Eliminating Malaria in the American South

An Analysis of the Decline of Malaria in 1930s Alabama

Daniel Sledge, PhD, and George Mohler, PhD

Until the 1930s, malaria was endemic throughout large swaths of the American South. We used a Poisson mixture model to analyze the decline of malaria at the county level in Alabama (an archetypical Deep South cotton state) during the 1930s. Employing a novel data set, we argue that, contrary to a leading theory, the decline of malaria in the American South was not caused by population movement away from malarial areas or the decline of Southern tenant farming. We elaborate and provide evidence for an alternate explanation that emphasizes the role of targeted New Deal–era public health interventions and the development of local-level public health infrastructure. We show that, rather than disappearing as a consequence of social change or economic improvements, malaria was eliminated in the Southern United States in the face of economic dislocation and widespread and deep-seated poverty. (*Am J Public Health*. 2013;103:1381–1392. doi:10.2105/AJPH.2012.301065)

OVER THE PAST DECADE, AID agencies such as the World Health Organization, the Gates Foundation, and the United States Agency for International Development (USAID) have paid increasing attention to the problem of malaria in the Global South. The World Health Organization estimates that there were around 216 million cases and 655 000 deaths in 2010, whereas another recent study finds that there were approximately 1.24 million malaria deaths in 2010.[1] As development economists such as Jeffrey Sachs have argued, malaria is a central factor in the Global South's economic underdevelopment.[2]

Until the 1930s, malaria played a similarly devastating role in the Southern United States. Throughout much of the American South, both *Plasmodium vivax* and *Plasmodium falciparum* were endemic.[3] The distribution of malaria deaths (largely from *P. falciparum*) in the years around 1920 is shown in Figure A (available as a supplement to the online version of this article at http://www.ajph.org).[4] As in the contemporary Global South, widespread malaria hindered the development of social capital, curtailed agricultural and industrial productivity, and deterred outside investment and migration.

Beginning in 1934, however, malaria mortality in the American South entered a marked and permanent decline (Figure 1) Although mortality statistics are an imperfect means of gauging the extent of malaria's effect on Southern society, which came largely in the form of sickness rather than death, they represent the only workable and consistent proxy for morbidity available.[5] From a peak of 3.7 deaths per 100 000 Americans in 1933, the mortality rate declined to 1.1 per 100 000 in 1940.[6]

"Our understanding of the elimination of malaria in the American South has potentially significant implications for our approach to the malaria problem abroad."

It might have been expected that American mobilization for World War II would cause the disease to reemerge. During the war, large-scale population movement occurred within the Southern United States. Following the war, infected troops returned from malarial areas abroad, such as North Africa and the South Pacific. Nonetheless, the disease continued to fade into irrelevance within the United States.

Our understanding of the elimination of malaria in the American South has potentially significant implications for our approach to the malaria problem abroad. The prevailing view of malaria's decline has been articulated by the historian Margaret Humphreys. Beginning with an important 2001 book, Humphreys has argued that social change was the primary cause of the decline of malaria in the American South during the 1930s. Public health interventions during the period, she maintains, had little effect.

"Although New Deal programs included drainage projects to combat malaria," Humphreys writes in a recent article,

> these were poorly planned and likely had little impact. More important were agricultural programs that paid landowners to take land out of production and other measures that resulted in the depopulation of the southern countryside.[7]

It was the "removal of the malaria carrier/victim from the vicinity of the anopheles mosquito," Humphreys argues in *Malaria: Race, Poverty, and Public Health in the United States*, "that probably had the largest effect on the decline in the plasmodium's presence."[8]

As Humphreys notes, this analysis appears to shed little light on the relative merits of malaria control strategies available in the contemporary Global South:

> Facilitating a similar population translocation in the hyperendemic areas of Africa and Asia is neither feasible nor desirable.

Noting the apparent success of the post–World War II DDT campaign conducted by the Communicable Disease Center (the predecessor of the Centers for Disease Control and Prevention) in eliminating the few residual pockets of the disease in the United States, Humphreys writes that "It is hard to know whether the American DDT spraying campaign would have been successful" without large-scale population movement away from malaria-endemic areas.[9]

We analyzed the decline of malaria in Alabama, an archetypical Deep South cotton state that experienced high levels of malaria incidence well into the 1930s. We assessed the theory that movement of tenant farmers away from mosquito breeding grounds caused by the 1933 Agricultural Adjustment Act was the central factor in the decline of Southern malaria. Finding that this theory is not supported by the available evidence, we argue that targeted public health interventions, along with the development

Note. Texas became the last state to enter the Death Registration area in 1933. The states included in the Registration area remained consistent from 1933–1945. The sharp decline in malaria mortality in the early 1930s is likely a result of the severe drought that affected much of the South during those years.
Source. US Census Bureau, Annual Mortality Statistics, 1928–1936; US Census Bureau and Public Health Service, Vital Statistics, 1937–1945.

FIGURE 1—Malaria death rate per 100 000 estimated population: US Death Registration Area, 1928–1945.

of state and local public health infrastructure, represent a more plausible explanation.

POPULATION MOVEMENT AND THE DECLINE OF MALARIA

Margaret Humphreys's analysis of the decline of Southern malaria centers around the effects of the Agricultural Adjustment Act (AAA) and its successor, the Soil Conservation and Domestic Allotment Act (passed as a substitute after the Supreme Court found the AAA unconstitutional).[10]

Signed into law in May 1933, the AAA was the centerpiece of the Roosevelt administration's plan to stabilize and, it was hoped, reinvigorate American agriculture in the face of recurrent cycles of boom and bust and the decline of commodity prices. The AAA's core principle was straightforward: cash payments or a combination of cash payments and options to purchase commodities from the government would be used to induce farmers to limit the size of their crops. This, in turn, would raise the prices of depressed commodities. In the South, cotton and tobacco were the primary crops targeted by the legislation.

The effects of the AAA on the Southern economy were substantial. When the AAA was signed into law, the 1933 growing season was already under way. As a result, much of the already planted cotton crop had to be uprooted. By the end of August 1933, the Department of Agriculture could report that more than 10 000 000 acres of cotton had been destroyed.[11] Previously languishing at 6½ cents, cotton prices rose to just over 10 cents a pound.[12]

The structure and implementation of the program, meanwhile, set in motion the decline of the system of farm tenancy and sharecropping that had emerged in the South following the Civil War. Beginning with the 1934 growing season, AAA contracts included strong incentives for Southern landowners to have farm acreage planted, cultivated, and harvested by wage labor rather than by farmers classified as tenants or sharecroppers.

