Tropical Medicine and International Health

VOLUME 9 NO 8 PP 846–856 AUGUST 2004

Historical review of malarial control in southern African with emphasis on the use of indoor residual house-spraying

Musawenkosi L. H. Mabaso[1], Brian Sharp[1] and Christian Lengeler[2]

1 *Malaria Research Programme, Medical Research Council, Durban, South Africa*
2 *Swiss Tropical Institute, Basel, Switzerland*

Summary Indoor residual house-spraying (IRS) mainly with dichlorodiphenyltrichloroethane (DDT) was the principal method by which malaria was eradicated or greatly reduced in many countries in the world between the 1940s and 1960s. In sub-Saharan Africa early malarial eradication pilot projects also showed that malaria is highly responsive to vector control by IRS but transmission could not be interrupted in the endemic tropical and lowland areas. As a result IRS was not taken to scale in most endemic areas of the continent with the exception of southern Africa and some island countries such as Reunion, Mayotte, Zanzibar, Cape Verde and Sao Tome. In southern Africa large-scale malarial control operations based on IRS with DDT and benzene hexachloride (BHC) were initiated in a number of countries to varying degrees. The objective of this review was to investigate the malarial situation before and after the introduction of indoor residual insecticide spraying in South Africa, Swaziland, Botswana, Namibia, Zimbabwe and Mozambique using historical malarial data and related information collected from National Malaria Control Programmes, national archives and libraries, as well as academic institutions in the respective countries. Immediately after the inception of IRS with insecticides, dramatic reductions in malaria and its vectors were recorded. Countries that developed National Malaria Control Programmes during this phase and had built up human and organizational resources made significant advances towards malarial control. Malaria was reduced from hyper- to meso-endemicity and from meso- to hypo-endemicity and in certain instances to complete eradication. Data are presented on the effectiveness of IRS as a malarial control tool in six southern African countries. Recent trends in and challenges to malarial control in the region are also discussed.

keywords malaria, control, indoor residual spraying

Introduction

Control of malaria represents one of the world's greatest public health challenges, especially in sub-Saharan Africa where most of the disease occurs nowadays. In the past decades, efforts to control malaria have been met with mixed success. Since the discovery of the connection between *Anopheles* vectors and malarial transmission in 1897, vector control strategies have been the most widely used malarial control measures. Before World War II vector control measures included environmental sanitation through drainage and landfills to eliminate the larval mosquito habitat; biological control through the use of larvivorous fish in ponds; larviciding with oil and Paris green. All these methods were effective, especially in Europe, but malaria continued to be a problem on a global scale (Najera 2000).

The availability of dichlorodiphenyltrichloroethane (DDT) and other insecticides in the 1940s marked a new era for malarial control in the world. The effectiveness of DDT against indoor resting mosquitoes led to the adoption of the Global Eradication Programme of Malaria in 1955, coordinated and supported by the World Health Organization (WHO). For the first 10 years (1957–66) the results were spectacular; malaria was completely eradicated in the United States as well as in the former Soviet Union and European countries. Disease incidence was also significantly reduced in many countries in the tropical region of South-East Asia, India and South America. However, gains made in some of the countries, particularly in the tropical regions, could not be sustained and there were reverses due to financial, administrative or operational problems, resistance or behaviour of vectors, or to the inadequate development of basic health services (Najera 2001). The time-limited eradication policy was eventually abandoned in 1969 and replaced by a long-term Global Malaria Control Strategy in 1992.

In Africa, south of the Sahara, several malarial eradication pilot projects were initiated between the 1940s and the 1960s in countries such as Liberia, Cameroon, Nigeria, Senegal, Burkina Faso, Benin, Togo, Rwanda, Burundi, Uganda, Tanzania and Kenya. The intention was to assist governments to improve techniques to the point where transmission was interrupted and eradication could be undertaken. These pilot projects demonstrated that malaria was highly responsive to control by indoor residual spraying (IRS) with insecticides (mainly DDT). Significant reductions in anopheline vectors and malaria were recorded but transmission could not be interrupted (Payne *et al.* 1976; Kouznetsov 1977; Bradley 1991; Najera 2001). Subsequently, international interest in malaria and funding for malarial research and control declined in most countries on the continent. As a result residual spraying was not taken to scale in large parts of sub-Saharan Africa with the exception of southern Africa and islands such as Reunion, Mayotte, Zanzibar, Cape Verde and Sao Tome.

In southern Africa the first experimental adult mosquito control with pyrethrum was carried out in 1931 in KwaZulu-Natal, South Africa and this led the way for the worldwide use of residual insecticides against adult mosquitoes (de Meillon 1936). By the 1940s, large-scale malarial control operations based on house-spraying with DDT and benzene hexachloride (BHC) were successfully initiated in South Africa, Zimbabwe and Swaziland. The danger of unexpected epidemics was minimized; morbidity and mortality were drastically reduced, and in certain areas such as southern KwaZulu-Natal the disease was eradicated (Kouznetsov 1977).

Today malaria is a resurging global phenomenon, with explosive epidemics, altered geographical distribution and resurgence in areas where it had been brought to low levels (Roberts *et al.* 2000). It is clearly important therefore to look at the history of malaria and its control in regions where significant and sustained strides were made towards control, particularly in Africa. In this paper, we examine the historical impact of vector control on the malarial situation in southern Africa, and how the control programmes evolved in the region with an emphasis on the use of IRS, which has been and continues to be the backbone of malarial control in the region.

