

A STUDY OF THE SUITABILITY FOR THE CONTINUED USE OF DDT FOR  
MALARIA CONTROL

by  
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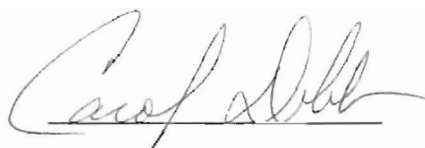
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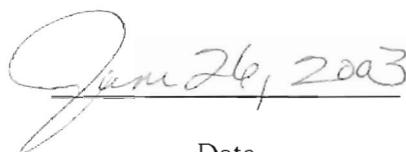
The Evergreen State College

by

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Date

## ABSTRACT

Malaria has plagued humankind throughout history. Human malaria is caused by four species of parasite from the genus *Plasmodium*. The parasite is transmitted between humans by mosquitoes from the genus *Anophelines*. It currently infects between 300 and 500 million people each year and kills approximately 1.5 million. The disease causes extensive suffering and economic losses, mostly in third-world countries. The parasite is treated using Quinine, made from bark of the Cinchona tree, or any of several antimalarial drugs. The parasite has developed resistance to several of these treatments around the globe. Dichlorodiphenyltrichloroethane, or DDT, was developed and used as an insecticide against *Anophelines* mosquitoes. It was also used as a broad-spectrum insecticide in agriculture as well. Extensive use of DDT greatly reduced incidence of malaria worldwide, but its use has diminished due to environmental concerns. DDT has been shown to cause thinning of eggshells in birds and has been linked to endocrine disruption and impaired development in birds and other animals. DDT is persistent in the environment and has bioaccumulated throughout the world's food web. While most humans have DDT residues in their bodies, it has not been shown to cause any human disease. While DDT use has been reduced, malaria is reemerging in many areas of the world. An attempt to ban its use worldwide was modified to allow its continued use for malaria control. It remains an effective antimalarial tool in many areas. Malaria transmission is likely to increase as the mean global temperature rises. Although many would like DDT to be completely banned, it should continue to be available as a tool in malaria control.

## TABLE OF CONTENTS

I. Introduction.....	1
Summary of Disease to the Present.....	1
Malaria in the United States.....	2
Human Costs of Malaria.....	3
Life Cycle.....	4
Historical Malaria Control Efforts.....	5
Reemergence of Malaria.....	7
Operation Roll-Back Malaria (RBM).....	8
II. Adverse Effects of DDT on Wildlife.....	9
Eggshell Thinning in Birds.....	9
Lake Apopka Studies.....	10
III. Ubiquitous Nature of DDT.....	10
Deep Oceans.....	12
IV. Human Levels.....	13
South Africa Data.....	14
India Data.....	16
Mexico Data.....	17
Brazil Data.....	18
V. Discussion.....	18
Human Health Effects.....	19
Effects of Malaria Control after Cessation of Spraying.....	21
Cost Comparisons with Alternative Insecticides.....	24
Resistance to Pesticides and Drugs.....	25
Vector Resistance.....	25
Parasite Resistance.....	27
Implications from Global Warming.....	28
VI. Summary and Recommendations.....	30
References.....	33
Appendix A: Current Malaria Transmission Areas	
Appendix B: Current Areas of Parasite Resistance	
Appendix C: Projected Increase in Transmission Areas Assuming a Two-Degree Fahrenheit Temperature Increase	

## LIST OF FIGURES

Figure 1. Parasite Life Cycle.....	5
Figure 2. Parasite Incidence and House Spray Data from Pan American Health Organization Data.....	21
Figure 3. Parasite Index for School Children from Four Villages in Madagascar Highlands.....	24
Figure 4. Relationship Between Fever Deaths and Precipitation in the Punjab Region, 1868 to 1908.....	29
Appendix A. Current Malaria Transmission Areas	
Appendix B. Current Areas of Parasite Resistance	
Appendix C. Projected Increase in Transmission Areas With a Two-Degree Fahrenheit Temperature Increase	

## LIST OF TABLES

Table 1. Loss of Economic Growth in African Countries Due to Malaria.....	3
Table 2. Organochlorine Levels in North Atlantic Cod.....	12
Table 3. Organochlorine Levels in Atlantic Fish.....	13
Table 4. Organochlorine Levels in Monterey Bay Fish.....	13
Table 5. Blood Serum Levels.....	14
Table 6. Liver Function Parameters.....	15
Table 7. Changes in Alkaline Phosphates by Age for Exposed and Unexposed DDT Workers.....	15
Table 8. Blood Serum Levels from Two Areas in Mexico.....	17
Table 9. Summary of DDT levels for Various Endemic Areas.....	19
Table 10. Parasite Survey Results for Schoolchildren in Madagascar Highlands before and after OPID Program.....	23
Table 11. Abundance of <i>Anophelines funestus</i> in Villages of the Madagascar Highlands before and after OPID Program.....	23
Table 12. 1990 Comparison of Insecticides, from World Health Organization Data.....	25
Table 13. Mortality of <i>Anopheles fluviatilis</i> to IICH and DDT.....	26

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## **I. INTRODUCTION**

In the 1950's, malaria was considered to be endemic in over 140 countries. Although this number has dropped to a little over 100 countries, more than 2.4 billion people are still at risk (World Health Organization, 2000). The primary reduction has occurred as a result of in-house spraying using dichlorodiphenyltrichloroethane, or DDT, to repel the parasite's primary vector, various species of mosquitoes belonging to the genus *Anopheles* (Tren and Bate, 2001). DDT was originally synthesized in 1874 by Otto Zeidler, but its insecticidal properties were not discovered until 1939 when Paul Mueller tested it as part of a screening study (Committee on the Future Role of Pesticides in US Agriculture, National Research Council, NRC, 2000, p24). It came into widespread use as a pesticide in the 1940's. Due to environmental concerns, its use in the U.S. was abandoned in the 1970's, but it is still used in other countries, primarily for control of malaria. Because DDT is fairly inexpensive and the amount of exposure to humans is thought to be low and the reduced malaria benefits are high, international debate about DDT's use continues (Longenecker et al, 2001).

While many groups such as WWF, Greenpeace, and Physicians for Social Responsibility have called for the outright ban of DDT worldwide, many health professionals feel that continued use of DDT for malaria control is justified (Tren and Bate, 2001). The purpose of this study is to determine if DDT should still be used for malaria control, given its historical and present problems.

### **Summary of Disease to the Present**

Malaria is a parasitic disease that has been with us throughout history. The introduction of agriculture around 7000 B.C. led to larger populations of settled people with more favorable conditions for malaria transmission. Human malaria is caused by four species of parasite of the genus *Plasmodium*. *P. vivax* is responsible for the majority of infections, while *P. falciparum* is the most deadly. *P. malariae* causes the highest fevers (106 to 107 degrees Fahrenheit), but is rarely fatal. *P. ovale* produces a tertian infection that occurs at night at regular intervals. It is possible to be simultaneously infected by more than one species (Wargo, 1998,p 19). The

parasite is transmitted by about 60 different species of mosquito of the genus *Anophelines* (Reiter, 2001). Clinical malaria generally involves bouts of fever followed by periods of remission. Diagnosis is generally done by visual inspection of erythrocytes, or red blood cells (Institute of Medicine, IOM, 1991 p24). Depending on the malarial species involved, the fevers tend to occur on either every third or fourth day, which gave rise to the term tertian and quartan fevers (Reiter, 2001). Although the majority of infections are caused by *P. vivax*, *P. falciparum* infections are on the rise (IOM, 1991). After relative control, malaria is reemerging as a health issue in parts of the world. Between 300 and 500 million people are infected with the parasite each year and over 1.5 million people die from the disease (Kondrachine and Trigg, 1995), many of them being children and pregnant women. Causes of death include cerebral edema, renal failure, pulmonary failure and anemia (Butler, 2000). Appendix A contains a map showing the current infectious areas for the world. The malaria problem is exacerbated by the parasite's ability to become resistant to traditional treatment as well as the vector's ability to become resistant to various pesticides (Mutabingwa et al, 2001).

In areas of intense, but stable, malaria transmission, most of the adult population has some protection from the disease through acquired immunity, but pregnant women and young children are particularly at risk. In areas where malaria transmission is less stable, all age groups may be vulnerable to the disease and epidemics may occur. In Africa, 75% of the population lives in area of stable malaria transmission while 18% of the population lives in areas of unstable malaria transmission (WHO, 1995).

### **Malaria in the United States**

Two species of malaria, *P. vivax* and *P. Malariae*, are believed to have been introduced by the English settlers at Jamestown, Virginia. *P. falciparum* is believed to have been introduced through the importation of African slaves sometime after that in the early 1600's. The parasite moved westward throughout the North American continent as settlement occurred. As many as 500,000 cases of malaria were reported annually in the United States as recently as the early 1900's. (IOM, 1991, p 38).



In general, malaria incidence in the United States peaked around 1875. Although this was well before any vector-control programs came about, factors such as population shift from rural to urban areas, improved drainage projects, and better health and nutrition helped bring the disease under control. All 48 contiguous states contain species of *Anopheline* mosquitoes that are capable of malaria transmission (Zucker, 1996). The disease has been eradicated in the United States, and current cases of malaria in this country are primarily imported from foreign visitors or returning U.S. travelers and returning military personnel. The Centers for Disease Control (CDC) estimates that it receives between 1000 and 1500 cases per year (CDC, 2002).

### Human Costs of Malaria

Beyond the human suffering and mortality attributed to malaria, the disease inflicts heavy financial burdens on some of the world's poorest counties (Tren and Bate, 2001). School absenteeism attributed to malaria can be as high as 28% in some areas. The annual estimated direct and indirect cost of malaria is more than two billion dollars for Africa alone (World Health Organization, 2000). Table 1 lists the percentage of annual income lost between 1980 and 1995 for several African countries.