AAA payments for "wage labor" farmland taken out of production, notes the economist Gavin Wright, could be kept by the landowner. Meanwhile, "the benefits from reductions in the tenants' acreage (including croppers) had to be shared [with the tenant]."[13] The new set of incentives and decrease in cotton acreage resulted in a notable decline in farm tenancy: between 1930 and 1940, the total number of farms operated by individuals classified as tenants and sharecroppers in Alabama decreased from 166 420 to 136 224.[14]

In *Malaria: Poverty, Race, and Public Health in the United States*, Humphreys argues that malaria incidence fell in the American South as a consequence of "rural depopulation." Implementation of the AAA, Humphreys writes, led to depopulation

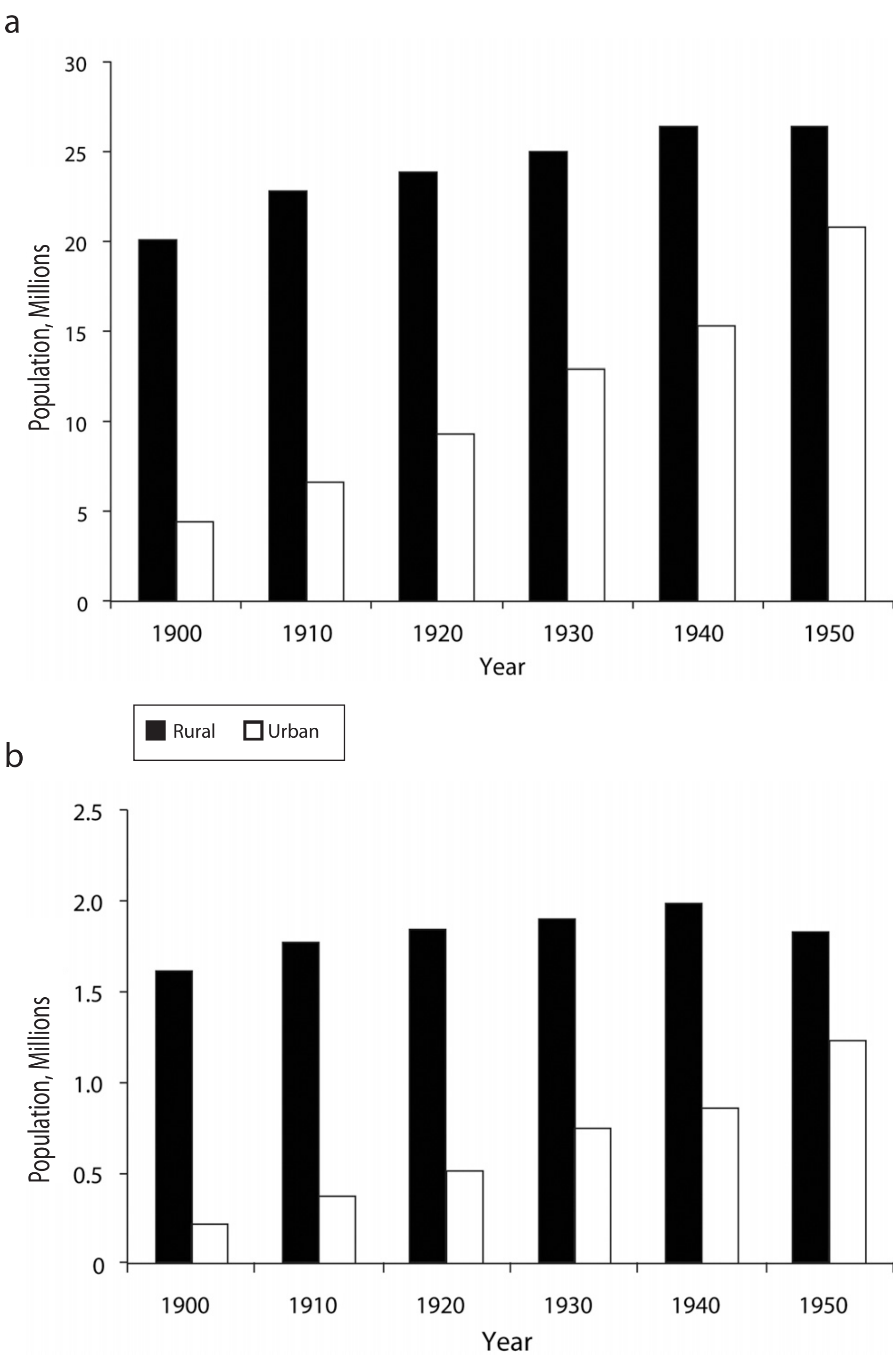
> since to landowners the incentives for capital investment and decreased land use made large-scale farming more profitable than renting out small parcels to tenants..

As landlords pushed tenants off of the land, writes Humphreys, "rural shack dwellers moved to town, or to the north, losing in the process their close proximity to the swamps."[15]

In arguing that the rural South was depopulated following the implementation of the AAA, Humphreys cites the accounts of sociologist Gunnar Myrdal and historian Jack Kirby.[16] US Census Bureau population data, however, demonstrate that the rural South was not depopulated over the course of the 1930s. Figure 2 charts the rural–urban composition of the Southern United States and of Alabama from 1900 to 1950.[17] Urban areas are defined as incorporated areas with a population of 2500 or more.

Between 1900 and 1950, the South's rural population increased from 20 102 642 to 26 419 039. Between 1930 and 1940, the critical years of malaria's decline, the rural Southern population increased from 24 953 385 to 26 375 418. Meanwhile, the growth in the percentage of Southerners living in urban areas slowed during the 1930s compared with the preceding decade. From 1920 to 1930, the Southern population went from 28.1% urban to 34.1% urban. Between 1930 and 1940, however, the population went from 34.1% urban to 36.7% urban.

A similar trend can be seen in Alabama, where the rural population grew from 1 611 983 in 1900 to 1 833 534 in 1950. Rather than being depopulated between 1930 and 1940, rural Alabama grew by 75 045 people. Alabama's population was 21.7% urban in 1920, 28.1% urban in 1930, and 30.2% urban in 1940. As James N. Gregory suggests in a careful and data-driven recent study of Southern out-migration, the 1930s are best understood as an "interlude" between two phases of migration, one starting near the beginning of the 20th century and the other set in motion by World War II.[18]



Note. The definition of the "South" used here is the census definition, which encompasses the former Confederacy; Washington, DC; and the border states of Delaware, Maryland, West Virginia, Kentucky, and Oklahoma.
Source. Adapted from *Census of Population*.[17]

FIGURE 2—The rural and urban population in 1900–1950 for (a) the South and (b) Alabama.

