidae; the main parasites of humans are *Ancylostoma duodenale* and *Necator americanus* (Brooker et al. 2004). Adult hookworms attach to the wall of the small intestine, where they feed on haemoglobin from red blood cells (haematophagy) (Shalash et al. 2021). They copulate and lay eggs in the small intestine, which are then passed in the faeces (Loukas et al. 2016). Eggs hatch in the soil into saprophytic L1 larvae, before moulting into L2, then L3, larvae in 5-10 days (Brooker et al. 2004; Loukas et al. 2016). L3, the infective stage, move towards heat and movement, actively seeking hosts, and entering them percutaneously through hair follicles (Gaze 2014). Once inside the body, they migrate through the capillaries into the lungs, ascending the trachea until involuntary coughing moves them into the gastrointestinal track where they are swallowed, thereby entering the alimentary canal (Chapman et al. 2021; Loukas et al. 2016). Host blood loss is directly dependent on burden; infection with a small number of hookworms is often asymptomatic, but higher burdens can produce iron-deficiency anaemia (Chapman et al. 2021; Loukas et al. 2016). It is therefore necessary to distinguish between infection – the presence of live parasites within a host – and disease – illness caused by the parasite. In the early 20th century both infection and disease were widespread across the circum-Caribbean region, from the American South to Suriname (Hoefte 2009; Pemberton 2003; Tikasingh et al. 2011).

By 1919, the RF had largely retreated from its earlier rhetoric of 'eradication' in favour of 'control', having realised that 'though the problem of complete eradication seems simple in theory, it is not so in fact' (Howard 1919).[3] But they still envisaged 'control' as a step along the way to extinction: in his initial pitch to the Jamaican colonial government in 1915, Hector Howard (RF International Health Board director for the West Indies) urged that his proposed measures be adopted so that hookworm could be 'controlled and ultimately eradicated'.[4] Margaret Jones and James Riley have both noted the 1920s as an important period in the changing medical landscape of Jamaica, as life expectancy, access to sanitation, public health services and health education were improved (Jones 2013; Riley 2005). Both credit Washburn and the JHC with a role in this, though both emphasise the crucial role played by Jamaican groups and individuals in shaping their own health. Resurveys of areas in which the JHC had operated between 1919 and 1922 showed dramatically reduced prevalence of infection following treatment of those found infected by JHC mass-testing (Figure 1), indicating that humans were rapidly

[3] C.f. NA CO/137/742 B.E. Washburn to Dr Hunt (Superintending Medical Officer) 6th Sept. 1920.
[4] NA CO/137/711 H.H. Howard to Colonial Secretary, Feb 8th 1915.

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disentangling themselves from hookworm, perhaps inching this obligate parasite in the direction of extinction. With the reduction in control efforts at the end of the RF programmes, there is some evidence of a rebound in hookworm prevalence, but very little data is available (Tikasingh et al. 2011). More recent surveys show hookworm to be now uncommon, with reported prevalence in the 1990s ranging from 0 to 6% (Tikasingh et al. 2011). The JHC was an important event in the extinction story of hookworm, even though it did not intend to bring about its immediate demise.

