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South Africa's War against Malaria
Lessons for the Developing World

by Richard Tren and Roger Bate

Executive Summary

Malaria imposes enormous human suffering and economic costs on many poor countries. For South Africa, which has a relatively minor malaria problem for a developing country, from 2000 to 2002 the economic cost ranged between US$15 million and US$41 million, excluding estimates of the human suffering and estimates of lost investment in malarial areas.

The methods of controlling and treating the disease are well known and include indoor residual spraying of insecticides. One insecticide in particular, DDT, revolutionized indoor residual spraying because it was cheap, easy to use, and long lasting.

Because of DDT's continuing effectiveness and the need to rotate insecticides to prevent insect resistance, many countries still rely on DDT for malaria control. As this paper shows, when countries bow to international pressure and stop using DDT, the effects can be disastrous. Malaria control programs, therefore, must use indoor residual spraying of DDT to reduce the overall disease burden, so that countries can afford to purchase expensive, but effective, new drugs to treat the remaining cases.

Despite the value of DDT, ongoing environmentalist campaigns against its use, and indeed against any sort of indoor residual spraying, severely hamper control of the disease. Although the UN's Stockholm Convention on Persistent Organic Pollutants, which aims to reduce or eliminate the use of certain chemicals, gives DDT an exemption for use in public health programs, the convention will most likely increase the cost of DDT use and make malaria control more difficult.

Many "green" groups built their reputations by their campaigns to ban DDT during the 1970s. The same groups now influence donor agencies and the World Health Organization that refuse to support indoor residual spraying and continuously encourage malarial countries to move away from DDT. If this trend continues, many efforts to roll back malaria will be fruitless.

Richard Tren is director of Africa Fighting Malaria and Roger Bate is a visiting fellow at the American Enterprise Institute.

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Introduction

In almost all countries, life expectancy at birth is higher today than it has ever been. A child born in a high-income country can expect to live to over 78 years of age. In a low-income country, on the other hand, that child can expect to live to only about 60.[1] The difference in life expectancy between rich and poor countries is significant. It is worth noting, however, that following World War II most people in rich countries could expect to live to only 65. At the turn of the 20th century, they could realistically expect to live to only 40.[2]

People in rich countries expect to live longer because of economic growth and the attendant increase in income, which then translates into improved nutrition, proper sanitation, and clean water. Growing wealth and the concomitant advances in medical and public health technologies decrease the incidence of communicable diseases in rich countries and contribute to important advances against diseases in poor countries. One such technology is the use of the insecticide dichlorodiphenyltrichloroethane (DDT) to combat malaria.

During World War II the Allied Forces used DDT to halt the spread of louse-borne typhus and to control malaria. Inspired by its effectiveness, public health officials used DDT to eradicate malaria from Europe and the United States. However, the scourge of malaria persists in less affluent parts of the world. The World Health Organization estimates that malaria infects between 300 million and 500 million people every year and kills more than 1 million. Most people who die are children: one child dies every 20 to 30 seconds.

Because DDT is readily available, those deaths could be avoided. Unfortunately, the influence of Western environmentalists is preventing many poor countries from using DDT to control the spread of malaria. This paper will point to the highly successful use of DDT in South Africa and argue that DDT is an essential part of any malaria control program. We will estimate the economic costs of malaria to South Africa, because malaria is not only a human tragedy but also a significant inhibitor of economic growth.

The focus of this paper will be on South Africa, because of a unique set of circumstances surrounding the use of DDT in that country. After South Africa stopped using DDT in 1996, malaria cases increased. In KwaZulu Natal province, for example, malaria cases increased from around 8,000 in 1996 to almost 42,000 in 2000. In 1996 only 20 people died from malaria in KwaZulu Natal, but that number increased to more than 340 in 2000. South Africa found that restricting the choices available to malaria control programs, especially as the malaria parasites continue to develop resistance to the drugs used to treat patients, is costly and reintroduced DDT in 2000.

What Is Malaria?

The word "malaria" is derived from the Italian for bad (*mal*) and air (*aria*), because it was thought that the disease was caused by the presence of foul air emanating from swamps and bogs.[3] In 1880 Alphonse Laveran, a French army physician stationed in Algeria, discovered that malaria is caused by a genus of parasites called *Plasmodium*. In 1898 a British army physician stationed in India, Dr. Ronald Ross, realized that mosquitoes transmitted that parasite. Shortly thereafter, one of the world's leading zoologists at the time, the Italian Giovanni Batista Grassi, identified the genus of the disease-spreading mosquito: *Anopheles*.[4] Understanding the role that the *Anopheles* mosquito, the malaria vector, plays in the transmission of the disease allowed Ross and others to develop programs targeted against the mosquito so as to halt the spread of the disease. (Appendix 1 details the life cycle of the malaria parasite.)

Malaria in South Africa

The parasite *Plasmodium falciparum* causes around 90 percent of the malaria cases in

South Africa as well as in the rest of Sub-Saharan Africa. *P. vivax, P. malariae*, and *P. ovale*, which are far less dangerous parasites, cause the remainder.[5] Globally, there are about 3,500 species of mosquito, but only two mosquitoes or vectors transmit malaria in South Africa. Those are *Anopheles arabiensis* and *A. funestus*.

P. falciparum malaria cases can be either uncomplicated or severe, and the treatment regimen varies accordingly. Uncomplicated malaria usually results in mild fevers and minimal vomiting and does not result in any delusions or other mental problems. Uncomplicated malaria does not normally require hospitalization; affected patients usually remain ambulatory. Severe malaria usually occurs in people who either have their immune systems suppressed or have no immunity at all. Young children and pregnant women are particularly at risk, as well as people who travel to malarial areas and have not developed prior immunity.

The symptoms of complicated malaria include convulsions, impaired consciousness, and respiratory distress that may take the form of acidosis, acute respiratory distress syndrome, or pulmonary edema.[6] Patients can also become jaundiced, start hemorrhaging, experience renal failure, and go into circulatory shock.

Physicians treat uncomplicated or mild malaria cases with sulfadoxine-pyrimethamine or quinine in combination with either doxycycline or clindamycin. In the case of drug-resistant strains, malaria is cured with a combination therapy of artemether-lumefantrine or artesunate and sulfadoxine-pyrimethamine. Medical staff treat most uncomplicated cases and then send patients home. However, complicated malaria requires intensive treatment and hospitalization. Complicated malaria usually calls for intravenous quinine treatment along with doxycycline and primaquine.

Pregnant women, young children, and individuals who are immuno-suppressed are particularly at risk from the disease. Data suggest that those people who are co-infected with HIV/AIDS have a higher risk of developing severe malaria.[7] In addition to malaria, inadequate and underfunded health care systems are unable to cope with a wide range of diseases, including HIV/AIDS, hepatitis, tuberculosis, and cholera. Tragically, many of those diseases are both preventable and treatable.[8]

Analysis of Economic Costs of Malaria

Knowing what a disease costs an economy can help the government focus spending and prioritize decisions. The following analysis of the economic costs of malaria to South Africa estimates the direct and indirect costs of the disease. Direct costs of malaria include the costs to individuals and to health services. Indirect costs are the costs to the economy of lost productivity due to malaria, the costs of lost future earnings in the case of death from malaria, and the costs incurred through days lost in education.