Only the far-western portion of the malaria-endemic United States experienced large-scale rural out-migration during the 1930s. In parts of Arkansas, Oklahoma, and Texas, drought and soil erosion led to the "Dust Bowl" migration that caught the attention of journalists and was described in popular works such as John Steinbeck's *Grapes of Wrath*.[19]

PUBLIC HEALTH INTERVENTIONS AS AN ALTERNATIVE EXPLANATION

From any perspective, the overall decline in malaria deaths in the South after 1933 is surprising. Malaria is a disease of poverty, and the rural South was hit particularly hard by the Great Depression. Economic dislocation, along with the increase in potential mosquito-breeding grounds where cotton or other cash crops had been grown, might have been expected to further increase the likelihood of malaria outbreaks in the region.[20]

We argue that the decline of malaria in the South was a consequence not of out-migration of tenants caused by the AAA but of federally sponsored public health interventions, most notably large-scale drainage efforts. After 1936, the expansion of federal intervention in the development of state and local public health infrastructure helped to ensure that drainage and other public health efforts were better organized and that measures were in place to prevent the disease from reemerging.

Drainage work had proven effective in limiting malaria long before the 1930s. The United States successfully employed drainage measures in Cuba following the Spanish-American War and then in the Panama Canal

Zone. During World War I, the US Public Health Service (PHS) used drainage to limit the transmission of malaria in "Extra-Cantonment Zones," areas of intensive public health intervention surrounding military bases that were primarily located in the American South.[21] In the aftermath of World War I, PHS officers continued small-scale antimalaria and general public health work in the South. At times cooperating with agents from the Rockefeller Foundation's International Health Board, these officers engaged in a variety of experiments and developed pilot programs in malaria control.

During the 1920s, PHS workers developed inexpensive methods for screening farm tenant homes and experimented with the use of the larvicide Paris green.[22] At the same time, PHS officers expanded the relationships the service had developed with Southern state and local governments during World War I and experimented with federal–state–local cooperation in the development of local public health infrastructure.[23]

Between World War I and the beginning of the New Deal, drainage work was viewed as a prohibitively expensive way of attempting to rid the South of malaria. Beginning in the winter of 1933–1934, however, the federal Civil Works Administration put unemployed Southerners to work on drainage projects. Loosely supervised by the PHS, these early efforts appear to have at times been ineffective and even counterproductive.[24]

The Civil Works Administration was dissolved in early 1934, and the drainage program was continued by the Federal Emergency Relief Agency. In 1935, the federal Works Progress Administration (WPA) began providing labor for drainage projects and continued to do so throughout the 1930s. By the end of the decade, public health workers were increasingly focused on the development of methods of lining ditches to make them more permanent.[25]

In 1935, Congress passed the Social Security Act (SSA).[26] Title VI of the SSA authorized federal grants-in-aid of $8 million annually for the development of state and local public health infrastructure and for the training of public health workers. Amendments to the SSA in 1939 raised this figure to $11 million.[27]

Title VI funds, which were administered by the PHS, first became available in 1936.[28] The funds were tied to requirements that states increase spending on public health and were allocated under a formula that took into account special health problems (including malaria), economic need, and the need for trained personnel.[29]

Alabama benefited substantially from the new program. The state legislature's appropriation for the State Board of Health stood at $376 581 in 1935 and $258 119 in 1936. In 1936, the Alabama State Board of Health received $157 192 in Title VI funding. In 1937, the first full state fiscal year that Title VI was operational, the Board received $255 299 in Title VI funds, while the state legislature appropriated $326 591. By 1940, the State Board of Health was receiving $330 059 in Title VI funds and $430 000 from the state legislature.[30]

Additional federal money came from the Tennessee Valley Authority (TVA), which coordinated with officials from the state, counties, and the PHS in an attempt to ensure that the construction of dams along the Tennessee River in northern Alabama would not spark outbreaks of malaria.[31] Taking money from Title VI, the TVA, and other federal sources into account, the State Board of Health's total cash on hand grew from $377 438 in 1935 to $1 281 693 in 1940.[32] Meanwhile, total state spending for engineering, sanitation, and other budget items mentioning malaria or mosquitoes grew from $44 640 in 1935 to $106 008 in 1940 (figures cover state fiscal years).[33]

Although it is likely that some public health workers participated in more than one training program and were counted more than once, the PHS recorded that in the federal fiscal years 1936 through 1940, Title VI money was used to train 213 Alabama public health workers in areas that included administration, sanitary engineering, and laboratory techniques.[34] By providing a more permanent basis for malaria control through greater federal–state–county coordination, fully staffed county health departments, and money for the training of state and local public health workers, Title VI helped to both advance and solidify the gains in malaria control being made by the public works agencies.

The program, fully operational by the end of 1936, marked a turning point in the elimination of Southern malaria. L.L. Williams (who had headed the PHS's malaria control investigations since 1927) could now report that, in 1937,

> A state-wide malaria control plan, covering organization and procedure, was adopted by the southern state health departments. Under the stimulus of social security funds a

> large number of adequately trained personnel has been added to state malaria control units both in the field and laboratory.[35]

The scope of the drainage work now underpinned by increasingly high-quality public health infrastructure was massive. As a later report from the Army Medical Department noted, it was estimated that overall the works projects "involved a daily average of 211,000 men for 6.5 years working on malaria control drainage in an average of 250 counties." In the American South as a whole, it was estimated that, by the time the nation entered World War II, 544 414 acres of mosquito breeding sites had been drained through the construction of 33 655 miles of ditches.[36]

DESCRIPTION OF THE DATA AND VARIABLES

Was the decline of malaria in the American South a result of rural depopulation caused by the decline of tenant farming following the 1933 AAA, a result of targeted New Deal public health interventions, a mixture of the two, or the consequence of some other factor or factors? To better understand the dynamics of Southern malaria during the 1930s, we assembled a novel data set (available from the authors), consisting of five elements:

1. Malaria mortality data for each of the 67 counties in Alabama in the years 1930, 1931, and 1933–1940. We compiled these data from the Alabama State Board of Health's *Annual Reports* and *Vital Statistics*, with the exception the 1931 data, which were provided by the Alabama Department of Public Health. Despite the assistance of the Department of Public Health, we were unable to obtain county-level mortality data for 1932. Malaria deaths in year i and county j are denoted by the response variable y_i^j. The mean, standard deviation, and maximum of y_i^j over these years and counties are 3.9134, 4.2699, and 40, respectively.
2. US Census Bureau data on total population and rural population for each of the 67 counties in Alabama in the years 1930 and 1940.[37] Following the standard census definition for both years, we defined an individual as living in a rural area if he or she lived outside of an incorporated area with 2500 or more residents. We retrieved data from the National Historical Geographic Information System (NHGIS). Population (in units of 100) in year i and county j is denoted by the explanatory variable n_i^j. The mean, standard deviation, and maximum of n_i^j over these years and the 67 counties are 408.9, 535.9, and 4599.3, respectively. Rural population (in units of 100) in year i and county j is denoted by the explanatory variable nr_i^j. The mean, standard deviation, and maximum of nr_i^j over these years and the 67 counties are 289.5, 153.4, and 1407.2, respectively.
3. Data on federal WPA drainage efforts in each of the 67 counties in Alabama in the years 1935 through 1940 (in units of 100 000 cubic yards of excavation). Data are for the individual county as a whole (meaning there is no distinction between rural and urban areas). We compiled these data from the Alabama State Board of Health's *Annual Reports*. Drainage completed in year i and county j is denoted by the explanatory variable d_i^j. The mean, standard deviation, and maximum of d_i^j over these years and the 67 counties are 0.0923, 0.2610, and 3.2703, respectively.
4. Palmer Drought Index (PDI) data for Alabama in the summer months of years 1929 through 1940. Average summer PDI values range from 4.0 or less (extreme drought) to 4.0 or more (extremely wet), with negative values indicating drought and positive values indicating increased moisture. The minimum and maximum of r_i over these years are 4.0000 and 1.9167, respectively.
5. US Census Bureau data on the number of farms operated by tenants (in units of 1000) in each of the 67 counties in Alabama in the years 1930 and 1940. We retrieved data from the NHGIS. The number of tenant farms in year i and county j is denoted by the explanatory variable t_i^j. The mean, standard deviation, and maximum of t_i^j over these years and the 67 counties are 0.0226, 0.0099, and 0.0623, respectively.

Although we could compile a complete state data set only for Alabama, there are strong reasons to believe that the state's experience was typical. The dynamics of Alabama's rural population during this period were consistent with those of the rest of the region. In addition, the state is geographically diverse, encompassing a coastal plain, river bottom lands, a belt of land dominated by cotton monoculture during the 1930s, and hilly and mountainous country in the north.

POISSON MIXTURE MODEL

We modeled the number of malaria deaths in a year by using a Poisson approximation to the binomial distribution. Because of geographic heterogeneity, we allowed for the possibility of different individual risk levels across different counties. We assumed that there are three categories of counties, indexed by *k*, representing high, intermediate, and low mortality rates per individual. The use of more than three categories could lead to problems in identification because posterior parameter distributions were not sufficiently separated.

If $\lambda_{i,k}^{j}$ denotes the expected number of malaria deaths in year *i* in county *j* falling into risk category *k*, then the response variable y_i^j is Poisson with parameter,

$$(1) \quad \lambda_i^j = \sum_{k=1}^{3} \lambda_{i,k}^{j} w_k^j,$$

where w_k^j is the probability that county *j* belongs to category *k*. We modeled the Poisson parameters $\lambda_{i,k}^{j}$ as

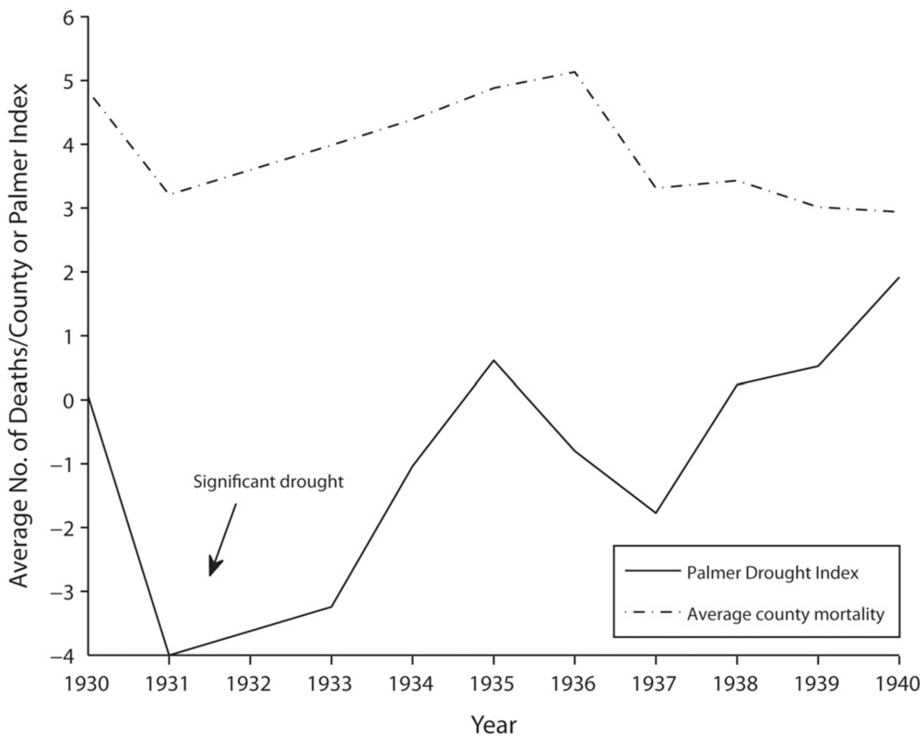
$$(2) \quad \lambda_{i,k}^{j} = n_i^j p_{i,k}^{j},$$

where the rate per 100 individuals, $p_{i,k}^{j}$, is given by the log odds ratio,

$$(3) \quad \log(p_{i,k}^{j}/(1- p_{i,k}^{j}))= a_k + b_1 s_i^j + b_2 d_i^j + b_3 r_i + b_4 r_{i-1} + b_5 t_i^j + b_6 s_i^j r_{i-1}.$$

The variable s_i^j denotes the cumulative drainage completed in county *j* in the years leading up to (but not including) year *i*. The reason for two explanatory drainage variables is that although cumulative drainage may reduce the risk of malaria in a given region, the actual labor involved may create conditions conducive to mosquito breeding or expose workers to malaria, temporarily increasing the risk of mortality.[38]

Because drought is significantly correlated with the mortality rate, we included in the model the effect of drought, with a time lag of one year. This correlation may be due in part to the time scales associated with mosquito population levels, infection, or reproduction of the malaria parasite. We also included an interaction term between the weather and drainage variables, as we expected the effect of drainage on reducing the mortality rate to be higher in years where the risk of malaria is high, but less important in years where the malaria rate is already low due to weather. We implemented both population variables n_i^j and nr_i^j for the Poisson rate. We selected n_i^j as it maximized the log-likelihood.



Note. Palmer Drought Index is shifted to the right by one year.

FIGURE 3—Average number of malaria deaths for each year per county and Palmer Drought Index.

