Impact of DDT re-introduction on malaria transmission in KwaZulu-Natal

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Objectives. To determine whether the re-introduction of DDT in KwaZulu-Natal had any effects on malaria transmission in the province.

Design, setting and subjects. The 2000 malaria epidemic in KwaZulu-Natal has been attributed to pyrethroid-resistant anopheles mosquitoes in the area. Previous studies have shown that these mosquitoes are still susceptible to DDT. To determine whether DDT re-introduction had any impact on malaria transmission in KwaZulu-Natal, the following variables (pre- and post-epidemic) were investigated: (*i*) the number of reported cases; and (*ii*) the distribution of *Anopheles funestus* in relation to the insecticides sprayed.

Outcome measures. The notified malaria cases and the distribution of *A. funestus* were measured to determine the effects of DDT re-introduction on malaria transmission.

Results and conclusion. After DDT re-introduction, the number of malaria cases decreased to levels lower than those recorded before the epidemic. *A. funestus* appears to have been eradicated from the province. The combination of an effective insecticide and effective antimalarial drugs in KwaZulu-Natal has resulted in a 91% decline in the malaria incidence rate. Unfortunately the continued exclusive use of DDT within the malarious areas of the province is threatened by the emergence of insecticide resistance.

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Malaria remains a serious health problem in South Africa. Recent estimates suggest that 4.8 million people (10% of the population) are affected by the disease.[1] In South Africa malaria is categorised as seasonal and unstable, with the mosquito *Anopheles arabiensis* the major malaria vector, while the parasite *Plasmodium falciparum* accounts for the majority of malaria-related morbidity and mortality.[1]

In a survey of South African anopheles, Ingram and De Meillon[2] found the principal malaria vectors to be *A. gambiae* and *A. funestus*. Initially a kerosene pyrethrum mixture was used to control these mosquitoes, but in 1946 this mixture was replaced by DDT,[3] which was used both as an adulticide and larvicide.[4] As a consequence of sustained DDT use, the predominantly indoor resting mosquito species *A. gambiae* s.s. and *A. funestus* s.s. were eliminated from South Africa.[4] However, because of mounting pressure from environmentalists and increasing scientific evidence of the adverse environmental effects of DDT, its use as a larvicide was discontinued in the early 1960s and it was prohibited for agricultural use in 1976.[5]

Use of DDT for malaria control purposes was phased out by 1996.[5] Reasons for discontinuing DDT spraying included mounting pressure on the government to protect the environment from hazardous chemicals, resistance to DDT spraying by the communities within malaria risk areas who were opposed to the residue being left on sprayed surfaces, and the discovery of a suitable alternative insecticide, deltamethrin (Department of Health – unpublished internal communication, 2000). Deltamethrin, a synthetic pyrethroid, was found to be as cost effective as DDT; it had a residual life that spanned the malaria season in South Africa, and was considered environmentally friendly.[6]

Somewhat perplexing was the increase in malaria cases recorded at health facilities during the winter months (usually a period of low malaria transmission) following the introduction of pyrethroid insecticides. Between 1996 and 1999 reported malaria cases increased from an average of 600 cases per month to over 2 000 cases per month (Department of Health – unpublished data, 2000). Intensive entomological surveys, conducted with the aim of identifying the potential cause of this increase, revealed the presence of *A. funestus* in pyrethroid-sprayed houses.[7] Further studies on these mosquitoes showed them to be resistant to pyrethroids but still susceptible to DDT.[7]

After consultation with experts, both local and international, the Department of Health recommended that DDT be used to control this resistant vector, as it was the cheapest and most effective insecticide available (Department of Health – unpublished Malaria Advisory Group minutes, 2000). Between 1996 and 1999 pyrethroid insecticide spraying was carried out in all structure types, but following the re-introduction of DDT in March 2000 pyrethroids were only used in Western-type structures (cement-plastered or painted), while DDT was used in traditional (mud, reed or wood) structures (KwaZulu-Natal Malaria Advisory Group – unpublished minutes, 2000). It is therefore essential to determine whether DDT re-introduction

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has had an impact on malaria transmission, both in terms of reducing malaria case numbers and eliminating *A. funestus* from the province.

