ELIMINATING MALARIA

Case-study 4

Preventing reintroduction in Mauritius

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ACKNOWLEDGEMENTS

ACRONYMS AND ABBREVIATIONS

DDT   dichlorodiphenyltrichloroethane

IRS   indoor residual spraying

WHO   World Health Organization

GLOSSARY

The terms listed in this glossary are defined according to their use in this publication. They may have different meanings in other contexts.

Active case detection

The detection by health workers of malaria infections at community and household level in population groups that are considered to be at high risk. Active case detection can be conducted as fever screening followed by parasitological examination of all febrile patients or as parasitological examination of the target population without prior fever screening.

Annual blood examination rate

Number of examinations of blood slides for malaria by microscopy per 100 population per year

Case-based surveillance

Every case is reported and investigated immediately (and also included in the weekly reporting system)

Case definition (elimination programmes)
autochthonous

A case locally acquired by mosquito-borne transmission, i.e. an indigenous or introduced case (also called 'locally transmitted')

imported

A case the origin of which can be traced to a known malarious area outside the country in which it was diagnosed

indigenous

Any case contracted locally (i.e. within national boundaries), without strong evidence of a direct link to an imported case. Indigenous cases include delayed first attacks of *Plasmodium vivax* malaria from locally acquired parasites with a long incubation period.

induced

A case the origin of which can be traced to a blood transfusion or other form of parenteral inoculation but not to normal transmission by a mosquito

introduced

A case contracted locally, with strong epidemiological evidence linking it directly to a known imported case (first generation of an imported case, i.e. the mosquito was infected from a case classified as imported)

locally transmitted

A case locally acquired by mosquito-borne transmission, i.e. an indigenous or introduced case (also called 'autochthonous')

malaria

Any case in which, regardless of the presence or absence of clinical symptoms, malaria parasites have been confirmed by quality-controlled laboratory diagnosis

Case investigation

Collection of information to allow classification of a malaria case by origin of infection, i.e. imported, introduced, indigenous or induced. Case investigation includes administration of a standardized questionnaire to a person in whom a malaria infection is diagnosed.

Case management

Diagnosis, treatment, clinical care and follow-up of malaria cases

Case notification

Compulsory reporting of detected cases of malaria by all medical units and medical practitioners, to either the health department or the malaria elimination service (as laid down by law or regulation)

Certification of malaria-free status

Certification granted by WHO after it has been proved beyond reasonable doubt that the chain of local human malaria transmission by *Anopheles* mosquitoes has been fully interrupted in an entire country for at least 3 consecutive years

Elimination

Reduction to zero of the incidence of infection by human malaria parasites in a defined geographical area as a result of deliberate efforts. Continued measures to prevent re-establishment of transmission are required.

Endemic

Applied to malaria when there is an ongoing, measurable incidence of cases and mosquito-borne transmission in an area over a succession of years

Epidemic

Occurrence of cases in excess of the number expected in a given place and time

Eradication

Permanent reduction to zero of the worldwide incidence of infection caused by human malaria parasites as a result of deliberate efforts. Intervention measures are no longer needed once eradication has been achieved.

Evaluation

Attempt to determine as systematically and objectively as possible the relevance, effectiveness and impact of activities in relation to their objectives

Focus

A defined, circumscribed locality situated in a currently or former malarious area containing the continuous or intermittent epidemiological factors necessary for malaria transmission. Foci can be classified as endemic, residual active, residual non-active, cleared up, new potential, new active or pseudo.

Gametocyte

The sexual reproductive stage of the malaria parasite present in the host's red blood cells

Hypnozoite

The dormant stage of the malaria parasite present in the host's liver cells (limited to infections with *P. vivax* and *P. ovale*)

Incubation period

The time between infection (by inoculation or otherwise) and the first appearance of clinical signs

Intervention (public health)

Activity undertaken to prevent or reduce the occurrence of a health condition in a population. Examples of interventions for malaria control include the distribution of insecticide-treated mosquito nets, indoor residual spraying with insecticides and the provision of effective antimalarial therapy for prevention or curative treatment of clinical malaria.

Local mosquito-borne malaria transmission

Occurrence of human malaria cases acquired in a given area through the bite of infected *Anopheles* mosquitoes.

Malaria-free

An area in which there is no continuing local mosquito-borne malaria transmission and the risk for acquiring malaria is limited to introduced cases

Malaria incidence

The number of newly diagnosed malaria cases during a specified time in a specified population

Malaria prevalence

The number of malaria cases at any given time in a specified population, measured as positive laboratory test results

Monitoring (of programmes)

Periodic review of the implementation of an activity to ensure that inputs, deliveries, work schedules, targeted outputs and other required actions are proceeding according to plan

National focus register

Centralized database of all malaria foci in a country

National malaria case register

Centralized database of all malaria cases registered in a country, irrespective of where and how they were diagnosed and treated

Outpatient register

List of patients seen in consultation in a health facility. The register may include the date of consultation; patient's age, place of residence and presenting health complaint; tests performed; and diagnosis.

Parasite prevalence

Proportion of the population in whom *Plasmodium* infection is detected at a particular time by means of a diagnostic test (usually microscopy or a rapid diagnostic test).

Passive case detection

Detection of malaria cases among patients who, on their own initiative, go to a health post for treatment, usually for febrile disease

Population at risk

Population living in a geographical area in which locally acquired malaria cases occurred in the current year and/or previous years

Rapid diagnostic test

An antigen-based stick, cassette or card test for malaria in which a coloured line indicates that plasmodial antigens have been detected

Rapid diagnostic test positivity rate

Proportion of positive results among all the rapid diagnostic tests performed

Receptivity

Relative abundance of anopheline vectors and existence of other ecological and climatic factors favouring malaria transmission

Re-establishment of transmission

Renewed presence of a constant measurable incidence of cases and mosquito-borne transmission in an area over a succession of years. An indication of the possible re-establishment of transmission would be the occurrence of three or more introduced and/or indigenous malaria infections in the same geographical focus, for 2 consecutive years for *P. falciparum* and for 3 consecutive years for *P. vivax*.

Relapse (clinical)

Renewed manifestation of an infection after temporary latency, arising from activation of hypnozoites (and therefore limited to infections with *P. vivax* and *P. ovale*)

Sensitivity (of a test)

Proportion of people with malaria infection (true positives) who have a positive test result

Slide positivity rate

Proportion of microscopy slides found to be positive among the slides examined

Specificity (of a test)

Proportion of people without malaria infection (true negatives) who have a negative test result

Surveillance (control programmes)

Ongoing, systematic collection, analysis and interpretation of disease-specific data for use in planning, implementing and evaluating public health practice

Surveillance (elimination programmes)

That part of the programme designed for the identification, investigation and elimination of continuing transmission, prevention and cure of infections and final substantiation of claimed elimination.

