Role of residual spraying for malaria control in Belize

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ABSTRACT: We studied the impact of reduced residual spraying in Belize by developing a logistic regression model on relationships between numbers of houses sprayed (mostly with DDT) and numbers of malaria cases. We defined the “minimum effective house spray rate” (MEHSR) as the level of spraying that will prevent increases in malaria rates for a defined population. Under the total coverage approach (all houses sprayed), the MEHSR for Belize was 134.6. The model also showed that the odds for decreasing malaria is 1.086 for each increase of 10 houses sprayed per 1000 population. In further testing, highly significant and differential changes in malaria rates were documented for paired groups of years with house spray rates that were either above or below the MEHSR. Numbers of malaria cases since 1995 are used to show how stratification methods are used in Belize to spray fewer houses (at levels below the MEHSR of 134.6). Journal of Vector Ecology 27(1): 63-69. 2002.

Keyword Index: Malaria, DDT, residual spraying, Belize, Central America, malaria control.

INTRODUCTION

Falciparum and vivax malaria infections were severe public health problems in Belize prior to the beginning of DDT spraying. Over 10% of all certified hospital/dispensary deaths in Belize were due to malaria in 1930 (Scott, 1932). In 1939, an estimated 40% of all hospital patients and 50% of the population outside the urban center of Belize City had malaria (Faust 1949).

The systematic collection of malaria data was started in 1959 but malaria rates in Belize were already low because of earlier uses of DDT. DDT was used and malaria rates declined throughout the 1950s (PAHO 1960). As described in the national plan (British Honduras 1956) for malaria eradication, UNICEF helped Belize begin spraying in 1950. This program reportedly reduced malaria rates by 80% even before the eradication program was initiated in 1957. With the initiation of the eradication program in 1957, the heavy burden of malaria was lifted from Belize (Brown et al. 1976). By 1963, the disease had virtually disappeared and the entire country was placed in a “consolidation phase” the same year (PAHO 1986). Even the nature of malaria infections changed as a result of the house spray program. Falciparum malaria infections exceeded vivax malaria infections by more than 3-fold in 1959 (PAHO 1994). Today, vivax malaria is consistently the dominant form of human malaria and infections of \textit{Plasmodium falciparum} occur infrequently (e.g., average annual falciparum index [AFI] from 1985 to 1992 was 0.7).

Although the annual levels of spray effort varied greatly, spraying was almost continuous up through the early 1990s. As noted by Attaran et al. (2000), Belize was pressured to stop using DDT by the United States Agency for International Development. Opposition to public health use of DDT also came from environmental and agricultural advocacy groups. In 1988, Belize banned the use of DDT for agriculture and greatly reduced its use in public health. Belize abandoned nationwide coverage with routine house spraying the
following year, while continuing limited focal spraying operations in areas experiencing high rates of malaria. Spray operations were greatly limited in 1990-1991 (PAHO 1994) and malaria rates increased. Despite the trend of increasing malaria, the National Pesticide Control Board temporarily suspended all use of DDT for malaria control in 1993 (Dr. Vanzie, personal communication). The Government of Mexico provided selective DDT spraying in bordering regions of Belize from 1993-1995.

The quantitative relationships between DDT spraying and malaria rates in Belize are the subject of this report. Data for 36 years of malaria control activities in Belize have been analyzed. Data sources included statistics compiled by the Pan American Health Organization (PAHO 1994, 1995, 1996, 1997 and 1998) and unpublished data from the Vector Control Program in Belize. We introduce the concept of a “minimum effective house spray rate” (MEHSR) as a baseline for the total coverage approach to malaria control. The MEHSR is that level of spraying that will prevent increasing malaria incidence. Data for Belize are analyzed in a logistic regression model to precisely define the MEHSR. Under total coverage, all houses in endemic areas are supposed to be sprayed. The results of the total coverage approach to spraying, which ended in 1995, are then compared with a stratification approach that was used from 1996 to 1998. After 1995, both DDT and deltamethrin were used for residual spraying; but emphasis was still on use of DDT.

The three major parameters discussed in this paper are the annual parasite index (API), the house spray rate (HSR), and the annual blood examination rate (ABER). The three indexes are based on total national population with API being the annual number of slide positive cases per 1000 population, the HSR being the annual number of houses sprayed per 1000 population and ABER being the annual number of slides examined per 100 population. Technically, the HSR is a measure of house spraying events, not a measure of number of houses sprayed. In a conventional spray program, each house was sprayed 2 times each year. Thus, an HSR of 100 means 50 individual houses were sprayed per 1000 population (not 100 houses).