The direct costs of malaria control and treatment are relatively easy to calculate from South African Department of Health data. Estimating the indirect costs of malaria, such as lost productivity, entails making various assumptions about the productivity of individuals in malarial areas and the time that they would spend off work or be unproductive as a result of the disease.

Malaria imposes other costs, particularly on children who have suffered cerebral malaria, are unable to complete school, and therefore have compromised their career opportunities and future earnings. Because of the extreme difficulty of estimating these types of costs, the cost estimates below should be seen as conservative and static.

The direct costs of malaria include the time that medical personnel spend testing for malaria and then treating and nursing malaria patients. The cost of the drugs and the testing equipment has also been included in the calculations, as have general hospital expenses such as food and bedding. Expenditures on malaria control programs, such as those for personnel, insecticides, entomologists' time,

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and other scientific charges, have also been included in these direct costs.

In calculating the indirect productivity losses, the average wage rate of people in malarial areas has been used as a proxy for productivity. Mortality losses have been estimated by calculating the present value of lost future earnings of people who have died from malaria. No attempt has been made to put a figure on the costs of children's lost education. However, that is a factor that should not be underestimated.

Another cost that has not been quantified is the investment opportunities lost because of malaria. The risk associated with malaria can act as a deterrent to investors and tourists. In South Africa the malarial areas all lie in prime tourism areas, and the mere fact that visitors will have to take malaria prophylaxis could deter them from visiting those areas. The importance of that issue is demonstrated by the fact that many tourist resorts in nonmalarial areas strongly promote the fact that they are nonmalarial.[9]

During the height of South Africa's malaria epidemic in 2000, we estimate (Table 1) the direct and indirect costs of malaria to have been approximately US$41 million.[10] After the malaria epidemic was controlled (through the use of DDT in indoor residual spraying programs), the cost that the disease imposed on the country fell to around US$15 million. We should repeat that these are very conservative estimates, as we have not attempted to estimate the value of lost investment to the malarial regions that could arise because of investor nervousness about the disease. South Africa's malaria problem is relatively minor compared with that of the rest of southern Africa, where it is frequently the primary cause of mortality and morbidity (as it is, for example, in Zambia).[11] The economic costs of the disease in these areas will be considerably more severe than in South Africa.

South Africa's Malaria History

The main malarial areas in South Africa are the low-altitude parts of Limpopo province, Mpumalanga province, and KwaZulu Natal.

Table 1
Summary of Economic Costs of Malaria (thousands of rand)

	1996	1997	1998	1999	2000	2001	2002
Number of malaria cases	23,907	20,513	22,690	50,321	61,934	25,731	15,074
Direct costs							
Malaria control program	55,000	60,000	68,000	79,000	90,000	96,000	102,000
Cost of treating and hospitalizing patients	6,979	6,203	8,151	16,319	21,179	11,324	8,210
Indirect costs							
Malaria patient lost productivity	7,664	10,276	8,272	16,322	19,972	11,497	6,194
Family care—lost productivity	116	132	161	373	497	224	142
Mortality costs	38,175	38,890	59,140	131,170	151,410	46,678	40,247
Cost per case	4,514	5,630	6,352	4,824	4,580	6,443	10,341
Total (rand)	107,935	115,503	144,148	242,759	283,697	165,796	156,793
Total (US$ 000)	25,122	25,069	26,059	39,711	40,906	19,271	14,909

Note: The exchange rates used were the current US$/rand exchange rates obtained from the South African Reserve Bank, http://www.reservebank.co.za/.

Currently, of the approximately 40 million people in South Africa, 10 percent, or 4 million, live in a malaria risk area. Though malaria continues to be a problem, the effects of malaria were much more severe in the past. Malarial epidemics in the affected provinces brought economic activities to a standstill throughout the first half of the 20th century. The movement of laborers into malarial areas to work on railway lines and to develop agriculture exacerbated the problem. Many of those laborers came from nonmalarial areas and therefore had no immunity to the disease.

In 1932, for example, KwaZulu Natal reported 22,132 deaths from malaria in a population of 1,819,000 people, a mortality rate of 1.2 percent.[12] Malaria incidence in the Limpopo province and Mpumalanga was equally severe during this period.[13] Similarly, heavy rains in 1939 caused several outbreaks of malaria, one of the most severe occurring in Limpopo province. This outbreak led to tens of thousands of cases and 9,311 deaths in a population of 1,108,800 (0.8 percent mortality rate), which affected farming and economic activities.[14]

In the 1920s the South African government responded by using oil and Paris Green to combat malaria. Paris Green, a widely employed and effective insecticide, remained the main method of mosquito larva control until 1946.[15] The government also used the spray version of the pyrethrum insecticide, an insecticide derived from the chrysanthemum flower, which was sprayed within residential dwellings weekly. It proved an effective vector control.[16] Draining the larval sites also proved successful in some instances. The use of the eucalyptus tree was especially important in maintaining the drainage of these mosquito-breeding areas.[17]

Introduction of DDT

It was the adoption of DDT as the mainstay of the malaria control program in South Africa in 1946 that caused Transvaal cases to decline to about one-tenth of the number reported in 1942 and 1943. In KwaZulu Natal the introduction of DDT in 1946 led to the rapid reduction of the adult vectors captured in the routine spray checks that the South African Department of Health conducts. In some areas of South Africa DDT spraying was so successful that it was stopped altogether and only reintroduced after periods of heavy rains, when malaria cases tend to rise.[18]

DDT is relatively cheap, easy to produce, and highly efficient in the fight against malaria. Spraymen mix the insecticide, a white powdery substance, with a suspension substance and spray it on the inside walls of houses where mosquitoes rest. That process is known as indoor residual spraying. Suspended DDT is usually sprayed at a concentration of 2 grams per square meter and leaves a white stain on the wall. That white stain is sometimes unpopular with the residents; however, it does make it easy for malaria control officers to see at a glance which houses have been sprayed. Malaria control officers appreciated not only the effectiveness of DDT but also the fact that it lasted a long time. Unlike pyrethrum, which had to be sprayed every week, DDT had to be sprayed only once or twice a year, greatly reducing costs and allowing the expansion and improvement of malaria control programs.[19]

In many respects South Africa was fortunate to have a relatively minor malaria problem, adequate funding for malaria control, and the scientific resources to ensure effective control. One of the significant advantages of DDT is its cost-effectiveness, although in recent years certain pyrethroid insecticides have come down in price. One in particular, deltamethrin, is now sold at the same price as DDT.[20] As Table 2 shows, however, DDT is still cheaper than most other insecticides. The low cost and continued efficacy of DDT mean that within a given budget more houses can be sprayed and more people protected. Given the very limited financial resources that most African governments have for fighting malaria, this cost consideration is crucial.