**Table 1. Loss of Economic Growth in African Countries Due to Malaria, 1980 to 1995 (Tren and Bate, 2001).**

Country	Percent loss	Country	Percent Loss	Country	Percent Loss
Benin	18%	Gabon	17%	Niger	17%
Botswana	5%	Gambia	18%	Nigeria	18%
Burkina Faso	18%	Ghana	18%	Rwanda	18%
Burundi	18%	Guinea Bissau	14%	Senegal	18%
Cameroon	18%	Kenya	18%	Sierra Leone	17%
Central African Rep.	18%	Madagascar	18%	South Africa	1%
Chad	17%	Malawi	18%	Togo	18%
Congo	18%	Mali	17%	Zambia	18%
Congo, Dem. Rep.	17%	Mauritania	15%	Zimbabwe	18%
Cote d'Ivoire	18%	Namibia	10%	Total	10%

Several studies have been conducted to measure the economic impacts of malaria. One study found that farm families with malaria cleared sixty percent less land than families that were malaria free. Despite all that has been done, malaria's effect on overall productivity has not been satisfactorily determined (Institute of Medicine, IOM, p 238).

## **Life Cycle**

The mosquito life cycle contains four stages: egg, larva, pupa, and adult. The adults emerge from the egg sometime between seven and twenty days. *Anopheles* females can survive up to one month in moderate temperatures and humidity, which allows sufficient time for the malaria parasite to develop. During a human blood meal, the mosquito either transfers the parasite to the human host, if it already carries the parasite, or picks the parasite up from an already infected person and can then transfer it to another person (Speilman and D'Antonio, 2001, p 168).

The parasite's life cycle is complex. It has a liver phase, a blood phase, and a mosquito phase. It can reproduce either sexually or asexually, depending on what phase of its life cycle it is in. It has three individual stages in the mosquito and two stages in the human host. It has been divided by scientists into about a dozen steps. Figure 1 shows the parasite's life cycle in its mosquito and human host (IOM, 1991).

After the parasite has been introduced by the mosquito, sporozites invade liver cells where they develop into schizonts, each of which contain between ten and thirty thousand merozoites, which are released to the bloodstream and invade red blood cells. Once inside these cells, each merozoite matures into schizonts each containing 8 to 32 merozoites, causing the cell to rupture, which then allows them to invade new red blood cells (IOM, 1991, p 25-28). It takes the parasite anywhere from 6 to 16 days to invade the red blood cells.

Once in the red blood cells, the parasite can easily be detected by visual examination of blood smears using a microscope. It is at this point when infected individuals develop the symptoms and pathologic characteristics of the disease. *P. vivax* and *P. ovale* can remain dormant in the liver tissue as hypnozoites, and can cause relapse of the disease many months or even years later. In general, parasites

continue to proliferate until either the host dies or they are checked by either an immune response or antimalarial drugs (Poser and Bruyn, 1999).

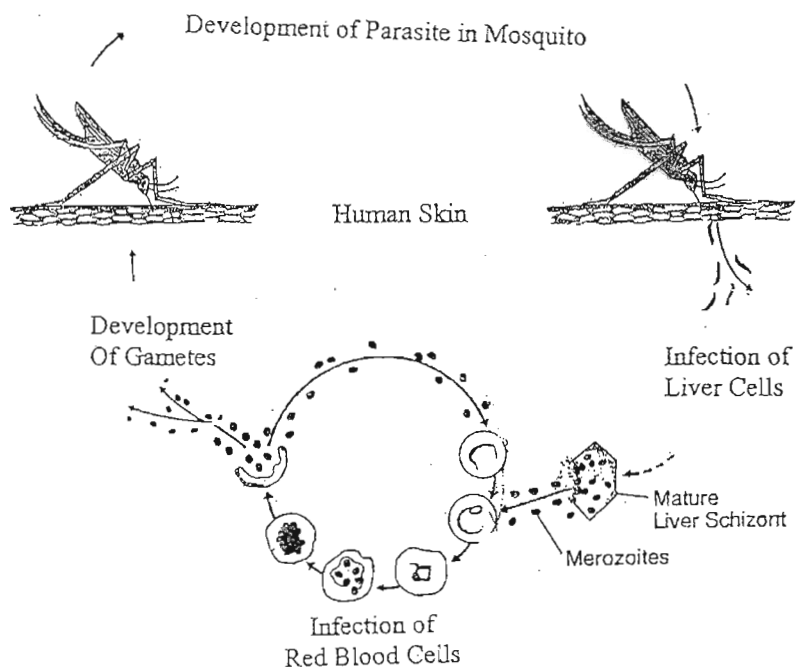


Figure 1. Parasite Life Cycle (Adapted from Sherman, 1998, p 9.)

### Historical Malaria Control Efforts

South American Indians used bark from the Cinchona tree to treat early malarial fevers. When the bark was brought back to Europe in the 1600's by returning missionaries, it became the treatment of choice there as well. In 1820, the alkaloid quinine was identified as the active ingredient (IOC, 1991, p39). Early attempts at malaria control primarily consisted of the use of quinine. Quinine has unpleasant side effects, which provided the impetus for continued research for better treatments (Speilman and D'Antonio, 2001, p 94).

Early mosquito control efforts, before the advent of DDT, consisted mainly of environmental modifications such as drainage and landfills or by application of insecticidal chemicals (Reiter, 2001). After development of organic pesticides in the 20<sup>th</sup> century, many countries turned to these faster and more economical control methods, but these successes were short lived. Insecticide resistance occurred in almost all cases (Carmichael, 1972).

In the developing countries, post WWII malaria control policies have traditionally been implemented and organized by the World Health Organization (Baird, 2000). DDT was used in early eradication efforts for control of *Anophelines* mosquitoes. It was heavily applied for agricultural purposes as well. It has become pretty well established throughout the world. DDT has been identified as a persistent organic pollutant (POP), a class of chemicals which have been linked to both cancer and endocrine disruption, and which can adversely affect growth and development in both animals and humans (Key et al, 1998). It has been cited in EPA documents as a probable human carcinogen (EPA, 2000), although this has never been proven scientifically (Roberts et al, 2000; Henderson, 2000). A recent agreement, signed by several countries, allows continued use of DDT for malarial control throughout the world (Maurice, 2001). DDT is credited with helping more than 1 billion people live free of malaria (Turusov et al, 2002).

During WWII, malaria was a major problem for the war effort on both sides. At some points, up to two-thirds of the men in many fighting units were either sick with the disease or recovering from it. The US military conducted extensive research in an effort to bring malaria under control, and they were largely effective. A high level of international cooperation devoted to eliminating endemic malaria existed in the years following WWII. The United Nations Rehabilitation and Relief Administration was formed in 1943, with the U.S. as the principal financial backer, was active in many malaria control projects. Under the Interim World Health Organization, the first Expert Committee on Malaria met in 1947, and in 1948 the World Health Organization (WHO) was officially formed (IOC, 1991, pp 40-41).

A global malaria eradication campaign was adopted in May 1955, at the Eighth World Health Assembly, in Mexico. Oddly, this global resolution was never

reviewed by an expert committee prior to the debate and vote by the World Health Assembly. The campaign consisted of widespread use of DDT for indoor and outdoor spraying for mosquito control and antimalarial drugs to kill the parasite in humans. Support for the campaign was not unanimous. Many public health officials from the tropics argued that eradication should not be attempted in stable areas, where the majority of the population had acquired immunity. They argued that if control measures broke down, malaria would return and large numbers of people who would normally have immunity would now be vulnerable to the disease (Packard, 1998).

Such an approach had been used to eradicate malaria from some countries by the end of WWII (Trigg and Kondrachine, 1998). The program was successful in many areas. India, which prior to 1945 reported 75 million new cases and 800,000 deaths each year, had by 1964 had an annual parasite index (API), which is the number of cases per 1000 persons, of only 0.00098. This represents approximately one case of malaria per 1 million people (Baird, 2000). By 1961, twenty percent of people once plagued by the disease now lived in areas free of malaria (Speilman and D'Antonio, 2001). Malaria was eradicated in the United States, Japan, Korea, Taiwan, Spain, Italy, the Balkans, Greece, and northern Africa, all areas which had been seasonally malarious though recent history (Baird, 2000).

### **Reemergence of Malaria**

In 1969, after realizing that total malaria eradication was probably not possible, WHO shifted its emphasis from malaria eradication to malaria control. As part of this policy shift, the use of DDT was deemphasized and its use for in-house spraying for mosquito control has been reduced as a result (Butler, 2000). At the same time that in-house spray rates have been reduced, malaria rates have increased in many parts of the world. In Brazil, malaria cases were reduced by 50% between 1960 and 1974 through the use of DDT and the drug chloroquine. Between 1974 and 1991 the number of cases rose almost tenfold (Gusmao, 1998). In Peru, malaria cases dropped from 95,000 in 1944 to 1500 in 1965. In 1997, Peru's hardest hit district alone reported over 120,000 cases (Butler, 2000). It has also reappeared in areas where it has previously been eradicated, including North and South Korea,

Armenia, Azerbaijan, and Tajikistan. The frequency of malaria cases imported into developed countries has increased, as well (Roberts et al, 2000). Resistance to antimalarial drugs has also been a major factor in worldwide malaria resurgence (Reiter, 2001).

DDT was widely used as a pesticide beginning in the 1940's. Although no longer used in the U.S., it is still used in other countries, primarily for control of malaria. Because DDT is fairly inexpensive and the amount of exposure to humans is thought to be low and the reduced malaria benefits are high, international debate about DDT's continued use continues (Longenecker et al, 2001). The chemical has clearly been shown to be persistent and to concentrate in the lipid tissues of organisms and has also been shown to be transported to upper latitudes via long-range atmospheric transport and oceanic currents (Hargrave et al, 2000). A shift away from spraying strategies and DDT has substantially contributed to the deterioration of vector control programs in the developing world (Baird, 2000). This shift has been due more to social pressures than to resistance in the insect vectors (Coetzee and Horne, 1999). The amount being used in this role is a small percentage of the amount used when DDT was in widespread use for agriculture.

### **Operation Roll-Back Malaria**

The World Health Organization recently launched their Roll Back Malaria (RBM) program with the aim of reducing the global malaria burden 50% by the year 2010. Core elements of this program include rapid diagnosis near the home; the use of insecticide-treated bednets and environmental measures for vector control; preventative malaria treatment for pregnant women; improved epidemic awareness and response; and research for new medicines, vaccines and insecticides (Teklehaimanot et al, 2001). The initial emphasis will be placed in the sub-Saharan African region (WHO, 2000).

