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LESSONS OF HISTORY? ANTI-MALARIA STRATEGIES OF THE INTERNATIONAL HEALTH BOARD AND THE ROCKEFELLER FOUNDATION FROM THE 1920S TO THE ERA OF DDT

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In a recent article on "The Economic and Social Burden of Malaria," authors Jeffrey Sachs and Pia Malaney have called for drawing on "the lessons of history [to] serve us well as we look to the future in our battle against [malaria]."[1] A rich source for understanding the potentials and pitfalls of anti-malaria strategies is the history of two Rockefeller-endowed entities, the International Health Board (1913–1928) and the Rockefeller Foundation (1913–present), that created new approaches to malaria control in the first half of the 20th century.[2,3] It is fair to say that this era experienced a revolution in malaria control, and that in their global activities the Rockefeller Foundation (RF) and its predecessor in public health—the International Health Board (IHB)—were, if not at the center, then very near the center of that revolution. [Throughout this article, I will use the adjective Rockefeller when referring to officers, field workers, and activities of both organizations, because they were created through the philanthropy of John D. Rockefeller, Sr., and merged in 1928.]

Assessing the results of anti-malaria work created certain controversies and sharpened disagreements both within and without the organizations. Yet, the IHB and the RF, or more properly their officers and staff, usually acted with such surety, with such an overwhelming sense of mission and confidence, that the moments of conflict, or indecisiveness, or disappointment, or anger were few. Only from a more distant perspective can we see particular issues sharply defined, pivotal, and controversial, yet as way-stations to the ambiguous lessons of malaria eradication in the mid-20th century.

Certainly, there is a didactic value in looking at the moments of controversy in the Rockefeller-malaria story, because they illuminate an evolving strategy, particularly the growing intention to completely eradicate malaria, not merely control it. Moreover, they present a more human side to what is often depicted by historians as a monolithic public health organization that swept aside doubts, objections, and resentments in pursuit of, or in support of, American global hegemony.[4,5]

Malaria was the third of the three diseases that the Rockefeller Foundation (and its preceding Rockefeller-funded public health organizations) attacked globally. Following an anti-hookworm campaign in the American South beginning in 1909 (which metamorphosed into a world-wide campaign in 1913), the Rockefeller operatives enthusiastically initiated a yellow-fever campaign in 1915 that immediately drew them into Latin America and then into Africa. The anti-malaria campaign took root at about the same time, but seemed to be a sideline of the Rockefeller institutions (as tuberculosis, influenza, and typhus were) until the 1920s.

It is worth pausing to consider why in the first two decades of the 20th century malaria was not as attractive as hookworm and yellow fever to an organization looking for diseases that might be controlled, or perhaps even eradicated, in the space of a few years or a couple of decades. In the case of hookworm, there was an apparent quick "cure" available—the ingesting of thymol, chenopodium, or carbon tetrachloride, followed by Epsom salts—which physically rid the body of a visible pest. The public was receptive to anti-hookworm work: no one doubted that it was a good idea to eliminate "worms" from the body. The hope, and the goal, of the Rockefeller philanthropoids in selecting hookworm as the first disease is explicit in the name of the organization created in 1909: the Rockefeller Sanitary Commission for the Eradication of Hookworm Disease.[6]

Yellow fever, although not as susceptible to visible demonstration as a disease, created dramatic and well-publicized epidemics, so that virtually everyone understood its public health threat and wanted to end it. The recent identification of the mosquito vector, and demonstrations in Cuba and Panama of the possibility of minimizing yellow fever outbreaks by controlling the vector, presented a workable strategy for control. Moreover, it seemed possible that study of the disease could result in identifying the germ, and that might lead to development of an inoculation. Indeed, when, with the support of the IHB, Hideyo Noguchi of the Rockefeller Institute for Medical Research turned his attention to yellow fever in 1918, he quickly identified a virus that appeared to be its cause and developed a vaccination based on it. While his work was shown

within a few years to be erroneous, it began a program that ended two decades later with RF researcher Max Theiler's Nobel Prize-winning yellow fever vaccine.[7]