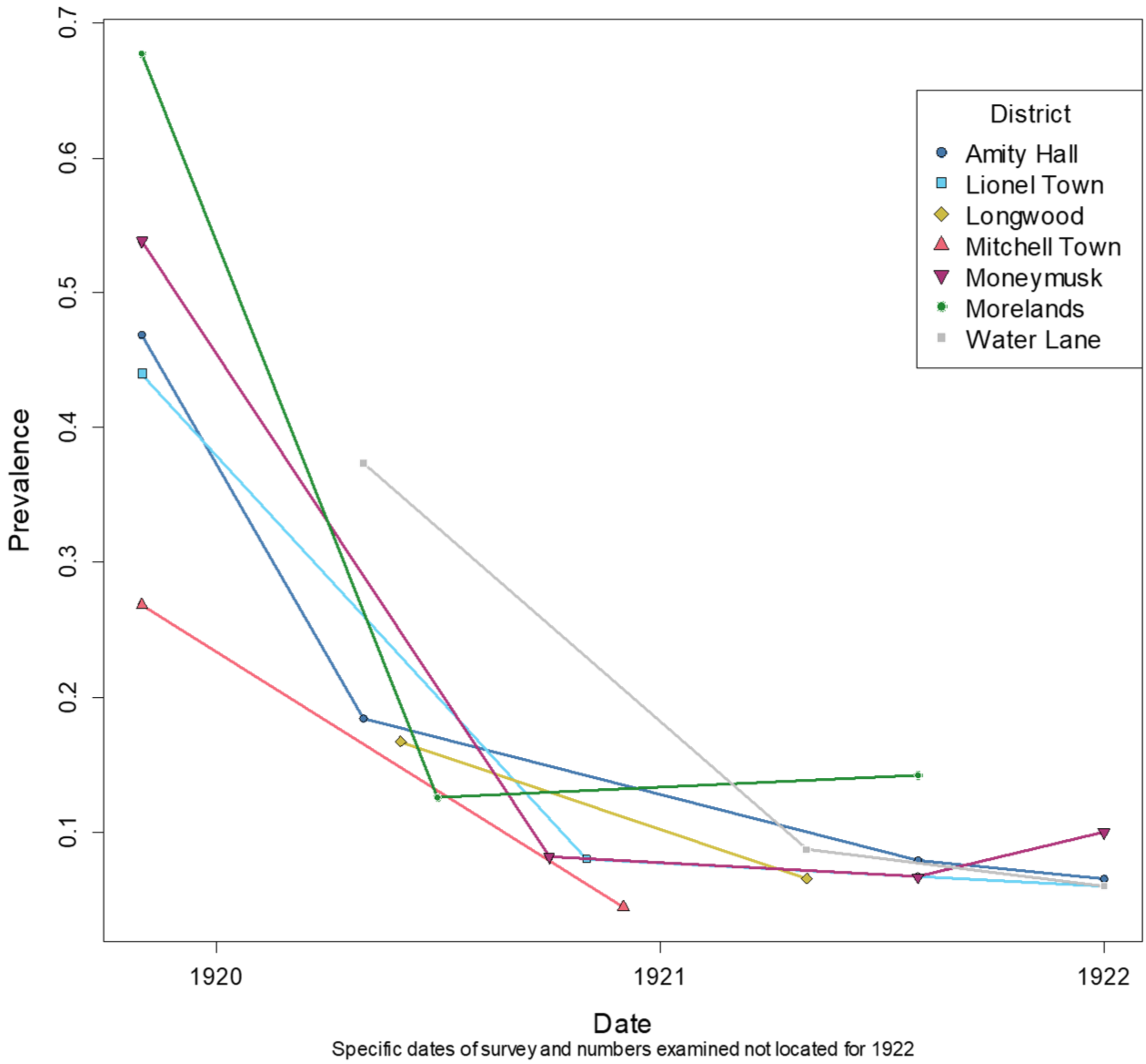

Figure 1: Results of prevalence surveys for hookworm infection in seven districts of Vere, St Catherine, pre- and post-JHC campaign, 1919-1922. Data from NA CO/141/85 85 'Report of the Jamaica Hookworm Campaign for 1921' Sup. *Jam. Gaz.* 45:21 (1922) and NA CO/141/87 'Report of the Jamaica Hookworm Commission', Sup. *Jam. Gaz.* 47:2 (1924).

This paper explores the environmental and social influences on hookworm infection and describes how the planned extinction of hookworm was initiated as a result of the effect it was perceived to have on working capacity. Eugene Richardson has criticised epidemiology for the 'appalling silence of mathematical models' which privilege proximate risk factors and conceal a major cause of disease and death in the Global South: historical colonial and continuing neocolonial extraction (Richardson 2020). This current paper, by contrast, uses spatial epidemiology to integrate environmental and social analysis, demonstrating that temperature, rainfall, vegetation and the presence of plantations all shaped the prevalence of hookworm infection. Steven Palmer has argued that plantations led to increased burdens, and therefore increased pathogenicity, of hookworm (Palmer 2010); this paper explores the interactions of environment, hookworm and plantations as well as variations in burden between individuals.

Ideological & Economic Drivers of Extinction: Hookworm as a labour problem

This section explores how hookworm was viewed by the RF and the colonial authorities as a threat to labour productivity, necessitating hookworm's eradication. It uses reports and correspondence from the UK Colonial Office (CO) to examine the ways in which officials, doctors and plantation managers viewed hookworm, and why they desired its treatment and ultimate extinction.

As early as 1915, Howard wrote to the colonial secretary that 'the prevalence of ankylostomiasis among the labouring classes causes an enormous economic loss each year', a point which an anonymous official highlighted by means of a pen-drawn line to the left of the paragraph.[5] The CO found Howard's report 'far from reassuring'.[6]

By this point, the Jamaican government was already interested in hookworm. From at least 1913, it published monthly reports on hookworm from the public general hospitals, asked for reports on sanitation from its local health officers and began embarking on efforts to deworm prisoners, estate labourers and immigrants arriving from India as indentured labourers.[7] The settings of this 'thymolising' (thymol was the drug used to purge hookworm) are revealing – they are not only spaces where the state can enforce treatment through coercion, but also spaces which revolved around work. Prisons and indenture alike enforced regular working patterns to maximise productivity, and hookworm treatment formed a part of this. Deworming immigrants did not prevent hookworm becoming established on the plantations – it already was – but it ensured that labourers arrived on the plantations able to work at maximum capacity.

In 1920 Washburn wrote that 'Hookworm dissase [sic] is an important economic problem in Jamaica the control of which will result in increased health and wealth for the people'.[8] Inability to work became a specific symptom of hookworm disease: Washburn asserted that a hookworm victim

[5] NA CO/137/711 H.H. Howard to Colonial Secretary, Feb 8th 1915.
[6] Ibid.
[7] NA CO/141/76 'Island Medical Office Report' Sup. *Jam. Gaz.* 36:18 (2nd October 1913).
[8] NA CO/137/742 B.E. Washburn to Dr Hunt (Superintending Medical Officer) 6th Sept. 1920.

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> feels weak and is unable to do a full day's work because his knees become tired and his back aches and he cannot carry a load; and his poor work leads people to think that he is lazy.[9]

The blood loss and anaemia arising from heavy burdens of hookworm are biological processes; but this linkage to inability to work showcases that the symptomatology of a disease is shaped by the preoccupations of the society in question.

The Jamaica Hookworm Commission absorbed a societal preoccupation with work. The Jamaican upper classes (largely white) and middle classes (largely light-skinned people of mixed heritage; for a full discussion of the relationship between class and colour in Jamaica see (Altink 2019)) combined the metropolitan view of work as inherently virtuous with racist anxiety about the need to 'civilise' the darker-skinned working classes (Moore and Johnson 2011). Ken Post has explained this in terms of a contest between peasant (small settler) and capitalist (plantation) modes of production (Post 1978). Jamaican elites felt that small settlers and labourers should prioritise paid work on plantations rather than shaping their working patterns around their own economic needs (Moore and Johnson 2011); but the labouring classes valued economic independence, landownership, and the freedom these provided, irrespective of elite accusations of laziness (Smith 2004). 'In the Caribbean', Brian Moore and Michelle Johnson argue, 'civilisation equalled hard work on the plantations' (Moore and Johnson 2011). Juanita de Barros has similarly noted that in the Caribbean 'the effects of hookworm disease…on labor productivity convinced medical researchers and those who funded their work that it had to be eradicated' (Barros 2014).