Alternatives to DDT are actively being researched, but in many cases DDT represents the most effective strategy currently available. Through widespread use the chemical has become cosmopolitan in nature. Trace amounts of the chemical can

be found virtually anywhere on earth (EPA, 2000). It is found at the bottom of the ocean, it is found in most plant and animal tissues, and it is also found in humans.

## II. ADVERSE EFFECTS OF DDT ON WILDLIFE

DDT has been studied extensively since it came into use as a pesticide in the 1940's. These studies have focused on both wildlife and human exposure. A strong correlation has been made between DDT and abnormalities in wildlife. This was one of the key points made by Rachel Carson in *Silent Spring*. The results of the human studies are a lot less clear.

Numerous studies have been done on both wildlife and human exposure. Warnings of wildlife damage were made as early as 1946. Tests performed in 1945 and 1946 showed that birds and fish could suffer DDT poisoning by field applications, but that the long-term effects were still unknown (Nelson and Surber, 1947).

Reproductive and developmental abnormalities observed in North American gulls were supported by laboratory studies. Specifically, gulls injected with DDT at concentrations found in wild gulls induced abnormalities similar to those observed in the wild gulls which included skewed sex ratios, behavioral modifications, and gonadal abnormalities (NRC 1999, p5).

In rat studies, immature females injected with DDT had a significant increase in uterine wet weight, and newborn females injected with DDT showed an early development of puberty and loss of fertility. DDT has also been shown to impair learning in rats and locomotor ability in mice. The *o,p'*-DDT isomer has estrogenic properties, while the DDT metabolite *p,p'*-DDE, has been shown to have anti-androgenic properties (NRC, 1999, p 121). Bioassays to determine DDT's carcinogenicity in rats and mice found no correlation (NIH, 1978).

### **Eggshell Thinning in Birds**

It was observed in the 1960's and 1970's that many bird species populations were declining in North America when individuals were unable to successfully incubate eggs because the eggshells were abnormally thin. Many of these species

have made dramatic comebacks since DDT use was banned in the United States and background levels in nature decreased over time. It has since been well established that DDE played a significant role in the eggshell's thinning (Committee on Hormonally Active Agents in the Environment, NRC, 1999, p165).

Adult animals can generally tolerate higher levels of pollution than their offspring can. The eggshell thinning may have hidden the effects from other pollutants by killing the embryo. Since the reduction in DDT use, more chicks have been surviving and have been showing other abnormalities that have been linked to dioxin, furans, and certain PCBs (Colborn et al, 1997, p155).

### **Lake Apopka Studies**

In Lake Apopka, Florida, dicofol, a pesticide which was contaminated with up to 15% DDT, was accidentally spilled in 1980. Alligator eggs collected between 1984 and 1985 contained DDT concentrations ranging from 3.4-7.6 ppm for the eggs collected in 1984 and .89 to 29 ppm for the eggs collected in 1985. These levels are above those required to reduce hatchling success and cause deformities. Juvenile alligators hatched from eggs collected there have exhibited gonadal and genital abnormalities as well as abnormal levels of testosterone in males and estradiol in females. Alligator populations declined dramatically in the years following the spill (Committee on Hormonally Active Agents in the Environment, NRC, 1999, p155-158).

### **III. UBIQUITOUS NATURE OF DDT**

In order to understand the total ubiquity of DDT on the planet, some basic understanding of the physical, chemical, and biological processes involved is required. No single cycle is extremely complex, but the cycles overlap and are interconnected with each other. DDT is easily dispersed through runoff and atmospheric transport. In the aquatic environment, the half-life of DDT can range from a few days in high-energy environments, to more than 150 years (EPA, 2000). Once released to the environment, chemicals like DDT and polychlorinated biphenyls, or PCBs, are readily absorbed and accumulated in organisms throughout



the global food web. They remain stored in living tissue for long periods of time (Rodricks, 1992).

The overall cycle is well illustrated in *Our Stolen Future*, where a story is told about an imaginary molecule of another persistent organic pollutant (POP), polychlorinated biphenyl, or PCB-153. Its hypothetical journey and bioaccumulation is described as it makes its way from inception at the Anniston, Alabama, plant in 1947, through many years and several trophic levels, to end up in a polar bear in the northern Arctic (Colborn et al, 1997).

An excellent study illustrating these bioaccumulative effects was undertaken by George Woodwell, et al, who identified DDT in seawater at 50 parts per trillion and followed DDT levels through the trophic web. DDT was found in plankton at 40 parts per billion, in pickerel at 1 part per million, and in cormorants at 26 parts per million. The overall increase in concentration from seawater to the cormorants was by a factor of 520,000. Similar processes occur in terrestrial systems. Leaf residue containing DDT transfers it to the soil, which is then biomagnified in earthworms, which are then eaten by robins, etc. (Wargo, 1998, p140-141).

Once in the ocean, the compound can be transferred to fresh water and terrestrial food webs via migration of anadromous fish. In the Copper River area of Alaska, pollutant transport was compared between lakes that receive migrating anadromous fish and lakes that do not. DDT residues were shown to be transported by Sockeye Salmon (*Oncorhynchus nerka*) and biomagnified in Arctic Graylings (*Thymallus arcticus*). Graylings in the salmon-spawning lakes had significantly higher levels of both DDT and PCBs than did graylings in the salmon-free lakes. PCB levels were 1024 ppb in the Salmon-fed lakes and only 548 ppb in the Salmon-free lakes. DDT levels were 239 ppb in the Salmon-fed lakes and only 41 ppb in the salmon-free lakes (Ewald et al, 1998).

PCB levels have also been well studied in Arctic marine mammals, and numerous studies have identified them in body tissues of indigenous arctic peoples (Muir et al, 2000; O'Hara et al, 1999).

## Deep Oceans

Looser, et al., (2000) studied three ocean regions, representing different geographic regions. The North Atlantic receives most of its river pollutants from the eastern United States and from the Gulf of Mexico, which in turn receives pollutants transported north by the Gulf Stream. Atmospheric input generally occurs from the northern West Wind Belt, which collects most of the atmospheric emissions from the United States and Canada.

The South Atlantic differs in that it receives much lower inputs from the continents. It also receives wind input from the southern circumpolar West Wind Drift. The water from the Amazon River mainly flows northward to the Gulf of Mexico via the Gulf Stream currents.

The third region selected was the deep-sea canyon associated with the Monterey Bay Marine Sanctuary off the coast of California. This area receives localized inputs from the Salinas River and is intensely used for agriculture.

In all areas the levels of contaminants were significantly different between the surface-water and the deep-water fishes. While the levels between species and individual fish will vary somewhat, some general trends are suggested. Table 2 shows pollutant levels in Cod Liver oil taken from North Atlantic cod from the years 1984 and 1993. The Levels of DDT and other toxins have significantly dropped since 1984.

**Table 2. Organochlorine Levels (ppb) North Atlantic Cod 1984-1993 (Looser, 2000).**

Pollutant	Cod Liver Oil-1984	Cod Liver Oil #1-1993	Cod Liver Oil #2-1993
Total DDT	1200	30	33
Total Chlordanes	227	18.5	19
Dieldrin	145	5.8	7.5
Total HCH	75	1.7	n.d.

Table 3 shows levels of organochlorine residues for Atlantic fish, both surface-dwelling and deep-sea-dwelling between the years 1994 and 1998. There were no samples collected to represent the North Atlantic surface-dwelling fish, but they were assumed by the authors to be similar to the South Atlantic surface-dwelling fish. The OC levels are significantly higher in South Atlantic deep-sea fish than in

surface dwelling fish. This may indicate that the deep-sea fish are being exposed to higher concentrations of OC's than are their surface counterparts.

**Table 3. Organochlorine Residues (ppb) Atlantic Fish (Looser, 2000).**

Pollutant	North Atlantic Deep-sea (Halibut)		South Atlantic Surface (Snoek)		South Atlantic Deep-sea (Kingclip)	
	1994	1998	1994	1998	1994	1998
<b>Total DDT</b>	555	220	63	78	200	175
<b>Total Chlord.</b>	188	120	n.d.	7.5	8	8.6
<b>Dieldrin</b>	67	44	5.3	5.0	n.d.	3.2
<b>Total Toxoph</b>	330	155	15	15	22	22
<b>Total HCH</b>	12	11.4	15	1.0	98	35

Table 4 shows the results from the Monterey Bay area. Note that the toxophene and chlordane levels are actually higher in the surface species. This is probably due to recent pesticide inputs of these compounds relative to the significantly older applications of DDT. Overall, these data suggest a similar situation to other areas discussed previously.

**Table 4. Organochlorine residues (ppb) Monterey Bay Fish (Looser, 2000).**

Sample	Petrale Sole (surface)	Rockfish (surface)	Dover Sole (deep-sea)	Thornyhead (deep-sea)	Brittle star (deep-sea)
<b>Year</b>	1995	1994	1995	1995	1995
<b>Total DDT</b>	1260	1875	2380	2420	3340
<b>Total Chl.</b>	54	51	28	33	130
<b>Dieldrin</b>	1.3	7.6	5.6	7.6	66
<b>Total Tox.</b>	67	71	24	40	80
<b>Total HCH</b>	11	19	20	17	12

Although the levels between species and individual fish vary, the results obtained suggest a trend of the deep-sea floor becoming the ultimate sink for many of these compounds. The potential impacts for deep-sea fauna should not be underestimated. (Looser, 2000).

Indeed, no living organism can be considered DDT-free. It is most easily stored in fatty tissues, and would probably take from 10 to 20 years to disappear if all exposure were to suddenly cease (Turusov et al, 2002).

#### **IV. HUMAN LEVELS**

DDT residues have been shown in humans from several studies (Bouwman et al, 1991; van Wendel de Joode et al, 2001; Ayotte et al, 2001; Yanez et al, 2002).

FDA tests done in 1950 using fat samples from 75 people not occupationally exposed to the chemical revealed an average tissue level of 5.3 ppm DDT (Dunlap, 1981, p249). This level increased to 15.6 ppm in 1956 and dropped to 3 ppm in 1980 (Turusov, 2000).