Malaria was not as clear-cut a candidate for success as the other two. Regarding its potential as a solvable problem, it had in its favor the clear identification of the insect vector (the *Anopheles* mosquito) and the centuries-old knowledge of quinine as an effective prophylactic.[8,9] However, malaria did not have the drama of yellow fever—many people lived with the disease for years. More seriously, the etiology of malaria was undeniably complex. No one expected to develop a malaria vaccine quickly. Why, then, did the Rockefeller public health juggernaut commit itself to malaria?

There were three central reasons. Most importantly, trials of mosquito-control measures (screening houses, oiling water, draining standing water, distributing larva-eating minnows) in the American South in the 1910s proved successful. When they were joined with spraying Paris Green, which was shown in the early 1920s to be an effective mosquito larvicide, there was a package of techniques that begged to be tested and refined. The experience of World War I was also significant in a negative way: serious malaria outbreaks in military camps and in European and Middle Eastern military campaigns demonstrated that the disease could easily become epidemic in the northern hemisphere in times of crisis. Finally, the very effectiveness of quinine had minimized attempts to control malaria by other means, and the door was open for new strategies.

When the IHB began malaria work in 1915, it did not immediately "go global." Instead, it focused on small towns and rural areas in the United States, recognizing the "need of further facts . . . [and of] studies of various kinds."[10] In collaboration with the United States Public Health Service and local governments, malaria work slowly expanded from demonstration projects in a few counties in Arkansas and Mississippi to nearly 150 sites in twelve states of the United States in 1923.[9] By that time, the IHB also carried out malaria research in Brazil, Nicaragua, Puerto Rico, El Salvador, the Phillippines, and Palestine.[10]

In 1923, Paris Green is first mentioned in Rockefeller accounts of anti-malarial work. A double salt of copper and arsenic, it had been used for insect control in agriculture for some time, and in 1921 a United States Public Health Service officer showed that it was effective as a mosquito larvicide when sprayed on water.[11] While for some years oil had been spread on larvae-infested water as a means of making it nearly impossible for the larvae to breathe, it was far more effective to poison them with Paris Green.[12–14] The mosquito larva, which lives in pooled, stagnant, or slow-moving water, must come to the surface to poke its air tube out of the water to breathe, even though it feeds below the surface. This makes it vulnerable to a poison such as Paris Green that, when mixed with a light inert powder, floats on the surface of water.

After Rockefeller field workers started to use the Paris Green strategy, dramatic reductions in numbers of mosquito larvae at treated sites seemed to be the determining factor in lower malaria rates in sampled human populations. In 1926–1927, the IHB carried out work at Fajardo in Puerto Rico, and reported that "Paris Green has proved a highly effective weapon. . . . The malaria incidence at Fajardo has been steadily reduced and no longer plays a major role in producing disability in the community."[15]

Almost simultaneously with the advent of Paris Greening (it quickly became a verb in the Rockefeller lexicon), Rockefeller officials claimed that field work in Brazil demonstrated that "Quininization has not been found to be an indispensable aid" in malaria control, violating a long-standing dictum of malariologists.[16] Studies in the United States in 1924 showed that quinine did not permanently eliminate the malaria parasite from the bloodstream, and it was asserted that the short-term use of quinine therefore was of "little use as a public health measure."[17] This revelation caused no little consternation in the American public health community, as well as other medical establishments throughout the world that had become committed to quinine distribution and administration. The Rockefeller institutions' unequivocal adoption of mosquito-control as an article of faith often put them in conflict with local medical figures, who thought that the Rockefeller approach neglected the needs of sufferers. Rockefeller officers, who usually had medical training, sometimes accused local medical practitioners of resenting the loss of income that occurred when the rate of malaria infection declined.