MATERIALS AND METHODS

We employed published methods for standardizing ABERs, and the standardized ABER values were then used to develop standardized APIs (Roberts et al. 1997, Attaran et al., 2000). The average ABER from 1965 through 1979 was used as a standard value. The years 1965 to 1979 were selected because effective levels of surveillance and control of malaria were maintained during those years. The average ABER was used to standardize the APIs.

Total Coverage

The total coverage approach to malaria control meant that all houses within endemic areas were sprayed twice each year with DDT at the rate of 2 g/m² of wall surface. Annual parasite indexes were graphed across years from 1959 to 1994 to show fluctuations and patterns of malaria incidence in Belize.

A logistic regression model was developed within SAS (SAS Institute, Cary, NY) that employs the HSR as a predictor variable and a binary response variable that was derived from standardized API data. A binary response variable was obtained by examining the change in APIs from one year to the next. A given year was assigned a value of “0” if API increased the following year, and a “1” if API declined the following year. Binary data on malaria indexes were arrayed against corresponding HSRs over 34 years, up through 1993, and used in the logistic regression model to evaluate impact of numbers of houses sprayed in one year on numbers of cases the following year.

To visualize the interactions encompassed in the logistic regression model, relative to the MEHSR, direct interactions between control measures and numbers of malaria cases were plotted as yearly API and HSR data points on y- and x-axes, respectively. Differences in malaria rates between groups of years, as identified in this graph, were compared with rank-order statistics and tested for significance in the Mann-Whitney test (Siegel 1956).

Total coverage versus stratification

The impact of total coverage (1959 to 1995) versus the stratification approach (1996 to 1998) for malaria control was evaluated by comparing the results of house spray rates used during the two intervals of time (1959 to 1993 versus 1996 to 1998).

RESULTS

Total coverage

Systematic collections of malaria data in Belize were started in 1959, but malaria rates were already low because of earlier uses of DDT. As shown in Figure 1, malaria indexes increased from 1978 to 1995 and again from 1992 to 1994. Belize went from an annual parasite index of < 1.0 in the mid-1970s to a standardized API of 38.5 in 1995.

The logistic regression model was used to define the impact of malaria control measures for 34 years of
malaria control data. The model is
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\log \left( \frac{p}{1-p} \right) = -1.1156 + 0.00829 \times \text{HSR}; \text{ where } p = \text{probability of decreasing malaria.} \]
The Hosmer-Lemeshow test (Hosmer and Lemeshow 1989) showed a significant fit of the model to the data \( \left( H_0 \right. \) model fits the data, \( p = 0.59 \), so \( H_0 \) is not rejected). We have defined a threshold level of spraying that will prevent increases in numbers of malaria cases as the minimum effective house spray rate (MEHSR). The MEHSR value for Belize was 134.6/1000 population. This model suggests that an HSR <134.6 was associated with increasing malaria and an HSR > 134.6 was associated with decreasing malaria during the following year. For 17 of 36 years the HSR was sufficient to reduce the malaria index during a subsequent year. Using this model, the odds for decreasing malaria are 1.086, which equates to \( 10^{0.00829} \), for each increase of 10 houses sprayed per 1000 population.

Figure 2 illustrates the functional relationship between higher house spray rates and reduced malaria. This plot identified 3 pairs of sequential year groups (e.g., year groups A and B, C and D, and E and F). For each pair of sequential year groups, one group is above (e.g., groups A, C, and E are above) and one group is below the MEHSR (represented by a vertical line intersecting the x-axis in Figure 2).

Differences in malaria indexes between year groups were analyzed with the Mann-Whitney test (Siegel 1956). The groups occurred in chronological order and were tested in the same order. We employed a directional hypothesis, viz., malaria indexes for year group A are stochastically larger than indexes for year group B. The same hypothesis was employed with tests for year groups C versus D, and E versus F. We rejected the hypothesis in the test with groups A versus B (\( p = 0.2 \)), accepted the hypothesis for test of C versus D (\( p < 0.002 \)), and accepted the hypothesis for test of E versus F (\( p < 0.001 \)).