Methods

This study was conducted in malaria-endemic regions of KwaZulu-Natal. To facilitate the implementation of interventions the malaria epidemic region is divided into administrative areas. In this study the term 'area' refers to the malaria control spatial divisions and not to geographical divisions.

Since malaria is a notifiable medical condition, all malaria cases detected at provincial health facilities are reported monthly to the national Department of Health. Reported cases are based on definitive diagnosis, using either rapid tests or microscopy. Malaria morbidity data for this study were obtained from both the national and the KwaZulu-Natal Departments of Health.

Data regarding insecticide usage in the epidemic areas were obtained from the Geographical Information System (GIS) maintained at the Medical Research Council. Geographical positioning system (GPS) co-ordinates, the type of material used to construct the homestead, and the insecticide used were recorded when homesteads were visited by surveillance officers of the KwaZulu-Natal Malaria Control Programme.

The entomological surveillance team of the KwaZulu-Natal Malaria Control Programme collected data on *A. funestus* distribution within the province. Following World Health Organization (WHO)[8] procedures, window exit traps and pyrethrum knockdown spray catches were used to monitor adult anopheles mosquito prevalence. Although extensive collections were undertaken in the malaria-affected areas of the province, *A. funestus* mosquitoes were found in selected areas. Entomological data were used to determine the effect of DDT on the distribution of *A. funestus* in the province by cross-referencing the insecticide data with the distribution data.

The 1996 - 2002 malaria morbidity data were analysed using inferential statistics.

Results

Case data

The disease trend for KwaZulu-Natal from 1980 to 2003 shows that the burden of disease has increased markedly over the past 24 years (Fig. 1). Malaria case data obtained from the Malaria Information System show that there was a dramatic increase in the number of malaria cases reported soon after the spraying of DDT was discontinued at the end of 1995. The increase in cases from the mid-1990s is readily apparent and this coincides with the period when DDT was not used in the province. However, after DDT use was reintroduced in March 2000 there was a huge decrease in the number of cases from approximately 42 000 in 2000 to less than 2 100 in 2002.

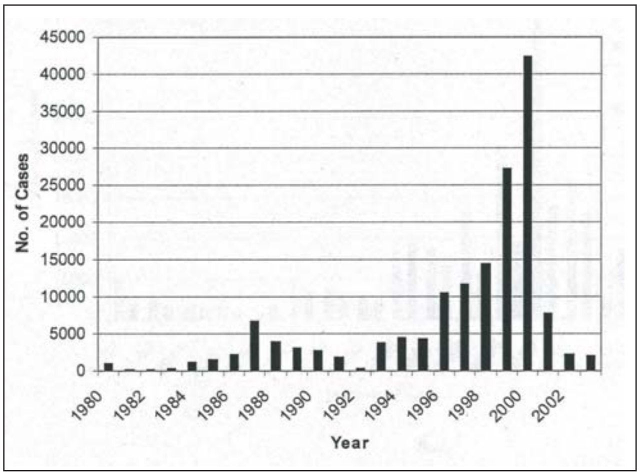

Fig. 1. Malaria trends in KwaZulu-Natal, 1980 - 2003.

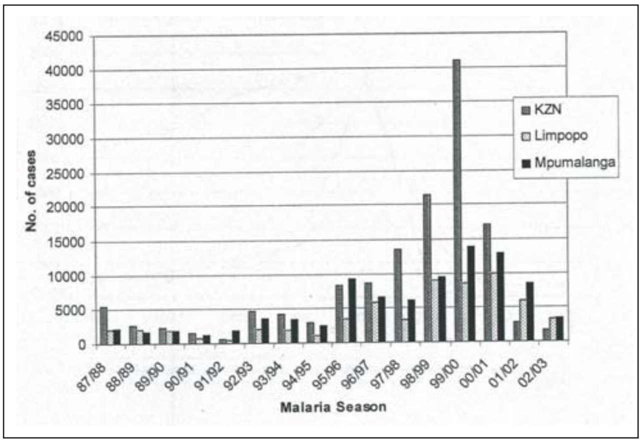

Fig. 2. Malaria cases in the three malaria-affected provinces.