Transmission intensity

Rate at which people in a given area are inoculated with malaria parasites by mosquitoes, often expressed as the 'annual entomological inoculation rate', which is the number of inoculations with malaria parasites received by one person in 1 year

Transmission season

Period of the year during which mosquito-borne transmission of malaria infection usually occurs

Vector control

Measures of any kind against malaria-transmitting mosquitoes intended to limit their ability to transmit the disease

Vector efficiency

Ability of a mosquito species, in comparison with another species in a similar climatic environment, to transmit malaria in nature

Vectorial capacity

Number of new infections that the population of a given vector would induce per case per day at a given place and time, assuming conditions of non-immunity. Factors affecting vectorial capacity include: the density of female anophelines relative to humans; their longevity, frequency of feeding and propensity to bite humans; and the length of the extrinsic cycle of the parasite.

Vigilance

A function of the public health service during a programme for prevention of reintroduction of transmission, consisting of watchfulness for any occurrence of malaria in an area in which it had not existed or from which it had been eliminated and application of the necessary measures against it

Vulnerability

Either proximity to a malarious area or frequent influx of infected individuals or groups and/or infective anophelines

SUMMARY

The aim of this case-study is to provide a comprehensive description and analysis of malaria control, elimination and prevention of reintroduction in Mauritius. Given the dearth of evidence on prevention of reintroduction, the case of successful malaria elimination in Mauritius presented an opportunity to review evidence and learn lessons to assist other countries and the wider global community in making decisions and formulating strategies for malaria elimination. A mixed-methods approach of qualitative and quantitative data collection and analysis was used. A comprehensive review of the literature and Government documents was conducted, supplemented by observation of the programme and 50 interviews based on semi-structured questionnaires with policy-makers and with past and present programme personnel. Budget and expenditure data for the periods of elimination and prevention of reintroduction were obtained from technical reports, programme reviews and financial documents from the Government of Mauritius.

Plasmodium falciparum, *P. vivax* and *P. malariae* and two of their vectors, *Anopheles funestus* and *An. gambiae sensu lato*, were imported into Mauritius in the mid-1800s, and, after a violent epidemic in 1867 that killed 12% of the country's population (121 deaths per 1 000 population), the disease became hyperendemic on the island (*1*). Initial control efforts, comprising major environmental management projects, widespread distribution of quinine and extensive larviciding, began in 1908 and

were intensified in 1943. These activities paved the way for a malaria elimination campaign between 1948 and 1951 that included island-wide indoor residual spraying (IRS) with DDT (dichlorodiphenyltrichloroethane) and targeted larviciding, both based on robust entomological surveillance and geographical reconnaissance. The campaign also strengthened passive case detection and established active case detection by mobile surveillance teams. The average mortality rate from malaria dropped from 6 per 1 000 population per year (1932–1948) to 0.6 (in 1951, the end of the campaign). The clinical attack rate also decreased markedly, from 105 per 1 000 population per year in 1948 to 2.6 in 1951, and the predominant vector, *An. funestus*, was eliminated. After the campaign, malaria transmission continued to decline, with only sporadic indigenous cases detected; the last indigenous case of that era was recorded in 1968, and elimination was certified by the World Health Organization (WHO) in 1973 (*2*).

In 1975, indigenous *P. vivax* malaria was reintroduced in Mauritius when Cyclone Gervaise devastated the island, creating abundant new breeding places (Figure 1), and after hundreds of migrant workers arrived to help with clean-up and reconstruction, presumably importing malaria parasites (*2, 4*). *P. vivax* transmission persisted because of the continued presence of *An. gambiae* s.l. and the heavy cyclones that struck Mauritius at least once every subsequent year (*5*). The epidemic peaked in 1982, with 623 indigenous cases (*6*) (Figure 1). Mauritius launched its second campaign to eliminate local transmission with a combination of focal IRS; targeted larviciding, fogging and use of larvivorous fish; limited mass drug administration with chloroquine; and intensive active case detection. This campaign reduced the number of indigenous cases to 3 by 1989 (*5*). All the interventions were based on entomological surveillance, geographical

Figure 1. Key indicators of malaria control, elimination and prevention of reintroduction in Mauritius, 1948–2008
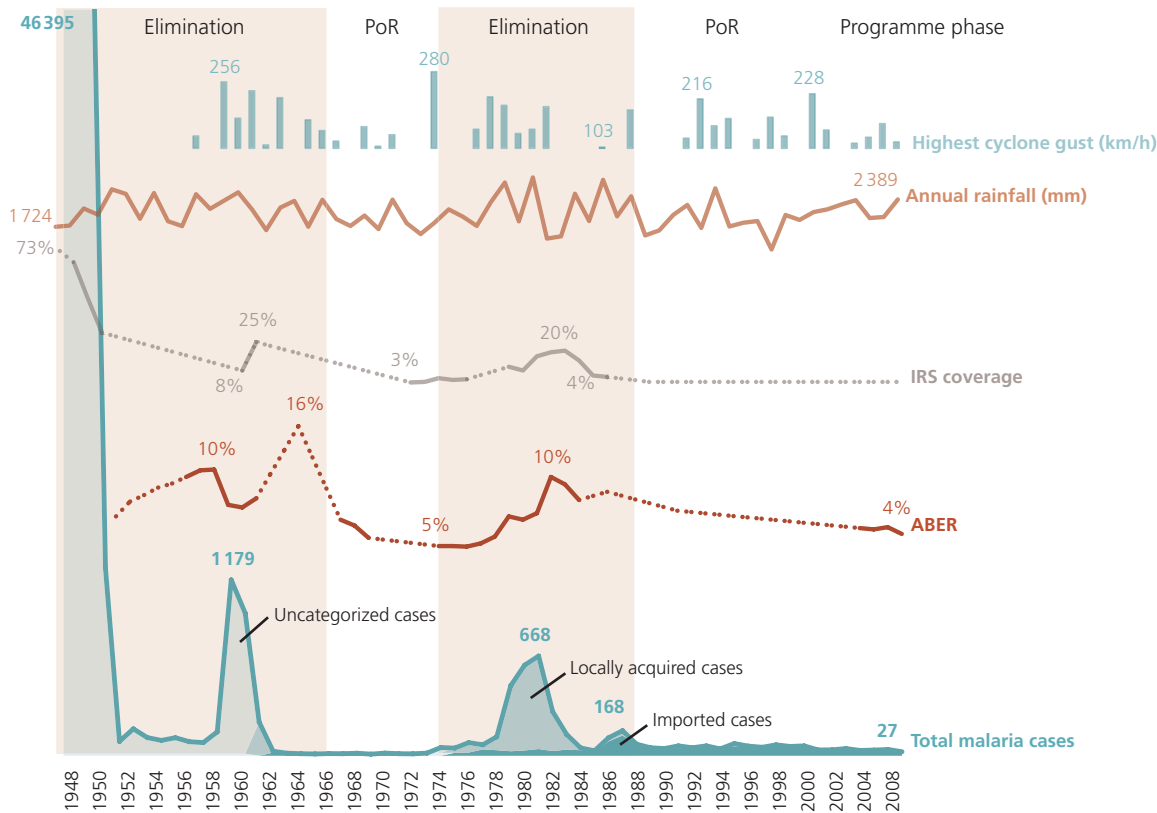
From reference *3*. PoR, prevention of reintroduction; IRS, indoor residual spraying; ABER, annual blood examination rate

reconnaissance and passive case detection. After small outbreaks of indigenous *P. vivax* malaria, with 13 cases in 1992 and 17 cases in 1996, the last case of indigenous malaria was recorded in 1997 (*7*).