The doctors working on the hookworm campaign valued work and economic productivity. They frequently referred to plantation managers benefitting from hookworm treatment producing more productive labour, using phrases such as 'the estate managers have expressed themselves as highly pleased with the benefits of the treatment…and the increased working ability of their employees'; 'estate labourers can do more and better and more regular work after being treated for hookworm disease'; and 'treatment for hookworm disease results in a noticeable increase in the working capacity of individual labourers'.[10] These reports also often include letters from plantation managers, who also viewed hookworm in primarily economic terms. H.B. Walcott, manager of the Amity Hall Estates, wrote that:

> Many individual labourers have had their health improved and this has resulted in their ability to do more regular work. Formerly there was a great deal of time lost from sickness, but since the hookworm campaign it has been rare to find a labourer who is unable to give full time. This is the most important economic factor resulting from the campaign…[11]

[9] NA CO/141/85 'Report of the Jamaica Hookworm Campaign for 1921' Sup. *Jam. Gaz.* 45:21 (19th October 1922).

[10] NA CO/141/84 'Report of the Jamaica Hookworm Campaign for 1920' Sup. *Jam. Gaz.* 44:22 (15th December 1921); NA CO/141/88 B.E. Washburn, 'Report of the Jamaica Hookworm Commission for 1924' Sup. *Jam. Gaz.* 48:7 (23rd April 1925); NA CO/141/91 B.E. Washburn, 'Report of the Co-operative Health Work in Jamaica during 1927', Sup. *Jam. Gaz.* 51:5 (26th April 1928).

[11] NA CO/137/742 B.E. Washburn to Dr Hunt (Superintending Medical Officer) 6th Sept. 1920.

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Washburn attributed improvements in (and enforcement of) sanitation by the plantations of lower Clarendon to the JHC demonstrating the ‘great economic importance’ of hookworm and sanitation.[12]

The pathology arising from loss of blood to hookworm was principally understood in economic terms. Hookworm became an economic threat to both the social and individual bodies, as it was understood to inhibit the host’s ability to work. This represented both an economic threat and an ideological one, as plantation work was deemed inherently ‘civilising’ by the colonial authorities. Thus hookworm was defined as a major problem, necessitating control measures and placing it on the path to extinction. The fact that hookworm was viewed as a threat to work necessitated its destruction across society, as promoting work was a societal, even civilizational, concern for the colonial elites.

Parasites, Environment & Plantations

But what was the relationship between hookworm and the plantations valued by the colonial elites? Palmer has argued that plantations turned benign hookworm infections into hookworm disease, as plantations provided large densities of hosts, poor sanitation, and thus ‘ideal ecologies’ for the parasite’s transmission, facilitating greater worm burdens (Palmer 2010). This section uses spatial epidemiology to untangle the relationship between parasite, environment and plantations, using data collected by the JHC across Jamaica.

The JHC eradication methodology was the RF ‘intensive method’ (Howard 1919). After securing cooperation and funding from the local Parochial Board, an area of operations was selected, and divided into ‘districts’ of around 500 people.[13] The Commission took a census of the number of people in a district before testing as many people as possible across all ages and genders for hookworm using salt flotation or centrifuging of faecal samples.[14] As well as adult workers, the JHC thought it important to test children, on whom they felt hookworm had ‘dire effects’, stunting growth and hindering their education and therefore their future opportunities and economic usefulness (this was another reason why hookworm’s extinction was thought desirable).[15] Those whose samples were found infected with hookworm were treated with anthelmintics, usually thymol and chenopodium.[16] Previous epidemiological studies of hookworm using data collected by the RF have focused on the United States, where the ‘dispensary method’ was used alongside surveys of schoolchildren (Anderson and Allen 2011; Elman et al. 2014). These dispensaries were local spectacles, held in a public place and attempting to draw the local population to come forward for testing and treatment (Ettling 1981). Though successful at drawing crowds, the dispensaries did not aim to survey entire communities: dispensary and school-based records of hookworm therefore form a less complete sample than was obtained by the JHC. This is the first study to use historical data on hookworm prevalence collected by the intensive method.

The numbers of individuals examined and infected with hookworm from 368 districts was located in monthly and annual reports found in the *Jamaica Gazette* between 1919 and 1931 in the UK National Archives, Kew, and from the annual reports of the Island Medical Department between 1932 and

[12] Ibid.
[13] NA CO/141/84 sup. *Jam. Gaz.* 44:22 ‘Report of the Jamaica Hookworm Campaign for 1920’ (1921).
[14] Ibid.
[15] NA CO/141/88 B.E. Washburn, ‘Report of the Jamaica Hookworm Commission for 1924’ Sup. *Jam. Gaz.* 48:7 (1925); NA CO/141/85 ‘Report of the Jamaica Hookworm Campaign for 1921’ Sup. *Jam. Gaz.* 45:21 (1922).
[16] Ibid.

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1936, accessed in the University of the West Indies Medical Library, Kingston. The hookworm commission eventually worked in all parishes, but data was only available for districts in 9 parishes, including a single district in Westmoreland.

To assign a latitude and longitude to each district, the namesake towns or villages of the district were searched for firstly on a 1901 map of the island, and secondly on an 1895 map.[17] If a district could be located from these maps, a pin was dropped on the same location in Google Maps, and the latitude and longitude of the pin was used. If a district could not be located from the older maps, the name of the district was searched for in Google Maps and the location of the present-day town was used. If no town was found, the coordinates of a church, school, police station or road bearing the name of the district was used. 309 districts were located this way and 21 districts were located by consulting maps held in the National Archives according to the same method.[18] In total 330 districts were located, in which 169,380 people were tested for hookworm.