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Table 2
Cost Index Associated with Malaria Control, per Square Meter

Chemical Group	Insecticide	Indoor Residual Spraying Insecticide Cost / m^2 (US cents/first year)
Organochlorine	DDT	0.014
Carbamate	Bendiocarb	0.038
Pyrethroid	Alphacypermethrin	0.019
	Deltamethrin	0.014
	Lambdacyhalothrin	0.028

Source: Data from South African Department of Health, Sub-Committee on Vector Control, 2002.

The South African government, however, funds its malaria control program very well and so cost was not the primary consideration in the choice of insecticide. South Africa continued to use DDT until 1996. While DDT was in use, the total number of malaria cases remained well below 10,000, and there were seldom more than 30 deaths per year. That improving situation however was not to last long, for malaria control officers faced a new and unexpected threat: the environmental lobby.

The Greens Move against DDT

After South Africa stopped using DDT in 1996, malaria cases increased. In KwaZulu Natal province, for example, malaria cases increased from around 8,000 in 1996 to almost 42,000 in 2000.

Numerous environmentalist groups oppose the use of DDT in malaria control on the grounds that it can lead to environmental damage. The attacks against DDT began with Rachel Carson's book *The Silent Spring*, which was first published in 1962. That work popularized the scare about DDT and claimed that its use was having widespread and devastating impacts on wildlife and human health.

Since the introduction of DDT in the mid-1940s, all populations globally have had some exposure to it, one way or another. Research in the 1950s already indicated that DDT and its derivatives accumulated in adipose (human and animal fat) tissue.[21] There is evidence that DDT and its metabolites accumulate in natural food chains by a process of biological concentration in the ecosystem, with the result that organisms higher up the food chain have higher levels of DDT-type compounds in their body tissue than those at lower levels. One study showed that tigerfish had the highest levels, followed by blue kurper, and the omnivorous butter catfish. DDT and its metabolites were also shown to accumulate in water birds and other birds of prey.[22]

One of the most vociferous campaigners against the use of DDT has been the World Wildlife Fund. The WWF believes that adverse health effects of DDT observed in laboratory animals point to potentially negative human health impacts. According to the WWF, DDT and its metabolites can interfere with various biological processes of the endocrine, immune, nervous, and reproductive systems.[23] In addition, the WWF claims that DDT causes birth defects and thinning of the shells of eggs of certain birds and that it has brought several species close to the brink of extinction. The WWF also claims that the estrogenic and anti-androgenic properties of DDT can lead to feminization or demasculinization.[24]

Every year scientists publish new laboratory studies linking DDT to various deleterious effects in wildlife and humans. Yet, to date, no scientific study has been able to replicate a case of actual human harm from DDT, despite more than five decades of its use

around the globe. The U.S. National Cancer Institute classifies DDT as a possible human carcinogen, but it has a lower carcinogen rating than coffee. Indeed, there is no convincing evidence that DDT or its metabolites are carcinogenic to humans.[25]

No study has been able to link the use of DDT by sprayers with any negative human health impact, even though sprayers work with the chemical many hours every day. Indeed, Hindustan Insecticides has tracked and studied the medical histories of employees at the Indian DDT production facility and has found no cases of cancer associated with DDT. Most of the employees would have handled and worked around DDT for most of their working lives, and yet they suffered no ill effect associated with the chemical.[26]

The environmental impacts of DDT are also highly questionable. During the years in which DDT was widely used in agriculture in the United States, the bird population actually increased. The U.S. Audubon Society conducts an annual bird count at Christmastime. In 1941 the number of robins recorded was 19,616, yet the count increased to 928,639 in 1960 after several years of very heavy agricultural use of DDT.[27] There were birds, particularly raptors, whose population declined; however, most of the declines occurred before the introduction of DDT. The bald eagle flirted with extinction during the 1930s, mostly because of hunting. Even during the 1960s, autopsies of bald eagles found that gunshot wounds, electrocution, or injuries resulting from flying against buildings caused 71 percent of deaths. The autopsies revealed that only 4 of the 76 bald eagles autopsied had died of disease, and the scientists did not link any of those diseases to insecticide poisoning.[28]

The Political Nature of the Ban on DDT

Despite the weak evidence relating DDT to negative human and environmental impacts, the public pressure that resulted from *Silent Spring* and the anti-DDT movement prompted the U.S. Environmental Protection Agency to hold scientific hearings in 1972 on the validity of the claims made against DDT.

DDT eradication was first and foremost on the EPA's agenda because it was important for the newly formed agency to demonstrate that it could take bold and decisive steps. Thus, it should come as no surprise that from the outset the EPA process was more political than scientific in nature. The EPA held seven months of hearings, with scientists giving evidence both for and against the use of DDT. At the end of the hearings, the hearing examiner, Edmund Sweeney, ruled that the scientific evidence provided no basis for banning DDT. The head of the EPA, William Ruckelshaus, overturned that ruling, even though he didn't attend a single hour of the proceedings. Ruckelshaus argued that the pesticide was "a warning that man may be exposing himself to a substance that may ultimately have a serious effect on his health."[29]

Statements made by Charles Wurster, the chief scientist for the Environmental Defense Fund, the organization chiefly behind the move to ban DDT, support the view that it was important for the EPA and environmentalists to succeed in banning DDT, so that their success would afford them greater powers to act in other areas. Wurster is quoted in the *Seattle Times* of October 5, 1969, as saying: "If the environmentalists win on DDT, they will achieve a level of authority they have never had before. In a sense, much more is at stake than DDT."[30]

Indeed, prior to becoming the head of the EPA, Ruckelshaus, as assistant attorney general, had supported the use of DDT. At the time he stated that DDT had an "exemplary record of safe use" and that the claims of its carcinogenicity were "unproven speculation."[31] A year later, however, when addressing the Audubon Society, he said that he was deeply suspicious of DDT and that the EPA had streamlined policy and could suspend the use of DDT at any time. He later said that as head of the EPA he was a maker of policy and not an advocate of the government, as he had been in the Department of Justice.[32]

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The political nature of the banning of DDT for agricultural use was subsequently confirmed when it appeared that much of the scientific basis for the ban contained in *Silent Spring* was either wrong or exaggerated. The 1972 edition of *Silent Spring* even testified to that. On the back cover of the book was the following: "No single book did more to awaken and alarm the world than Rachel Carson's *Silent Spring*. It makes no difference that some of the fears she expressed ten years ago have proved groundless or that here and there she may have been wrong in detail." It is interesting that the publishers freely admit to the alarmist nature of her book yet are reluctant to admit that it in fact does make a very big difference that Carson's fears were wrong.

The Stockholm Convention

Most of the environmental concerns resulting from the use of DDT came from its application in agriculture. With some degree of government subsidy supporting the use of DDT in most Western countries, farmers used enormous quantities of the pesticide to treat their crops, often hiring crop-duster planes to spray very liberal applications of the chemical over their fields. The unscientific banning of DDT may have proved costly for farmers around the world, but there were alternative agricultural insecticides available to them. Although most countries followed the lead of the United States and banned DDT for agricultural use, the bans did not halt the use of DDT in disease control, and public health use continued in parts of Africa, Latin America, and Asia.