Since the start of the second prevention of reintroduction programme in 1998, Mauritius has experienced only imported and introduced *P. vivax* and *P. falciparum* cases by maintaining a rigorous passenger screening programme, an extensive response to any positive case and island-wide larviciding based on entomological surveillance. Combined with prompt diagnostic tesing at a malaria laboratory, effective treatment and distribution of free prophylaxis to travellers, Mauritius has prevented the reintroduction of malaria to date, despite its relatively high receptivity and vulnerability.

Per capita expenditure for malaria control was highest in 1948–1949 at the start of the first malaria elimination campaign, at US$ 5.75 (2008 US$); after a reduction to US$ 2.99 in 1960, expenditure increased to US$ 5.39 during the scaling-up of interventions to confront the resurgence in 1982–1983. The total annual cost was highest in 1982–1983 at approximately US$ 5.2 million and in 1984–1985 at US$ 4.9 million. The total annual cost of the current programme for preventing reintroduction is US$ 2.5 million (US$ 2.06 per capita). The Government of Mauritius was and continues to be the primary source of funds, although WHO has contributed some financial and other resources since the 1960s.

The experience in Mauritius demonstrates that it is possible to eliminate malaria and prevent its reintroduction even in a country with relatively high transmission

potential. Throughout the history of malaria in the country, the Government maintained strong political and financial commitment to achieving and sustaining elimination. Residents are legally obliged to participate in environmental management and vector control, resulting in high coverage of populations at risk with effective interventions. Entomological surveillance and geographical reconnaissance with detailed hand-drawn maps were used extensively and effectively to identify transmission foci and provide information for interventions. Mauritius's unique passenger screening programme closely tracks people arriving from malaria-endemic countries in order to reduce the importation risk.

Overall, Mauritius' approach to elimination and prevention of reintroduction throughout the twentieth century was—and continues to be—multifaceted and comprehensive. These lessons from the Mauritius case-study can be used as a basis for elimination and prevention of reintroduction in the southern African region and globally.

INTRODUCTION

The malaria elimination case-study series

During the past decade, there has been renewed interest in malaria elimination by governments, donor agencies and technical organizations, encouraged by success stories around the world and the call for a new global eradication target by Bill and Melinda Gates. In response to dramatic reductions in malaria transmission in several African countries at around the same time, the African Union and the Southern African Development Community set targets for malaria elimination in a number of low-endemic member states, including Botswana, Namibia, South Africa and Swaziland (8).

Despite this increased attention, relatively little is known about strategies and programmes for elimination and for preventing reintroduction after elimination. In the four decades since the end of the Global Malaria Eradication Programme, most funding and research for malaria has been directed to controlling the disease in areas of high endemicity. Therefore, large gaps in the evidence base for elimination interventions have persisted, including the epidemiology of the disease in areas of low transmission (9). History has shown repeatedly that malaria elimination can be tenuous and the effects of resurgence devastating (10). In many countries in which malaria has been eliminated, including countries in Europe and the United States of America, significant malaria vigilance operations are maintained, which contain occasional incidents of local transmission (11). Even less is known about maintaining elimination in areas with high receptivity and vulnerability.

To assist countries in making well-informed decisions on whether or how to pursue malaria elimination, it is important for them to learn from other countries'

experiences in eliminating and preventing reintroduction, especially in similar eco-epidemiological settings. The WHO Global Malaria Programme and the Global Health Group of the University of California, San Francisco, in collaboration with national malaria programmes and other partners and stakeholders, are conducting a series of case-studies on the elimination and prevention of reintroduction of malaria. The objective of this work is to build evidence to support intensification of malaria control and elimination to achieve international targets.

The aim of this series of case-studies of 10 countries and areas is to provide insights and lessons for moving towards elimination or preventing reintroduction in disparate geographical and ecological settings. The countries and areas covered in the series are: Bhutan, Cape Verde, Malaysia, Mauritius, Philippines, La Réunion, Sri Lanka, Tunisia, Turkey and Turkmenistan.

The University of California, San Francisco Global Health Group and the Clinton Health Access Initiative collaborated with the Mauritius Ministry of Health and Quality of Life on this case-study of Mauritius' successful experience of elimination and prevention of reintroduction. The methods used for data collection and analysis are described in Annex 1.

Malaria in southern Africa

Remarkable progress has been made in southern Africa to reduce morbidity and mortality from malaria during the past decade (12); four countries, Botswana, Namibia, South Africa and Swaziland, have declared their intention to eliminate malaria within the next 5–10 years (13–16). Substantial funding for malaria and political commitment in the region have resulted in the intiation of elimination activities. The Mauritius experience is especially relevant

to these countries, as it is the only country in the region to have successfully eliminated malaria (*17*), and the experience provides evidence about what is required to achieve and maintain elimination in the long term.

Malaria in Mauritius

As information on the elimination and prevention of reintroduction of malaria in sub-Saharan Africa and globally is limited, the story of malaria in Mauritius offers unique lessons and detailed insights from a country that remains highly receptive and vulnerable to malaria transmission. Mauritius' remarkable success was achieved by an almost military-style offensive against the disease, based on detailed intelligence and sustained vigilance. While the island nation benefits from relative isolation, the strategies and activities used provide important lessons for both insular and mainland countries.

After the introduction of malaria in Mauritius in the mid-1800s, the disease was hyperendemic, until the malaria elimination campaign between 1948 and 1951 resulted in a dramatic decline in transmission, achieving zero indigenous malaria transmission by 1969 and elimination certification in 1973. Malaria resurged in 1975, leading to a second campaign that once again eliminated indigenous transmission in 1998. Since then, Mauritius has maintained an effective programme for prevention of reintroduction, despite its receptivity and vulnerability.

The Mauritius case-study was made possible by the country's impressive record-keeping, and a vast amount of information was available to the researchers. Detailed documentation of the country's malaria activities by the Government and WHO over time allowed comprehensive collection and analysis of the information included in this report.