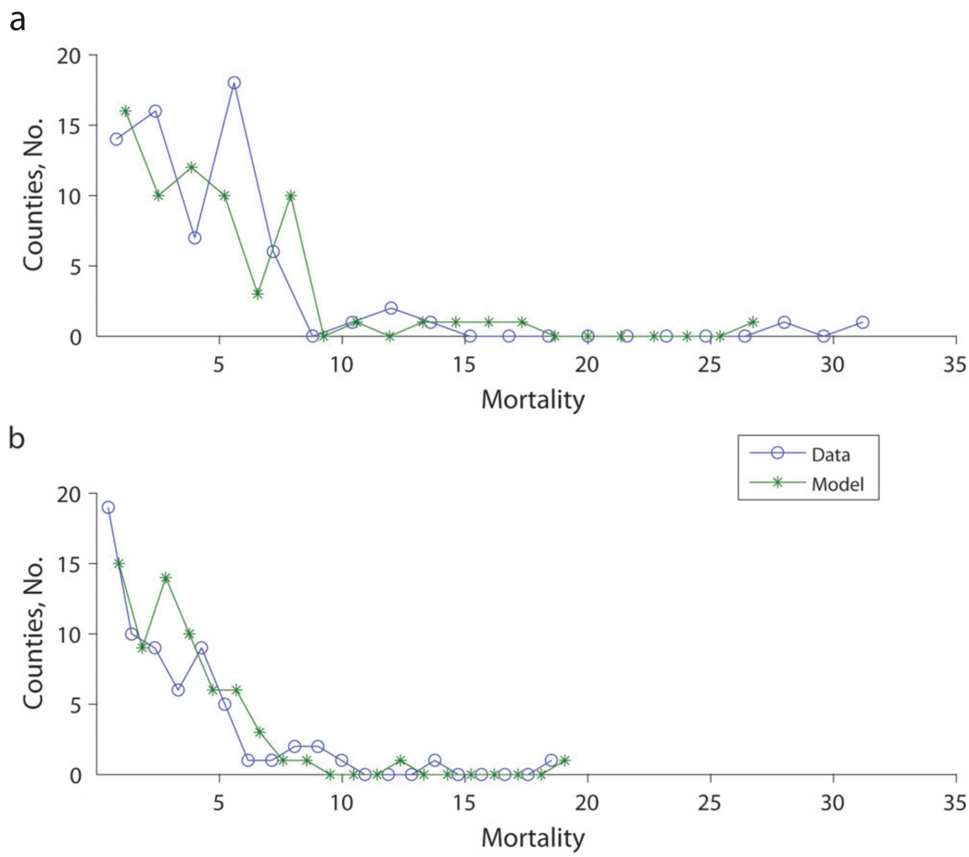


FIGURE 4—Distribution of mortality rates (data) and of mortality mean corresponding to fitted model, across all counties of Alabama in (a) 1930 and (b) 1940.

BAYESIAN ESTIMATION

We estimated the model parameters by using a Bayesian framework coupled with data augmentation and Gibbs sampling.[39] Let z_k^j denote a latent random variable assuming value 1 or 0 depending on whether county j belongs to category k. Bayesian sampling then consists of alternating between sampling the z_k^j variables from w_k^j, conditioned on knowing the component parameters (a_k, b_l), and sampling the component parameters conditioned on the current values of z_k^j. We estimated values of n_i^j inside the time interval using linear interpolation between the values in 1930 and 1940.

For the tenant farm variable, t_i^j, we set values up to 1934 to the 1930 values and then used linear interpolation between 1934 and 1940. We chose this interpolant because of the timing of the implementation of the AAA, which resulted in a decline in the number of Southern farms operated by tenants.

We used an uninformative Gaussian prior for each of the component parameters with a standard deviation of 100. We used a random walk Metropolis algorithm with normal proposal density to the posterior distribution with the variance tuned to yield acceptance rates between 25 and 50. The number of Metropolis steps used was 2×10^5 with a burn in of 10^5 steps. We used a visual inspection of the trace plots and auto correlation functions of the parameter series to verify convergence of the Markov chain.

FINDINGS

In Figure 3 we plotted the average number of malaria deaths for each year per county and the PDI, r_{i-1}, shifted to the right by one year.

The variation in the first half of the decade is consistent with changes in weather conditions, whereas in the second half of the decade, as weather conditions became more conducive to malaria infection and mortality, a general decline is observed in the mortality rates.

In Figure 4 we plotted the distribution of mortality rates across all counties in 1930 and 1940, as well as the distribution of the mortality mean of each county corresponding to the fitted model. In 1930, the rate distribution is characterized by a heavy tail and generally higher rates compared with the 1940 distribution. The model is able to account for both the overdispersion within each year and the shortening of the tail of the distribution over the decade.

In 1936, the model significantly underestimates the mortality rate. A reasonable explanation for this disagreement is the implementation of Title VI of the SSA, which released funding during 1936 for the development of state and local public health infrastructure as well as the training of public health workers. We suggest that this resulted in higher-quality drainage, maintenance, and disease surveillance work, with an effect manifested beginning in the 1937 malaria season.

We determined the parameter estimates of the explanatory variable coefficients along with the difference in Akaike information criterion (AIC) values for the model with and without each parameter. A greater difference in these values indicates the preferred model. In other words, the greater the negative difference in the AIC, the more explanatory value the variable has.

Unsurprisingly, weather is a crucial variable. The average summer PDI in a given year (b=–0.073; SE=0.012; AIC=–42.8) and the average summer PDI in the preceding year (b=0.042; SE=0.013; AIC=–18.8) are important explanatory factors in annual malaria mortality. These variables rank first and second, respectively, in explaining variation in malaria mortality.

Works Progress Administration drainage projects in a county also play an important role in accounting for malaria mortality. The amount of drainage work in a given county in a given year (b=–0.001; SE=0.001; AIC=–14.6) and the cumulative drainage in preceding years in a given county (b=–0.038; SE=0.067; AIC=–9.8) rank third and fourth, respectively, in explaining the variation in malaria mortality among the variables considered. The interaction term between the weather and drainage variables (b=–0.084; SE=0.034; AIC=–4.6) ranks fifth in terms of its ability to explain variation in mortality rates.

The number of tenant farms in a given year in a given county (b=0.34; SE=0.32; AIC=–2.8) is the least explanatory variable included in the model. This is an important finding. If the argument that the movement of tenant farmers away from swampy rural land (either to town or out of the region) resulted in the demise of malaria was correct, we would expect to find the opposite, that the number of tenant farms in a given year in a given county was (after weather) the most explanatory variable.

Put plainly, a parsimonious model for predicting malaria mortality in a given county in a given year would need to consider both weather conditions and the extent of WPA drainage work completed, but could safely exclude the number of farms operated by tenants.

Simulations conducted at each step of the Metropolis sampling algorithm, meanwhile, provide evidence against the claim that population movement was the main cause of the decline of Southern malaria. In particular, we sampled from λ^{j}_{1940} as well as from the estimated malaria mortality rate assuming no drainage was excavated (thus using the individual rates from 1930, but population levels from 1940). In Figure B (available as a supplement to the online version of this article at http://www.ajph.org), we plotted the posterior distribution of the overall number of simulated deaths in 1940 with and without the drainage excavation. The drainage program in Alabama reduces the average number of simulated deaths from 274 to 237.