The public health use of DDT was always completely different from the agricultural use. When sprayed in tiny quantities on the inside walls of houses, DDT simply does not escape into the wider environment and poses little or no threat to wildlife. Nonetheless, various environmentalist groups continued to press for a complete ban on the production and use of DDT. The most significant threat to the continued use of DDT in disease control came with the Stockholm Convention on Persistent Organic Pollutants.

The Stockholm Convention came out of a decision made in 1995 by the United Nations Environment Program Governing Council to develop a legally binding instrument to control certain chemicals. The convention initially targeted 12 chemicals, known as the "dirty dozen," arguing that those chemicals "pose major and increasing threats to human health and the environment."[33]

DDT is certainly the most effective of those chemicals in malaria control. However, the other chemicals play an important role in agriculture and certain production processes in the developing world. None of the industrialized nations driving the Stockholm Convention, such as the United States and Canada, uses those chemicals.

The UNEP held five negotiating committee meetings between June 1998 and December 2000 where governments negotiated and finally agreed on the final text of the convention. At the initial negotiating meeting it seemed that the convention might unconditionally ban DDT, a position supported at the time by environmental groups such as the WWF. Country delegates interviewed by the authors in Geneva in September 1999 and in Johannesburg in 2000 denied that they had ever contemplated a ban on DDT. But political memories are often short, and it is difficult to know what the result of pressure from the greens would have been had it not been countered by pro-DDT members of the health community.

The countries that still rely on DDT for disease control are mostly less developed and could not afford to match the large numbers of delegates sent by European countries or the United States. Usually, the less-developed countries could afford to send only one or two delegates to the negotiating committee meetings. Almost invariably, those delegates came from government environmental agencies. Some of the representatives were not even aware that their countries were using DDT for disease control, as their health departments had failed to correctly brief them.

Despite those problems, however, the efforts of some countries, particularly South

Africa, secured an exemption for the use and production of DDT. The Stockholm Convention lists DDT in Appendix B, as opposed to Appendix A, which would have required complete elimination. Appendix B allows any country that registers to seek exemption for either production or use of DDT specifically for disease control. No other use of DDT is permissible, and UNEP, along with WHO, reserves the right to reassess the necessity for DDT in disease control every three years. (Appendix 2 lists countries that secured exemptions from the DDT ban.)

The Stockholm Convention will come into force on May 17, 2004. Already, 29 countries have formally stated that they will be applying for DDT exemptions. Only three of those countries, China, India, and the Russian Federation, requested exemptions to both produce and use DDT.

Continued Pressure

Pressure to reduce the use of DDT still continues despite the exemption granted by the Stockholm Convention. In India such pressure is not limited to environmental groups such as Greenpeace and Toxics Link. The Indian Department of Trade and Industry has encouraged the National Anti-Malaria Program to limit the use of DDT because of its potential impact on agricultural exports. The DTI argues that exports of agricultural produce to developed-country markets could be jeopardized by illegal leakages of DDT from the public health sector to the agricultural sector. Of course this is not the first time that pressure groups have used environmental concerns, whether based on good science or not, to protect Western markets from cheaper imports from developing countries.

The fact that Europe and North America banned DDT seems to legitimize the concerns of the DTI. However, banning the use of DDT will not help India to develop economically. It will only make the NAMP's already difficult task more difficult. A far better solution would be to change the procedures for the procurement and use of DDT so that illegal and corrupt leakages to the agricultural sector are reduced and, it is hoped, eliminated. At the same time, it would be entirely legitimate for the Indian government (and other governments) to pressure wealthy countries to stop using unscientific and unfounded arguments as a trade barrier against their cheap agricultural exports.

In the latter half of 2002, UNEP and WHO began holding workshops in African countries to discuss the implementation of the Stockholm Convention and the eventual phaseout of DDT in malaria control. Although that is consistent with the wording of the Stockholm Convention, it discourages countries that could use DDT effectively to save lives.

It appears, however, that some African countries are attempting to challenge the pressure from UNEP, WHO, and donor agencies and are opting to use DDT where appropriate. In late November 2002 the Ugandan minister of health announced that his country would use DDT in malaria control. The U.S. Agency for International Development severely criticized that decision, maintaining that DDT was dangerous.[34]

South Africa did not escape environmentalist pressure, which was a major consideration in the decision to completely remove DDT from South Africa's malaria control program.[35] That was done in KwaZulu Natal and Mpumalanga in 1996 and in the Northern province in 1999. (Other social and practical considerations that influenced that decision are explained in Appendix 3.) What followed was one of the worst malaria epidemics that the country has ever witnessed.

The Fall of DDT and the Rise of Malaria

Once the South African Department of Health decided to remove DDT from malaria control, the obvious choice as a replacement was a synthetic pyrethroid insecticide. Those insecticides are considered better for the environment because they are less persis-

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tent than DDT and degrade faster. Almost all pesticide manufacturers have developed synthetic pyrethroid products for the agricultural market. Their application in agriculture can create problems for the public health use of the same insecticide. Even on Western farms where technological competence is high, it is difficult to prevent sublethal doses of pesticide from reaching some insects. In South Africa weak dilutions definitely escape as runoff from fields. The result is resistance among *A. funestus* to synthetic pyrethroids and a dramatic increase in the malaria infection rate.[36]

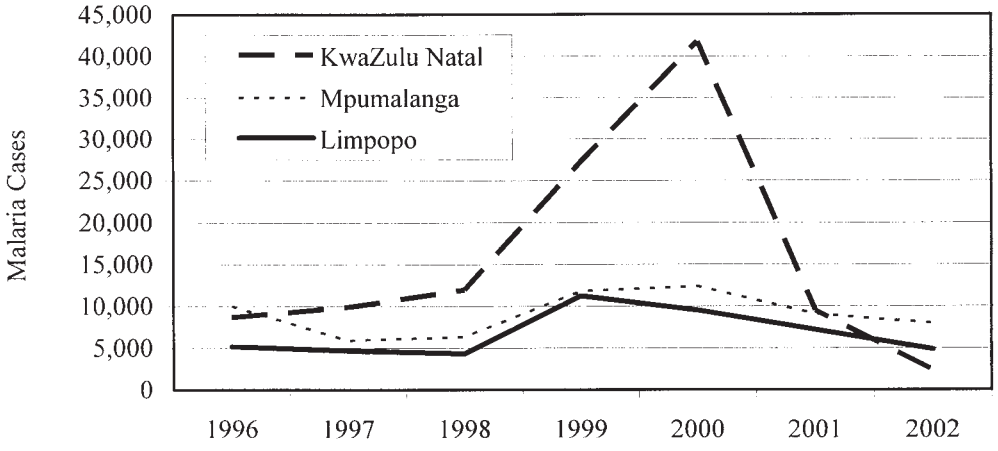
A. funestus had not been seen in South Africa for about 30 years, and it was thought that the malaria control programs in the past had completely eradicated it in South Africa. However, it was widespread in neighboring Mozambique and resistant to pyrethroid insecticides. Thus the mosquitoes simply crossed the border back into South Africa and became established. *A. funestus* feeds only on humans and lives primarily in human dwellings. Those two factors make it a highly efficient malaria vector as they greatly increase the probability that it will transmit the malaria parasite. Before long the number of malaria cases began to rise.