Selected countries and data collection

This review focuses on six southern African countries for which historical malarial data and related information could be accessed, i.e. South Africa, Swaziland, Botswana, Namibia, Zimbabwe and Mozambique. The intensity of malarial transmission in the region varies considerably and includes malaria-free areas as well as unstable and stable transmission areas. Among the selected countries malaria is predominantly stable in Mozambique, which as a result has the greatest burden of the disease. In the other five countries, malaria is predominantly unstable. These areas are often prone to epidemics which can result in high levels of morbidity and mortality if not prevented or contained. IRS is the main vector control strategy in these countries, and over 13 million people are currently protected by IRS in the region (SAMC 2000).

Malarial data and related information used were collected as part of the MARA/ARMA project (Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique) through literature searches and country visits (MARA/ARMA 1998). Data sources included National Malaria Control Programmes, national archives and libraries, as well as academic institutions in the region.

In South Africa, Sharp *et al.* (1988), le Sueur *et al.* (1993), and Sharp and le Sueur (1996) documented the history of malarial control from the early 1930s to the mid-1990s. A number of unpublished documents and reports were also sourced from Dr Frank Hansford of the former National Institute of Tropical Diseases in Tzaneen, South Africa.

In Swaziland, early malarial control efforts (1947–57) are well documented in published and unpublished papers by the chief medical officer Dr O. Mastbaum. Consistent records of malarial data are also available from annual reports produced by the Ministry of Health since 1947 as well from various WHO reports.

In Botswana, the Ministry of Health and Central Statistics compiled the only available consistent malarial information since 1980. Prior to this, only scanty information dating back to the 1930s and early 1950s could be sourced from national archives, as well as from two WHO reports produced in 1962 and 1974 (WHO 1962; Chayajabera *et al.* 1975).

In Namibia, past malarial data and related information were available from a 1950 publication by Dr B. de Meillon (de Meillon 1951). A series of malarial data from the 1960s until the early 1990s were sourced from the National Institute of Tropical Diseases in Tzaneen as well as from numerous WHO reports before and after 1990. However, since the early 1990s the National Vector-borne Disease Control Programme (NVDCP) within the Ministry of Health has been responsible for malaria and related information.

In Zimbabwe, Alves and Blair (1953, 1955), Harwin (1969, 1979), and Taylor and Mutambu (1986) give a historical account of malarial control efforts in that country from the mid-1940s to the mid-1980s. Some information is also contained in a number of unpublished

reports from the Blair Research Institute in Harare, Zimbabwe.

The 20-year history of malarial control experience (1946–56 and 1960–69) in southern Mozambique is documented in a number of unpublished reports (Soeiro 1956; Ferreira 1958; Schwalbach & de la Maza 1985). Recent information on malarial control in Mozambique was sourced from Barreto (1996) and Sharp *et al.* (2001).

Malarial situation before control with indoor residual spraying

Prior to the introduction of IRS, malaria was hyper-endemic with intense seasonal transmission in endemic areas of most countries in the region. Pre-control spleen and parasite rates from random surveys carried out in selected areas in South Africa (Wilson *et al.* 1950), Swaziland, Botswana (Mastbaum 1944), Namibia (de Meillon 1951), (Mastbaum 1957a), Zimbabwe (Alves & Blair 1953) and southern Mozambique (Martins 1941) were highest in young children and there was a decline in infection with increasing age indicative of a fairly stable transmission (Table 1). The geographical distribution of malaria was also more extensive, and most countries experienced severe epidemics.

In South Africa malarial epidemics used to extend as far southwards down the east coast as Port St Johns (eastern Cape) and as far inland as Pretoria in the northern part of the country (le Sueur *et al.* 1993). In Swaziland, the highest infections were found in the lowveld (150–500 m) and relatively low infections were found in the middleveld (500–1000 m), while malaria was absent from the highveld zone (1000–4000 m) (Figure 1).

In Botswana, very little information is available on the malarial situation prior to the implementation of IRS. However, in 1939 a travelling dispensary noted the disease as occurring all year round in the riverine communities, indicating fairly stable transmission in these areas, while in villages away from such areas, it was distinctly seasonal with fewer cases seen during winter months. The spleen rate varied from 40% to 84% in different villages (Medical Officer 1939).

In Namibia, the only information available on the malarial situation before the beginning of the IRS operation in the mid-1960s is from studies by de Meillon (1951) and Schoeman (1951). These surveys showed that malaria was highest in the north-eastern part of the country decreasing towards the west, varying from meso- to hypo-endemic in the central districts, and fading to an epidemic-prone situation in the southern part of the country.

In Zimbabwe, a more stable transmission was found to occur in low lying areas and frequent epidemics occurred at higher altitude (Taylor & Mutambu 1986). In southern Mozambique, the Maputo region experienced stable seasonal transmission (Soeiro 1956; Ferreira 1958; Schwalbach & de la Maza 1985).

Malarial vectors of the *Anopheles gambiae* complex and *A. funestus* were also widespread and found in high densities indoors throughout the malarial areas in South Africa (Swellengrebel & de Meillon 1931), Swaziland (Mastbaum 1957a), Botswana (Mastbaum 1944), Namibia (de Meillon 1951), Zimbabwe (Alves & Blair 1955) and Mozambique (Soeiro 1956).

Implementation of indoor residual spraying programmes

Table 2 summarizes the start of IRS programmes in the region and changes in residual insecticides applied over time. The first trial testing of the residual application of insecticides for malarial control in southern Africa was carried out in 1931 in KwaZulu-Natal, South Africa and by 1932 a widespread residual house-spraying programme using pyrethrum was undertaken. In 1946, DDT replaced pyrethrum as the insecticide of choice (Sharp *et al.* 1988; le Sueur *et al.* 1993). In 1956, malaria became a notifiable disease, total coverage of all malarial areas was achieved for the first time in 1958, and by 1970 South Africa had a well-structured malarial control programme (Sharp & le Sueur 1996). In 1996, the pyrethroid deltamethrin was introduced for IRS in line with international trends to replace DDT. Subsequently, *A. funestus*, which had disappeared since the 1950s re-emerged in 2000 and was shown to be pyrethroid-resistant (Hargreaves *et al.* 2000). As a result, national policy reverted to the use of DDT, and surveillance has since indicated that *A. funestus* has again disappeared (Ministry of Health 2003).