In Figure 5a we plotted the estimated population levels in high-risk, medium-risk, and low-risk counties in 1930 and 1940. The population level rises in every category from 1930 to 1940, providing some evidence against the claim that high-risk areas were depopulated during the 1930s.

In Figure 5b we also plotted the estimated rural population levels in high-risk, medium-risk, and low-risk counties in 1930 and 1940. Here, the population level rises in all three categories from 1930 to 1940 (though only slightly in the high-risk category), providing strong evidence against the claim that high-risk rural areas were depopulated during the 1930s.

Finally, in Figure 5c we plotted the estimated number of tenant farms in high-risk, medium-risk, and low-risk counties in 1930 and 1940. A 9000, 15 000, and 6000 drop in the number of tenant farms in high-, medium-, and low-risk counties occurred between 1930 and 1940. The decline of tenant farms did not result in declines in rural population in any of the three malaria risk categories.

“A parsimonious model . . . would need to consider both weather and the extent of WPA drainage work, but could safely exclude the number of farms operated by tenants.”

As a final means of attempting to demonstrate an impact on mortality rates from the decrease of tenant farms, we set aside the Poisson mixture model of mortality. Considering the decline of tenant farms in a county during the 1930s as an independent variable and the change in malaria mortality in a county as a dependent variable, we get a correlation coefficient of 0.11. By comparison, the correlation coefficient between cumulative drainage in a county and the malaria mortality rate in a county is 0.29. This finding further undermines the argument that decreases in the number of tenant

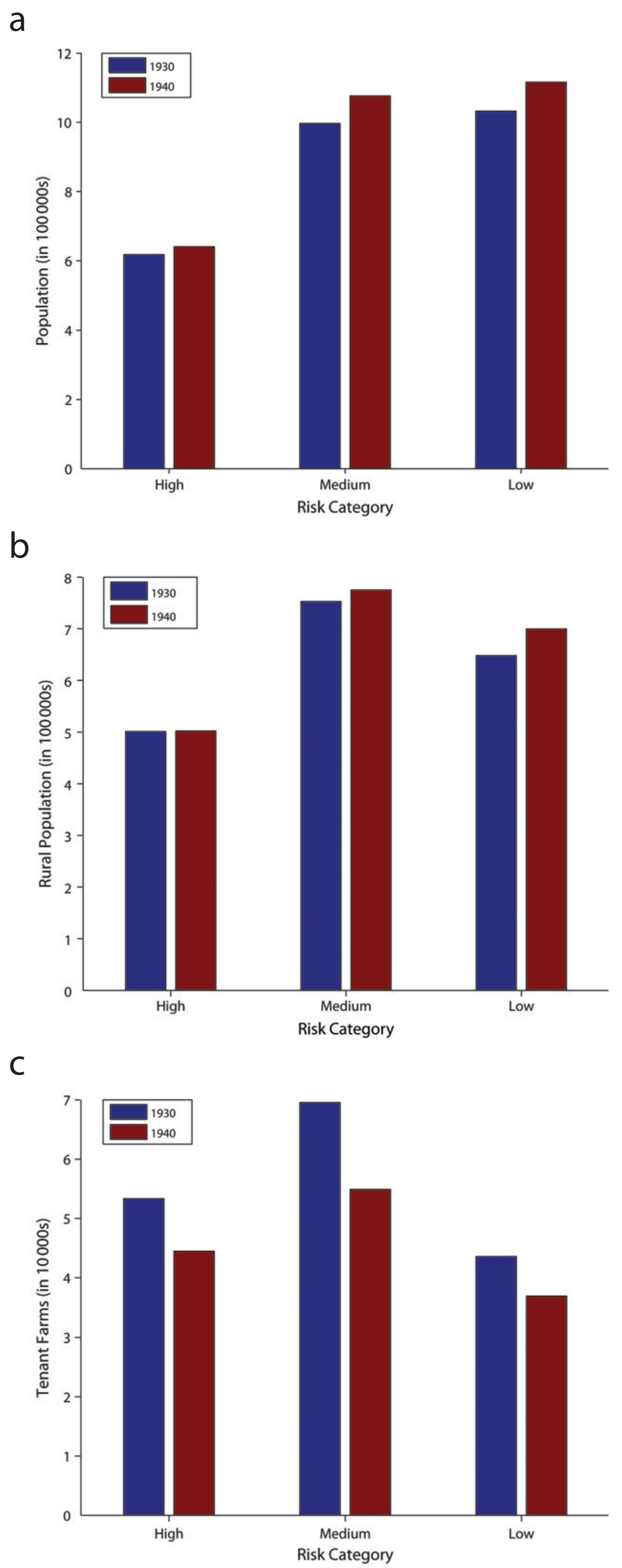


FIGURE 5—Estimated population in the 3 risk categories for malaria mortality in Alabama in 1930 and 1940 for (a) the total population, (b) the rural population, and (c) tenant farms.

farms led to decreases in malaria mortality during the 1930s.

Overall, the results of this analysis draw attention to the importance of modeling county-level data rather than data at the state or national level. Although aggregate malaria mortality rates are correlated with both aggregate reductions in tenant farms and aggregate drainage excavation, only aggregate drainage excavation explains the variations in mortality rates observed across counties.

PERMANENT GAINS

Wisely, contemporary public health workers expressed only a restrained optimism about the decline of malaria during the late 1930s. For some, the decline of malaria appeared consistent with a broader cyclical pattern of malaria incidence. In 1938, Tulane University malariologist Ernest Carroll Faust suggested that the national malaria death rate, "which developed to a peak so suddenly in 1933," had

> apparently reached its trough, and that, unless unusual circumstances supervene, an average rise in the rate may again be anticipated in 1938 or 1939.[40]

That malaria remained an ongoing threat in the face of substantial federal efforts suggested, in addition, that a resurgence might occur when spending was reigned in.[41]

As the PDI data makes clear, weather conditions in Alabama were indeed favorable for an increase in malaria mortality during the late 1930s. Well into the 1940s, public health authorities remained skeptical that malaria rates would not rise again. American mobilization for World War II, in particular, appeared to heighten the threat of an increase in malaria.

Beginning in March 1942, however, the PHS implemented emergency control measures similar to those used during World War I.[42] Despite the sudden influx of workers and soldiers into known malarial areas in the American South and the eventual return of military personnel infected with malaria abroad, no new epidemic occurred. Instead, the continuation of drainage, screening, and larvicide projects under the auspices of the PHS's Malaria Control in War Areas program (and its successor, the Communicable Disease Center) and state and local health departments guaranteed that malaria, already largely suppressed, did not reemerge as a significant public health threat.