Environmental data were extracted from WorldClim 2.0 (https://www.worldclim.org/; Precipitation and Temperature), ISRIC (www.soilgrids.org; Soil Sand Content, Soil Grain Size and Soil Water pH) and NASA MODIS (https://terra.nasa.gov/data/modis-data; Normalised Difference Vegetation Index (NDVI)). Values were averaged across a circle with a 500m diameter centring on the coordinates assigned to the district using *extract* from the *raster* R package. Presence of a plantation was taken from the list of estates in the 1919 *Handbook of Jamaica* – if a district name was found listed as the location of one or more plantations, this was noted in the dataset as both a binary indicator and as a categoric variable of the crops grown.[19] Districts which encompassed plantations were not always named after them, but in the absence of any information about the boundaries of the districts a namesake plantation strongly suggests that the plantation formed a major component of the district. 55 districts had associated plantations, mostly in the parishes of St Catherine (13) and St Mary (25).

Prevalence of hookworm infection was analysed after logit transformation to normalise residuals. A generalized least squares model with an exponential correlation coefficient of distance to account for spatial autocorrelation (*gls* from the *nlme* R package) was created to describe how prevalence varied across districts. Models using untransformed, log, and 2nd and 3rd order polynomial transformations of temperature and precipitation were created and Akaike Information Criterion (AIC) values were used to select the best fit. To select one precipitation and temperature variable each from the range of possible variables, models using these transformations were fitted to mean monthly temperature, minimum temperature, temperature of the coldest month and temperature of the hottest month alongside mean monthly precipitation, total annual precipitation, precipitation of the wettest month

[17] E. Stanford, *Jamaica* (London: 1901) (49x60cm), David Rumsey Collection; NA CO/137/742 C. Liddell, 'Map of the Island of Jamaica, Prepared for The Jamaica Handbook' (1895).

[18] NA CO/700/JAMAICA37 'Sugar map of Jamaica, shewing sugar estates in 1790 and 1890'; CO/700/JAMAICA44 'Jamaica. General map showing products 8 miles to 1 inch'; CO/1047/513 'Jamaica General Map'; CO/700/JAMAICA50 'Jamaica'; CO 700/JAMAICA52 'Jamaica'; MFQ 1/885 'Map of Jamaica shewing the divisions of districts, and towns in which district courts are held'; WO/252/1065 'Spanish Town and surrounding country: Ordnance Survey Map'; WO/78/2424 'Jamaica: map showing roads, railways, counties, parishes, towns, schools and churches'; WO/78/567 'Jamaica. Map of the eastern part of the island…'.

[19] *Handbook of Jamaica for 1919* (Kingston, Government Printing Office, 1919).

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and precipitation in the driest month in all possible combinations of one rainfall and one temperature variable. The best fit model included precipitation in the driest month (as a second-order polynomial) and temperature of the coldest month (as a second-order polynomial).

Transformations of the remaining environmental variables were selected according to the same method by comparing models using untransformed, log and polynomial transformations using AIC values. NDVI and soil sand content were left untransformed, but soil pH fitted best when log-transformed and soil grain size as a second-order polynomial. Following this, the function *dredge* (from the *MuMIn* R package) was used to find the model which best described how prevalence of hookworm infection varied with environmental factors.

JHC census data was available for 343 of the 368 districts; across these districts 99.2% of those censused (n=176,836) were tested for hookworm infection. Hookworm was most prevalent in the central mountains, and less prevalent along the southern coast (Figure 2). Prevalence ranged from 8.29% infected (n=712) in Hayes Cornpiece, Clarendon, to 96.7% (n=489) in Leinster, St Mary. The mean prevalence was 63.4% across all districts and 62.3% across all located districts.

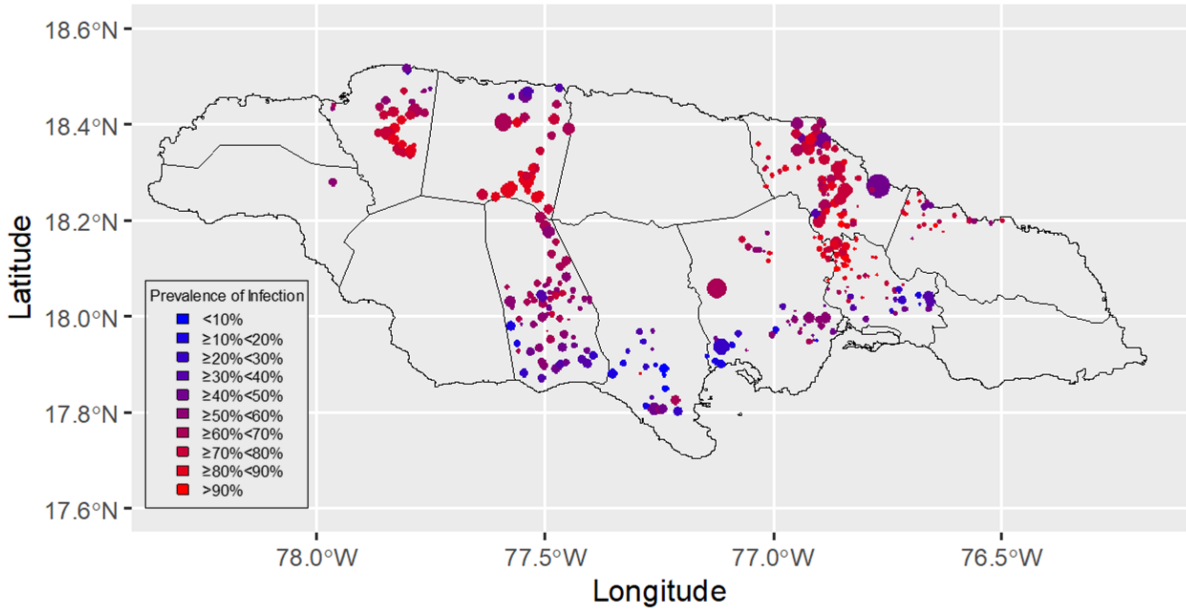

Figure 2: Prevalence of hookworm infection in 330 districts of Jamaica, 1919-1936. Data from NA CO/141/83-93 *Jamaica Gazette;* CO/137/781-797 'Hookworm Reports'; UWI, Medical Department Annual Reports. Dots scaled according to the number of individuals examined in each district. Redder dots indicate a higher prevalence of infection, larger dots indicate more individuals were tested.