COUNTRY BACKGROUND

Geography, population and economy

The Republic of Mauritius is located in the Indian Ocean off the east coast of Madagascar. It consists of nine administrative districts on the island of Mauritius and three island dependencies, Agalega Island, Cargados Carajos Shoals and Rodrigues (Figure 2). The Island of Mauritius has an area of 2 040 km2 and a coastline of 117 km, with coastal plains leading to mountains that encircle a central plateau; the highest point is Mont Piton, at 828 m. The warm, dry winter is in June–November, while the hot, wet summer lasts from December through May (18). Mauritius is the only island in the Republic that is receptive to malaria transmission.

Mauritius has a population of over 1.3 million (2012 estimate), 42% of whom live in urban areas (18). The ethnic groups are Indo-Mauritian (68%), Creole (27%), Sino-Mauritian (3%) and Franco-Mauritian (2%).

After independence from the United Kingdom in 1968, Mauritius developed rapidly from a low-income, agriculture-based economy to a middle-income country with a diverse economy, with growth in industry, finance and tourism and greatly improved health and other social outcomes. The economy is currently based on sugar, tourism, textiles, clothing and financial services, and the gross domestic product per capita is US$ 15 100 (2011 estimate) (18).

Health system and population health profile

Mauritius is divided into five health regions, in which a regional public health superintendent is responsible for public health. There are 13 health offices in the five health regions and one health office in Rodrigues. The Communicable Disease Control Unit and the Vector Biology and Control Division oversee malaria and other vector-borne diseases and are directly controlled by the Division of Preventive Health Services in the Ministry of Health and Quality of Life.

Mauritius has made significant progress in health outcomes and experienced an epidemiological transition from communicable to noncommunicable and chronic diseases in the second half of the twentieth century (19). Table 1 lists the health indicators for Mauritius.

Table 1. Mauritius health profile

Indicator	Outcome	Year
Life expectancy at birth, M/F (years)	69.7/77.0	2011
Total expenditure on health as percentage of gross domestic product[a]	2.23%	2012
Mortality rate of children under 5 years (per 1 000 live births)	14.7	2010
Physicians (density per 1 000 population)	1.17	2010
Nurses (density per 1 000 population)	2.8	2010

From Health Statistics Unit, Ministry of Health and Quality of Life
[a] From Principal Health Economist, Ministry of Health and Quality of Life

Figure 2. Map of Mauritius
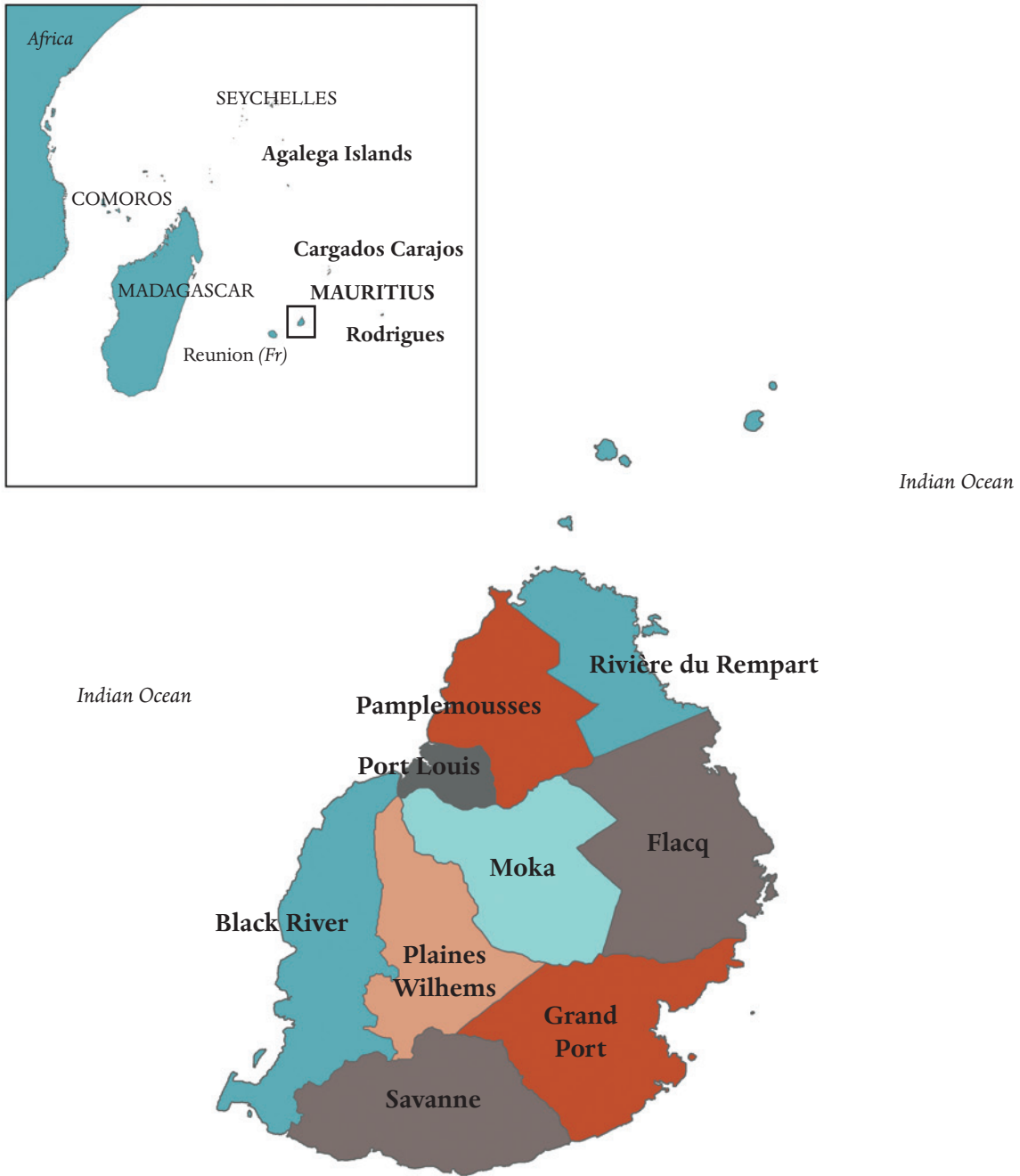
HISTORY OF MALARIA AND MALARIA CONTROL

Mauritius has a rich history of malaria control, elimination and prevention of reintroduction (Figure 3).

Parasites and vectors

Malaria in Mauritius in the early and mid-1900s was due to *P. vivax*, *P. falciparum* and *P. malariae*. As microscope examination was not systematic until 1952, the species was identified in only small samples of all reported malaria cases (*20*). By the late 1950s, *P. malariae* had nearly disappeared (2% of all cases), and only *P. vivax* (39%) and *P. falciparum* (48%) remained, with sporadic mixed or unidentified infections (*21*). The resurgence in 1975 was due to *P. vivax*, which sustained local transmission through

1987, after which the number of indigenous cases dropped nearly to zero. During the years between 1981 and 1987, all reported cases of *P. falciparum* malaria were imported except for one indigenous case recorded in 1986 (*7*). After elimination of local transmission in 1998, the imported infections were due to *P. vivax* (44%) and *P. falciparum* (47%), with 8% mixed and 1% unidentified (Figure 4) (*22*). *P. ovale* has never been detected in Mauritius.