The adoption of Paris Green and the downplaying of quinine not only permitted a clear strategic choice in favor of anti-mosquito regimen, it also underpinned a much stronger commitment of Rockefeller resources to anti-malaria work. The IHB's funding of malaria projects roughly doubled from 1924 to 1925, and remained at that level for the next several years. There was now a strong technological bias to the work: studying malaria as a disease was downplayed, and elaborating effective mosquito-control strategies was emphasized.

Why did the anti-mosquito approach appeal so strongly to the Rockefeller public health enterprise? Clearly, its base in the United States was a major factor—the bias of American society toward technologi-

cal solutions of problems has been remarked on since colonial times, and the Rockefeller public health officers were exemplars of that character.[18–20] Moreover, Rockefeller philanthropy came of age during the Progressive era's fascination with experts, particularly scientists and engineers. Such experts tended to propose technical solutions that fit nicely with the Rockefeller philanthropies' desire to steer clear of political or social entanglements because of the association of the Rockefeller name with the ills of monopoly capitalism.[21]

Technical approaches also tended to yield immediately quantifiable results that justified equivalent expenditures of funds. Tables of houses screened, pipes laid, acres sprayed, spleens measured, and blood samples examined flowed from the field back to the offices in New York. A statistician was employed continuously to analyze the flood of information and to extract meaning from the correlations.

Finally, as I have indicated already, the technological approach to disease control distanced the Rockefeller Foundation from medical and medically-related approaches to a considerable degree, so that individual cures were less important than a measurable decrease in disease incidence. Although the RF financed clinics and health units of various sorts where diseases were treated beginning in the late 1920s, the archival record suggests that the clinics may have been viewed at least as much as instruments for observing the variables in results of disease conditions, as means of disease control.[22,23]

The first full-blown manifestation of the Rockefeller malaria program was in Italy, where from 1923 to 1951 roughly one-sixth of all Rockefeller malaria monies were spent. In 1924, ostensibly at the invitation of the Italian government, but clearly at the instigation of the International Health Board, Rockefeller public health officer Louis Hackett left the yellow-fever control program in Brazil and went to Italy to initiate a malaria-control demonstration program. Following the Rockefeller tradition of the preceding decade, Hackett began his work with a survey of the existing Italian anti-malaria program, which was regarded as one of the most thorough in the world.[24,25]

Hackett observed that malaria was endemic in several regions of Italy, was most prevalent in Sardinia, and that the Italian government's program focused on two approaches: the distribution of quinine to all who wanted it, and the flooding of malarial swamps in the expectation that over time they would become silted in and become productive farm land. This latter program, known as bonification, drew on Italy's long tradition of excellence in hydraulic engineering.[26] While he was impressed by the Italian government's dedication to malaria control, Hackett did not like the concept of a fifty-year period before the results of bonification could be realized. He also accepted the Rockefeller position that quinine distribution was a palliative, and not a solution to the problem. It was his view that "the [Italian] government has developed an elaborate machinery for taking care of the sick individual, but no provision is made for the study of the local causes of malaria [or] the control of Anophelene mosquitoes."[27] He therefore proposed a program in Italy of controlled tests of anti-malarial measures, aimed at developing an effective system that was demonstrably cheap enough that it could in the future be supported by local governments.[27]

The Italian government found Hackett's recommendation disappointing, "since it led directly away from the official program [of quininization] of twenty-two years' standing . . . . [and] Furthermore [the government] considered that the situation called for financial rather than technical assistance (there being no lack of the latter in Italy). . . ."[27] Nonetheless, Hackett found a receptive partner in the Italian malariologist Alberto Missiroli, and beginning early in 1925 they plunged ahead, establishing a laboratory in Rome with IHB funding and creating field stations where they began a series of observations and experiments. They studied the habitats and habits of local mosquitoes; with an engineer provided by the IHB they drained or filled swamps and re-engineered watercourses to give them a stronger flow; they introduced a genus of larvae-eating fish (*Gambusia*), and spread Paris Green. They included in their approach the distribution of quinine, and even tried the exotic new strategy (ultimately fruitless) of x-raying spleens as a control measure. After two years, they came to the conclusion that the most effective technique in their arsenal was the use of Paris Green as a larvicide.[24]