CONCLUSIONS

We have considered two alternative explanations for the decline of malaria in the American South. We have elaborated and considered the argument that the decline of malaria occurred because of rural depopulation following the implementation of the 1933 AAA. As we have shown, the Southern United States did not lose rural population during the period of malaria's demise, but rather gained rural population. The decline in the number of farms operated by tenants did not lead to a decline in rural population.

As an alternative, we argue that targeted public health interventions (particularly large-scale drainage), underpinned by the federally backed development of state and local public health infrastructure, led to the demise of malaria in the South. As evidence, we provide a discussion of the scope of public works drainage projects during the New Deal, a discussion of the federal program for the development of local public health infrastructure (Title VI of the SSA), and a detailed analysis of the decline of malaria in Alabama.

Employing a Poisson mixture model of malaria mortality in Alabama during the 1930s, we have shown that the amount of WPA drainage work completed contributed substantially to the decline of malaria at the county level. The increased impact of drainage after 1936 provides support for the argument that local public health infrastructure played an important role in securing malaria's demise.

We found that the argument that the decline of Southern tenant farming led to the decline of malaria is not supported by the available evidence. Of the variables included in the model, the number of tenant farms in a given county in a given year was the least explanatory. Had movement from tenant farms to Southern towns or out of the region played an important role in the demise of Southern malaria, this variable would be expected to rank only after weather in terms of ability to explain variation in malaria mortality.

The importance of drainage, public health infrastructure, and other measures such as screening in the elimination of malaria in the American South was largely overlooked during the 1950s and 1960s, as DDT and chloroquine appeared briefly to offer hope that worldwide eradication might be accomplished. The evolution of DDT-resistant mosquitoes and chloroquine-resistant strands of malaria, however, eventually caused those concerned with the world's ongoing malaria problem to refocus their energy on more mechanically oriented malaria-control techniques, such as the use of insecticide-impregnated bed nets.

There are, of course, significant differences between the contemporary Global South and the American South of the 1930s. In particular, several well-known obstacles confront malaria control efforts in sub-Saharan Africa. *Anopheles gambiae*, the primary malaria vector in sub-Saharan Africa, is the world's most efficient transmitter of malaria. It has a strong preference for human blood and is not easily diverted to livestock. Meanwhile, consistently high temperatures ensure that malaria reproduces more quickly in sub-Saharan Africa than it did in the Southern United States and that there is no period during which transmission of the parasite is suspended.[43]

In addition, our conclusions must be tempered by the limitations imposed by the available data. We were only able to compile a complete data set for Alabama. Census tract–level data do not exist for most of Alabama during the 1930s, meaning that we cannot account for microlevel movements within counties. It should also be noted that our drainage data are county level and are not divided into rural and urban categories. As a result, we are unable to consider more refined questions, such as the impact of drainage projects on urban areas.

Focused on drainage efforts but employing a mixture of methods, public health workers successfully broke the chain of malaria transmission in the United States. The development of local public health infrastructure helped to ensure that the "big push" of drainage projects during the New Deal did not result in an only temporary decline of malaria.

Millions of people now inhabit the formerly malarial South without fear of infection. The region is economically integrated with the rest of the nation and consistently attracts outside investment, tourists, and migrants from the rest of the United States and from abroad. Importantly, the region's economic growth was not a cause of malaria's decline, which occurred within the context of ongoing and deep-seated poverty. In the present day, disease surveillance, drainage measures, and screening work to ensure that, on those occasions when malaria is reintroduced from outside of the United States, the chain of transmission does not begin again. ■

About the Authors

Daniel Sledge is with the Department of Political Science, University of Texas, Arlington. George Mohler is with the Department of Mathematics and Computer Science, Santa Clara University, Santa Clara, CA.

Correspondence should be sent to Daniel Sledge, Department of Political Science, University of Texas at Arlington, Box 19539, 601 S Nedderman Dr, Arlington, TX 76019 (e-mail: dsledge@uta.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

This article was accepted September 1, 2012.

Contributors

D. Sledge developed the article's argument, did research into the development of health infrastructure, conceived the idea of using quantitative data to examine the decline of malaria, and identified and collected data. G. Mohler identified and implemented an appropriate model for analyzing the data and suggested and found potential variables.

Acknowledgments

Funding for data entry came from the University of Texas at Arlington.

We thank Jenna Green for her extensive effort in compiling the data necessary for this article and for her helpful feedback. We also thank Richard Bensel and Jennifer Erickson for reading and commenting on an earlier version.

Endnotes

1. C.J. Murray, L.C. Rosenfeld, S.S. Lim, et al., "Global Malaria Mortality Between 1980 and 2010: A Systematic Analysis," *Lancet* 379 (2012): 413–431.

2. J.L. Gallup and J.D. Sachs, "The Economic Burden of Malaria," *American Journal of Tropical Medicine and Hygiene* 64 (2001): 85–96.

3. See M.A. Barber and W.H.W. Komp, "The Seasonal and Regional Incidence of Types of Malaria Parasites," *Public Health Reports* 44, no. 34 (1929): 2048–2057. In a study of 1517 cases of malaria, Barber and Komp found that 44% were *P. vivax*.

4. K.F. Maxcy, "Epidemiological Principles Affecting the Distribution of Malaria in Southern United States," *Public Health Reports* 39 (1924): 1113–1127; Kenneth F. Maxcy, "The Distribution of Malaria in the United States as Indicated by Mortality Reports," *Public Health Reports* 38 (1923): 1125–1138.

5. On this point, see E.C. Faust, "Malaria Mortality in the Southern United States for the Year 1936," in *Symposium on Malaria: Some of the Papers and Reports Presented Before the National Malaria Committee, Meeting Conjointly With the Southern Medical Association at Its Thirty-First Annual Meeting, New Orleans, Louisiana, November 30–December 3, 1937* (Birmingham, AL: National Malaria Committee, 1938), 20.

6. The methodology used to determine these rates and number of states (48) within the Death Registration Area remained consistent throughout this period. Texas, the final state to join the Registration Area, was first included in 1933. See *Mortality Statistics, 1933: Thirty-Fourth Annual Report* (Washington, DC: Bureau of the Census, 1936), 37; *Vital Statistics of the United States, Part I* (Washington, DC: Bureau of the Census, 1939), 24.

7. Humphreys, "How Four Once Common Diseases Were Eliminated From the American South," *Health Affairs* 28 (2009): 1734–1744 (quote on 1737).

8. Humphreys, *Malaria: Poverty, Race, and Public Health in the United States* (Baltimore, MD: Johns Hopkins University Press, 2001), 112.