Total coverage versus stratification
Stratification consisted of spraying the 10 most malarious villages in each of 6 districts. This approach resulted in approximately 24,000 house-spraying events; which, for a population of 230,000 inhabitants, translates into an HSR of 104. This HSR was lower than the minimal effective HSR of 134.6. With an HSR of 104, there was a progressive reduction in numbers of malaria cases from the high of 10,400 in 1994; 9,413 in 1995; 6,324 in 1996; 4,014 in 1997; and 2,000 cases in 1998. After 1995, DDT and deltamethrin were both used for spraying, although major emphasis was still placed on use of DDT.

DISCUSSION
As we described, our synthesis of information is largely based on data reported by the Ministry of Health in Belize, and compiled and reported by the Pan American Health Organization for the period 1959 to 1996. We understand that these data can be characterized as weak. However, the link between numbers of houses sprayed with insecticides and malaria incidence is a powerful relationship as defined in data from many countries and environmental settings within the Americas (Roberts et al. 1997). Just as it is obvious when DDT-sprayed houses function to reduce malaria incidence, it is equally obvious that malaria incidence increases when these control measures fail or when spray coverage is not adequate.

Events in Mexico from 1980 to 1985 (PAHO 1994); Peru from 1989 to 1998, as reported by Guarda et al. (1999); and Belize show that malaria can intensify and spread rapidly when house spray programs are reduced or eliminated. These examples, along with analyses reported by Roberts et al. (1997, 2000), provide clear evidence that malaria is not only increasing in numbers of cases but it is also increasing in geographical distribution. Mouchet et al. (1997, 1998) reported similarly close associations of increasing malaria with reduced numbers of houses sprayed with DDT for Madagascar and areas of Africa. Observations by Mouchet et al. (1998) on the use of DDT for malaria control in Madagascar have now been confirmed and more fully documented by Jambou et al. (2001).

Many environmental, biological, social and economic factors influence numbers of malaria cases. However, our logistic regression model showed that reductions in numbers of houses sprayed with DDT were associated with increased numbers of malaria cases. Relationships between the two parameters were strong and allowed us to define, for total coverage, an MEHSR of 134.6. Based on our model, spraying 134.6 houses per 1000 population will prevent increases in numbers of cases. The model also defined a 1.086-fold decrease in malaria risk with each 10-unit increase in numbers of houses sprayed per 1000 population.

Figure 2. Standardized annual parasite indexes (APIs) versus annual house spray rates (HSRs) for Belize from 1959 to 1995. Standardization procedure described by Roberts et al. 1997. The API is the annual number of slide-diagnosed cases of malaria per 1000 population. Houses were sprayed with DDT and the HSR represents the number of house-spraying events/year/1000 population. A logistic regression model \( \log\left(\frac{p}{1-p}\right) = -1.1156 + 0.00829 \times \text{HSR} \) was used to define the minimum effective house spray rate (MEHSR), which equates to a standardized HSR of 134.6 (illustrated with vertical line intersecting the x-axis). Differences in malaria indexes between sequential year groups were tested with the Mann-Whitney test (Siegel 1956). Differences between year groups A and B were not significant (p=0.2). Differences between year groups C and D, and E and F were highly significant (p<0.002 and p<0.001, respectively). Data extracted from Pan American Health Organization reports (PAHO 1994 and 1995).
malaria indexes remained low during 1963 and 1964, but started to increase afterward. The very low numbers of malaria cases meant there were few gametocyte donors, so there was limited potential for malaria transmission. Also, groups A and B were small, spanning only 3 and 4 years, respectively. The factors of few years plus few gametocyte donors at the beginning of group B years probably accounted for the absence of statistically significant differences in malaria indexes between the two groups of years. Subsequent year groups (e.g., C-D and E-F) covered a minimum of 6 years each, so greater changes in malaria indexes occurred with changes in house spray rates.

Increased malaria in 1966 resulted in increased spraying during group C years and malaria indexes dropped. After 1973, reduced levels of spraying during group D years allowed malaria indexes to spiral upwards, as shown with the dotted arrows connecting data points for sequential years (Figure 2). These conditions resulted in highly significant differences in malaria indexes between groups C and D. The upward spiral ended after 1983. Spraying was increased above the MEHSR during years for group E. The period from 1984 to 1989 was characterized with lower and more stable malaria indexes. Spraying was greatly reduced after 1989 and this launched the most recent period of increasing malaria. Differences in malaria indexes between E and F year groups were highly significant.