In Swaziland, the malarial control programme was launched in 1945. Residual indoor spraying with DDT was initiated on a limited scale in 1947 (Mastbaum 1955). By 1950, coverage of all malarial areas was achieved. During the 1951–52 transmission season, BHC was introduced due to a shortage of DDT. From 1955–56, the efficacy of dieldrin *vs.* BHC was evaluated and no significant difference was found in the vector population density and number of malarial cases in areas sprayed with the two insecticides. However, dieldrin was discontinued due to higher cost (Mastbaum 1956, 1957a). Focal spraying, partly with BHC and partly with DDT, was carried out in the 1960s (Delfini 1969). From the 1980s, all inhabited structures in malarial areas were sprayed with DDT and

Table 1 Pre-control spleen and parasite rates from random surveys carried out in selected areas in Swaziland (Mastbaum 1957a), Botswana (Mastbaum 1944), Namibia (de Meillon 1951), South Africa (Wilson *et al.* 1950), Zimbabwe (Alves & Blair 1953) and southern Mozambique (Martins 1941)

South Africa (1932)

	Transvaal and northern KwaZulu-Natal transmission season	
Age groups (years)	Spleen (%)	Parasite (%)
0–1	63	60
2–5	92	91
6–10	87	76
11–15	74	64
16–25	52	51
>25	46	34

Swaziland (1945–48)

	Lowveld area (500–1000 m)				Middleveld area (150–500 m)			
	Transmission season		Non-transmission season		Transmission season		Non-transmission season	
	Spleen (%)	Parasite (%)	Spleen (%)	Parasite (%)	Spleen (%)	Parasite (%)	Spleen (%)	Parasite (%)
<1	17	38	11	13	5	14	1	2
1–5	64	76	47	51	23	31	9	15
6–10	68	78	61	56	23	32	16	20
11–15	49	55	42	37	24	43	13	13
16–20	30	49	26	23	20	37	6	11
>20	29	44	19	15	18	36	6	8

Botswana (1944)

	Ngamiland south non-transmission season		Chobe non-transmission season	
	Spleen (%)	Parasite (%)	Spleen (%)	Parasite (%)
0–5	43	33	86	73
6–14	42	18.3	44	55
>14	25	8.3	11	11

Namibia (1950)

	Kavango transmission season		Ovambo transmission season	
	Spleen (%)	Parasite (%)	Spleen (%)	Parasite (%)
0–1	48	74	30	19
2–5	79	90	34	58
6–10	52	75	36	63
11–20	30	65	26	60
21–30	13	48	9	50
>30	10	25	7	33