Human consumption of top predators in food webs transfer OC's stored in animal fat to humans. Inuit people living in the Arctic are far removed from industrial activities, but their diets, which include large amounts of food derived from marine mammals, have resulted in high levels of DDT metabolites in their fatty tissues and breast milk (NRC, 1999, p92). The benefits of breast-feeding, however, are currently believed to outweigh the risk of chemical exposure, even at the high end of the exposure range (NRC, 1999).

### South Africa Data

A study was conducted by Bouwman et al, of two populations in Kwazulu. One population was from an area where DDT has been sprayed annually in dwellings for malaria control since 1976. The unexposed control group was from Port Shepstone in southern Natal province where malaria does not occur, and no DDT has been used for any purpose since 1996. Table 5 shows blood serum DDT levels and Table 6 shows liver function parameters between the two groups.

Although the mean levels of total DDT in serum were 23 times higher than the control group, liver function parameters between the two groups showed a normally distributed range of values. Levels of gamma-glutamyl transferase (GGT) were twice as high in the exposed group as the control, but both values fell within the normal laboratory range.

**Table 5. Blood Serum Levels (Bowman et al, 1991)**

Parameter	Exposed	Control
N	71	77
Age	22.4	28
Males	33	20
Females	38	57
DDE	103.4	5.95
DDD	.21	.015
DDT	37.3	.077
Total DDT	140.9	6.04

**Table 6. Liver Function Parameters (Bowman et al, 1991)**

Parameter	Exposed	Control	LNR (normal range)
N	63	74	
AT	4.5	2.4	0-25
AP	332	338	73-207
YGT	30.8	15.4	8-38
TP	83.6	81.8	60-80
ALB	44.8	44.3	38-48
Alt	6.1	4.5	0-29

In fact, liver function parameters varied more with age and alcohol consumption. They were better predictors of liver levels than was exposure to the pesticides (Bouwman et al, 1991). Table 7 shows a comparison of alkaline phosphates for the exposed and control groups, further divided into age groups. No differences were found for AP or any other liver parameters for DDT or its metabolites between the exposed and control groups (Bouwman, 1991).

**Table 7. Changes in Alkaline Phosphates (AP) by age for exposed and unexposed DDT workers (Bowman et al, 1991).**

Age	Exposed Group	Control Group
3-10	480.5 (302-944)	493.7 (212-810)
11-20	500.1 (211-678)	407.9 (123-826)
21-30	124.8 (71-194)	181.5 (94-266)
31-40	158.1 (92-243)	107.0 (72-142)
41-50	114.3 (87-165)	150.5 (143-158)
51-60	219.5 (171-268)	164.0 (111-224)
61-70	173.8 (153-207)	182.7 (117-214)

Note: Minimum and maximum values shown in parentheses.

Edward Laug first discovered in 1951 that breast milk from nursing U.S. mothers contained an average level of 0.13 mg/l of DDT (Wargo, 1998, p 169). A study conducted in the Kwazulu area of South Africa showed that in sprayed areas, DDT makes its way into human breast milk and is subsequently passed on to nursing infants. Nursing mothers in the DDT exposed area showed mean DDT levels of 574.89 ug/l in their milk and unexposed controls showed levels of 22.07 ug/l. This represents almost a 25-fold increase in DDT levels. The amount of DDT passed on to the infants as a result ranged from 0.1 to 0.375mg/kg/day. The allowable daily intake (ADI) for infants is only 0.005 mg/kg/day (Bouwman et al, 1990a).

## India Data

In India, where DDT and HCH have been used extensively for control of vector-borne diseases, they have been detected in blood and adipose tissue. Twenty samples of human milk were collected each from Bharat Heavy Electricals Limited (BHEL) and Bahadrabad, both of which lie in the Hardwar District (Dua et al, 1996). The Bahadrabad area still uses HCH and DDT for malaria control, while the BHEL area has used bioenvironmental methods and has not utilized insecticides since 1986. Total DDT levels of human breast milk samples taken from the BHEL area ranged from .002 to .085 mg/kg with a mean value of .021 mg/kg. Total DDT levels in samples collected from Bahadrabad, where they still use pesticides, ranged from 0.020 to 0.503 mg/kg with a mean value of 0.145 mg/kg. Bovine milk samples also showed elevated levels. The mean value for total DDT in Bovine milk from the BHEL samples was 0.008 mg/kg while the mean value for the samples collected from Bahadrabad was 0.029 mg/kg. This study shows a strong correlation between DDT spraying for malaria control and DDT residues in human and bovine milk (Dua et al, 1997).

Dua et al also measured DDT levels in soil, water, and whole blood in the BHEL and Bahadrabad areas of Hardwar district. Fourteen soil samples were collected from each area. Samples from the BHEL area showed total DDT levels ranging from 0.0 to 9.60ug/kg with a mean value of 3.68 ug/kg. The samples from the Bahadrabad area ranged from 21.1 to 1833 ug/kg with a mean value of 270.5 ug/kg. Levels in the BHEL might be a result of aerial transport and long persistence in the soil. Drinking water samples from BHEL showed no DDT detected while samples collected from Bahadrabad ranged from .01 to .12 ug/l with a mean value of 0.07 ug/l. This is well below the maximum permissible limit of 1.0 ug/l established by the World Health Organization (Dua et al, 1996).

Total DDT levels in whole blood samples from BHEL ranged from 0 to 25.0 ug/l with a mean value of 4.71 ug/l, while the samples from Bahadrabad ranged from 4.33 to 90.7 ug/l with a mean value of 38.1 ug/l. This study showed significant differences in DDT levels for soil, water, and whole blood between the two study areas (Dua et al, 1996).

## Mexico Data

Yanez et al (2002), measured DDT levels in surface soil and blood serum in two malarious areas in Mexico. One area, Chiapas, still used DDT for malaria control, and the other area, Oaxaca, had switched to synthetic pyrethroids two years earlier. In Chiapas, surface soil total DDT levels ranged from 3316 to 8229 ug/kg for eight samples, two of which were indoor samples while 6 were from outdoor sources. In Oaxaca, where DDT use had been stopped two years previously, surface soil total DDT concentrations ranges from 140 to 2562 ug/kg for six samples, three of which were from indoor sources and three of which were from outdoor sources.

Blood serum levels are shown for both children and adults in both localities in Table 8. DDT levels were significantly higher in Chiapas than they were in Oaxaca for both children and adults. Since there was no DDT applied in Oaxaca, there are no data for DDT sprayers. In both regions, levels were higher in the children than in the adults, and they were even higher than some of the sprayers in Chiapas. The high levels in the children can be explained as a result of ingestion of human breast milk, which represents

**Table 8. Blood Serum DDT Levels from Two Areas in Mexico (Adapted from Yanez et al, 2002).**

Group	CHIAPAS		OAXACA	
	Mean	Range	Mean	Range
Children	67.8	21.8-113.1	20.4	7.5-53.3
Adults	27.1	11.2-57.1	13.2	3.1-29.6
Sprayers	165.5	73.7-216.8		

the children's main source of food for the first two years of its life. Although breast milk was not investigated in this study, the situation is probably similar to the Kwazulu study, where DDT was found to be transmitted to the nursing infant from the mother via the breast milk. A second reason for higher levels among children in Chiapas is that during DDT spraying household dust and adjacent surface soil is highly contaminated with DDT, and children are exposed through dermal contact during play.

## **Brazil Data**

In Sao Paulo, Brazil, serum DDT levels were compared between 26 workers engaged in spraying DDT and hexachlorohexane (HCH) and 16 unexposed workers. Total DDT levels for the exposed worker ranged from 7.5 to 473.5 ug/l with a mean value of 76.9 ug/l. Total DDT levels for the unexposed group ranged from 5.1 to 32.9 ug/l with a mean value of 16.1 ug/l. The background levels are likely due to previous widespread DDT use in Brazil for agricultural purposes (Minelli and Ribeiro, 1996).

In a study by Torres et al (2002) DDT residues were found in urban soils, river sediments, and fish samples in the Madeira and Tapajos River watersheds, both of which are important goldmining areas in the Brazilian Amazon. In the Rato River area in the Tapajos Basin, soil samples yielded total DDT concentrations ranging from 281 ug/kg at the riverbank to 1224 ug/kg in the village. This negative gradient as you move toward the river may be explained by evaporation of some DDT metabolites and photooxidation that occurs on the deforested riverbank. River sediment samples ranged from 3.2 to 61.5ug/kg. In the Madeira River area, DDT concentrations were much lower, with soil values ranging from 4 to 123 ug/kg and sediment values ranging from 0.01 to 1.1 ug/kg. In fish samples that were analyzed from both basins, total DDT levels ranged from 7 to 536 ug/kg. In general, DDT levels were lower than in major agricultural areas where large amounts of DDT were previously used (Torres et al, 2002).

## **V. DISCUSSION**

While excess use of DDT for agricultural purposes has resulted in trace amounts of the chemical being found throughout the biosphere and has been associated with harmful effects to wildlife, it has never been proven to cause widespread harm to humans. In many parts of the world, the use of DDT still works for control of malaria vectors. Most of these areas are undeveloped countries that do not have large public health budgets (Murdock, 2001). In addition, changes in weather patterns due to global warming can potentially aid in the spread of malaria vector habitat, and therefore, the spread of the parasite as well (Reiter, 2001). The parasite has been able to develop resistance to introduced treatments and is likely to



continue to do so (NRC, 2000, p55). This condition has also been an inhibiting factor in vaccine development, as well.

The data shown from malaria endemic countries (Brazil, Mexico, India, and South Africa) imply that the DDT burden is distributed world-wide, and further, that it has been there for about as long as DDT spraying has been in operation. Although it is persistent in nature, overall levels have dropped since agricultural use of DDT was discontinued, and this trend should likely continue.