As stated above, our analyses targeted relationships between numbers of houses sprayed with DDT and numbers of malaria cases. Our logistic regression model quantified the relationship for Belize and a significant fit of the model to actual data was obtained. Additionally, we found highly significant differences in malaria indexes between groups of years with HSRs above or below the MEHSR. In combination, these findings evidence a cause-effect relationship between numbers of malaria cases and numbers of houses sprayed with DDT in Belize.

Since a high proportion of the population in Belize is thought to be at risk of malaria (PAHO 1994), the MEHSR for Belize is very high. Given that the HSR is based on total population, the MEHSR would be much lower for countries where only a small fraction of population is actually at risk of malaria, such as Brazil.

Reduced residual spraying in Belize not only allowed re-emergence of vivax malaria, it also allowed an increase in infections of *P. falciparum*. The incidence of falciparum malaria increased in 1992, 1993 and 1994 (e.g., annual falciparum indexes of 0.89, 1.22 and 1.9, respectively) (PAHO 1994). These data should be a warning that falciparum malaria can re-emerge with de-emphasis of residual spraying, even in Central America.

During the time of increasing malaria, Belize examined options for spraying with alternative insecticides. Deltamethrin was thought to be the primary candidate. Depending on whether 2 or 3 annual spray cycles were employed, the purchase, storage and use of deltamethrin would have been 2.8 to 4.1 times more expensive than DDT. Use of deltamethrin would have increased the annual insecticide expenditure from 21.4% of Belize’s malaria control program budget (with DDT) to 59-87% (with deltamethrin), to spray 15,000 houses 2 times per year. Fortunately public concern about resurgent malaria allowed the MOH to reinstate use of DDT for malaria control in 1995. The results of control efforts from 1995 to 1998, described below, show the difference between stratification versus total coverage approaches to malaria control.

For the total coverage approach, the MEHSR is 134.6. Based on a population of 230,000 people, 30,958 (134.6 x 230) house-spraying events would be required just to keep malaria rates from increasing. With total coverage, an even higher HSR would be needed to reduce malaria rates. With budgetary constraints, total coverage was not possible in 1996. Consequently, the MOH opted for a stratification approach that resulted in approximately 24,000 house-spraying events per year, equating to an HSR of 104.

Reduced numbers of malaria cases suggest that the stratified approach to spraying progressively decreased numbers of malaria cases in Belize through 1998. Since greater numbers of slides were examined each year after 1994 than during preceding years, a reduced ABER does not account for the reduced numbers of cases. Low or unusual patterns of rainfall may have contributed to reductions in numbers of cases. However, it seems improbable that this factor alone could account for the rapid and continuous (over multiple years) decline in rate of malaria that began with and accompanied the renewed house spray program. Collectively, these data suggest that targeting house-spraying operations according to malaria risk factors can result in reduced malaria with fewer houses being sprayed.

Spraying DDT on house walls has long been known to be a powerful tool for the prevention of malaria, yet the method of use has remained unchanged for almost 50 years. Lack of funds for operational research has blocked progress in converting house spray programs from eradication to control functions. Recent work by Casas et al. (1998) showed acceptable control of indoor biting by malaria vectors when only a narrow band of DDT was sprayed on house walls. This modification alone might greatly reduce the amount and cost of residual spraying of house walls in many environments. There are other options for improving use of the house
spray approach to malaria control, e.g., spraying DDT on house walls once a year in lieu of every 6 months (e.g., as suggested by Rozendaal et al. 1989). Additionally, remote sensing and geographic information system (GIS) technologies have been used to accurately predict the presence, and in some cases, the abundance of vectors at specific sites (Wood et al. 1991, Beck et al. 1994, Pope et al. 1994, Rejmankova et al. 1995, Roberts et al. 1996, Rejmankova et al. 1998).

Potentially, predictive capabilities combined with a fully functional GIS that is linked to a national database on malaria cases could be used for greatly improved targeting of spray operations at the household level. Preliminary analyses suggest that this approach could result in large reductions in amount of insecticide used and costs of malaria control programs. Regardless, no improvements will occur unless there are changes in policies and guidelines for support of field research and for support of both small and large-scale field trials.

REFERENCES CITED


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