As shown in Figure 1, the number of cases in KwaZulu Natal began to rise rapidly after the government stopped using DDT in 1996. By 1998 the number of cases was also increasing in Mpumalanga and Northern province. Between that time and 2000 there had been an approximate 400 percent increase in malaria cases in KwaZulu Natal, traditionally the province with the highest malaria rate. By 2000 the number of deaths in the province reached more than 340, over three times the level while DDT was in use.

While the reemergence of *A. funestus*, as a result of insecticide resistance to synthetic pyrethroids, was the primary reason for that malaria epidemic, there were other factors that contributed to the rise in cases. First, since the end of apartheid and the institution of free elections in South Africa in 1994, there has been an increase in trade and travel between Mozambique and South Africa. That increased movement of people continuously introduces new parasites to the area and increases the probability that malaria will be transmitted.

Second, the incidence of drug resistance began to rise during the 1990s with the increasing treatment failure rate of sulfadoxine-pyrimethamine (Fansidar®), which was

Figure 1
Annual Number of Notified Malaria Cases per Province (1989–2001)



Source: South African Department of Health, "Malaria Cases per Province," 2003, http://www.doh.gov.za.

the first-line treatment. Treatment failure reached 60 percent in 1999–2000, and the Department of Health decided to introduce a new and more effective therapy.[37]

Last, there was increased rainfall at the time of the epidemic. That may have provided more breeding pools for *A. arabiensis*, which can breed in small puddles. It is difficult to pinpoint the exact impact that rainfall would have had. However, what is certain is that the floods would have disrupted malaria control programs, would have prevented malaria control officers from getting to houses, and would have stopped malaria patients from reaching clinics.

The South African government first reintroduced DDT in the worst affected province, KwaZulu Natal, in 2000. By 2001 the DDT spraying began to pay dividends, and there was a 77 percent reduction in cases. The trend continued as the DDT spraying was repeated in 2002. There was a further decline of 74 percent in cases that year. Figure 2 shows the effects of spraying and not spraying with DDT.

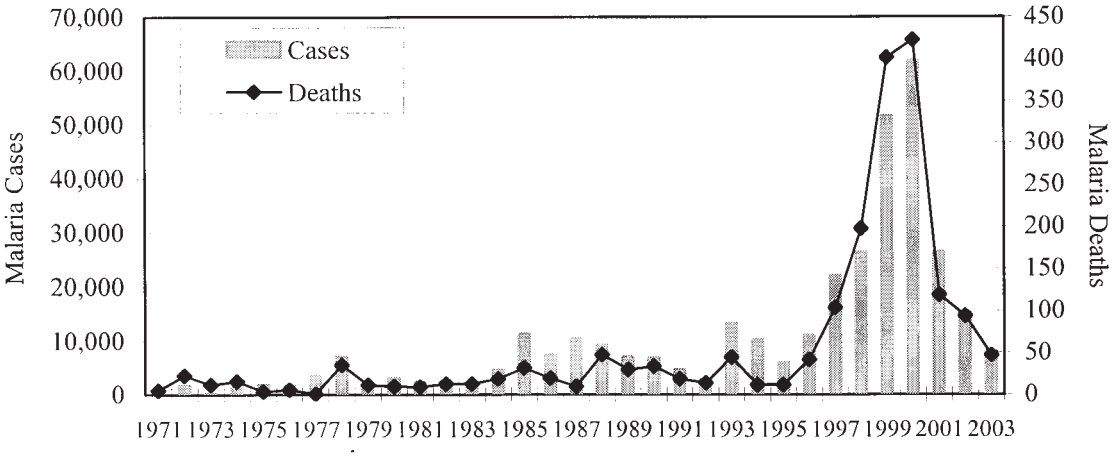
The Department of Health was conscious of the environmental and human health concerns that many environmental groups had raised with regard to DDT and therefore engaged the Endangered Wildlife Trust, a leading South African environmentalist group, to train the sprayers so that they used as little DDT as possible and never inappropriately. The EWT was, and is, fully supportive of the decision to use DDT in malaria control as it recognizes that a sick and poor population is far worse for the environment than any possible trace amounts of DDT.

Making sure that DDT is used carefully is not solely an environmental issue. As it is banned for all other uses, DDT is the one insecticide over which public health officers have complete control. It therefore makes sense for them to ensure that it is used carefully and sprayed properly so as to reduce the chance that insecticide resistance will develop.

Even though many groups, including WHO and UNEP are calling for the reduction and eventual phaseout of DDT from malaria control, the chemical remains an important part of any program. Efforts to reduce its use foundered in the late 1990s, and it was made abundantly clear that malaria control efforts require all available tools. South Africa's experience shows that it is folly to rule out any alternative when dealing with a disease that is so difficult to control.

South Africa's experience shows that it is folly to rule out any alternative when dealing with a disease that is so difficult to control.

Figure 2
Annual Number of Notified Malaria Cases and Deaths due to Malaria in South Africa (1971–2002)



Source: South African Department of Health, *National Malaria Update* (Pretoria: SA Department of Health, 2003).

Campaigners against DDT frequently rely on DDT studies undertaken by scientists when DDT was used as an agricultural insecticide. The widespread and indiscriminate agricultural use of DDT has unfortunately tainted the public health establishment's view of DDT. In public health, DDT is used in tiny amounts in carefully controlled and selective sprayings, whereas in agriculture DDT was sprayed over very wide areas with little control.

Scientific studies conducted during the 1990s show that the skin poorly absorbs DDT in powder form, and that accounts for the safe handling record of DDT.[38] However, studies have recorded that people living in households treated with DDT have higher levels of DDT in their bodies.[39] Recording heightened levels of DDT in humans is one thing; proving that that leads to ill health is another. For instance, in all the years of DDT use and with numerous scientific studies of its effects, not one case-controlled study of DDT's human carcinogenicity has been affirmatively replicated. Despite that, there are still widespread claims that DDT is a human carcinogen.[40]

The potential risks associated with DDT have to be weighed against the very real threat of dying from malaria. When used in malaria control, DDT is sprayed carefully and in very small quantities. Because of this careful use, a study of its use led by Professor Henk Bouwman of Potchefstroom University concluded that there were no significant variations in the levels of DDT in the environment before and after spraying.[41]

Alternatives to DDT include carbamate (bendiocarb), pyrethroid (cyfluthrin, deltamethrin, lambdacyhalothrin), and organophosphate (fenitrothion). The most noticeable benefits of DDT are its low cost, low toxicity, effectiveness, and long-term activity. DDT is applicable to most surfaces, except painted surfaces, on which malaria control officials may use pyrethroids.

Erratic use of pesticides, as is often the case in developing countries where political and economic inefficiency exist, accelerates the immunity of the vector to the chosen pesticide. In many cases, to effectively combat the probability that the mosquito may develop immunity to the pesticide, as is evident in India where in some regions the vector has become resistant to DDT, malaria control officers can use certain combinations of pesticides.