The resulting model (Table 2) showed that hookworm was more prevalent in districts with a namesake plantation, more prevalent in wetter areas and had a curvilinear relationship with temperature (Figure 3). NDVI, a measure of vegetation quantity, was positively associated with hookworm prevalence, suggesting that hookworm was more prevalent in more rural areas.

Table 2: Generalised Least Squares Model of the prevalence of hookworm infection to various environmental variables in 330 districts of Jamaica, 1919-1936

Variable	Coefficient Value	Standard Error

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Precipitation in the Driest Month (mm)	8.70	±0.396
Precipitation in the Driest Month (mm, squared)	-1.45	±1.46
Precipitation in the Driest Month (mm, cubed)	-0.264	±1.12
Temperature in the Coldest Month (°C)	-2.88	±1.78
Temperature in the Coldest Month (°C, squared)	-0.36	±1.47
Temperature in the Coldest Month (°C, cubed)	3.70	±1.13
Presence of a Plantation in 1918	0.362	±0.0990
Normalised Difference Vegetation Index (NDVI units x 10^6)	1.11	±0.555

Table 3: Comparison of selected model with models incorporating fewer or additional environmental variables. Transformations of Precipitation, Temperature and NDVI as in Table 2

Variables	Model AIC	Delta-AIC
Precipitation, Temperature, NDVI and Presence of a Plantation	649	-
Precipitation, Temperature, NDVI, Presence of a Plantation and Soil Sand Content	650	1
Precipitation, Temperature, NDVI, Presence of a Plantation and Soil pH (logged)	651	2
Precipitation, NDVI and Presence of a Plantation	651	2
Precipitation, Temperature and Presence of a Plantation	651	2
Precipitation, Temperature, NDVI, Presence of a Plantation and Soil Grain Size (2nd-order polynomial)	652	3
Temperature, NDVI and Presence of a Plantation	654	5
Precipitation, Temperature, and NDVI	661	32

Table 4: Generalised Variance Inflation Factors of variables in the model shown in Table 2

Variable	Generalised Variance Inflation Factor
Precipitation in the Driest Month (mm, 3rd-order polynomial)	2.55
Temperature in the Coldest Month (°C, 3rd-order polynomial)	2.79
Presence of a Plantation in 1918	1.03
Normalised Difference Vegetation Index (NDVI units x 10^6)	1.23

The selected model provided the best fit to the data with the fewest variables. Neither the addition of soil sand content or soil water pH, nor the removal of temperature or NDVI significantly changed model performance (delta-AIC<3; Table 3). However, the removal of precipitation or presence of a plantation, or the addition of soil grain size significantly impaired model performance; this suggests precipitation and plantations were of greater importance than temperature or vegetation. Generalised Variance Inflation Factors for the selected model (calculated using *vif* from the *car* R package) indicated only modest collinearity between variables included in the final model (GVIF<5; Table 4).

The positive relationship of prevalence and precipitation in the driest month is consistent with desiccation killing hookworm larvae in the soil, thereby reducing transmission (Ajjampur et al. 2021; Elman et al. 2014; Loukas et al. 2016; Mudenda et al. 2012; Wardell et al. 2017). Hookworm was least prevalent in the hottest areas, which was unexpected, as hookworm eggs and larvae typically survive temperatures up to 35-40°C (Mudenda et al. 2012; Udonsi and Atata 1987; Yaro et al. 2021). This may be because the hotter coastal plains of Jamaica were also drier, less densely vegetated, and more exposed to sunlight, leading to hookworm larvae dying from desiccation in hot, dry soils at temperatures which were themselves insufficient to kill them. In 1927 Washburn attributed his observation that 'more people are infected with hookworms in mountainous districts than in the dry sandy plains near the coast' to desiccation.[20] Temperature scales inversely with elevation; the colder,

[20] 'Facts about Hookworm Disease' *Jamaica Public Health* 1:7 (1927).

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wetter mountains appear to have been more hospitable to hookworm. Vegetation has been found important in other studies as leaves shade soil thereby protecting hookworm larvae from desiccation (Ajjampur et al. 2021; Mudenda et al. 2012; Wardell et al. 2017). Greater exposure to L3 among rural small settlers and agricultural labourers was also likely important.