Zimbabwe (1948)/Bushu reserve transmission season

	Parasite (%)
1–3	72

Southern Mozambique (1937–38)/Maputo region

	Spleen (%)	Parasite (%)
<1	56	80
1–5	69	92
5–10	53	83
10–15	38	72

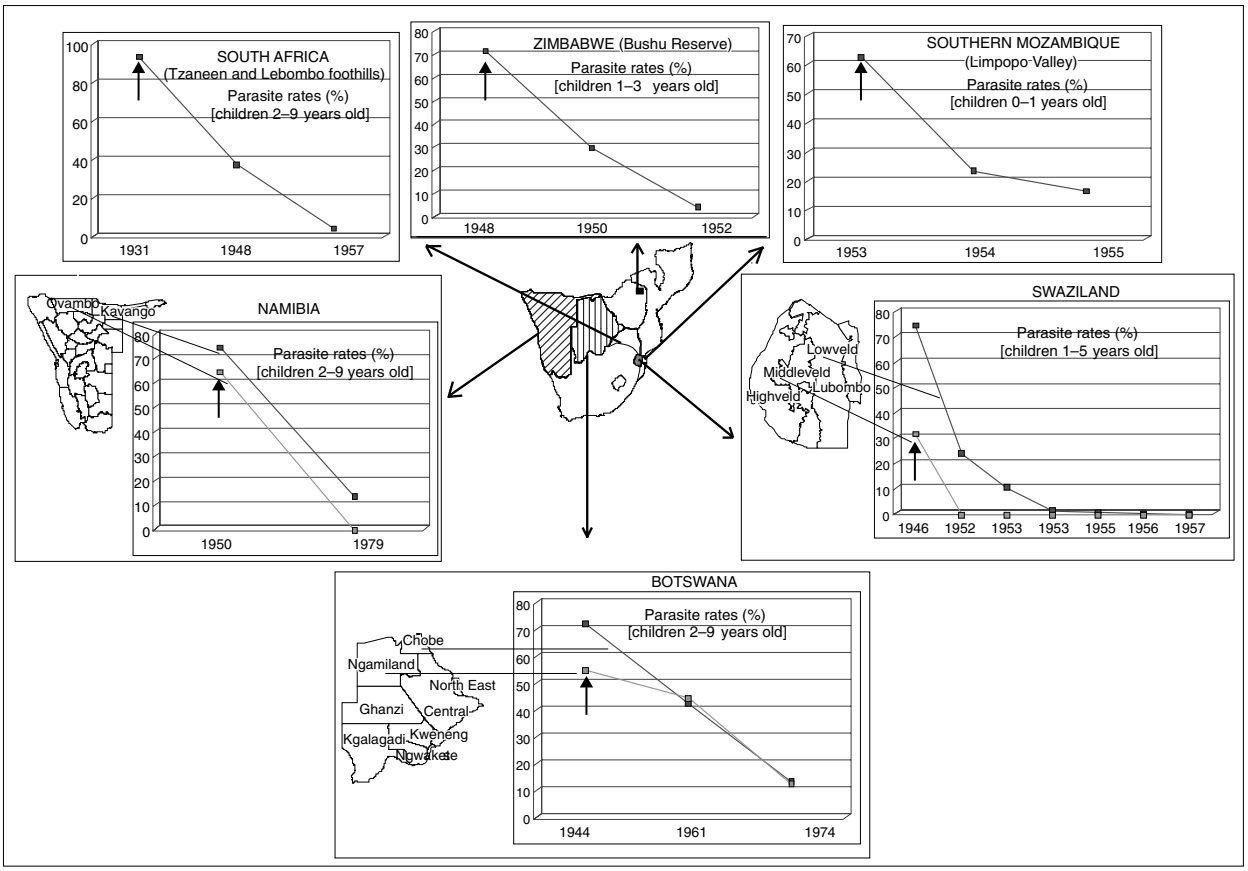

Figure 1 Parasite rates before and after the inception of malaria control by indoor residual spraying (IRS) (arrows show the start of IRS) in Swaziland, Botswana, Namibia, South Africa, Zimbabwe and southern Mozambique (for references on country data see main text).

later with synthetic pyrethroids (cyfluthrin) in houses with painted walls.

In Botswana, the National Malaria Control Programme was initiated in 1974. However, malarial interventions including spraying of human habitations have been reported as far back as the mid-1940s (Mastbaum 1944). In the 1950s, indoor house-spraying with DDT became the main vector control method (Freedman 1953). DDT remained the insecticide choice until 1971 when Fenitrothion was tried but abandoned again in 1972 because of low efficacy (Chayajabera *et al.* 1975). In 1973, residual spraying with DDT in the malarial districts of Ngamiland, Chobe and Francistown resumed, and in the 1980s a comprehensive vector control programme was organized which led to improved spraying coverage. In 1998, Botswana stopped the use of DDT and introduced pyrethroids (deltamethrin and lambda-cyhalothrin) as alternative insecticides as a consequence of a lack of availability of good quality DDT (Ministry of Health 1999).

In Namibia, residual spraying with DDT was first carried out in 1965. However, it was only in the 1970s that full coverage of the malarial regions (Ovambo, Kavango and Caprivi) was achieved (Hansford 1990). In 1991, a comprehensive malarial control programme was launched under the auspices of the NVDCP within the Ministry of Health and Social Services. To date residual spraying with DDT is being done in traditional housing, with carbamates (bendiocarb) applied only in western-type housing.

In Zimbabwe, indoor house-spraying pilot projects with DDT began as far back as 1945. A large-scale house-spraying programme was initiated in 1949 (Alves & Blair 1953, 1955). Spraying operations were later extended to other parts of the country as part of a 'barrier' spraying programme to prevent epidemics and to limit the spread to malaria-free areas. These operations continued until the late 1970s and after 1980 the malarial control programme was reviewed with the aim of reducing morbidity and mortality rather than only preventing epidemics (Taylor & Mutambu

Table 2 The start of indoor residual spraying (IRS) in countries in the southern African region, the start of malaria control programmes and changes in residual insecticides applied over time

Country	Year	Start of IRS and changes of insecticides over time
South Africa	1931	Pyrethrum (experimental IRS)
	1946	DDT and BHC introduced
	1958	Coverage of all malarial areas achieved
	1960–96	DDT
	1997–99	Deltamethrin (policy change)
	2000	DDT (resistance to pyrethroids)
Swaziland	1945	IRS introduced and programme launched
	1947–50	DDT (coverage of all malarial areas in 1950)
	1951–60	BHC (shortage of DDT) dieldrin tried but was costly
	1960–67	BHC and DDT (focal spraying)
	1968–2000	DDT (cyfluthrin in houses with painted walls)
Botswana	1946	IRS introduced (limited scale)
	1950–71	DDT (improved coverage)
	1972	Fenitrothion tried and abandoned (low efficacy)
	1974	Programme launched
	1973–97	DDT
	1998–2000	Deltamethrin and lambda-cyhalothrin (policy change)
Namibia	1965	IRS introduced (limited scale)
	1970	Coverage of all malarial areas achieved
	1965–2000	DDT (bendiocarb in western type residential areas)
Zimbabwe	1945	IRS introduced (pilot projects)
	1949	Programme launched
	1957–62	DDT and BHC
	1972–73	BHC (equally effective as DDT but cheaper)
	1974–87	DDT (resistance to BHC)
	1988–2000	Deltamethrin and lambda-cyhalothrin (policy change)
Southern Mozambique	1946	IRS introduced (selected southern areas)
	1946–56	DDT and BHC (coverage of all targeted areas in 1950)
	1960–69	DDT (only in Maputo region)
	1993	Deltamethrin and lambda-cyhalothrin (major towns)
	2000	Bendiocarb (selected southern areas)

For references on country data see main text.

1986). In 1988, DDT was replaced by deltamethrin and lambda-cyhalothrin due to the international lobby against persistent organic pollutants (Freeman 1995).