An. gambiae s.l. was identified in Mauritius in 1900 (known at the time as *An. costalis* (Theobald) (*25*), and *An. funestus* (Giles) was found in 1922 (*4*). *An. funestus* was eliminated during the malaria elimination campaign in 1948–1951, probably because of its extremely anthropophilic and endophilic behaviour (*26*). In contrast,

Figure 3. Timeline of malaria and malaria control in Mauritius

Mid-1800s
Malaria parasites and vectors imported into Mauritius on incoming ships bringing slaves and labourers from malaria-endemic southern Africa and India

1850–1900
Population increased from 100 000 to 300 000 on the island

1865
Malaria becomes endemic

1867
P. falciparum malaria epidemic, killed 10% of the population

1907
Dr Ross visited Mauritius, established the malaria control programme

1943
Parasite index of newborns was 55% in coastal regions and 75% for 4-year-old children surveyed

1946
IRS pilot study with DDT

1948–1951
Elimination campaign with island-wide DDT spraying

1952
An. funestus is eliminated, malaria-dedicated laboratory established

1960
WHO Malaria Eradication Programme established in Mauritius to improve surveillance

1968
Last indigenous malaria case of that era

1969–1974
Prevention of reintroduction

1973
WHO certification of malaria elimination

1975
Resurgence of indigenous *P. vivax* malaria

1982–1988
Elimination campaign with focalized interventions and intensified active case detection

1997
Last indigenous malaria case

1998–present
Prevention of reintroduction

An. gambiae s.l., identified as *An. arabiensis* in 1975 (*27*), played a secondary role to *An. funestus* before 1950 and was not eliminated, probably because of its exophilic and zoophilic behaviour. It remains the primary malaria vector (*28*).

Figure 4. Parasite species detected in Mauritius, 1949–2008
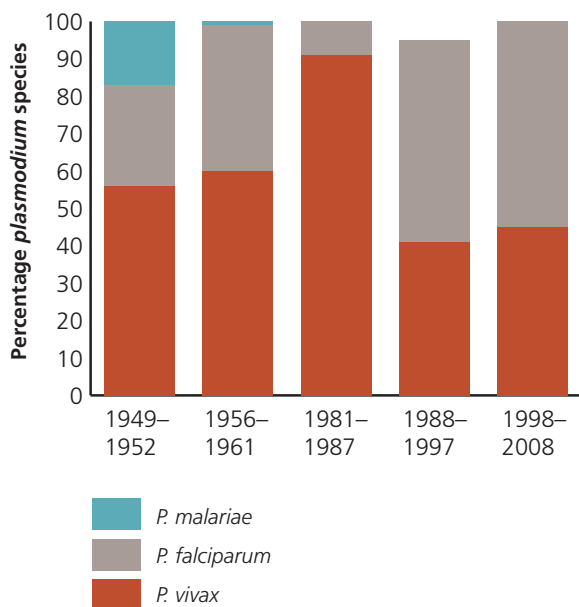
From references *22–24*

Other potential vectors of malaria in Mauritius include *An. merus* (Dönitz), a brackish water species of the *An. gambiae* complex, found only in a few coastal localities; *An. coustani* (Laveran), for which circumstantial evidence suggests that it is not a malaria vector in Mauritius; and *An. maculipalpis* (Giles), which is encountered very rarely on the western coast (*4*). Additional notes on malaria vectors in Mauritius are given in Annex 2.

Pre-control

Mauritius was uninhabited until the Portuguese arrived in the 1500s; in 1638, the Dutch established a small, short-lived colony and imported slaves from Madagascar (*1*). The island was abandoned in 1710, but the French East India Company re-established a colony in 1715 and ceded the island to the French Government in 1764. In 1810,

the French lost a battle over Mauritius to the British, who then occupied Mauritius until the country gained independence in 1968. Settlers imported thousands of slaves from Madagascar until 1833, when slavery was abolished; they then imported over 25 000 indentured servants from India to work on the sugar plantations. It was during these years, from the early 1800s to 1860, that malaria parasites and their vectors were probably imported on ships carrying these passengers from malaria-endemic East Africa and South Asia (*1*). The specific parasite species were unknown but were presumably *P. falciparum*, *P. vivax* and *P. malariae*, given the speciation later confirmed by microscopy. As sugar was the main industry on the island, extensive irrigation canals were required (*29*). With recurrent cyclones and a tropical climate, the island therefore had favourable conditions for mosquito breeding (*26*).

In 1867, a violent malaria epidemic occurred in Mauritius, resulting in 40 000 deaths in a population of 330 000, with 6 000 deaths occurring during just 1 month in urban Port Louis (*26*). Before the epidemic, fevers were described in contemporary reports as typhoid fever, 'Bombay fever' or 'the common fever' (*30*). Whether these fevers were in fact due to malaria has been the subject of an extensive, well-documented debate (*30*, *31*). The consensus was that the fevers were not due to malaria, although there were significant outbreaks of the disease in 1858–1859, 1862 and 1865, before the 1867 epidemic (*32*). After the epidemic, Mauritius was notorious throughout the world for its intense malaria transmission, making the achievement of elimination just over 100 years later that much more remarkable (*1*).

In 1897, Dr Ronald Ross showed that the *Anopheles* mosquito transmitted malaria, and in 1907 he visited Mauritius to conduct a comprehensive entomological and parasitological survey (Figure 5). At the conclusion of the survey, he recommended and established antilarval activities, environmental management projects and widespread distribution of quinine, which remained the foundation of the malaria programme for the next 30 years (*31*).

Figure 5. Ronald Ross in Mauritius in 1908 in a cartoon published in the local newspaper on Ross' departure from the island

In the top right-hand corner is written 'Dedicated to the official Aesculapiuses.' The comments ascribed to the mosquitoes are 'You're leaving, no way, old man' and, at the bottom, 'If the Major stays, we've had it; if the Major goes, we're saved!'

From reference *1*

The rate of enlarged spleens among children in routine surveys between 1916 and 1930 was 10–16% (Figure 6). Such surveys were conducted twice a year on an average of 16 000 children each time (*33, 34*). The control activities during the 1920s and 1930s included use of oiling and of larvivorous fish in *Anopheles* breeding sites, routine spleen surveys, sporadic blood surveys, distribution of quinine, entomological surveillance and major 'antimalaria works', or environmental management projects. A malaria advisory committee was established in 1933 to guide malaria control (*35*). By 1942, the mortality rate from malaria was 7.5 per 1 000 population, representing 26% of all deaths, and 58 901 people were treated for malaria at Government institutions out of a total island population of 407 744 (144 per 1 000 population) (*36*). Dysentery, diarrhoea, enteritis and tuberculosis were the other major causes of death during this period. Because of the lack of microscopy facilities at the time, cases of these diseases were suspected to be malaria and treated with Paludrine (proguanil hydrochloride). To the frustration of the Director of Medical Services, Dr Rankine, "despite periodic visits of renowned malariologists and sanitarians", malaria continued to be the principal cause of death (*36*).