A comparison of the malaria cases reported from the three malaria-affected provinces showed that between 1987 and 2001 the province reporting the highest number of cases was KwaZulu-Natal (Fig. 2). Mpumalanga reported the second highest number, with Limpopo recording the lowest number. However, during the 2001/2002 and 2002/2003 malaria seasons KwaZulu-Natal recorded the lowest number of cases, while the general trend in the other provinces was maintained.

Seasonal KwaZulu-Natal malaria case data from 1987 showed that reported case numbers peaked during the 1999/2000 malaria season (Fig. 2). A decreasing number of cases were reported in subsequent malaria seasons, with the lowest number of cases being reported during the 2002/2003 season (Fig. 2). This decline in case numbers coincided with DDT re-introduction. A comparison of the case data from before the reintroduction of DDT (1996 - 1999) and after the reintroduction of DDT (2000 - 2004) showed that there was a significant decrease in the cases reported following the re-introduction of DDT ($t = 3.720$, $p < 0.003$, 95% confidence interval (CI): 2 363.99 - 9 212.85)

Entomological data

Entomological data for the period under review showed that *A. funestus* was present in the north-eastern parts of KwaZulu-Natal bordering the highest malaria-risk areas in Mozambique where this vector species is commonly found. However, the only member of the *A. funestus* species complex implicated in malaria transmission in South Africa, *A. funestus* s.s was found in only 3 areas, namely Mlambo, Makanis and Ndumu (Keith Hargreaves – personal communication, 2003).

A. funestus influenced malaria transmission in certain areas of KwaZulu-Natal after developing resistance to pyrethroid insecticides. Malaria trends and control strategies in areas where members of the *A. funestus* species complex were found were analysed to assess the impact, if any, of DDT re-introduction on malaria transmission.

Situation analysis of areas with *A. funestus*

Case data

As expected, most malaria cases were reported from the highest-risk malaria areas in northern KwaZulu-Natal, namely Ndumu and Makanis (Fig. 3). Malaria case numbers peaked in all areas, with the exception of Shemula in 2000 which coincided with serious flooding of the region. Following the use of DDT in 2000, there was a significant decrease in the annual number of malaria cases compared with the pre-epidemic morbidity ($F = 5.701$, $p < 0.02$) in these areas. However, the number of cases fell to below 500 in all areas except for Mamfene. Mamfene reported almost twice as many cases as all the other areas during 2001. This anomaly was further explored using the insecticide data.

Insecticide data

In most areas where *A. funestus* mosquitoes were found more than 50% of the structures were sprayed with DDT, except for Mamfene where only 42% of structures were sprayed. The

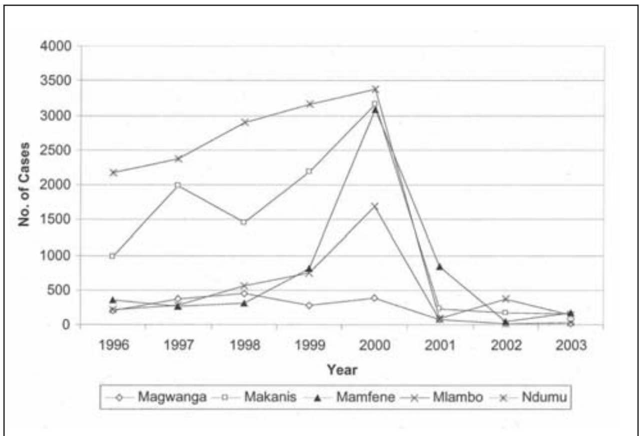

Fig. 3. Malaria case data for the areas where members of the A. funestus *group were collected in northern KwaZulu-Natal.*

Table I. Different structure types found in the *A. funestus*-infected areas

Area	No. of traditional structures (%)	No. of Western structures (%)
Mlambo	4 991 (55)	4 037 (45)
Magwanga	1 200 (58)	868 (42)
Makanis	2 201 (56)	1 724 (44)
Mamfene	7 046 (42)	9 489 (58)
Ndumu	5 248 (51)	5 117 (49)
Shemula	7 091 (51)	6 729 (49)

number of structures that required spraying was highest in Mamfene ($N = 16\ 535$), of which only 7 041 were traditional structures. Comparing the number of structures in the different areas it is evident that Mamfene, which had the highest number of structures to be sprayed with DDT (Table I), required the most amount of time to complete the spraying. The effect of the DDT was diluted because of the higher number of pyrethroid-sprayed structures in the area (Table I). This might explain why this area took the longest time to respond to DDT spraying.