In 1927, at about the same time that Hackett's and Missiroli's hard work had brought them to the point of focusing on larviciding, the League of Nations commission on malaria issued a report, in part based on a brief visit to Italy that included observations of the IHB project. According to Hackett,

> The keynote of [the commission's] report [was] the conviction that our knowledge of the mosquito transmission of malaria has not helped us in the struggle against the disease, and may in fact have led us away from the right path. The Commission . . . felt that we should, above all, strengthen the arm of the private and public physician with the frank aim of mitigating

> by medical assistance the lot of those who had fallen victims to a disease . . . bound eventually to succumb to an improvement in the social condition of the masses of malarious people everywhere.[28]

That is, the commission held the view that a general improvement in sanitation, including better sewerage and water supplies, would lower the malaria incidence more effectively than attempting mosquito control. This view outraged Hackett, who called the report "an appeal to 'right living' as a substitute for measures based on a knowledge of disease."[13,28] He could not understand how any informed malariologist could dismiss the promise of an anti-larval strategy, especially when early in their experimental work in Sardinia, he and Missiroli had concluded that the "costly quininization" program was "not time or money well expended," because it did not prevent new outbreaks of malaria.[29]

The Rockefeller heirarchy had no doubts about the value of the work in Italy: one officer visiting the Hackett-Missiroli operation in 1930 praised it as "one of the finest pieces of scientific practical work [in malaria control] done . . . in any part of the world."[30] Without hesitation the larvicidal strategy developed in Italy was extended to other locales in the Mediterranean and the Balkans, and then almost everywhere that the Rockefeller Foundation was engaged in antimalarial work. Paris-greening became the centerpiece.[31] Some officers began to speak not only of control of mosquitoes, but also of eradication.[32]

Still, the Foundation's mosquito-control work sometimes yielded ambiguous results. Even in Italy, where there were immediate declines in malaria cases, it was difficult to show consistent reductions in malaria infection rates in every district.[33] At the malaria field station in Petritch, Bulgaria, where mosquito control through the extensive drainage of an agricultural area was at first heralded as one of the great Rockefeller success stories of the 1930s, statistical reviews indicated only modest changes in malaria rates.[31] Interestingly, the Rockefeller assessment of the work in Bulgaria began to focus on "the reclamation of large areas of land . . . [which] cannot fail to have an effect on the natural history of malaria quite beyond our feeble ability to measure."[34] The long-term vision of environmental change that Hackett had ridiculed in Italy a decade before became an acceptable standard when short-term results were wanting.

But in spite of possible flaws, the technological strategy continued to drive the Rockefeller malaria program. Projects carried out in India from 1936 to 1942 under the direction of Rockefeller officer Paul F. Russell appear to have been highly-influential in firming up the anti-mosquito strategy and therefore laid the groundwork for the subsequent DDT revolution in malariology. Russell, a veteran of malaria-control work in the Philippines and a graduate of the Harvard School of Public Health, was assigned to India in 1935 to carry out malaria control trials in the Madras Presidency. He arrived convinced that "the distribution of quinine . . . has never in any place in any country been effective in controlling malaria," and that "malaria control . . . must consist mainly in a direct attack on the adult malaria-carrying mosquito in its day-time resting places, or on the larva of this mosquito in its breeding places, or on both at the same time."[35]