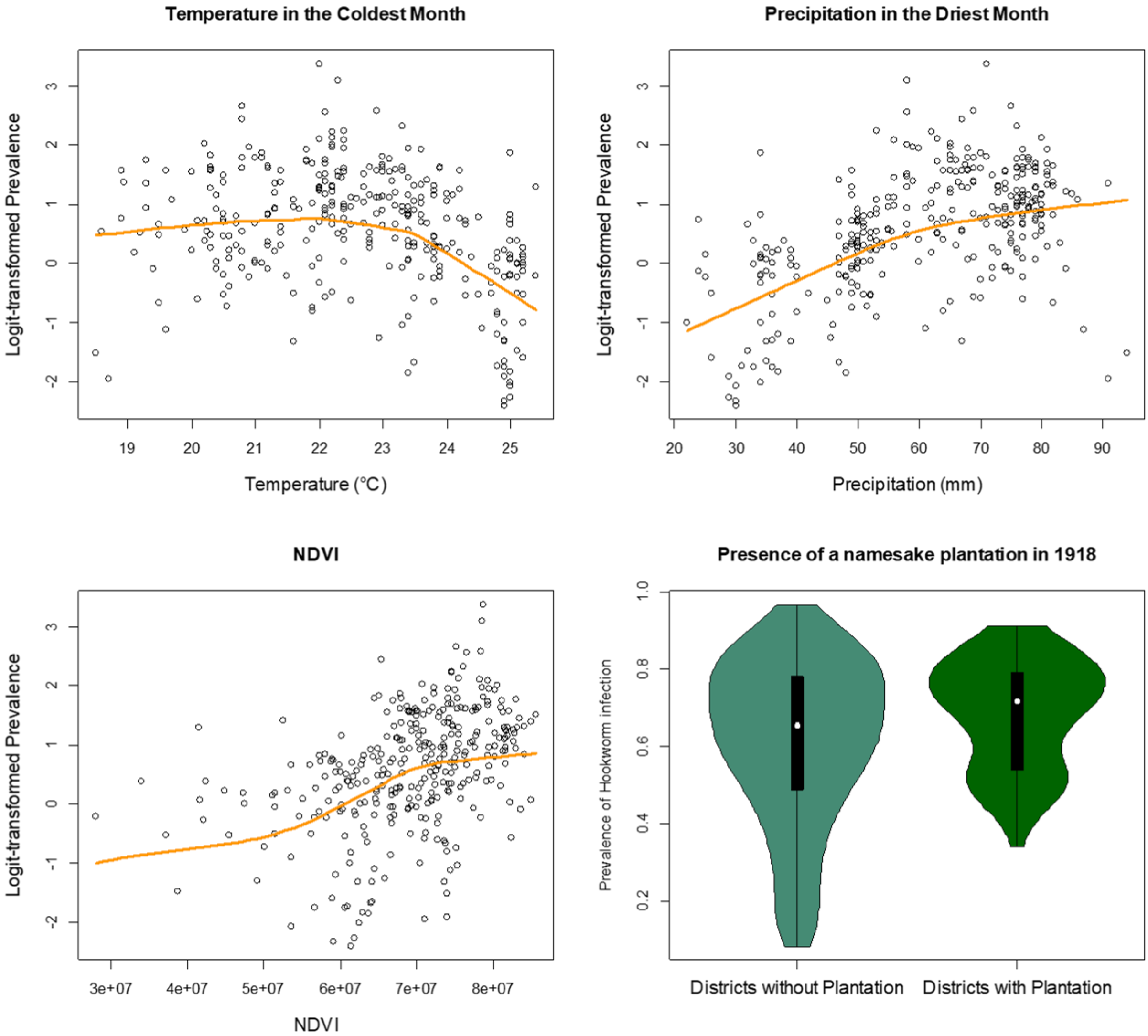

Figure 3: Logit-transformed prevalence of hookworm infection against mean temperature, mean precipitation, and NDVI, and violin plots showing prevalence of infection across districts with and without a namesake plantation, Jamaica, 1919-1936. Line represents a Loess smoothing of model predictions for each district.

Hookworm was more prevalent in districts with a namesake plantation, even after accounting for temperature, rainfall and vegetation. Ironically for those who defined civilization by plantation labour, the labour-hindering hookworm was more prevalent around plantations. These results support Palmer’s hypothesis insofar as they suggest that working conditions in plantations spread hookworm infection. This model assesses how likely people were to be infected, but Palmer’s argument hinges on the worm burden (how intensely people are infected). Nevertheless, mean intensity of infection

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typically increases with prevalence, though this relationship is non-linear (Anderson and May 1992). However, worm burdens typically also vary greatly between individuals, as is explored in the following section.

Worm Burden

This section examines the limited available evidence about burdens of hookworm in early 20th-century Jamaica, focusing mainly on quantitative evidence, but also discussing some of the qualitative evidence provided by the JHC. In most cases the JHC only recorded whether hookworm was present or absent in an individual, but there is some limited data available on burdens of hookworm during this period.

Worm counts on samples of 20-30 people were carried out in 1915, 1924 and 1931 (Figure 4). Two of these involved groups of people living together (orphans and prisoners), with a third carried out on hookworm-positive patients drawn from the general public. In each case, hookworm is markedly overdispersed, with most patients carrying only small numbers of worms (typically <100), and a small number of individuals carrying much larger burdens. The dispersal parameter *k* is used in epidemiology to describe the degree of parasite aggregation (Anderson and May 1992). A *k* close to zero indicates many parasites infecting few individuals, while a parasite population becomes more randomly dispersed as *k* approaches infinity. It was possible to calculate both *k* and the mean worm burden for the orphanage and prison samples as these included uninfected individuals; *k* was calculated by fitting a negative binomial generalised linear model with no explanatory variables (*glm.nb* in the *MASS* R package).

The mean intensities of infection were 46.6 for the prisoners and 68 among the orphans. k=0.862 (95% CL 0.362-1.36) among the orphans and k=0.491 (95% CL 0.267-0.714) among the prisoners. These k-values lie within the expected range of 0.1-10 for both hookworm and human macroparasites more generally, indicating strong overdispersion (Anderson and May 1992), but the mean worm burdens are higher than those reported from studies reviewed by Brooker *et al.*, which all report mean burdens <20 (Brooker et al. 2004).