Discussion

Archival malaria case data show that low levels of malaria transmission have occurred in South Africa since the early 1970s. A significant increase in the number of malaria cases was detected in KwaZulu-Natal following the discontinuation of DDT use in 1996 and the discovery of a pyrethroid-resistant vector mosquito species during the 1999/2000 epidemic. With the increasing burden of malaria morbidity and on the advice of experts, the national health department took the decision to return to DDT indoor residual spraying in March 2002. The effect of spraying was immediately made evident by the rapid decline in the number of cases reported from high-risk areas treated with DDT. A further decrease in malaria incidence occurred after the mop-up spraying in May 2000. It was evident that DDT contributed significantly to this decrease in morbidity since it was the only variable to have changed at the peak of the epidemic. Further gains in malaria control were made following the introduction of artemisinin-based combination therapy in February 2001.

The higher than expected number of winter cases of malaria was the first indication that *A. funestus*, which breeds and transmits malaria throughout the year, had re-invaded KwaZulu-Natal. Members of the *A. funestus* complex were found in 6 high-risk malaria-transmission areas in northern KwaZulu-Natal and in 1 low-transmission area, Dukuduku forest. Of the high-risk areas, Ndumu, Makanis and Mamfene have the highest risk rating. Although the first round of DDT spraying decreased malaria significantly in these 3 areas, the decrease in Mamfene was not as great in the other 2 areas. A malaria-area level analysis of structure types showed that in

Mamfene more structures were sprayed with pyrethroids than with DDT. Since *A. funestus* mosquitoes were resistant to pyrethroids, they were still able to feed inside pyrethroid-sprayed houses.

Since DDT was re-introduced, entomological surveillance teams have not found a single *A. funestus* mosquito in northern KwaZulu-Natal despite intensive collections in the malarious areas (Keith Hargreaves – personal communication, 2003). This is indicative that the vector has once again been eliminated from the province through the use of DDT. These findings corroborate those of Romi *et al*.,[9] who showed that in Madagascar *A. funestus* abundance and distribution was dramatically reduced as a consequence of indoor DDT application. Madagascar is the only other country besides South Africa to have re-introduced DDT for indoor residual spraying after it had been phased out.[10]

Although it can be argued that other factors such as the introduction of an effective drug and low rainfall could have contributed to the decrease in the number of malaria cases being reported, DDT spraying resulted in marked declines in cases reported immediately after the floods and before combination drug therapy was introduced. Vaughan Williams[11] attributed the decrease in malaria cases primarily to effective indoor residual spraying and pointed out that after the re-introduction of DDT, and despite heavy rains in November 2000, the malaria incidence dropped in December 2000, a time when it usually increases.

Despite the successes achieved in the past 3 years, the continued use of DDT in KwaZulu-Natal is being threatened due to the emergence of resistance,[12] and pressure from the communities. Alternatives to DDT house spraying do exist but they are not practical in most situations. Although promising, insecticide-treated bed nets have limited values in that they protect individuals under the net and not the entire household. Integrated vector management, an ecological approach against mosquitoes, is as yet only an experimental strategy that has never been used in a national malaria control programme.[13]

In South Africa DDT is the only insecticide with an 8-month residual life, and to which the vectors are currently susceptible. All other insecticides either have a short residual life necessitating two or more spray rounds and/or the resistance/susceptibility of these insecticides is unknown. The WHO[14] states that a premature shift to a more expensive and less effective alternative would be ill advised in terms of malaria control. Discontinuing DDT use without effective alternatives would have serious negative effects on the control of malaria and health status of the inhabitants in northern KwaZulu-Natal, as seen after the initial phasing out of DDT in 1996.

From this study it can be concluded that DDT re-introduction impacted positively on malaria control in KwaZulu-Natal by controlling the spread of the *A. funestus* mosquito. The phenomenal success in reducing malaria by 91% is attributed to many factors including the re-introduction of DDT, the introduction of artemisinin-based combination therapy and cross-border control initiatives. However, it should be borne in mind that artemisinin-based combination therapy would be far more costly without effective vector control, and hence the two strategies complement one another in reducing the burden of malaria.

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