DDT has not only saved lives and prevented debilitating illness; it has laid a more stable foundation for development and wealth creation in the malarial areas of South Africa. Malaria imposes very significant economic costs on the country, and by controlling the disease the Department of Health can assist people to complete their schooling and engage in productive work.

New Drug Therapy

Although the South African Department of Health recognizes that the single biggest factor in the control of malaria was the reintroduction of DDT, the introduction of new and effective drug therapies also played a significant role.[42] South Africa used a combination of chloroquine and pyrimethamine as the first-line treatment for malaria cases until the late 1980s.[43] Sulfadoxine-pyrimethamine, SP, which is also known by its brand name Fansidar®, then replaced chloroquine.[44] When resistance to Fansidar® exceeded 60 percent, the Department of Health decided to also introduce an artemisinin-based combination therapy (ACT), Coartem®.[45]

The rationale for combining the two drugs is that the combination reduces the probability that drug resistance will develop. A malaria sufferer can take artemisinin with another drug as separate pills, but the advantage of the single dose Coartem® is that it ensures that the patient takes two different classes of drug in the correct doses at the same time, which improves the likelihood of compliance with the therapy. Although the patented ACT is more expensive than the alternatives, it is important to remember that Coartem® is very effective. In addition, South Africa is

A well-managed indoor residual spraying program remains the best way of reducing the cost of the drug therapies.

introducing Coartem® only in areas where drug resistance to SP is common.

Of course, a well-managed indoor residual spraying program remains the best way of reducing the cost of the drug therapies. Certainly South Africa's use of DDT in its indoor residual program greatly reduced the budget required to fund the use of Coartem® because there were far fewer patients presenting at clinics with malaria to begin with. Thus, so far, the introduction of ACTs to South Africa has been successful and has contributed to the decline in malaria cases since 2000.

Is the WHO Failing the Rest of Africa?

The introduction of artemisinin-based therapies in the rest of Africa has been less successful. A recent survey of malaria drug allocation found that the Global Fund for AIDS, Tuberculosis and Malaria, with the WHO's advice, has been purchasing the old anti-malarial drug chloroquine. Chloroquine costs US$0.1 per dose but is largely ineffective in Africa because of widespread resistance. The drug was used very effectively for more than 50 years but has been retired for more than a decade, because resistance to it rose to over 80 percent in some locations. Unfortunately, artemisinin drugs have not been used. Though they cost 10 times more than chloroquine, artemisinin drugs are also much more effective.[46]

It is clearly better to treat fewer people well than more people badly, which is why the WHO came under criticism. One of the prominent critics was Professor Nicholas White, director of the Welcome Trust's South-East Asia Overseas Unit and one of the world's leading researchers on malaria drug resistance. According to White, "It is terrible to waste lives and money deploying a useless drug."[47]

The WHO and the Global Fund tried to avoid the blame by pointing fingers at each other and ultimately the health departments of the poor countries they were supposed to be helping. Dr. Vinand Nantulya, senior adviser to the head of Global Fund, said: "When the fund buys chloroquine it is because a country itself has asked for it. We would like artemisinin based combination therapies to be made available to all countries. . . . That is the best treatment. But we don't tell countries what to use. We leave it to WHO to guide the process in terms of technical support. We're a financing mechanism."[48]

Dr. Allan Schapira, WHO's Roll Back Malaria coordinator, claimed it would be better if countries asked the Global Fund to back artemisinin-based treatments. He went on to say that the combination therapies using chloroquine they were asking for were better than chloroquine alone.

According to the WHO and the Global Fund, therefore, the poor countries are at fault, because they were asking for the wrong drugs. But, according to Doctors Without Borders, WHO originally promoted artemisinin-based drugs in 2001 but backpedaled later. Thus, there is widespread confusion about which drugs WHO is recommending in Africa.[49]

Ultimately all aid and health agencies failed to do their job. According to Professor Robert Snow of the Kenyan Medical Research Institute, the Global Fund is doing a poor job at peer reviewing proposals from developing countries like Uganda, which asked for a combination therapy with a failure rate of over 30 percent, and the WHO is not providing the technical leadership that countries deserve.[50]

Summary and Recommendations

Despite the fact that malaria is easily preventable and cheaply treatable, the disease still imposes enormous economic and social costs on Africa. One of the most effective ways of controlling the disease is to spray residual insecticides, such as DDT, on the inside of houses to kill the adult *Anopheles* mosquito that spreads the disease. However, not only is the use of DDT shunned, but

Ultimately all aid and health agencies failed to do their job.

Removing political interference and biased environmentalist agendas from public health programs is one of the most essential steps for building a healthier Africa in the future.

many donor agencies and international bodies, such as the WHO, are actively trying to restrict its use.

South Africa has one of the most successful and well-funded malaria control programs, and it has ensured that the current malarial areas are around one-fifth the size they were before World War II. South Africa tried to reduce its reliance on DDT for a number of reasons. However, after one of the country's most serious epidemics, it became clear that South Africa still needs DDT to combat malaria and that the removal of DDT without the existence of effective alternatives is detrimental.

New and effective drugs are an essential part of any malaria control program, and South Africa's decision to introduce ACT in 2000 has greatly reduced both mortality and morbidity. Research efforts, to a large extent led by private research-based pharmaceutical companies, are producing some promising and moderately priced drugs, which can be distributed to even the poorest African nations. The logistic support and advice that research-based drug companies, such as Novartis, offer to health services in Africa are often invaluable.

Estimating the economic costs of any disease will always involve a certain amount of guesswork and a number of assumptions. However, we have attempted to estimate as accurately as possible the costs that malaria imposes on the South African economy. The direct costs of control and treatment and the indirect costs of lost productivity are substantial in South Africa, especially when we consider that the disease is relatively minor there compared with the rest of the developing world.

South Africa is in the fortunate position of not having to rely on donor funding for its malaria control program. It is able to use whatever technology or mix of anti-malaria measures it chooses. South Africa was, therefore, able to reintroduce DDT and change the treatment regime without outside interference. Most other African countries are not as lucky, given that they must rely on donor funding for their programs. That reliance forces those countries to comply with the donors' wishes, which invariably exclude indoor residual spraying and would never sanction the use of DDT.

Yet DDT in South Africa has succeeded. Therefore, it is of great importance that donors recognize the evident humanitarian and economic benefits of DDT and the benefits inherent in indoor residual spraying. Removing political interference and biased environmentalist agendas from public health programs, including refusing to ratify the Stockholm Convention and protecting intellectual property rights, is one of the most essential steps for building a healthier Africa in the future.

Appendix 1: Mosquitoes, Man, and Parasites—The Life Cycle of the Malaria Parasite

Four species of the malaria parasite infect man:

- *Plasmodium vivax*: This parasite is the common cause of tertian malaria wherein the fever occurs every 48 hours and does not usually cause serious complications.
- *P. falciparum*: This parasite causes the most dangerous form of tertian malaria. As with the tertian malaria caused by *P. vivax*, the fever occurs every 48 hours, but the patient may develop cerebral malaria. If not properly treated, cerebral malaria may be fatal.
- *P. malariae*: This strain of malaria is less common and causes quatern malaria, wherein the fever occurs every 72 hours.
- *P. ovale*: This is a very rare strain of malaria. However, it does occur in the western parts of the African continent.