**Table 9. Summary of DDT Levels for Various Endemic Areas. (Values shown are ppb unless otherwise stated, N/D= not determined)**

Country	Blood Serum	Breastmilk	Bovine Milk	Soil	Water	Infant Load (mg/kg/day)
Brazil	76.9	N/D	N/D	281-1224	N/D	N/D
Mexico	11.2-113.1	N/D	N/D	3316-8229	N/D	N/D
South Africa	140.9	575	N/D	N/D	N/D	N/D
India	38.1	145	29	270.5	0.07	0.1-0.375

### Human Health Effects

DDT primarily affects the central nervous system, and symptoms of acute poisoning would include vomiting, headache, fatigue, and convulsions. Death from acute poisoning is extremely rare and no syndrome of chronic DDT exposure has been recognized in humans (National Institute of Health (NIH), 1978).

Several studies have been done for occupational exposures of pesticide applicators. In KwaZulu no relationship between blood serum levels and age or worker or between worker and general population was established. (Bouwman et al, 1991). In Costa Rica, occupational exposure to DDT has been associated with a permanent decline in neurological functioning (van Wendel de Joode et al, 2001). Ayotte et al (2001) found a correlation between DDE (a DDT metabolite) levels and reductions in semen volume and sperm count in Mexican men.

Studies of factory workers with DDT serum levels ranging from 737 ug/l to 1373 ug/l showed no evidence for liver disease or abnormal liver function. In fact, no relation between cancer or overall mortality and blood serum DDT levels has been observed (Bouwman et al, 1994).

Maternal DDE levels have been shown to result in premature births and infant mortality (Longenecker et al, 2001). In the Kwazulu breast milk study, infants were getting dosages of between 20 and 75 times the ADI. While these levels are not expected to harm the mothers, these levels should be considered a possible health risk to the infants. This risk should be balanced against the known health benefits of breast-feeding, especially in developing countries. Contaminated water supplies could also lead to higher rates of diarrhea (Bouwman et al, 1990a).

High levels of DDT in fish caught for subsistence eating near Triana, Alabama, in 1978 caused elevated levels of DDT metabolites in the persons eating those fish. A correlation was established between these elevated levels and elevated serum triglycerides. No association was found for any other health effects (Committee on Environmental Epidemiology, NRC, 1991, p206). In South Africa, where DDT is used for malaria control, low levels of DDT were found in fish samples collected from the Pongolo River. No significant changes in levels were found before or after DDT application. The levels found in the fish were not found to pose health hazards from human consumption, but harmful effects to species in higher trophic levels such as alligators and eagles could not be ruled out (Bouwman et al, 1990).

A study of breast cancer patients and DDT/DDE tissue levels was conducted between 1994 and 1997. Adjusting for age, the DDT and DDT tissue levels were similar between the cases and controls. DDT levels were 51.8 ppb in the cases and 55.6 ppb in the controls and DDE levels were 736.5 ppb in the cases and 784.1 ppb in the controls. These results do not show association between DDT/DDE tissue levels and incidence of breast cancer (Zheng et al, 1999).

Two other studies collected and stored blood samples from healthy women. When some of the women later developed cancer, the blood samples were analyzed for high concentrations of DDT and PCBs. A New York University study found a fourfold risk of cancer for women with high levels of DDE, but a California study found no link between cancer and DDE levels (Colborn et al, 1997, p184).

## Effects of Malaria Control after Cessation of Spraying

The amount of DDT being used for malaria control is a small fraction of what was used for agricultural purposes when DDT use was common. In 1993, the Pan American Health Organization reported a total of 1,172,077kg of DDT being applied to house walls in all of South, Central, and North America. This represents about 6% of the amount used in 1968 in the US alone, where it was commonly applied to crops (Roberts et al, 1997).

An outright ban on DDT for malaria control could have significant health costs. After discontinuing the use of DDT in 1993, Guyana and Paraguay/Peru reported a 78% and 92% increase, respectively, in malaria cases. Ecuador increased its use of DDT in the same year and reported 62% decrease in new malaria cases (Roberts et al, 1997).

Throughout the Americas malaria rates have been increasing. At the same time in-house spraying has decreased. Figure 2 shows a graph reflecting annual statistics compiled by the Pan American Health organization for house spray rates and incidence of parasite appearance. In 1959, the annual parasite index (# of positive blood smears per 1000 persons) was 0.39. In 1996, the API was 2.46, and for persons in malaria-specific areas it was 12.50. During this same time frame the house spray rate (HSR) had decreased from 71.55 houses sprayed per 1000 persons to 4.12 (Butler, 2000).

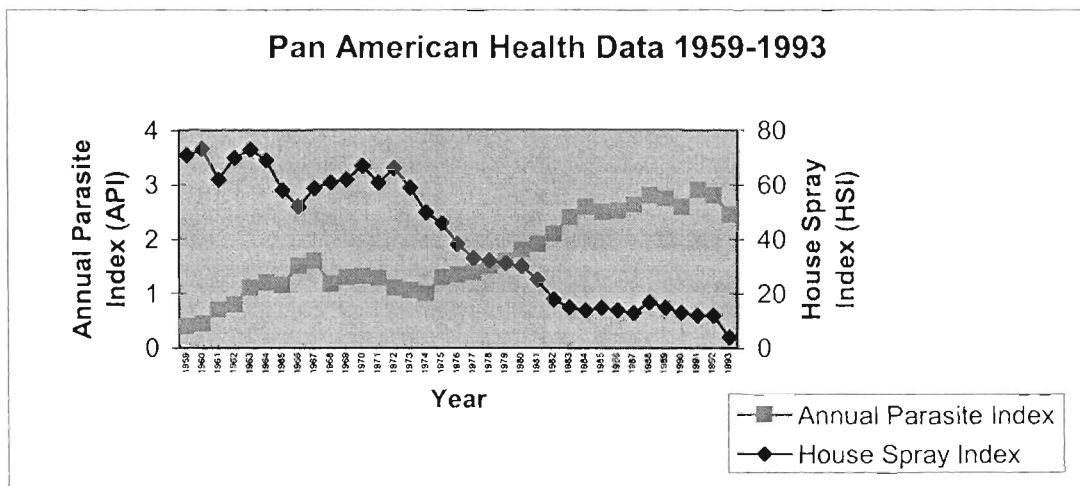


FIGURE 2. Parasite Incidence and House Spray Data from Pan American Health Association Data (Butler 2000)

A similar case exists in South Africa. In the provinces of Kwazulu-Natal and Mpumalanga a switch was made from using DDT to synthetic pyrethroids for in-house spraying while Swaziland continued the use of DDT. Malaria cases increased by 350% in Kwazulu-Natal and 185% in Mpumalanga while they remained steady in Swaziland (Govere et al, 2002). South Africa switched from using DDT to pyrethroids in the mid 1990s. After five years they switched back to using DDT after the *Anopheles* mosquitoes had become resistant to them. They had previously relied heavily on pyrethroids against plant pests, which likely contributed to the mosquitoes developing resistance (Raloff, 2000). Resistance to pyrethroids is appearing in field vector populations throughout the world (Roberts and Andre, 1994).

Romi et al, reported on a malaria control program using DDT in Madagascar, where malaria is the second largest cause of mortality and morbidity. The coastal regions are characterized by stable malaria while the highlands are characterized by unstable malaria due to weak and irregular rainfalls. In the highlands, the main malarial vector, *Anopheles funestus*, was eradicated as a result of malaria control campaigns carried out in the 1950's and 1960's that used DDT for indoor spraying and treatment with chloroquine. A military takeover in 1975 resulted in a disastrous economic decline, which created shortages of medicine and caused many of the health clinics to close (Reiter, 2001). As a result, *A. funestus* slowly recolonized the highlands, and a series of malaria outbreaks occurred, resulting in over 40,000 deaths between 1985 and 1990.

In response, a national control program was initiated in 1988 to stop the spread of the vector. Chloroquine was administered, and DDT was used for indoor spraying where the heaviest cases of malaria occurred, specifically, villages located between 1000 and 1500 meters in elevation. The program was funded by the World Bank and provided for five one-year vector control campaigns between 1993 and 1998. The campaigns were known as the Operation de Pulverisation Intra Domiciliare (OPID) Program. Based on parasite and vector surveys, the program was a success.

Tables 10 and 11 show the parasite index and the occurrences of the vector *A. funestus*, for the areas that were sprayed in the OPID vector control campaigns, and

they are further shown by the elevation at which the observations were made. The mean total parasite index, or the percentage of blood smears that were positive for plasmodium, dropped from 25.6 before OPID to 0.3 after the OPID campaigns. Figure 3 shows a gradual decline in TPI, year by year, for the villages of Antanetibe, Merimandroso, Analaroa, and Alasora. This figure clearly shows that after the DDT spraying campaigns started, the incidence of malaria decreased each year until it was practically nonexistent.

**Table10. Parasite Survey Results for schoolchildren in Madagascar highlands before and after OPID program (Romi et al, 2002).**

		Before OPID			After OPID		
		Total Parasite Index			Total Parasite Index		
Altitude (m)	# of villages	# subjects examined	mean	Min-max	# of subjects examined	mean	Min-max
900-1000	2	474	57.6	43.6-65.0	235	0	-
1000-1500	28	4272	23.8	0-72.2	2590	0.4	0-2.0
> 1500	2	309	1.3	0.6-2.3	206	0	-
<b>Total</b>	32	5055	25.6	-	3031	0.3	-

*Anopheles funestus* was common in the majority of the villages between 1000 and 1500 meters prior to the indoor residual spraying. Occurrence of the vector was dramatically reduced during the spraying campaigns.