9. Ibid, 152.

10. Agricultural Adjustment Act, Pub. L. No. 73–10, 48 Stat. 31, enacted May

12, 1933; Soil Conservation and Domestic Allotment Act. Pub. L. No. 74–461, enacted February 29, 1936.

11. "Pledge to Plow Cotton Under Being Observed: US Aids to Destroy Part of Crops if Farmers Fail to Do So," *Washington Post*, August 26, 1933:13; C. McD. Puckette, "King Cotton's New Adventure," *New York Times Magazine*, August 27, 1933:1–2.

12. G. Wright, *Old South, New South: Revolutions in the Southern Economy Since the Civil War* (Baton Rouge, LA: Louisiana State University Press, 1996), 227.

13. Ibid, 228–229.

14. "1930 Census of Population and Housing" and "1940 Census of Population and Housing," http://www.nhgis.org (accessed July 6, 2012); Minnesota Population Center, *National Historical Geographic Information System: Version 2.0* (Minneapolis, MN: University of Minnesota, 2011).

15. Humphreys, *Malaria*, 111.

16. Ibid, 111.

17. For these data, see *Census of Population: 1950, Volume II, Characteristics of the Population* (Washington, DC: Bureau of the Census, 1953), Table 15, p. 1–21.

18. J.N. Gregory, *The Southern Diaspora: How the Great Migrations of Black and White Southerners Transformed America* (Chapel Hill, NC: University of North Carolina Press, 2005), 28–32.

19. Ibid, 29–30, 64.

20. Humphreys, *Malaria*, 110.

21. See B.S. Warren and Charles F. Bolduan, "War Activities of the United States Public Health Service," *Public Health Reports* 34 (1919): 1243–1267; J.A. LePrince, "The Aftermath of Malaria Control in Extra-Cantonment Areas," *Southern Medical Journal* 13 (1920): 413–416; J.A. LePrince, "Mosquito Control About Cantonments and Shipyards," *Public Health Reports* 34 (1919): 547–553.

22. C.P. Coogle, "Preliminary Report of Screening Studies in Leflore County, Miss.," *Public Health Reports* 42 (1927): 1101–1112; J.A. LePrince and H.A. Johnson, "Development of a Power Dusting Device for Applying Paris Green as an Anopheline Larvicide," *Public Health Reports* 44 (1929): 1001–1017.

23. J.G. Townsend, "The Full-Time County Health Program Developed in the Mississippi Valley Following the Flood," *Public Health Reports* 43 (1928): 1199–1207; J. Ferrell and P. Mead, *Public Health Bulletin No. 222: History of County Health Organizations in the United States, 1908–33* (Washington, DC: United States Public Health Service, 1936).

24. L.L. Williams Jr, "Civil Works Administration Emergency Relief Administration Malaria Control Program in the South," *American Journal of Public Health* 25 (1935): 11–14.

25. L.L. Williams Jr, "Malaria Prevention Activities, 1938," in *Symposium on Malaria: Some of the Papers and Reports Presented Before the National Malaria Committee, Meeting Conjointly With the Southern Medical Association at Its Thirty-Second Annual Meeting, Oklahoma City, Oklahoma, November 15–18, 1938* (Birmingham: National Malaria Committee, 1939), 29.

26. Social Security Act. Pub. L. No. 74–271, 49 Stat. 620, enacted August 14, 1935, now codified as 42 U.S.C. ch. 7.

27. *Annual Report of the Surgeon General of the Public Health Service of the United States for the Fiscal Year 1940* (Washington, DC: United States Public Health Service, 1940), 4.

28. See *Annual Report of the Surgeon General of the Public Health Service of the United States for the Fiscal Year 1936* (Washington, DC: United States Public Health Service, 1936), 53.

29. Ibid, 53–55.

30. Data are from *Annual Report of the State Department of Public Health of Alabama* (Montgomery, AL: Wilson Printing Company) for the years 1936 through 1940 and cover state fiscal years, which lasted from October 1 of the preceding calendar year through September 30 of the named fiscal year.

31. E.L. Bishop, "Malaria-Control Activities of the Tennessee Valley Authority," *Public Health Reports* 51 (1936): 970–975; *Annual Report of the State Department of Public Health of Alabama, 1937*, 28, 191–200.

32. *Annual Report of the State Department of Public Health of Alabama, 1935*, 24; *Annual Report of the State Department of Public Health of Alabama,1940*, 76–77. The 1940 figure excludes the $57 276 given to the Board of Health by philanthropic agencies. The additional federal funding came from the PHS for venereal disease control and from the Children's Bureau for the care of mothers and young children.

33. Data on malaria-related spending are from the *Annual Report of the State Department of Public Health of Alabama*. Total spending in these categories was $54 195 in 1936, $85 949 in 1937, $97 620 in 1938, and $102 362 in 1939 (all spending in state fiscal years).

34. J.W. Mountin and E.K. Hankla, "Training Public Health Workers: Programs Sponsored by State Health Departments Under Title VI of the Federal Social Security Act and the Federal Venereal Disease Control Act (1936–44)," *Public Health Reports* 61, no. 21 (1946): 740, 746. The federal fiscal year went from July of the previous calendar year to the end of June in the named year.

35. L.L. Williams Jr, "Report of the Subcommittee on Malaria Prevention Activities, 1937," *Southern Medical Journal* 31 (1938): 818–819 (quote on 818).

36. J. Andrews and J. Grant, "Experience in the United States," in *Preventive Medicine in World War II, Volume VI, Communicable Diseases: Malaria* (Washington, DC: Office of the Surgeon General, Department of the Army, 1963), 69, 74.

37. "1930 Census of Population and Housing" and "1940 Census of Population and Housing"; *National Historical Geographic Information System: Version 2.0.*

38. Humphreys makes a similar argument. See Humphreys, *Malaria*, 100–101.

39. B.-J. Park, D. Lord, and J.D. Hart, "Bias Properties of Bayesian Statistics in Finite Mixture of Negative Binomial Regression Models in Crash Data Analysis," *Accident; Analysis and Prevention* 42 (2010): 741–749; J. Diebolt and C.P. Robert, "Estimation of Finite Mixture Distributions Through Bayesian Sampling," *Journal of the Royal Statistical Society. Series B, Statistical Methodology* 56 (1994): 363–375.

40. Faust, "Malaria Mortality in the Southern United States for the Year 1937," in *Malaria and Its Control: Some Papers Read at the 21st Meeting of the National Malaria Committee, Oklahoma City, Okla., Nov. 15–18, 1938* (Tallahassee, FL: National Malaria Committee, 1939), 4.

41. Ibid, 8–9.

42. Andrews and Grant, "Experience in the United States," 69, 74.

43. Sachs and P. Malaney, "The Economic and Social Burden of Malaria," *Nature* 415 (2002): 680–685.