In Mozambique, residual house-spraying with DDT and BHC was first introduced in 1946 in the southern part of the country in the semi-urban area of Maputo city and in the rural area of the Limpopo Valley (Soeiro 1956; Ferreira 1958). Between 1960 and 1969, residual spraying with DDT was carried out in southern Mozambique (Maputo region) as part of the malarial eradication experiment (Schwalbach & de la Maza 1985). The escalation of civil war in the late 1970s led to a complete breakdown of malarial control measures. Following the cessation of hostilities in the 1990s, IRS mostly with lambdacyhalothrin and partly with deltamethrin was re-introduced, but only in suburban areas of most provincial capitals (Barreto 1996). In 2000, IRS with carbamates (bendiocarb) was re-introduced in the rural parts of Maputo province as part of the Lubombo Spatial Development Initiative (LSDI), a trilateral agreement among Mozambique, Swaziland and South Africa aimed at protecting communities against malaria in the Lubombo region in order to create a suitable environment for economic development and promotion of eco-tourism (Sharp *et al.* 2001).

Impact of indoor residual spraying

The introduction of indoor residual insecticide spraying had a huge impact on the malarial situation in the region, particularly immediately after its implementation (Figure 1). Generally, in most of the countries under review other control measures such as attempts at drug prophylaxis, environmental sanitation and larviciding were tried prior to IRS, but with limited success.

In South Africa, a dramatic reduction in number of malarial cases was observed after the first indoor spraying with pyrethrum in 1932 in the KwaZulu-Natal province (le Sueur *et al.* 1993). Malarial cases for the month of April (peak month) dropped from about 1400 in 1931 to about 1000 in 1932 and to below 100 in 1934. Dramatic declines in hospital admissions due to malaria were also reported in the malarial areas of the former Transvaal province of South Africa, from 1177 cases during the 1945–46 transmission season to 601 in 1946–47 coinciding with the availability of DDT in 1946, and falling to 454 in 1948 and to a low of 61 cases in 1951. Parasite rates in children aged 2–5 years in the Tzaneen and Lubombo foothills were reduced from 94% recorded in 1931 (Swellengrebel & de Meillon 1931) to 38% in 1948 (Ministry of Health 1948) and to 4.9% between 1956 and 1957 (Brink 1958).

In Swaziland, considerable gains were made shortly after the implementation of residual spraying with total parasite rates in children 1–5 years being reduced from 75% in 1946 to 24% ($n = 409$) in 1952, 11% in 1953, 1.7% ($n = 1639$) in 1954, 1.1% ($n = 438$) in 1955, 0.7% ($n = 2248$) in 1956 and 0.4% in 1957 (Mastbaum 1954, 1955, 1957a,b; Ministry of Health, unpublished data). A similar reduction had already been achieved in the middleveld areas over the past three seasons.

In Botswana, initial IRS with DDT in the mid-1940s and the intensified residual spraying campaign in the 1950s are evidenced by the low parasite rates recorded by WHO in 1960 and 1979 in previously hyper-endemic districts. In Chobe district, parasite rates in 2–9-year olds were further reduced from 43% ($n = 575$) in 1961–62 to 14% ($n = 222$) in 1973–74 and in Ngamiland from 45% ($n = 944$) to 13% ($n = 564$) (WHO 1962; Chayajabera *et al.* 1975).

In Namibia, after the first residual spraying with DDT in 1965, average parasite rates in 2–9-year olds in the malarial regions of Kavango and Ovambo declined tremendously, from 83% ($n = 74$) in 1950 to 14% ($n = 1115$) in 1979 and from 65% ($n = 35$) to 0.1% ($n = 978$), respectively. In the Caprivi district, a pre-control survey in 1966 recorded an overall parasite rate of 32% and this declined to 2% by 1967.

In the Bushu Reserve in Zimbabwe, parasite rates in children aged 1–3 years declined from 72% in 1948 to 30% in 1950 following residual spraying, and further to 4.7% in 1952 (Figure 1). The same general pattern was shown by other surveys where control measures had been introduced (Alves & Blair 1953). Similarly, in the Mazoe Valley when a residual spraying programme with DDT was introduced for the first time in 1945 as part of a pilot project, malarial cases declined from 100 in 1946 to two in 1950 at a hospital situated in a sprayed area compared with 62 in 1946 and 68 in 1950 at an adjacent hospital in an unsprayed area (Blair 1951).

Following the introduction of residual spraying with DDT in Maputo, southern Mozambique, in 1946 malarial admissions dropped from 16% to about 8% in 1947 and to a low of 3% and 1% in 1953 and 1954, respectively. In the same region in a rural area in the Limpopo Valley after the introduction of malarial control in 1947, parasite and spleen rates in children under 1 year declined from 62.7% and 59.4%, respectively, in 1953 to 23.6% and 21% in 1954 and to 17% and 1% in 1955. Only spleen rates were given for children 2–10-years old in 1953, and these stood at 53.2%. They dropped to 26.7 in 1954 and declined further to 13.7% in 1955 (Soeiro 1956). Recently, dramatic reductions in malarial transmission have also been reported in the Maputo region after a year of successful control of vectors by IRS as part of as part of the LSDI (Sharp *et al.* 2001).

The application of IRS also greatly altered the entomological situation in the malarial regions of South Africa, Swaziland, Zimbabwe and parts of southern Mozambique. The principal vectors of the *A. gambiae* complex and *A. funestus* were reduced to negligible levels, and while the former could still be found outdoors the latter completely disappeared in certain parts. *Anopheles gambiae* is a species complex initially identified by Paterson in the early 1960s (Paterson 1964). It was generally presumed that the endophilic and endophagic *A. gambiae* s.s. was well controlled and possibly eradicated over large areas. On the contrary, other members of this complex, namely the exophilic and zoophagic *A. quadrimaculatus* (a non-vector species) persisted and *A. arabiensis* survived and is currently considered responsible for the remaining malarial transmission in areas under effective IRS (Hansford 1972; Sharp *et al.* 1990).