The complex story of a malaria infection begins with the female *Anopheles* mosquito[51]

as she takes a blood meal from a human. While feeding, the mosquito injects a small stream of parasites in the form of sporozoites (threadlike creatures that dwell in the mosquito's salivary glands) into the blood stream. These sporozoites make their way to the liver where they each enter a liver cell and become spores, or merozoites. For a period of approximately two weeks, they multiply greatly, destroying their host cell.

Until this stage, the human host of these parasites will not have experienced any malarial symptoms. That all changes when the spores burst out of their now destroyed liver cells and enter the blood stream. At this point, the unfortunate human will experience a clinical attack of malaria with high fevers and sweating. Each merozoite enters a red blood cell and devours the hemoglobin, and the parasite grows and grows until it fills more than half of the blood cell. This is known as the trophozoite phase. The next stage of the life cycle is the asexual multiplication of the parasites within the blood cell. A parasite's nucleus breaks into individual parts within the cytoplasmic matrix, and each part forms into a spore (or merozoite). These newly formed merozoites then burst out of the blood cell, ready to infect another blood cell and repeat the multiplication process.

Each of these stages occurs at the same time for all of the parasites within the body. Each new stage brings with it a new bout of fever, hence the 48-hour intervals of *P. falciparum* and *P. vivax* and the 72-hour intervals of *P. malariae*.

After several asexual reproductions, some of the merozoites become either male or female gametocytes, and, as the other merozoites do, they invade red blood cells. These sexual spores, however, do not multiply like their asexual relations; rather they increase in size, almost filling the blood cell, and circulate within the host's body, waiting to be ingested by the next female *Anopheles* mosquito that feeds on the unfortunate person.

The sexual cycle of the *Plasmodium* parasite then takes place in the gut of the mosquito. The male gametocyte transforms itself into many peculiar filaments that lash about as they make their way to the female gamete in order to complete fertilization. The fertilized egg then rests on the wall of the mosquito's stomach for two to three weeks,[52] after which the sporozoites burst out and travel to the salivary glands, ready to infect another human host.

Appendix 2: Countries That Have Requested Exemption for the Use or Production or Both of DDT

Country	Exemption
Algeria	Use of DDT for vector control
Bangladesh	Use of DDT for vector control
Brazil	Use of DDT in the production of dicofol
Cameroon	Use of DDT for disease vector control
China	Production of DDT as an intermediate
	Production and use of DDT for disease vector control
Comoros	Use of DDT for disease vector control
Cost Rica	Use of DDT for disease vector control
Côte d'Ivoire	Use of DDT for disease vector control
Ecuador	Use of DDT for disease vector control
Eritrea	Use of DDT for disease vector control
Ethiopia	Use of DDT for vector control

Country	Exemption
India	Production of DDT for use in vector control
	Use of DDT for vector control
Iran	Use of DDT for public health purposes
Kenya	Use of DDT in public health for vector control
Madagascar	Use of DDT for vector control
Malawi	Use of DDT for malaria control
Mauritius	Use of DDT for disease vector control
Morocco	Use of DDT for vector control
Papua New Guinea	Use of DDT for disease vector control
Republic of Korea	Use of DDT as a *de minimis* contaminant in dicofol
Russian Federation	Production of DDT for disease vector control
Saudi Arabia	Use of DDT for vector control
South Africa	Use of DDT for disease vector control
Sudan	Use of DDT for vector control in public health
Swaziland	Use of DDT in public health sector for malaria control
Togo	Use of DDT for vector control in line with WHO guidelines
Uganda	Use of DDT for disease vector control/public health purposes
Tanzania	Use of DDT for public health protection
Venezuela	Use of DDT for public health purposes
Yemen	Use of DDT for public health purposes
Zambia	Use of DDT for disease control
Zimbabwe	Use of DDT for disease vector control

Source: United Nations Environment Programme, "UNEP/POPS/CONF/INF/1/Rev 3," June 14, 2001.

Appendix 3: Insecticide Choices for Indoor Residual Spraying

Several factors forced experts to evaluate the role of DDT in malaria control. The white residue left by DDT, for example, caused a certain amount of resistance and resentment among householders in malarial areas. In some cases, after the spray teams visited, residents replastered their houses to cover the white marks. The increasing number of malaria cases in the replastered houses soon overcame the resentment. Once the residents recognized the value of DDT, they considered good health more important then aesthetics.

Although DDT remains effective in killing mosquitoes, bedbugs have developed resistance to it in some locations. The chemical does not kill those pests, but it does excite them, making them more active. That clearly became a nuisance to households and again caused a certain amount of resistance to the use of DDT. Using another insecticide along with DDT in order to kill bedbugs and other household pests has brought that problem under control.

Last, DDT is not effective on plastered and painted walls and can be used only on clay or cement walls or on wood and thatch as shown in Table A3.1. As the rural areas of South Africa become steadily wealthier, more families are choosing to build Western-style homes that are both plastered and painted. Therefore, there are fewer traditional African huts that are made of mud and thus are suitable for DDT spraying. That steady decline in DDT-appropriate structures contributed to the consideration of alternative insecticides.

The government introduced alternative insecticides, such as the synthetic pyrethroids Deltamethrin and Cyfluthrin, in place of

Table A3.1
Availability and Applicability of Pesticides in Use for Malaria Control

Chemical Group	Insecticide	Effective Duration	Surface				
			Clay	Cement	Wood	Thatch	Paint
Organochlorine	DDT	9–12 months	X	X	X	X	
Carbamate	Bendiocarb	5 months			X	X	X
Pyrethroid	Cyfluthrin	5 months	X	X	X	X	X
	Deltamethrin	9–12 months	X	X	X	X	X
	Lambdacyhalothrin	5 months	X	X	X	X	X
Organophosphate	Fenitrothion	1–1.5 months	X		X	X	

Source: South African Department of Health, *Guidelines for Vector Surveillance and Vector Control*, 1996.

DDT. Initially those pesticides proved to be effective and had some advantages over DDT. For example, those pesticides do not increase bedbug activity and do not stain walls, making them more socially acceptable. The environmental pressure groups also considered them more acceptable.[53]

Notes

1. United Nations Development Programme, *Human Development Indicators 2002* (New York: United Nations, 2002), http://hdr.undp.org/reports/global/2002/en/indicator/indicator.cfm?File=index_indicators.html.

2. Indur Goklany, "Economic Growth and Human Well-Being," in *Sustainable Development*, ed. Julian Morris (London: Profile Books, 2002), p. 25.

3. These are also known as wetlands. In the 19th century, however, they were considered a health hazard and almost no one opposed drying them up in the hope of saving human lives.

4. See Robert Desowitz, *The Malaria Capers* (New York: Norton, 1991), for more details.

5. South African Department of Health, *Malaria Treatment Guidelines* (Pretoria: SA Department of Health, August 2002).

6. Acidosis is a condition characterized by excessive acid in the bodily fluids. This can be caused by breathing difficulties when there are excessive amounts of CO_2 (which is acidic) in the body. ARDS, or acute respiratory distress syndrome, occurs when the lungs become inflamed and fluid accumulates in the air sacks or alveoli. Pulmonary edema refers to swelling of the lungs and the accumulation of fluid in the lungs.