To reinforce his conviction with evidence, Russell selected two villages in the same district and conducted annual spleen examinations in both; in 1938, 1939, and 1940, he supervised the spraying of one village's houses and agricultural buildings with pyrethrum extract mixed with kerosene with the aim of killing adult mosquitoes, but left the other village unsprayed. (Pyrethrum, derived from flowers in the chrysanthemum family, has a long history as an effective insecticide.) Distended spleens, which were an indicator of malaria infections, dropped from 68% to 6% in the first village over three years, while in the unsprayed village they remained steadily above 50%. These results were so spectacular that they reportedly were "more or less of a shock" to the Rockefeller team.[36] With the assistance of engineer Fred Knipe, who was transferred from Bulgaria in 1937, Russell also carried out a program of larva control by filling in pits, creating better drainage and water-control devices in rice fields, distributing mosquito-eating fish, and spraying Paris Green.[36,37] The development of suitable spraying equipment for the program in India, both for the killing of adult mosquitoes in houses and for the larvicidal treatment of bodies of water, became a focus of Knipe's work and provided a reservoir of knowledge that he and Russell took to other locales in the next two decades.[38,39]

It should be noted here that, in Russell's words, the work in India was "not at all a routine programme but it [was] essentially, in every phase, a programme of research."[39] Although it was intended to develop and demonstrate cheap and effective means of malaria control, and some of the work (such as filling or draining swamps) was more than temporary, when the program was completed in 1941, everything reverted to *status quo ante*. A summary of the completed antimalaria campaign in India that was written for the Rockefeller Foundation trustees described the situation frankly and with a touch of humor, but with little sym-

pathy for the people of the village that had experienced such an astounding effect from pyrethrum spraying:

> It is doubtful if any public health measure ever won so immediate and whole-hearted acceptance from a native population. Every householder welcomed the arrival of the spray man. People noticed the freedom from mosquito biting (and even from fever) and from other insect plagues also, for bedbugs, cockroaches, and scorpions by the thousands fell victims of the potent pyrethrum. Toward the end of the demonstration program, spraying was discontinued in the original village in which the trials were first made four years ago. Malaria promptly reappeared, and it wasn't long before protests and inquiries began to come in. "How have we offended you?" and "What can we do to get you to come back"? [they said.] Some of the more well-to-do villagers pleaded, "We'll do anything, we'll buy the [spray]guns, we'll buy the spray, we'll pay the man, if you'll only send him back with his sweet mist."[40]

When a few years later in Mexico, half-way around the world, Rockefeller Foundation staff carried out a similar experiment, spraying one village and leaving the other as a scientific control, they found that residents of the untreated village were not cooperative with the team making observations, being "somewhat antagonistic to the work, because they are not receiving any benefit from it."[41] The general framework for the Foundation's anti-malaria work clearly was scientific and not ameliorative.

It is useful to review here the Rockefeller strategy for anti-malaria work at the beginning of 1942, as the United States entered World War II:

(*1*) It was based on the control of mosquitoes and mosquito larvae, rather than the treatment of malaria. This required a thorough study of the mosquito and its habitat in each locale, so that an efficient and effective method of control could be devised.

(*2*) A variety of control methods were employed, including promoting screening of houses, covering cisterns and privies, and draining and filling standing-water areas—but increasingly the Rockefeller field officers focused on spraying insecticides, both for control of the adult mosquitoes and of the larvae.

(*3*) Rockefeller malaria-control programs were viewed by the RF as scientific, experimental, and temporary, even if the intent was to encourage governments to take over its progams, expand them, and make them permanent.

This strategy appeared to be effective enough that by 1940 the RF had a global anti-malaria program with substantial initiatives in North America, South America, the Caribbean, southern and eastern Europe, and the Indian subcontinent. The program would have continued relatively unchanged had not World War II and a new insecticide come into the picture.

War brought the Rockefeller Foundation into an alliance with military agencies of the United States government. The Rockefeller Foundation Health Commission was created early in 1942 as a means of reassigning its staff to support national defense. In the United States, the Foundation collaborated with the Malaria Control in War Areas program, which was intended to prevent outbreaks of malaria in the burgeoning military bases of the American south.[42] Outside of the United States, the Foundation sent its officers to help with malaria control at the new American bases in the Caribbean and then in the rear areas of the Pacific theater. Eventually, the Foundation staff returned to Italy with the Allied forces and in 1944–1945 renewed its malaria-control efforts there.