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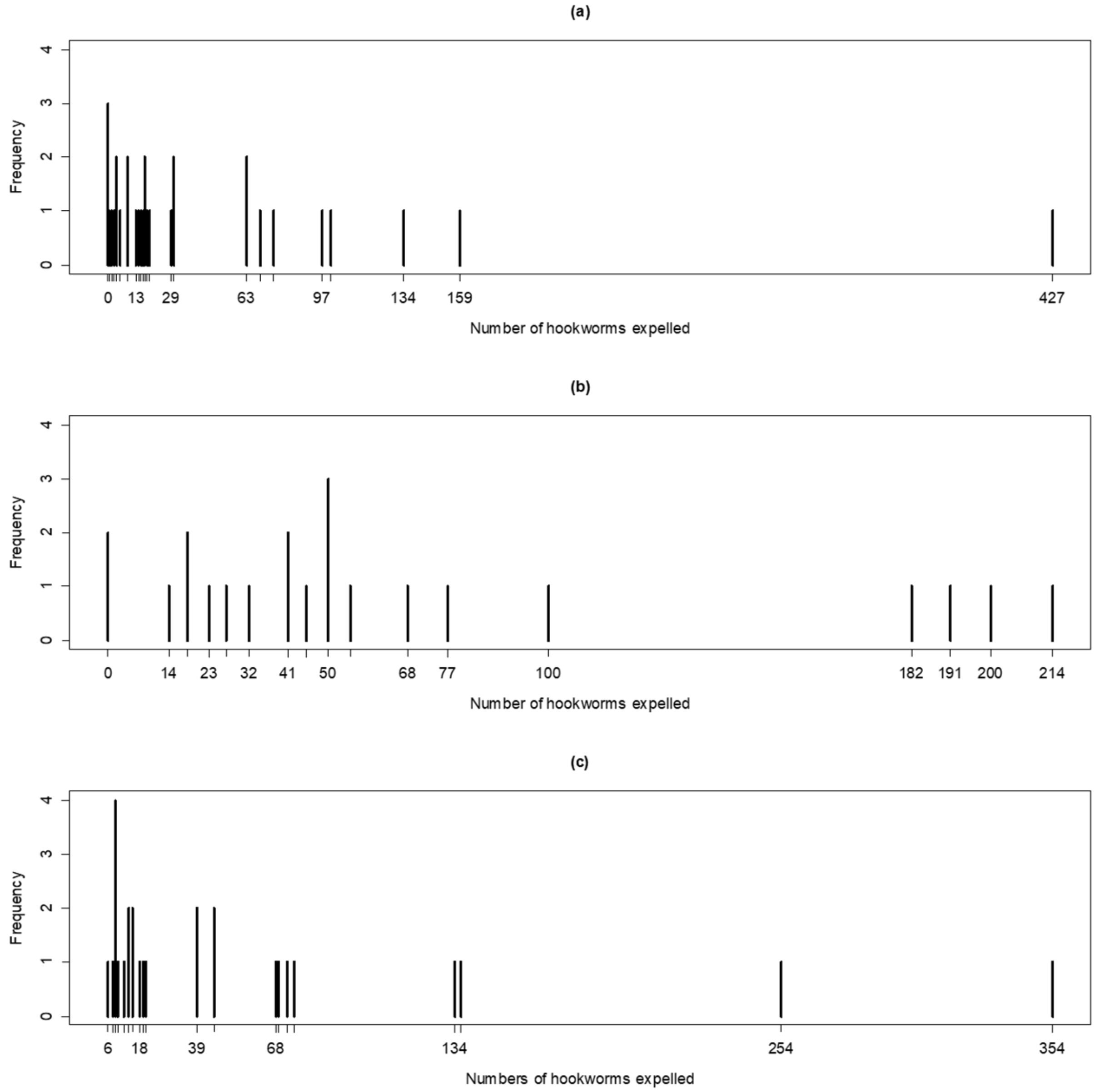

Figure 4: Numbers of hookworm expelled by treatment of: 31 prisoners (1915, a, k=0.491), 22 boys in Cross Keys Orphanage (1931, b, k=0.862) and 27 residents of Richmond (1924, c). Data from Annual Medical Reports, NA CO/141/79 Sup. *Jam. Gaz.* 34:14 (7th Sep. 1916); NA CO/141/88 Sup. *Jam. Gaz.* 48:7 (23rd Apr. 1925); NA CO/141/94 Sup. *Jam. Gaz.* (12th Nov. 1931). 1915 study on prisoners in the General Penitentiary used treatment of three days of a ‘low diet’ with thymol (60 ‘grains’ in two doses) followed by chenopodium (50 ‘minims’ in three doses) against the same dosages of both in reverse order. For the purposes of this study, the two groups were amalgamated. The 1924 study in Richmond used one dose of thymol followed by one dose of chenopodium only on infected individuals; the 1931 study does not explain its treatment methodology.

It can be assumed that all the residents of the orphanage lived together and shared very similar living conditions, but they still hosted very different burdens of hookworm. The number of months a resident had lived in the orphanage was not correlated with their burden (Spearman’s Correlation, S=1411, rho=-0.238, p=0.327). Similarly, prisoners lived and worked in close proximity, but one

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unfortunate prisoner nevertheless hosted 427 worms, while most had <20. As it is not known how long they had been imprisoned, it is possible that the majority of their worm burden was acquired before their imprisonment, but this itself demonstrates the risks of attributing burden to the socioecological conditions of a particular place when people could and did move between locations. The pathogenicity of hookworm is influenced by socioeconomic and socioecological factors, but individuals living in much the same conditions experienced hookworm very differently. A similarly high variation in burden despite similar environment has been reported from other studies of human helminths, and is likely to result from the aggregated distribution of infective stages in the environment, combined with inter-individual variation in genetic and behavioural susceptibility to infection (Quinnell et al. 2010; Wong et al. 1991).

This overdispersion and variation in disease is also qualitatively attested in medical reports. In 1931, Washburn noted that in Cross Keys, 'very few patients exhibited symptoms or signs of hookworm disease: the vast majority are carriers of, rather than sufferers from the disease'.[21] Before the JHC, in 1914 the District Medical Officer for Moneague remarked that many of those infected with hookworm 'not feeling sick in any way other than the general lassitude and weakness from anaemia…are unwilling to go 10 miles to hospital' for treatment'.[22] At the same time, a number of people did suffer terrible illness arising from hookworm. In 1915, while attempting to secure support for an eradication programme, Howard informed the CO that 'the severe types of the disease are quite common, deaths having been reported from several Districts'.[23]

While hookworm infection for many Jamaicans passed unnoticed, for the smaller number of individuals who carried large burdens, hookworm infection would have had a significant impact on their quality of life. This further helped persuade doctors and colonial officials that it had to be eradicated. Even in similar socioecological circumstances, however, hookworm burdens, and therefore pathology, varied significantly.