Figure 6. Rates of enlarged spleens among children, 1916–1930
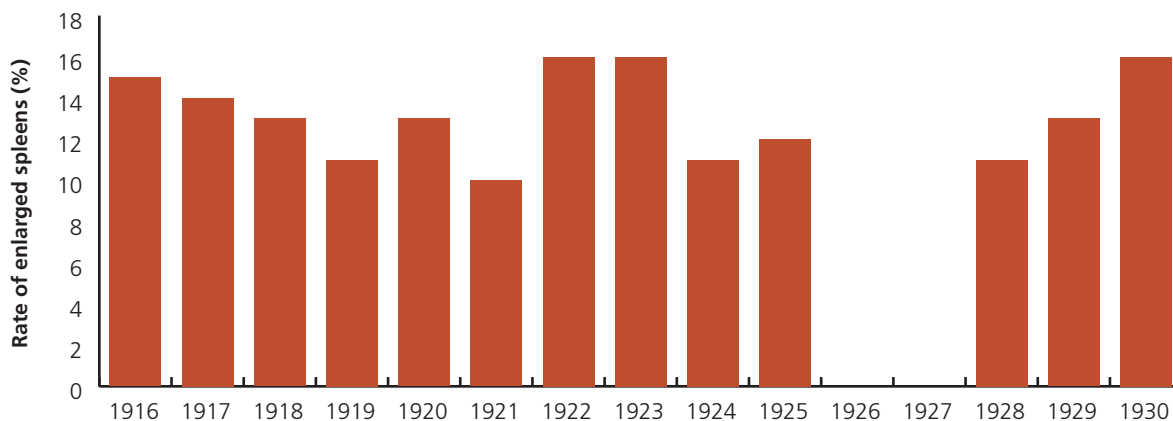
From references *33* and *34*. No data were available for 1926 and 1927.

Sanitation Division III within the Medical and Health Department of the Colony of Mauritius handled malaria and hookworm. This Division employed three medical officers, one entomologist, a number of microscopists and fieldmen, including *moustiquiers* and *cantonniers* responsible for entomological monitoring and environmental management, respectively. Medical officers generally considered that this system was insufficient and understaffed (*36*).

Initial efforts to control malaria (1943–1947)

The colonial government in Mauritius, in collaboration with the Secretary of State, decided in 1943 to "fight malaria on an island-wide scale" (*37*). Between 1943 and 1948, drought, new environmental management projects, extensive use of DDT on sugar estates and increased sales of Paludrine all contributed to a significant reduction in morbidity due to malaria, even before the elimination campaign began in December 1948 (*38*). Reconstruction of buildings and sugar-cane fields destroyed by large cyclones in 1945 involved extensive cleaning and drainage projects throughout the island (*39*). General improvements in environmental hygiene and an increase in the prosperity of the sugar industry after the cyclones contributed to economic and social development during this time. Improved health related to the declining malaria burden might have also influenced the pace and scope of development (*26*).

The proportion of deaths attributed to malaria dropped from an average of 24% in the early 1940s to 15% by 1948, and the number of cases of suspected malaria treated in hospitals decreased similarly, from 3 500 per year to around 2 000 in 1946 and 1500 in 1948 (*40*). Annual reports of the Medical and Health Department in the 1930s and 1940s describe numerous 'antimalaria works' and construction projects in villages throughout the island (*41*). Private sugar estates encouraged the use of DDT in dormitories and distribution of Paludrine to employees; the owners often lamented the morbidity on their estates.

Substantially fewer infections were imported than today, mostly because of the difficulty of travelling to the island in the 1940s. It was no longer legal to import slaves or indentured servants, and the flow of migrant workers to work on sugar plantation had slowed. At that time, military personnel transiting in and out of the country were the greatest risk for importation and were therefore under close surveillance by the health authorities, who often provided prophylaxis before they arrived on Mauritian soil (*42*).

The Director of Medical Services, Dr Rankine, established a malaria control committee and requested the creation of a malaria control board to advise the Government on policy, costs and programme implementation. There was a general lack of planning for antimalaria activities, until Dr Rankine introduced an island-wide environmental project in 1945 at a cost of US$ 20.5 million (US$ 47.80 per capita, 2008 US$) to improve sanitation and drainage systems and to reduce mosquito breeding sites (*36*). Dr Dowling, Officer in Charge of the malaria eradication scheme, indicated in later reports of the elimination campaign that the environmental projects continued until the island changed its strategy and workforce in 1948 towards eliminating malaria with DDT. By this time, the residential plateau and the business centre of Port Louis had become virtually free of malaria, largely due to these environmental projects, while the coastal regions remained highly endemic (*26*).

After a successful IRS programme in British Guiana (*26*) subsequent to global introduction of DDT in 1939 (*43*), Mauritius conducted a pilot project of IRS with DDT in one small, relatively isolated, hyperendemic village on the west coast of the island between 1946 and 1947. As few environmental projects had been conducted there, the investigators assumed that, given normal rainfall, any decline in the parasite rate would be due to DDT alone and not to other interventions or external factors. A prevalence survey among schoolchildren in the village in 1942 showed a parasite rate of 66%, with 30% positive for gametocytes. After three spraying rounds of DDT, a follow-up survey in June 1947 showed a marked decline in the parasite rate, to 32%, and of the gametocyte

positivity rate to 3.8% (Table 2) (*44*). The proportion of *P. vivax* infections increased during this time, while the proportions of *P. falciparum* and *P. malariae* decreased. The investigators monitored two nearby villages with no IRS intervention as controls. They found a significant difference in parasite prevalence in the general population of the sprayed village after spraying was completed in June 1947, the parasite rate having been reduced by two thirds (Table 3).

Table 2. Results of a survey of village schoolchildren during a pilot project of indoor residual spraying with DDT

	August 1946	March 1947	June 1947
Parasite index	66%	25%	32%
Gametocyte carrier rate	30%	3%	4%
No. of children surveyed	150	144	105
Proportion of parasites by species			
P. falciparum	54%	43%	16%
P. vivax	22%	42%	68%
P. malariae	24%	15%	16%

From reference *44*

Table 3. Results of a survey of the general population in a pilot village that received indoor residual spraying with DDT and two villages that did not receive spraying

	August 1946	March 1947	June 1947
Parasite index, pilot village	37.6%	10.5%	12.9%
Parasite index, control villages	–	–	46.5%
Gametocyte carrier rate, pilot village	3.4%	2.5%	2.2%
Gametocyte carrier rate, control villages	–	–	7.5%

From reference *44*

First campaign to eliminate malaria (1948–1968)

After the success of the environmental management projects and the DDT pilot study, the Mauritius Government, in collaboration with the Colonial Insecticides Committee in England, launched a campaign in 1948 to eliminate malaria from the country (*26*). The elimination campaign was conducted as an experiment to assess the degree of success obtainable with IRS alone, in the belief that both *Anopheles* vectors (*An. funestus* and *An. gambiae* s.l.), and the *Plasmodium* parasites could be eliminated from the island (*38*).