Malaria control on the Allied side was hindered by severe limits on quinine and pyrethrum, both of which were produced largely in areas either controlled by Japan or seriously affected by military operations. While Paris Green was still available in quantity, it was not effective against adult mosquitoes and thus did not provide the immediate strike necessary when troops moved into malarious areas. Malaria control had to depend on administration of the quinine-substitute atabrine and newer drugs such as chloroquine.[43]

Unanticipated help with the war on mosquitoes came from efforts to control typhus, which was expected to be a major problem in the European theater, as it had been in World War I. Researchers hoped that typhus could be controlled if an effective insecticide or perhaps insect repellant could be found for the typhus vector, the human body louse.

The primary center for testing insecticides and repellants in the U.S. was the laboratory of the Bureau of Entolomogy and Plant Quarantine of the United States Department of Agriculture in Orlando, Florida. Beginning in 1941, under the auspices of the wartime Office of Scientific Research and Development, the Orlando laboratory examined thousands of products. Not having the means to field-test the most promising of them, the Bureau turned to the Rockefeller Foundation and its far-flung network of field workers for assistance: a meeting in February 1942 established a working relationship between the Foundation and the Bureau. In the spring and summer of 1942, an RF officer carried out tests of lousicides on conscientious objectors at a camp in New Hampshire, and in the fall began a series of tests in Mexican villages.

In November 1942, a new government agency, the U.S.A. Typhus Commission, was established under the Surgeon General to monitor typhus conditions in war areas. Four Rockefeller Foundation officers immediately were appointed to the Commission, and two were sent to Egypt to study epidemic conditions there. One of the officers was Fred Soper, who had been involved in yellow fever and malaria campaigns for more than fifteen years. In June 1943, the Egyptian team was joined by three other Rockefeller officers and moved to newly-liberated Algeria and Tunisia to conduct trials of lousicides.

Just at that point, for the first time, small stocks of a new insecticide, DDT, became available. Identified and developed as an insecticide by the Swiss firm, Geigy, samples were shipped to the United States, Britain, and Germany in the fall of 1942. Tests at the Orlando laboratory demonstrated that it was highly effective against lice, and that it was promising as a mosquito larvicide. Industrial production commenced in the United States and Britain in the spring of 1943, but it was some months before large quantities were available.[44–46]

The Rockefeller team in North Africa carried out its first trials of DDT on German and Italian prisoners of war, then on the inmates of the jail in Algiers, and finally on the civilian population of a nearby town. The Rockefeller team's focus at this time was the testing of various mixtures of DDT and diluents in order to identify the best DDT mixture and the best means of applying it directly to the skin of subjects. (It had already been determined by tests in the United States that concentrations of up to 10% DDT on human skin appeared not to be toxic.) This experience was immediately useful when, after the Allied invasion of Italy, the city of Naples seemed on the verge of a typhus epidemic. DDT and pyrethrums were dusted on more than a million inhabitants, quelling the threat.

This set the stage for utilizing DDT in response to a potential malaria outbreak to the west of Rome early in 1944. For defensive purposes, the German army had flooded the region, creating ideal conditions for mosquito-breeding. After the liberation of Rome in June, Rockefeller officers quickly made contact with Alberto Missiroli and other Italian public health authorities and collaborated on developing a DDT assault on mosquitoes. Rockefeller studies in Mexico and the Caribbean, as well as work at the Orlando laboratory, had shown that DDT remained effective for six to eight weeks if sprayed on the inside walls and ceilings of houses and other buildings.[47]