7. South African Department of Health, *Malaria Treatment Guidelines*; and; John L Gallup and Jeffrey D Sachs, "The Economic Burden of Malaria" Harvard Center for International Development Working Paper no. 52, July 2000.

8. South African Department of Health, *Overview of Malaria Control in South Africa* (Pretoria: SA Department of Health, 1997).

9. For instance, many game farms in the Waterberg region of the Limpopo province and in the Eastern Cape province advertise the fact that they are nonmalarial.

10. Full discussion of direct and indirect economic costs of malaria is available on request from the authors.

11. National Malaria Control Centre, *Malaria in Zambia: Situation Analysis* (Lusaka, Zambia: Central Board of Health, 2000), p. 23.

12. The current malaria policy objective is to keep malaria cases at 100 per 100,000 people (0.1 percent) and to maintain a malaria case fatality rate below 0.5 percent.

13. South African Department of Health, *Overview of Malaria Control*.

14. Ibid.

15. The firm of William Sattler at Schweinfurt, Germany, first discovered Paris Green, copper aceto-arsenite, in 1814. They used it as a green pigment in paints (http://www.webexhibits.org). In the 1920s, two Americans, Barber and Hayne, discovered its larvicidal properties. Gordon Harrison, *Mosquitoes, Malaria and Man: A History of*

the Hostilities since 1880 (New York: Dutton, 1978), p. 186.

16. South African Department of Health, *Overview of Malaria Control*. Pyrethrum had been used widely as a well-established folklore insecticide in the Caucasus region and northwest Persia. John E. Casida and Gary B. Quistad, *Pyrethrum Flowers: Production, Chemistry, Toxicology, and Uses* (Oxford: Oxford University Press, 1995), http://www.sigmaxi.org/amsci/bookshelf/Leads96/Casida96-03.html.

17. The eucalyptus tree, an exotic tree imported to South Africa from Australia, is now very unpopular because of the amount of water that it consumes and the consequent effects that it has on ecosystems. Its beneficial uses in malaria control have long been forgotten, and frequently its economic benefits for the forestry sector are overlooked.

18. Richard Tren and Roger Bate, *When Politics Kills: Malaria and the DDT Story* (London: Institute for Economic Affairs, 2001), p. 23.

19. As we describe below, however, certain *Anopheles* species have developed resistance to this class of insecticide, greatly reducing the efficacy of these insecticides.

20. It is worth noting that DDT is only produced by government plants in India and China. It is extremely likely that were a competitive market for DDT to exist (as it does for pyrethroids) the price of DDT would probably be much lower than it is at present.

21. DDT derivatives include DDE (1.1-dichloro-2.2-bis-(4-chlorophenyl)-ethylene) and DDD (1.1-dichloro-2.2-bis-(4-chlorophenyl)-ethane).

22. H. E. Smit, H. Bouwman, and D. le Sueur, "DDT and Community Health," *Journal of Comprehensive Health* 3, no. 1 (1992): 175–78.

23. World Wildlife Fund, "Three Decades after Silent Spring, DDT Still Menacing the Environment," news release, 1998, http://www.panda.org/news/press/news_219.htm.

24. Ibid.

25. A. G. Smith, "How Toxic Is DDT?" *Lancet* 356, no. 9226 (July 22, 2000): 267–68.

26. Kawal Dhari, Hindustan Insecticides Ltd., personal communication, April 2002.

27. J. Gordon Edwards, "Science, Pesticides, and Environmentalist Policies," *Executive Intelligence Review* (December 10, 1999): 22.

28. Ibid.

29. Environmental Protection Agency, news release, http://www.epa.gov/history/topics/epa/20a.htm.

30. Quoted in Edwards, p. 22.

31. Quoted in ibid.

32. *Barron's*, November 10, 1975, quoted in J. Gordon Edwards and S. Milloy, "100 Things You Should Know about DDT," www.junkscience.com/ddtfaq.htm.

33. United Nations Environment Programme, "UNEP Decision 18/32 of the UNEP Governing Council: Persistent Organic Pollutants," May 25, 1995, http://www.pops.int/documents/background/gcdecision/18_32/gc1832en.html.

34. M. J. Kampala, "DDT Back in Use to Fight Malaria," *New Vision*, November 25, 2002, http://allafrica.com/stories/200211250410.html.

35. For instance, environmentalist groups such as the WWF, Pesticide Action Network, and the International POPs Elimination Network have, for many years, been pressing for the removal of DDT from health programs as part of their campaigns against persistent organic pollutants. Their campaigns were successful in influencing the World Health Assembly's resolution 50.13 of 1997, which called for the reduction and eventual elimination of the use of DDT in malaria control. See D. Moonasar and F. Hansford, "Malaria Control in South Africa," Inputs for Epidemiological Comments, SA Department of Health, 2001.

36. K. Hargreaves et al., "Anopheles funestus Resistance to Pyrethroid Insecticides in South Africa," *Medical and Veterinary Entomology* 14, no. 2 (June 2002): 181–89.

37. South African Department of Health, *Malaria Treatment Guidelines*.

38. Smit, Bouwman, and le Sueur, pp. 175–78.

39. H. Bouwman et al., "Serum Levels of DDT and Liver Function of Malaria Control Personnel," *South African Medical Journal* 79 (1990): 326–28.

40. Amir Attaran et al., "Balancing Risks on the Backs of the Poor," *Nature Medicine* 6, no. 7 (July 2000): 729–31.

41. H. Bouwman, A. Coetzee, and C. Schutte, "Environmental and Health Implications of DDT-Contaminated Fish from the Pongola Flood Plain," *Journal of African Zoology* 104 (1990): 275–86.

42. South African Department of Health, *National Malaria Update* (Pretoria: SA Department of Health, 2002).

43. After World War II, chloroquine was widely available throughout the malarial world, and it was not long before drug resistance began to emerge. The first instances of chloroquine resistance occurred in South America in the 1960s, but the rest of the world soon followed suit. It is perhaps a testament to the South African health services that chloroquine resistance didn't emerge in the country until the 1980s. Dr Frank Hansford, Malaria Advisory Group, personal communication, March 20, 2003.

44. South African Department of Health, *Malaria Treatment Guidelines*.

45. This drug is patented by Novartis International AG.

46. Gavin Yamey, "Malaria Researchers Say Global Fund Is Buying 'Useless Drug,'" *BMJ*, November 22, 2003, http://bmj.bmjjournals.com/cgi/content/full/327/7425/1188.

47. Quoted in ibid

48. Quoted in ibid.

49. Ibid.

50. Ibid.

51. The benign male *Anopheles* feeds only on nectar.

52. The length of time taken for the fertilized egg, or oocyst, to develop into the sporozoites depends on the type of parasites, the type of mosquito, and the climatic temperature.

53. Tren and Bate, p. 42.

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