Malarial situation over time

Over time major gains were made in most countries in the region as a result of large scale and sustained application of IRS. There was a shift in the geographical distribution of malaria coupled with a decline in the level of

transmission. In South Africa, malaria is now only found in the northern part of KwaZulu-Natal and in the low altitude areas of Limpopo and Mpumalanga (former Transvaal Province) (Sharp *et al.* 1988; le Sueur *et al.* 1993; Sharp & le Sueur 1996; le Sueur *et al.* 1996). In Swaziland, malaria is now confined to the lowveld area with occasional outbreaks in the middleveld (Ministry of Health 1991). In Botswana and Namibia, malaria still persists in endemic areas albeit at much reduced levels (Teklehaimanot *et al.* 1990; Ministry of Health 1999). In Zimbabwe, malaria was considered eliminated in the plateau area by 1956, and throughout the country transmission was brought down to very low levels (Taylor & Mutambu 1986). In Mozambique, although malarial transmission was never interrupted, dramatic reductions in malarial prevalence were achieved between 1960 and 1969, but mainly in the southern parts of the country where malarial control activities had been carried out since 1946 (Schwalbach & de la Maza 1985). Southern Mozambique has also benefited from recent vector control efforts by IRS (Sharp *et al.* 2001).

Recently collated parasite prevalence databases show that parasite rates in the countries under review have been kept at relatively low levels between the 1960 and 1980 (MARA/ARMA, unpublished data). Although this success was largely shaped by the quality and extent of IRS programmes, it was also strengthened by the development of good public health infrastructure coupled with effective malarial surveillance activities and improved socio-economic conditions. In addition, South Africa has also developed detailed maps of malarial risk areas to allow authorities to focus their spraying activities, thus facilitating cost-effective control (Sharp & le Sueur 1996; Booman *et al.* 2000; Martin *et al.* 2002).

However, since the mid-1980s these gains were being gradually eroded with malarial epidemics becoming frequent and more severe. In 1996, the entire region experienced one of the most severe epidemics recorded in recent times (le Sueur *et al.* 1996). The recent trend in the reduction of the impact of IRS has been attributed to a number of factors including environmental, biological and social constraints. Increased risk has been partly attributed to weather disturbances linked to global climatic events such as El Nino (le Sueur *et al.* 1996). The appearance of *Plasmodium falciparum* resistance to chloroquine in the mid-1980s (Deacon *et al.* 1994) and Fansidar resistance in South Africa (Bredenkamp *et al.* 2001) has contributed to an increase in malarial cases as treatment failure increased the pool of malarial infections for the following transmission season. Detection of *A. funestus* resistance to pyrethroids in KwaZulu-Natal, South Africa (Hargreaves *et al.* 2000) was a further reason for the reduced effectiveness of IRS. Behavioural avoidance of DDT sprayed surfaces by vectors due to its irritating effects also posed an effectiveness problem (Sharp *et al.* 1990). Social resistance to DDT application due to bedbug infestation, as they are resistant to DDT (Newberry & Jansen 1986) and replastering of sprayed walls because of the presence of DDT stains (Mnzava *et al.* 1998) reduced effective IRS coverage. Lack of proper supervision and/or skilled personnel is another mitigating factor because effective application of residual insecticides requires properly trained individuals. Population migration from uncontrolled areas also leads to the deterioration of malarial situation in neighbouring countries that have brought malaria under control (Delfini 1969; Sharp *et al.* 1988).

All these constraints coincide with the renewed interest in the control of malaria in sub-Saharan Africa. It is essential therefore that efforts be made to ensure that the effectiveness of IRS is not compromised, particularly in areas where it has been proved to work. Continued monitoring and evaluation of its impact is clearly of fundamental importance in this regard. For example, in South Africa this led to the detection of both insecticide and parasite resistance which led to policy change and improved effectiveness of control efforts. We also need to develop climate-based early warning systems to detect climate-driven epidemics and improve the impact of control efforts. International networking and cooperation towards strengthening malarial control programmes across the region is also of vital importance.

Today, with the availability of equally effective alternative interventions such as insecticide-treated (mosquito) nets (ITNs), choosing between IRS and ITNs is a matter of operational feasibility and availability of local resources (Lengeler & Sharp 2003). Appropriate application or integration of IRS with other interventions elsewhere on the continent has to be based on sound scientific research which takes into account the epidemiological setting, organizational capacity, social and financial considerations, as these in turn impact on operational feasibility and sustainability.

Conclusion

Evidence presented in this review confirms that malarial control by IRS has made epidemics less frequent and reduced malaria from hyper- to meso-endemicity and from meso- to hypo-endemicity at the southern fringe of transmission in tropical Africa. The development of large well-organized and well-funded control programmes in these areas led to selective and sustainable application of IRS over time.

Almost all the countries that successfully controlled malaria in southern Africa experienced an acceleration of economic growth immediately following the introduction of effective vector control measures with IRS. Countries that developed National Malaria Control Programmes during this phase and had built up human and organizational resources made significant advances towards malarial control. In addition, most southern African countries developed stronger health systems.

However, with the recent trends in malaria increasing and problems of drug and insecticide resistance, there is a need to find ways to improve sustainability, both financially and technically, if IRS is to maintain its role as an effective measure against malarial transmission. Already effective supplementary interventions such as ITNs and new drug therapies (artermisinin-based combinations) are available and the latter have been implemented to good effect in the republic of South Africa. Alternative vector control strategies such as rotational or mixed use of insecticides have also been proposed. South Africa has recently secured funding to carry out research on feasibility and effect of these strategies. New technologies using GIS as a platform to plan, implement and assess control activities are now available to help rationalize malarial control in time and space and hence minimize cost. To date, there is also a renewed interest and political commitment to controlling malaria in Africa through the Roll Back Malaria Partnership.

Indoor residual spraying is not a magic bullet, and its use in other areas should be planned carefully, after considering the major organizational, technical and financial implications. However, its track record in southern Africa and in many other areas of the world is outstanding and should certainly be considered when planning extended vector control activities in endemic areas.