The potential malaria crisis in central Italy created ideal experimental conditions, and the Rockefeller team tried a number of methods of mosquito control.[48] Aerial spraying was begun with Paris Green, but when a supply of DDT was available it was mixed with fuel oil and "sprayed from M-10 smoke tanks mounted on the wings of an A-20."[49] That proved insufficient, so "eventually three 100-gallon tanks of oil were mounted on the bomb bay of another A-20 and these were discharged through a tail vent." By testing, it was found that "a good dispersal of larvicidal oil was obtained when the plane[,] flying at 200 miles per hour[,] traveled at an altitude of 75 feet above the ground," and that there was a substantial kill of larvae when there was at least 3% DDT in the fuel oil.[49]

Simultaneous with the aerial spraying in the region west of Rome, the Rockefeller officers worked with British and Italian teams to organize the manual spraying of the interiors of houses and barns with 5% DDT in kerosene. Fred Knipe, who had joined the team in the spring of 1944, worked on adapting the sprayers to be efficient in the use of DDT and in spraying. As one member of the team reported:

> Using the pressures recommended by Mr. Knipe, all houses in the town of Fiumicino were sprayed with 5% DDT in kerosene between August 25th and September 6th. . . . A total of 3,013 rooms were treated with 403 gallons of DDT solution. . . . Before treatment was begun, 70.2% of the rooms examined contained [Anopheline mosquitoes] and that figure fell to zero and remained a negligible one for more than a month.[50]

The success of this project and experiments a few months later by Missiroli convinced the Italian civil authorities to begin a massive malaria control program based on DDT spraying. In January 1946, they began a five-year campaign and, after the first two years of the project, *Anopheles* mosquitoes were nearly exterminated in all of the formerly malarious regions of Italy.[50,51]

Possibly the most famous early DDT test was derived from these early experiments and successes. The Sardinian campaign, carried out in concert with Missiroli's program but supervised by Rockefeller personnel, attempted to use DDT to eradicate *Anopheles* from the entire island of Sardinia, consistently the most malarious district of Italy. Funded primarily by the United Nations Relief and Reconstruction Administration from 1946 to 1951, the Rockefeller officers organized a military-like campaign, teaching a corps of thousands of Sardinians to identify and spray with DDT every possible *Anopheles* breeding place on the island, sometimes removing acres of vegetation to allow effective spraying of swamps and slow-moving streams. Regular sampling of air and water identified

the recalcitrant pockets of mosquitoes that needed to be dealt with.[32,52,53]

The result of the campaign is well known: after saturating the island with DDT, malaria was eradicated. The mosquito, however, remained, even if in greatly reduced numbers. Sardinia was a showcase for the power of DDT, and veterans of that project, as well as the dozens of malariologists who visited there, helped to spread the DDT gospel worldwide. (The first meeting of the World Health Organization Expert Committee on Insecticides met in Cagliari, Sardinia, in May 1948, for example.)[54,55] By the end of the Sardinian campaign, other programs in Cyprus, Venezuela, the Netherlands, Taiwan, and Tobago in the Caribbean, some of which the RF also had a role in, had shown that DDT could dramatically reduce malaria incidence and could stop potential epidemics.[56–60]

In spite of these apparent accomplishments in malaria control, there were already some sources of concern, such as the early results of Rockefeller DDT studies in Mexico.[61] In November 1944, the Orlando laboratory had asked the Foundation to undertake DDT malaria-control work in Mexico, and had sent one of its entomologists to participate.[44] Spraying houses and outbuildings in April and May of 1945 in two towns in the state of Morelos resulted in a 99% reduction in the incidence of mosquitoes when measured two months later, and a 96% reduction in larvae, although no larviciding had been done. The next four seasons of spraying had similar results, but while the insecticidal campaign was successful, there was no conclusive decrease in the rates of malaria in the towns, in part because the malaria rate in both towns was relatively low to begin with. As Rockefeller officer Wilbur Downs put it, "I really wish we were working in an area of higher endemicity, so that our figures would illustrate results obtained more satisfactorily."[62]