Discussion

This paper has demonstrated that the prevalence of hookworm in interwar Jamaica was influenced by the environment (rainfall, temperature and vegetation), but also by socioeconomic institutions in the form of plantations. As John McNeill has most famously shown, the rise of sugar plantations transformed the ecology of the Caribbean, providing new opportunities for species such as *Aedes* and *Anopheles* mosquitoes, and consequently parasites such as malarial *Plasmodia* and the yellow fever *Flavivirus* (McNeill 2010). At least one species of hookworm, *N. americanus,* is thought to have been introduced to the Americas via transatlantic slavery (Hawdon and Johnson 1996). Plantations, drawing labourers into close proximity with limited sanitation remained significant sources of hookworm infection into the 20th century.

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[21] NA CO/141/94 'Hookworm Control Through Sanitation and Treatment', Sup. *Jam. Gaz.* 54:21 (12th November 1931).
[22] NA CO/141/77 'Annual Report of the Island Medical Department', Sup. *Jam. Gaz.* 37:21 (8th October 1914).
[23] NA CO/137/711 H.H. Howard to Colonial Secretary, Feb 8th 1915.

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Palmer (2010) has argued that while hookworm infection has been historically ubiquitous in tropical and warm temperate areas, hookworm disease (i.e., high-burden infections) became vastly more prevalent in the second half of the 19th century due to workers working in close proximity amidst 'ideal ecologies for the reproduction of the parasite in mines, railroad beds, and plantation soils'. Jamie Lorimer has extended this argument, dubbing hookworm a 'pathobiont', which, depending on socioecological context, can be harmful, harmless, or even beneficial (assuming that hookworm's modulation of their host's immune system protects against allergic and autoimmune disease) (Lorimer 2020). These arguments are partially supported by this study, which indicates that plantations did indeed promote the spread of hookworm infection. However, socioecological conditions were not the sole determinant of burden, which, as is typical of macroparasites, varied significantly even between individuals living together or in the same area. This resulted in varying levels of sickness, with some individuals seriously ill and others asymptomatic; hookworm varied according to both individual and socioecological factors. This paper supports the contention that plantations increased hookworm infections, but complicates it by demonstrating that individuals living in very similar conditions still hosted highly varied burdens of hookworm. Though hookworm remains a significant health problem worldwide, in Jamaica it was placed on the path of extinction because it was seen as a threat to labouring capacity; but the conditions of labour also shaped the distribution of hookworm. Plantations both spread and problematized hookworm, driving efforts to bring it to extinction.

Black scholars have long seen in the plantation a geographic prototype (McKittrick 2011) shaping Black lives in the Americas, and in recent years the plantation has also become emblematic of capitalist modernity and multispecies exploitation in the environmental humanities (these literatures are usefully reviewed by (Chao et al. 2023) and (Davis et al. 2019)). 'Plantationocene' has even been posited as an alternative to 'Anthropocene' (Haraway 2015), though it is unclear whether this refers to a geological or historical era. Within the Caribbean, the plantation is often regarded as the defining institution of the region's history (Burnard and Garrigus 2016; Watts 1987) and scholars continue to grapple with its long-term effects on Caribbean societies (e.g. (Beckford 1972; Patterson 2023)).

The post-emancipation plantation of the early 20th Century seldom features in these literatures, which generally focus on the slave plantation or the contemporary plantation. In this study, we find that 20th-century plantations had an ambivalent relationship with hookworm. Hookworm profited from the plantation, which aided its reproduction and transmission, but it was also expelled and killed by doctors anxious to render their patients fit for plantation work. Plantation work, that is, facilitated both hookworm's entry into and forced exit from human bodies. Sophie Chao has noted in her study of West Papuan oil palm plantations that monoculture allows parasites of the crop to thrive (Chao 2021); here we find that the plantation, in regimenting and concentrating human bodies alongside vegetal ones, made human bodies vulnerable to parasites as well. In West Papua parasites of the oil palm have become symbols of resistance to the colonization embodied by the plantation (Chao 2021). Hookworm, however, made its home not in the invading crop plant, but in the bodies of workers. In this light, hookworm infection could be considered another form of racialised violence inflicted upon Black and South Asian workers by the light-skinned colonial elites, who promoted plantation work they themselves would never perform. This was also then multispecies violence, with hookworm both as instrument and ultimately victim, killed when the time came for infections to be treated. As Katherine McKittrick has argued, however, scholars should, when naming the anti-black violence of the plantation, avoid naturalising it (McKittrick 2011; 2013). Hookworm shows this clearly: infection

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was widespread but not universal, it was not inevitable and it was treatable. The plantation did not condemn everyone to hookworm disease and experiences of hookworm varied widely.

We do not view the plantation as the singular space where people contracted hookworm; our data show that hookworm could be encountered across Jamaica, and was influenced by environmental, as well as human, factors. Rather, the plantation, in concentrating human bodies, amplified hookworm transmission within their ambit, further spatializing infection. At the same time, the plantation, requiring the kind of alienated paid labour colonial elites promoted, sat at the heart of the ideological desire to drive hookworm extinct in order to create a more productive labour force. This, for us, epitomises the ambivalent complexities of extinction: scholars and public alike desire a neat 'extinction story' (Rose et al. 2017) with a tragic 'endling' (Jørgensen 2017) and a clear moral lesson (Heise 2016), but history is rarely so tidy. Instead, we find extinction is historically contingent, driven by particular social, economic and ecological configurations, which may, as in this case, begin an extinction but disappear before the extinction is completed.

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Conflict of Interest Statement

The authors have no conflicting interests to declare.

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