Acknowledgements

We are grateful to Professor C. F. Curtis and Professor T. Smith for their valuable comments and suggestions on the manuscript. We also thank Ms Rosina Diseko of the Ministry of Health in Botswana and Dr Shiva Murugasampillay of the World Health Organization-Southern African Malaria Control Programme for their support and cooperation. Dr David Le Sueur, who has sadly died, critically revised the paper. Simon Kunene gave access to ministry of health documents in Swaziland, Richard Kamwi to those in Namibia, Shinaaz el Halabi and Dr Temba Moeti to those in Botswana, and Dr Stanley Midzi to those in Zimbabwe.

References

Alves W & Blair DM (1953) An experiment in the control of malaria and bilharzias. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **47**, 299–308.

Alves W & Blair DM (1955) Malaria control in Southern Rhodesia. *Journal of Tropical Medicine and Hygiene* **58**, 273–280.

Barreto A (1996) *Malaria in Mozambique – what had been done to control epidemics*. Department of Epidemiology, Ministry of Health, Maputo, Mozambique (unpublished).

Blair DM (1951) Report on malaria control in Southern Rhodesia. *Public Health* **15**, 100–103.

Booman M, Durrheim DN, la Grange K *et al.* (2000) Using a geographic information system to plan a malaria control programme in South Africa. *Bulletin of the World Health Organization* **78**, 1438–1444.

Bradley DJ (1991) Morbidity and Mortality at Pere-Taveta, Kenya and Tanzania, 1956–66: the effects of a period of malaria control. In: *Disease and Mortality in Sub-Saharan Africa* (eds RG Feachem & D Jamison) Oxford University Press, Oxford, pp. 248–262.

Bredenkamp BLF, Sharp BL, Durrheim DN & Barbes KI (2001) Failure of sulphadoxine-pyrimethamine in treating *Plasmodium falciparum* malaria in KwaZulu-Natal. *South African Medical Journal* **91**, 970–972.

Brink CJH (1958) Malaria control in the northern Transvaal. *South African Medical Journal* **32**, 800–808.

Chayajabera S, Sobti SK, Payne D & Braga F (1975) Malaria situation in Botswana: report on visit (December 1973–October 1974). WHO, Geneva (DOC.AFR/MAL/144)..

Deacon HE, Freese JA & Sharp BL (1994) Drug-resistant *Plasmodium falciparum* malaria in eastern Transvaal. *South African Medical Journal* **84**, 394–395.

Delfini DF (1969) *Report on short-term mission on malaria in Swaziland (26 February–23 May 1968)*. WHO, Geneva (WHO Document AFR/MAL/98).

Ferreira MJ (1958) *Report on malaria in Mozambique: analysis of the epidemiology, feasibility and planning of a malaria eradication campaign*. World Health Organization, Geneva (unpublished document).

Freedman ML (1953) *Malaria control*. The Botswana National Archives and Records Services (unpublished document).

Freeman T (1995) *A Review of the Epidemiology of Malaria Transmission and Distribution in Zimbabwe*. Blair Research Institute, Harare, Zimbabwe (unpublished document).

Hansford CF (1972) Recent trends in the control and treatment of malaria. *South African Medical Journal* **46**, 635–637.

Hansford CF (1990) *Malaria Control in Namibia. National Institute for Tropical Disease*. Department of National Health and Population Development, Tzaneen, South Africa (unpublished document).

Hargreaves K, Koekemoer LL, Brook BD, Hunt RH, Mthembu J & Coetzee M (2000) *Anopheles funestus* resistance to pyrethroid insecticides in South Africa. *Medical and Veterinary Entomology* **14**, 181–189.

Harwin RM (1969) Malaria control in Rhodesia. *Rhodesia Science News* **3**, 31–32.

Harwin RM (1979) Increase of malaria in Zimbabwe Rhodesia: fact or fiction? *Zimbawe Rhodesia Science News* **13**, 177–178.

Kouznetsov RL (1977) Malaria control by application of indoor spraying of residual insecticides in tropical Africa and its impact on community health. *Tropical Doctor* **7**, 81–91.

Lengeler C & Sharp B (2003) *Indoor Residual Spraying and Insecticide-Treated Nets: Reducng Malaria's Burden, Evidence of effectiveness for Decision makers*. Global Health Council, Washington, DC, pp. 17–24.

MARA/ARMA (1998) *Towards an atlas of malaria risk in Africa. First technical Report of the Mapping Malaria Risk in Africa/ Atlas du Risque de la Malaria en Afrique*. MARA/ARMA, Durban, South Africa. Available at http://www.mara.org.za.

Martin C, Bronwyn C, Fraser C & Sharp B (2002) The use of GIS-based information for malaria research and control in South Africa. *Health & Place* **8**, 227–236.

Martins P (1941) *Primeiro Dongress Medico de Laurenco Marques: contribuicao para a confeccao da carta sezonatica de colonia Mocambique, o paludismo na circunscricao do Maputo*. Sessoes das ceccoes, Parte social. Imprensa nacional de mocambique, Laurenco Marcus.

Mastbaum O (1944) Clinical and on entomological surveys in Botswana: Report by the Chief Medical Officer. The Botswana National Archives and Records Services (unpublished document).

Mastbaum O (1954) Observations of two Epidemic malaria seasons (1946 and 1953) before and after malaria control in Swaziland. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **48**, 325–331.

Mastbaum O (1955) *Organization and administration of malaria control in Swaziland: report of the malaria medical officer*. Department of Health, Swaziland (unpublished document).