**Table 11. Abundance of *Anopheles funestus* in villages of the Madagascar highlands before and after OPID vector control campaigns (Romi et al, 2002).**

Altitude (m)	# of villages	Before OPID			After OPID			
		# positive	Mean # of bites per person per night	Mean # of mosquitoes per room	# of villages	# positive	Mean # of bites per person per room	Mean # of mosquitoes per room
900-1000	2	2	47-112	47.4-82.2	4	3	0- 1.5	0-3.6
1000-1500	26	21	1.7-19.5	0.1-56	12	3	.08-.45	0.1-0.1
>1500	7	0	-	-	3	0	-	-
<b>Total</b>	35	23	-	-	19	6	-	-

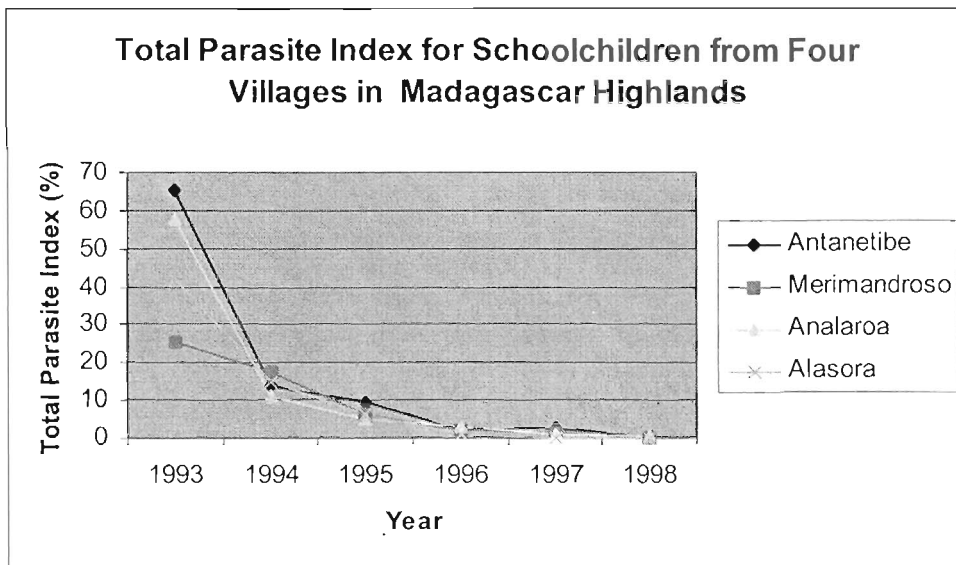


Figure 3. Parasite Index for Schoolchildren from Four Villages in Madagascar Highlands (Romi et al, 2002).

### Cost Comparisons with Alternative Insecticides

While developed nations can afford a variety of insecticides, health budgets in third-world countries are significantly less. Annual health budgets in these countries are often less than \$5.00 (U.S) per person. In these cases, any increases in cost become significant (Murdock, 2001).

The costs of alternative insecticides have been an issue in malaria control. Several cost studies have been conducted comparing the cost of DDT with other insecticides. Statistics from the Pan American Health Organization show that use of the insecticide malathion to be five times that of DDT (Roberts and Laughlin, 1997). Other organochlorine insecticides such as dieldren and gamma-BHC/HCH were used for malaria control until the 1960's but were discontinued due to toxicity in humans and also resistance in the target vector species (Walker, 2000).

Table 12, from Walker (2000), shows comparative prices for DDT and five other pesticides in use. All were more expensive than DDT, with Propoxur being the most costly at over twenty-three times the cost of DDT. While other insecticides may require less actual product to be used, their cost are greater. Because many of these countries are so poor, no realistic alternatives to DDT exist (Butler, 2000).

**Table 12. 1990 comparison of insecticides, from World Health Organization Data (Walker, 2000).**

Insecticide	Applications/6 months	Cost per Kg	Cost per house per 6 months
<b>DDT</b>	1	3.00	1.60
<b>Malathion</b>	2	2.10	3.36
<b>Deltamethrin</b>	1	25-28.00	5-5.60
<b>Permethrin</b>	2	30.00	6.00
<b>Fenitrothion</b>	2	7.50	12.00
<b>Propoxur</b>	2	9.30	37.20

### **Resistance to Pesticides and Drugs**

Resistance to chemicals is almost universal among pest species. Resistance acquisition occurs through evolutionary means. Over time, random genetic changes occur, which preadapt some individuals in populations to survive exposure to given chemicals. When these chemicals are used, these preadapted individuals will survive to reproduce and pass their genetic advantages on to their offspring (NRC, 2000, p55). Acquisition of resistance to one agent can assist in the development of resistance to other agents, such as the situation when South Africa switched from using DDT to synthetic pyrethroids, only to switch back again 5 years later, when the mosquitoes were showing resistance to them (Raloff, 2000).

### **Insecticide Resistance in the Vector**

Reports of insecticide resistant in mosquitoes appeared as early as the 1950's. In 1956, resistance by *Anopheles gambiae* from Nigeria was reported against dieldrin, chlordane, aldrin and benzene hexachloride, but remained susceptible to DDT in laboratory experiments (Coetzee and Horne, 1999).

As of 1983, 4 billion pounds of DDT had been applied to outside areas, mainly for agriculture, which greatly accelerated the pace of mosquito resistance. By 1959, seven species of Anophelines were resistant to DDT and another eight species were resistant to dieldrin. By 1962, the numbers of resistant species had increased to nine and twenty-six, and by 1969 had increased further to fifteen and thirty-seven. Fifty species have demonstrated some resistance to DDT as of 1994 (Wargo, 1998, p 51).

Insects naturally vary in their susceptibility to insecticides, and subsequent generations became resistant to even the highest dosages. In some cases, cross-resistance occurred to chemically similar compounds (Reiter, 2001), which happened with synthetic pyrethrum in South Africa (Raloff, 2000).

More recently, in India, *Anopheles fluviatilis* have become resistant to hexachlorohexane (HCH), which was introduced as a replacement for DDT. Studies by the Malaria Research Centre have shown malaria rates to be largely unaffected (Sarala et al, 1988). Table 13 shows a comparison of responses of *A. fluviatilis* to a one-hour exposure of HCH and DDT in four different districts. Mortality for HCH varied by location between 24.0 and 41.9 percent, while the DDT showed 100% mortality (Sahu and Patra, 1995).

**Table 13. Mortality of *A. fluviatilis* to HCH and DDT (Sahu and Patra, 1995).**

Primary Health District	HCH application, %mortality	DDT application, %mortality
Malkangiri	24.0	100
K Gumma	26.7	100
Korkunda	41.9	100
Khairput	26.6	100

Even when not outright killed by the insecticide, vectors often exhibit a characteristic known as excito-repellency, where the insecticide still adversely affects the vector of interest. These effects can range from resting on a sprayed surface for less time than an unsprayed surface, or avoiding it altogether, to completely avoiding rooms that have been sprayed (Najera and Zaim, 2001). Although the mosquitoes may show resistance to DDT, at least four anopheline species have demonstrated this 'excito-repellency' where the mosquito is not killed by the DDT, but avoids it nonetheless. The ultimate result of this behavior is that the mosquitoes do not bite humans or transmit malaria (Butler, 2000).

This excito-repellency, however, may well represent an evolutionary step towards resistance. Greece began DDT spraying in 1946. By 1949, large numbers of *Anopheles sacharovi* mosquitoes were observed in large numbers under road bridges, and soon were also observed in caves, culverts, and outbuildings. Within a few months they were able to remain in houses on walls treated with DDT (Carson, 1962, p 269).



The experience gained from several control programs shows that resistance to DDT occurred slowly, even factoring in previous usage of DDT for agricultural purposes. The proportion of resistant mosquitoes in the population increased slowly, and so DDT remained effective for a long time. In some areas of Central America, DDT was still effective, even when tests showed vector survivability of up to 40% (Najera and Zaim, 2001, p 45).

### **Drug Resistance in the Parasite**

The same mechanisms by which mosquitoes become resistant to insecticides allow the *Plasmodium* parasite to become resistant to antimalarial drugs. A wide range of drugs is used, and in recent years more emphasis has been placed on these than on insecticidal methods (Reiter, 2001). It is recognized that some level of resistance to the antimalarial drugs will be unavoidable in most countries (Sherman, 1998, p16). Appendix B shows the current occurrences of parasite resistance throughout the world.

Quinine, which is isolated from bark from the cinchona tree, was the primary treatment for malaria until synthetic antimalarials were developed between the two World Wars. The first isolated reports of resistance to quinine occurred in 1910 (Wargo, 1998, p53). Chloroquine, which was introduced at the end of WWII, was the primary antimalarial drug for the next four years due to its effectiveness, safety, and low cost. Parasitic resistance started to appear for chloroquine in the late 1950s to 1960's in Asia and South America, and now occurs in all endemic areas (Salako, 1991). Resistance to the main alternative to chloroquine, sulfadoxine/pyrimethamin, occurs in Southeast Asia and across South America. Mefloquine resistance is common in the border area between Cambodia and Thailand. Resistance to quinine also occurs in the Amazon region and in Southeast Asia (WHO, 2000).

Combination drug therapy has been widely accepted as a method to counter drug resistance in the parasite. Using drug combinations slows the development of the parasite's resistance to either drug, and therefore, helps prevent transmission of the disease. This technique has also been used with various levels of success in treating some cancers and AIDS (Key et al, 1999). Unfortunately, because malaria

occurs mostly in less-developed countries with small health-care budgets, the market for these drugs is often quite small (Tren and Bate, 2001).

The CDC currently recommends the following five prescription drugs for malaria control and treatment: mefloquine, doxycycline, malarone, chloroquine, and hydroxychloroquine sulfate. All have potential for mild side effects, which include itching, dizziness, nausea, vomiting, blurred vision, and sleep disorders. Doxycycline increases susceptibility to sunburn. Mefloquine can also have major side effects, which include severe anxiety, hallucinations, and seizures (CDC, 2003).

### **Implications From Global Warming**

Our planet's climate has always been in a state of flux. For the past 300 years or so the planet has experienced a warming trend. This trend has been exacerbated, according to some models, by human-induced activities. The ecology and survival of mosquitoes and the dynamics of the diseases that they help to transmit are strongly influenced by these climatic factors. Temperature, rainfall, and humidity are especially important (Reiter, 2001). As the global temperature rises, so can the area plagued by mosquitoes and the associated diseases they carry. This can occur in the vertical as well as the horizontal dimension as temperatures rise, the insects will find hospitable temperatures at higher elevations. The increased temperature also raises the rate of maturation of parasites. *P. falciparum* takes 26 days to fully develop at 68 degrees F, but matures in half the time at 77 degrees F (Epstein, 2000).

The global temperature will affect precipitation patterns, which will affect the ability of the vector to multiply. This ability is dependent upon whether stagnant or moving water is encountered and also in the type of vegetation present (Martens et al, 1997).