For the next three years until the project was completed, Downs persisted in viewing the work in Mexico as experimental, although Mexican officials were so impressed by the virtual elimination of mosquitoes and the apparent reduction of malaria that they pressed forward with anti-malaria work. Downs complained about the "tendency of the Government . . . to undertake DDT campaigns without preliminary investigation of malaria incidence and of the principal anopheline vectors."[63] It was reported that one leading Mexican public health officer proposed adding DDT to the water supply of Acapulco as an anti-malaria measure, and that another argued that "no malariologists, engineers, or entomologists are now necessary" in a malaria-control program based on DDT.[63]

The most visible and vocal Rockefeller malarioloist, Fred Soper, actually had similar ideas. In 1946 he argued against "long-term detailed entomological or malaria studies . . . unless residual DDT fails to greatly reduce [mosquito] densities which will be contrary to all previous experience."[64] Others in the organization disagreed: Paul F. Russell wrote in his book, *Malaria: Basic Principles Briefly Stated*, that DDT had quickly come to "[receive] blind reverence, while the study of mosquitoes and how to eliminate their breeding places [was] ignored." He argued that "sound practice involves individual consideration of each local problem to determine the logical solution in the light of available knowledge. Drainage and entomological research still have importance in malaria control in certain places."[65] In the remaining years of Rockefeller activity in malaria (which essentially ended with the termination of the RF's public health program in 1952), Russell's and Down's views were predominate; but it was Soper's approach that appealed to those who wanted to eradicate malaria, and greatly influenced the World Health Organization's global anti-malaria eradication program that began in 1955.

There were, in addition, environmental issues (generally ignored by the Rockefeller officers) that became apparent very soon in the DDT era. As early as 1946, resistence to DDT was observed in the common housefly; 137 species of insect pests had demonstrated some level of resistence to the effects of DDT by 1960. Moreover, DDT's broad-spectrum effect meant that animals depending on certain insects for food were at risk when DDT was used extensively. DDT's persistence also meant that it traveled readily up the food chain to affect the carnivores at the top: by the time Rachel Carson's book, *Silent Spring*, appeared in 1962, it was clear that the ability of fish-eating birds such as bald eagles, ospreys, cormorants, and pelicans to reproduce was seriously endangered by ingesting large amounts of DDT.[47] In sum, the attempted eradication of mosquitoes threatened to lead to the possible eradication of other species.

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The historical results of the anti-malaria programs fostered by the Rockefeller Foundation before the WHO campaigns of the 1950s and 1960s is itself a matter of controversy. Sachs and Malaney, whose call to bring history to the aid of anti-malaria programs I cited at the beginning of this article, have a generally positive view. They argue that:

> The elimination of malaria from wealthier countries in the 1930s to 1950s, such as the United States, Italy, Greece and Spain, was a result of both socioeconomic

> development and intensive antimalaria interventions. Improved housing, especially the provision of screened doors and windows, limit[ed] contact between mosquitoes and people. This, combined with efforts at environmental management such as the draining of swampland, which eliminate[d] the breeding grounds of certain vector mosquitoes, and indoor spraying of residual insecticides, such as DDT, successfully eliminated malaria from most temperate zone countries.[1]

This assessment is accepted by many malariologists and historians, who usually credit the Rockefeller Foundation with a key role in malaria control before the beginning of the WHO global eradication campaign in 1955.[66]

Others argue that the disappearance of malaria from the temperate zones and industrialized nations was due to more general factors. One informed observer states that:

> The migration of the rural population, the main support of malaria in past times, to urban areas, the improvement in housing conditions of those who remained in the country and last but not least, the general improvement in social and economic conditions led to the end of malaria in practically all the industrialized countries.[67]

As these contrasting views illustrate, the lessons of malaria control in the 20th century remain ambiguous. The Rockefeller approach—a single-minded, insecticide-based attack on malaria—may have been the most successful anti-malaria strategy of modern times, yet contributed to a legacy of resistant insects. Moreover, it brought us no closer to a cure for the disease itself. The technological path to malaria control has had its limits.

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