LEGAL FRAMEWORK AND FINANCIAL COMMITMENTS FOR ELIMINATION

In 1946, the Colony of Mauritius passed the Prevention of Malaria Ordinance that created the Malaria Advisory Board for "the purpose of research into and investigation of all problems and matters relating to the incidence of malaria and other mosquito-borne diseases in the Colony as well as for the purpose of advising Government generally on the measure to be taken for the control of such disease…" (*45*). This Board acted as a technical working group before and during the elimination campaign.

An executive order was passed by the Government in May 1948, authorizing campaign officers to enter houses for the purposes of spraying and collecting scientific data. This authorization covered all private buildings, ships and airplanes and Mauritian dependencies (*38*). The ordinance significantly reduced the refusal rate and allowed widespread coverage of interventions: during the 4 years of the campaign, only 3 households were prosecuted for refusal (*26*). In 1952, malaria was added to the list of notifiable diseases, and, in 1962, legislative measures were adopted limiting access to antimalaria drugs, to be obtained by prescription only (*46*).

The elimination campaign was financed by both the British Government and that of the Colony of Mauritius (*47*), and the Entomological Research Unit was paid for from the Development and Welfare Funds, a special pool from the British Government (*48*). Per capita Government health care spending increased steadily throughout

the campaign by about US$ 20 (2008 US$) annually but doubled in the early 1950s to US$ 41.50 by 1954 (*49*). Although there is limited information about the rapid increase in spending, the elimination campaign may have required additional funds (*42*).

The campaign was led by an officer in charge, with a chemist, five field officers, two entomologists (in 1951), a labour supervisor and a medical officer (*50*) (Annex 3).

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA VECTORS

Geographical reconnaissance

Geographical reconnaissance was used extensively throughout the malaria control and elimination programmes in Mauritius to identify foci of active or potential transmission, to guide interventions and to follow progress. A thorough survey was conducted before the elimination campaign to identify every house and structure on the island on hand-drawn maps, including estimates of the square footage of each structure. On the basis of the maps, the island was divided into six districts (A–F), each managed by a field officer with a team of *moustiquiers* who were trained in larval and adult mosquito catching and identification and were responsible for the 3 500 catching stations established throughout the island (Figure 7). The districts were then divided into 12 blocks, roughly equal in size and population, for administrative and operational use (*38*). The teams made alterations to the maps and drew small-scale maps for every town, village and hamlet in the sprayed zones on the basis of information obtained in the field (*20*).

Indoor residual spraying

One objective of the campaign was to investigate the most effective insecticide formulation for reducing vector prevalence and, ultimately, malaria transmission. The island was thus divided into three zones by the insecticide used for IRS (Table 4). DDT solution in kerosene was used in urban districts A and B (Zone I), which were wealthier areas, with painted houses and walls that were stained by any wettable powder. Zone II covered district

Figure 7. Map of districts for campaign operations, 1948
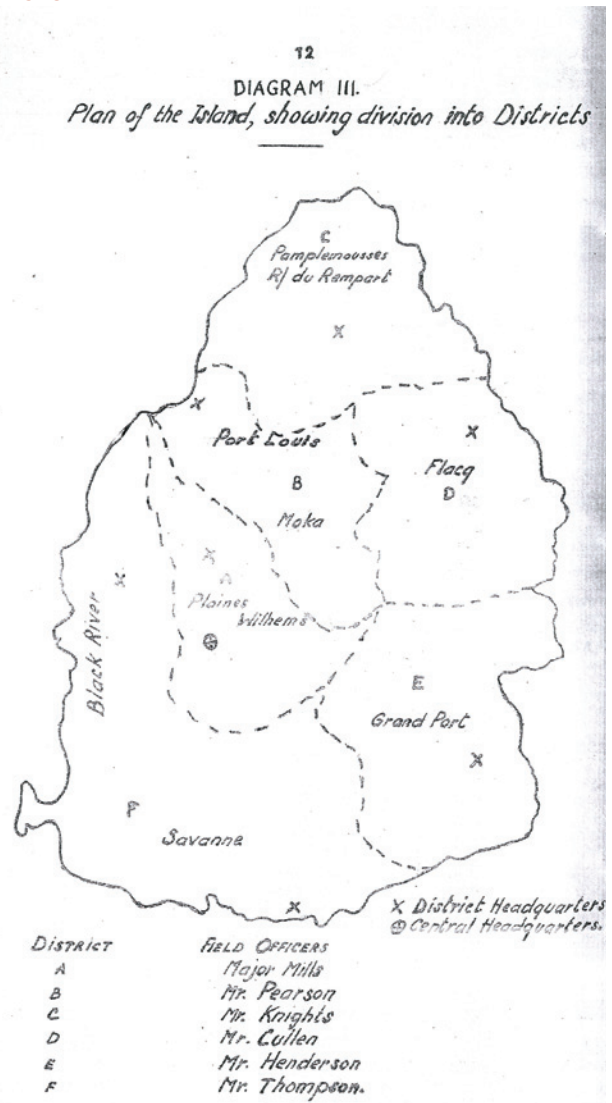
From reference *38*

C and was sprayed with gammexane wettable powder (benzene hexachloride). Districts D, E and F (Zone III) were sprayed with DDT wettable powder (*38*). DDT in kerosene was substituted when the wettable powder was refused (*20*).

Table 4. Spraying operations by district, 1948–1951

District	Insecticide zone	Insecticide
A Plaines Wilhems	I	DDT in kerosene solution
B Port Louis, Moka	I	DDT in kerosene solution
C Pamplemousses, Rivière du Rempart	II	Benzene hexachloride in water suspension
D Flacq	III	DDT in water suspension (wettable powder)
E Grand Port	III	DDT wettable powder
F Savanne, Black River	III	DDT wettable powder

From reference *20*

Figure 8. A team proceeding to spray a hut with residual insecticides

From reference *52*

Six headquarters for the campaign (one per campaign district) were established, with laboratories (three microscopists), offices and residences for field officers and spraying teams of about 50 men each based in every district (*26*) (Figure 8). Between IRS campaigns, teams were assigned to environmental projects (primarily drainage projects to reduce breeding sites), to spray new and redecorated houses and to continue training personnel (*38*).