While *Anophelines* mosquitoes are generally not found more than a few miles from their development area, they are readily transported by wind currents (IOM, p28). This phenomenon is likely to contribute to the mosquito's ability to spread as the mean annual temperature increases.

Localized epidemics due to climatic variations are already thought to have occurred. In Bangladesh, heavy rains in usually arid regions resulted in extensive

flooding that waterlogged areas surrounding extensive irrigation systems. Peru, Madagascar, and Ethiopia experienced epidemics following prolonged rains, high temperatures, and humid summers. In Sri Lanka in the 1980's, lack of normal monsoons resulted in the normally humid valleys experiencing pooling water from the rivers, which produced an environment conducive to the breeding of *A. culicifacies* in these areas (Sherman, 1998, p14).

Higher precipitation levels should create an increase in vector breeding sites and should result in an increased opportunity for the parasite to be transmitted between individuals (Lindsay and Birley, 1996). A correlation was found between fever deaths due to malaria and rainfall in the Punjab region near the India-Pakistan border. This correlation between precipitation and fever death is shown in figure 4.

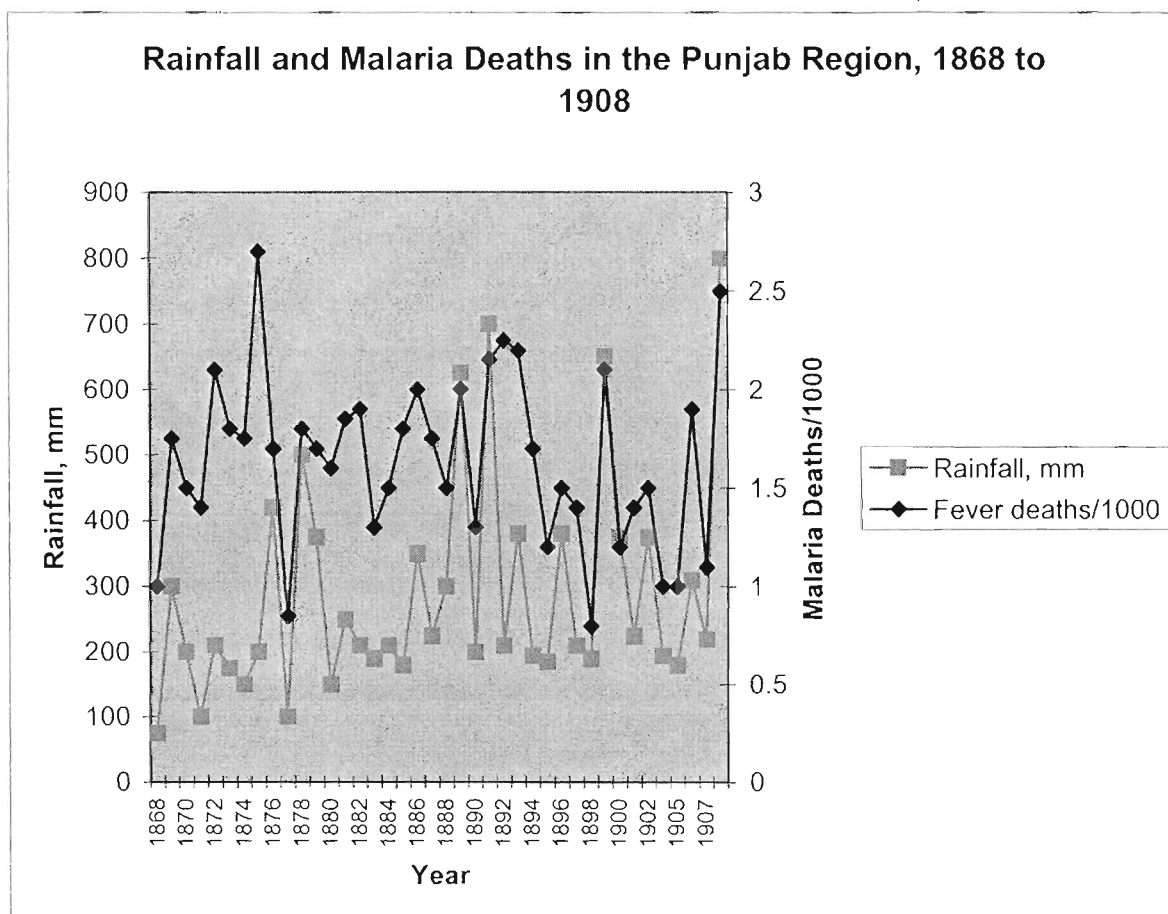


FIGURE 4. Relationship between fever deaths and precipitation (Lindsay and Birley, 1996)

The area of the world at risk of malaria could increase to up to 60% of the world's population (Epstein, 2000). Appendix C shows the current infectious areas and the potential increase in area with a two degree Fahrenheit increase.

A small number of malaria cases occur in the United States. The Centers for Disease Control (CDC) estimates that it receives between 1,000 and 1,500 cases per year. The majority of these cases are from travelers recently returning from malaria-endemic areas. A few cases, however, are believed to be mosquito-transmitted. Several competent malarial vector species exist in the United States (CDC 2002). Global climate change can only exacerbate this condition.

## **VI. SUMMARY AND RECOMMENDATIONS**

DDT has been shown to be very persistent in the environment. Mostly through excessive use as an agricultural pesticide in the middle 1900's, it has become ubiquitous in nature. It has bioaccumulated throughout the global food web and trace tissue levels of DDT have been found in numerous animal and human studies. Trace amounts have been found in soil and sediment samples around the world, as well as in the oceans.

Malaria has been a major pathogen to humans throughout history, and has caused much suffering and many millions of deaths. A major attempt was made at worldwide eradication of the disease in the middle 1950's. While not successful, it did significantly reduce the incidence of the disease. Since then, the parasite has become resistant to different drugs in different regions, and the vector mosquitoes have become resistant to certain insecticides.

Concerns about damage to nontarget organisms by DDT exposure resulted in significant reductions of its use beginning in the 1970's. Malarial rates have increased in several areas as a result. Reintroduction of DDT in South Africa and Madagascar has resulted in downward trends of malaria incidence in those areas. Without the excessive amounts of DDT used for agriculture in the 1950's and 1960's, human levels of DDT and its metabolites have decreased. Worldwide DDT levels in human breast milk are decreasing between 11 and 21% per year, and have dropped

from more than 5000 ug/kg to less than 1000 ug/kg (Butler, 2000). It is likely that DDT levels found in wildlife have decreased, as well.

New antimalarial drugs are expensive, costing as much eight dollars per pill and well beyond the affordability for most Third World countries (Speilman and D'Aantonio, 2001, p95). Initially one of twelve POP's to be banned worldwide, continued use of DDT for malaria control has been allowed (Maurice, 2001). The use of DDT for indoor spraying *does not* introduce sufficient amounts of DDT into the environment to bioaccumulate into the food chain (IOM, 1991, p 133; Tren and Bate, 2001). Attention must be paid to prevent rinsing of spray equipment or disposal of unused insecticide into natural bodies of water (Najera and Zaim, 2001).

DDT has not been shown to be a human health risk (Henderson, 2000; Roberts et al, 2000). There is little evidence of environmental harm when DDT is used indoors for control of *Anophelines* mosquitoes (Curtis, 2002).

While the symptoms of malaria can generally be treated, prevention of infection in the first place would be a more desirable condition. It is generally accepted that limited use of DDT should be allowed, especially where no reasonable alternatives exist, for public health purposes (Turusov, 2002). Although DDT's persistence makes for a long-lasting treatment, which does not require frequently repeated applications, it does accumulate in the environment, and exposure to the chemical does not end with substitution of another insecticide (Yanez et al, 2002). House spraying with DDT has its limitations, but it remains an effective antimalarial tool, which should continue to be used (Roberts et al, 2000).

For malaria control to be effective, the overall strategy must be flexible and continuously responsive to changes in effectiveness of various methods used. For insecticide applications, applicators must be trained in proper and safe methods of application and supervisors must insure that required protective equipment and clothing is in place both for the protection of the applicators as well as the community inhabitants (Najera and Zaim, 2001).

Increased monitoring of both malaria incidence and vector resistance is vital to an effective malaria control strategy. Although no actual assessments have been made since 1982, fewer students seem to be training in vector biology, and many of

the educators in the field have retired without being replaced (IOC, 1991, p 134). Jobs and training for field ecology and entomology is severely lacking, and fundamental changes in policy and funding for national and international public health organizations are required to improve this situation (Roberts and Andre, 1994).

It is not likely that any single method can be used to control malaria. Continued instances of parasite and vector resistance, as well as the implications of global warming can only exacerbate the situation. As long as DDT remains an effective insecticide against Anopheline mosquitoes, it should continue to be used where appropriate. Current WHO guidelines, as outlined in their Roll Back Malaria Campaign, calls for research into new medicines, vaccines, and insecticides. It also allows for the use of DDT where effective. In my opinion, this represents a sound public health policy.