Mastbaum O (1956) *Summary of activities of malaria control during 1955/56 season*. Report of the Malaria Medical Officer. Department of Health, Swaziland (unpublished document).

Mastbaum O (1957a) Past and present position of malaria in Swaziland. *Journal of Tropical Medicine and Hygiene* **60**, 119–127.

Mastbaum O (1957b) Malaria control in Swaziland. *Journal of Tropical Medicine and Hygiene* **60**, 190–192.

Medical Officer (1939) *Report on the Malaria Problem as Observed in Districts Served by Traveling Dispensary. No. 2*. The Botswana National Archives and Records Services (unpublished document).

de Meillon B (1936) The control of malaria in South Africa by measures directed against the adult mosquitoes in habitations. *Quarterly Bulletin of the Health Organization of the League of Nations* **5**, 134–137.

de Meillon B (1951) Malaria survey of South-west Africa. *Bulletin of World Health Organization* **4**, 333–417.

Ministry of Health (1948) *Annual Malaria Report*. Transvaal Department of Health, South Africa.

Ministry of Health (1991) *Annual Malaria Report*. Malaria control Unit, Department of Health, Swaziland.

Ministry of Health (1999) *Malaria, a manual for health workers in Botswana*. Epidemiology and Disease Control Unit, Community Health Services Division, Ministry of Health, Botswana.

Ministry of Health (2003) *National Malaria Update*. South African Department of Health.

Mnzava AEP, Ntuli VM, Sharp B, Ngxongo S, Mthembu JD & le Sueur D (1998) House spraying and replastering in KwaZulu-Natal. *South African Medical Journal* **88**, 1024–1028.

Najera JA (2000) Epidemiology in the strategy for malaria control. *Parassitologia* **42**, 9–24.

Najera JA (2001) Malaria control: achievements, problems and strategies. *Parassitologia* **43**, 1–89.

Newberry K & Jansen EJ (1986) The common bedbug *Cimex lactularius* in African huts. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **80**, 653–658.

Paterson HE (1964) Direct evidence of species distinctness of form A, B and C of *A. gambiae* complex. *Rivista di Malariologia* **43**, 191–196.

Payne D, Grab B & Fontaine RE (1976) Impact of control measures on malaria transmission and general mortality. *Bulletin of the World Health Organization* **54**, 369–377.

Roberts DR, Manguin S & Mouchet J (2000) DDT spraying and re-emerging malaria. *Lancet* **356**, 330–332.

SAMC (2000) *Malaria methods: towards better informed malaria control in Southern Africa*. A Southern African Malaria Control (SAMC)/World Health Organization (WHO) Bulletin, Harare, Zimbabwe.

Schoeman JJ (1951) Malaria incidence. *Public Health* **15**, 148–151.

Schwalbach JFL & de la Maza MC (1985) *A malaria em Mozambique (1937–1973)*. Republica Popular de Mocambique, Ministerio da Saude, Maputo, Mozambique.

Sharp BL & le Sueur D (1996) Malaria in South Africa – the past, the present and selected implications for the future. *South African Medical Journal* **86**, 83–89.

Sharp BL, Ngxongo S, Botha MJ, Ridl F & le Sueur D (1988) An analysis of 10 years of retrospective malaria data fron the KwaZulu areas of Natal. *South African Journal of Science* **84**, 102–106.

Sharp BL, le Sueur D & Becker P (1990) Effect of DDT on survival and blood feeding success of *Anopheles arabiensis* in northern KwaZulu-Natal, South Africa. *Journal of the American Mosquito Control Association* **6**, 197–202.

Sharp BL, Streat E, Kleinschmidt I *et al.* (2001) *Lubombo Spatial Development Initiative Malaria Control Programme. South African Malaria Conference Magoebaskloof*. Northern Province Department of Health and Welfare, South Africa.

Soeiro A (1956) *Malaria in Mozambique with a special reference to its control in a mainly urban region (lorenzo Marcus) and in a mainly rural region (Lumpompo valley)* (unpublished document).

le Sueur D, Sharp BL & Appleton CC (1993) Historical perspective of the malaria problem in Natal with Emphasison the period 1928–1932. *South African Journal of Science* **89**, 232–239.

le Sueur D, Sharp BL, Gouws E & Ngxongo S (1996) Malaria in South Africa. *South African Medical Journal* **8**, 936–939.

Swellengrebel NH & de Meillon B (1931) Malaria investigations in some parts of Transvaal and Zululand. *Publications of the South African Institute for Medical Research* **VI**, 245–274.

Taylor P & Mutambu SL (1986) A review of the malaria situation in Zimbabwe with a special reference to the period 1972–1981. *Transactions of the Royal Society of Tropical medicine and Hygiene* **80**, 12–19.

Teklehaimanot AT, Cano VI, Rietveld AEC (1990) *WHO Malaria (CTD/MAL) Mission to Namibia, 24 July 1990*. World Health Organization, Geneva.

WHO (1962) *Report of the World Health Organization Advisory Team on Malaria Eradication No.2*. Bechuanaland Protectorate July 1961–August 1962 (unpublished document).

Wilson DB, Garnham PCC & Swellengrebel NH (1950) A review of hyperendemic malaria. *Tropical Disease Bulletin* **47**, 677–696.

Authors

Musawenkosi L. H. Mabaso (corresponding author) and **Brian Sharp**, Malaria Research Programme, Medical Research Council, PO Box 70380, Overport, Durban, South Africa. Tel.: +27 31 203 4701; Fax: +27 31 203 4704; E-mail: mabasom@mrc.ac.za, sharpb@mrc.ac.za

Christian Lengeler, STI, Socinstrasse, 4002 Basle, Switzerland. Tel.: +41 61 284 8221; Fax: +41 61 271 7951; E-mail: lengeler@unibas.ch