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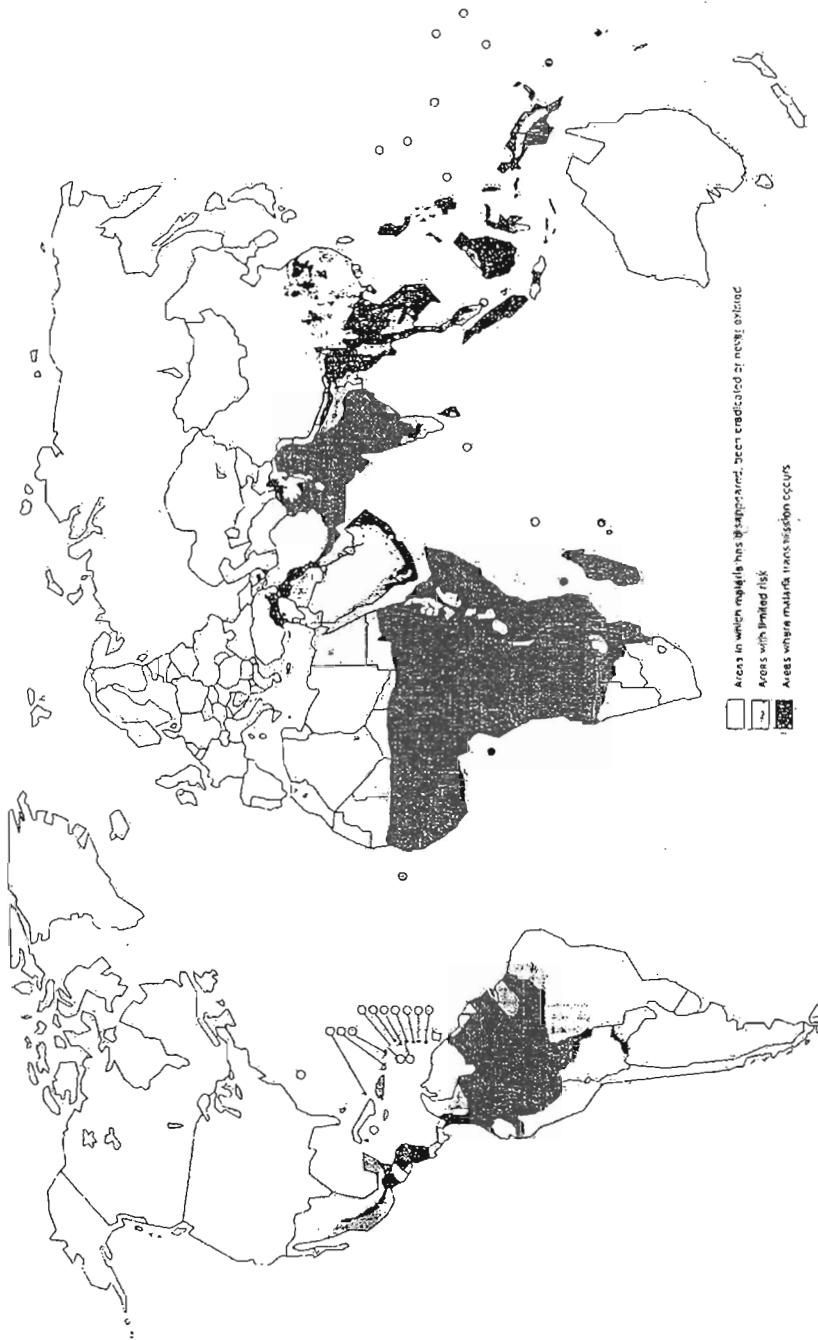
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## **APPENDIX A**

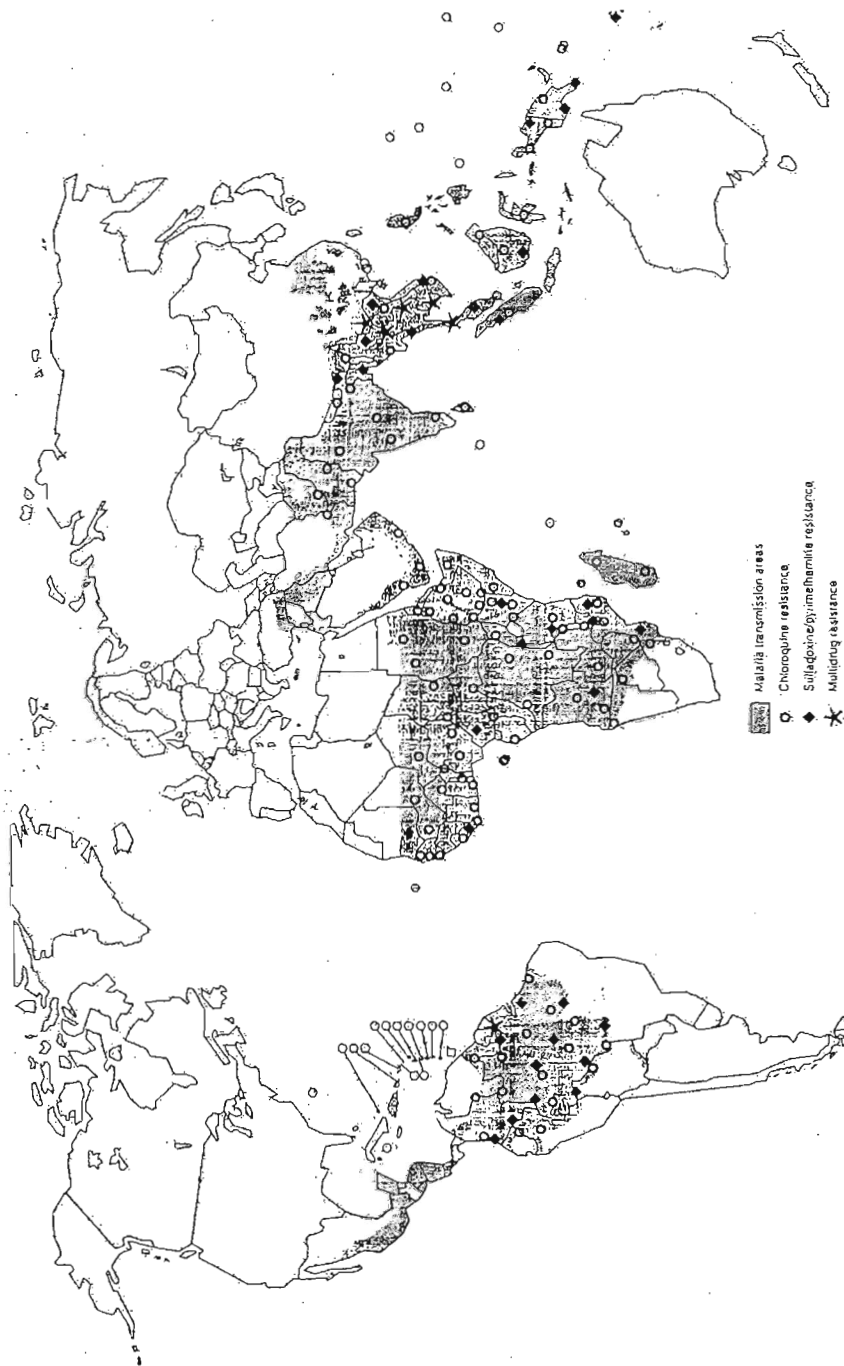
Global Malaria Transmission Areas



Global Malaria Transmission Areas (World Health Organization, 2000)

## **APPENDIX B**

Global Malaria Parasite Resistance

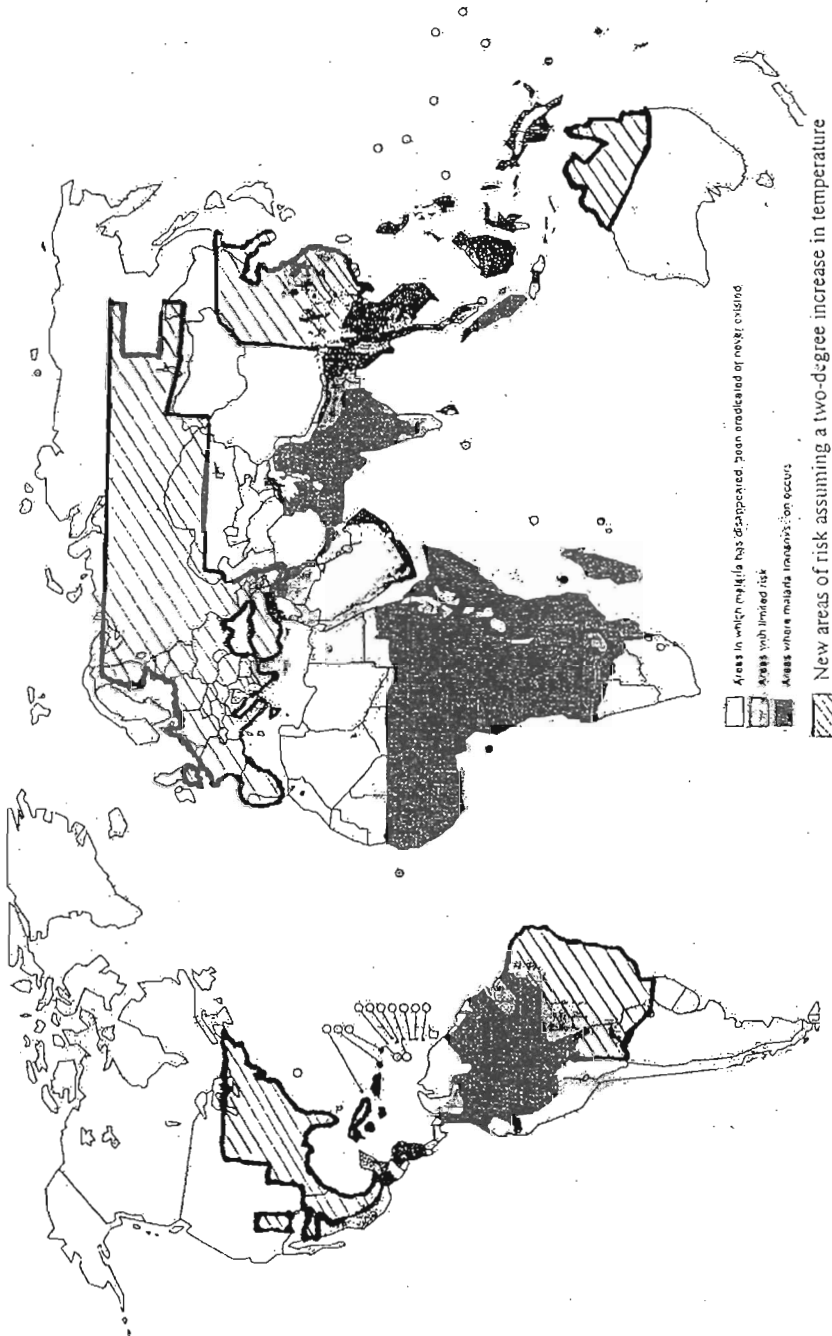


Incidence of Parasite Resistance (World Health Organization, 2000)

## **APPENDIX C**

Potential for Increase of Malaria Transmission Area Assuming a  
Two-Degree Fahrenheit Increase in Temperature





Potential for Increase in Malaria Transmission Area Assuming a Two-Degree Fahrenheit Increase in Temperature (Epstein, 2000, World Health Organization, 2000)