IRS began in Port Louis on 13 December 1948 and in the other five districts on 17 January 1949 and was completed by mid-May 1949. Teams tried to spray the high-transmission areas in their districts before the end of March. The central highlands were excluded from spraying as very few anophelines were found there and indigenous cases were rare, but the area was still included in prevalence surveys (*20*). The 'barrier' technique was used, in which teams sprayed the outskirts of towns to bar the entry of *Anopheles* mosquitoes (*51*).

The inhabitants were generally willing to help and offer their homes as catching stations, saying that they were proud to be supporting the campaign (*38*). According to programme officers, health authorities used the press and radio effectively, with special broadcasts to spread information about upcoming prevalence surveys and spraying campaigns. Sugar estate managers provided buildings for stores and staff to repair equipment.

In 1949, 75% of the population was protected by IRS. After 2 years of widespread IRS, the coverage of the total population had decreased to 31% as the malaria programme began targeting hotspots and withdrawing IRS in areas with low or no transmission (Figure 9).

By 1952, malaria transmission had shifted to an unstable seasonal pattern, whereas transmission had occurred year-round just 4 years earlier. Spraying continued, with an IRS campaign from 1952 to May 1953 in all coastal areas with high malaria transmission; however, the number of employees decreased, and many of the external experts left once the official campaign came to an end (*53*).

The reports of the campaign describe the challenges faced during IRS. Dr Halcrow, an entomologist who joined the team from England in 1951, found that during the peak time of *An. gambiae* s.l. activity at dusk, the human population was mainly outdoors, talking and cooking, receiving little protection from the residual insecticide (*54*). During a 22-month study of the nocturnal population and habits of *An. gambiae* s.l. after island-wide DDT spraying for 3 consecutive years, Halcrow found that only 3 of 704 houses contained *An. gambiae* s.l. The vector remained unique in its exophilic behaviour.

Figure 9. Population protected by indoor residual spraying, 1949 and 1951

- 1949, first spraying, covered 73% of total population
- 1951, third spraying, covered 31% of total population
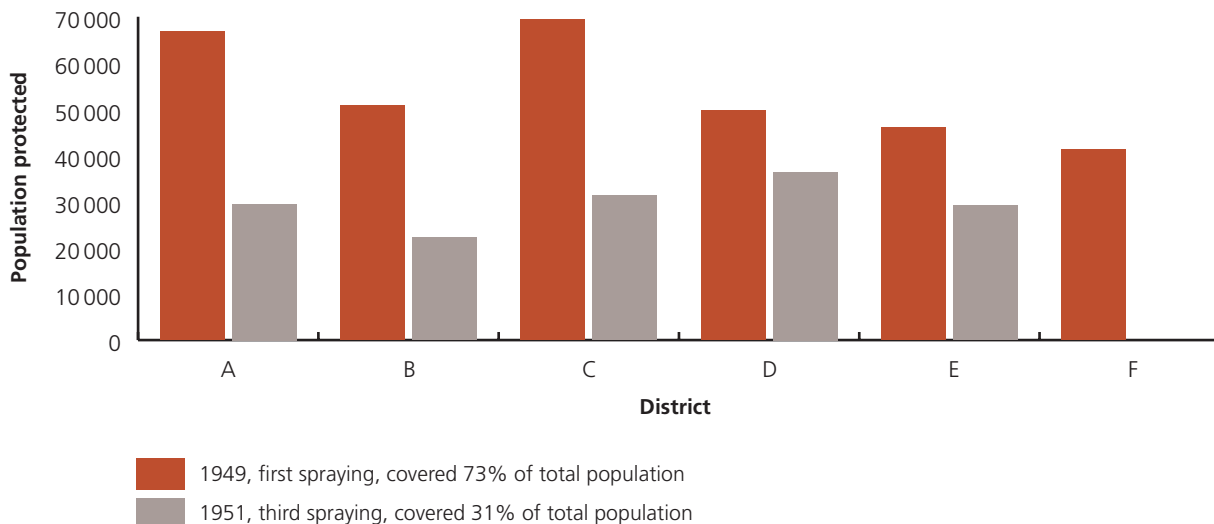
From references *20* and *52*

The Indian community that formed the majority of the population traditionally replastered the inside walls of their houses before the New Year, removing the insecticide that had been sprayed during IRS campaigns only weeks or months before. The spray season also coincided with the harvesting season, when families went to the fields at dawn to gather the sugar crop, leaving their houses locked, and only returned at dusk. Many of these problems were solved with the cooperation of Government officials, estate managers and village councils, who informed communities about IRS and the importance of spraying (*26*).

Another obstacle to spraying was community perception of the success of the IRS campaigns. Communities noted that the second and subsequent treatments of their houses with residual insecticide were not as effective as the first and judged the campaign on the basis of the visible effect on household pests. In response, a large-scale information, education and communication campaign was launched to inform communities about why subsequent IRS campaigns were necessary and to communicate basic information about anopheline behaviour (*26*).

Larviciding

Dr Ross established larviciding in positive and potential breeding sites throughout the island during his visit to Mauritius in 1907 (*31*). Larviciding continued until the mid-1940s, when attention turned to the elimination campaign and IRS.

In 1950, Dr Halcrow realized that *An. gambiae* s.l. were not reacting optimally to IRS, and the Government initiated a pilot larviciding scheme with Malariol (consisting of 70% diesel oil and 30% gas oil) in an attempt to eradicate *Anopheles* (*47, 51*). The intention was to identify and treat all permanent breeding places on the island during the dry season, a strategy that had proved successful in Cyprus (*55*). Larviciding was pilot-tested in Flacq, a district with a high density of both vectors, high malaria transmission and limited environmental interventions. In the coastal region of Flacq, 30 000 patches of water were demarcated, numbered and mapped, and, in October 1950, fortnightly larviciding was begun (*47*).

Authorization to conduct larviciding throughout Mauritius was given in March 1951. The island was divided into 12 blocks and subdivided into sections, each section being supervised by field technicians. Some existing spray teams were transferred from IRS to larviciding, and *moustiquiers* continued to monitor the prevalence of

vectors, as they did throughout the spray campaigns (*47*). After heavy rainfall in February 1952, however, it was decided that larviciding was less effective and economical when conducted throughout the island and should be conducted only in focal areas and in areas where cases were found (*26*).

Entomological surveillance

Marked reductions in the density of *Anopheles* and *Aedes* mosquitoes were seen by the entomologist and the *moustiquiers* by the end of the first IRS campaign. *An. funestus* had virtually disappeared (*20*). Between 1949 and the mid-1950s, the number of *An. funestus* decreased by 99.95% and the number of *An. gambiae* s.l. by 97.12% (Table 5) (*47*). By November 1950, only three adult *An. funestus* and one positive breeding site were found in an island-wide investigation. By December of that year, no *An. funestus* were found, and none were detected in 1951 (*56*). A decrease in vector density was also apparent in indoor collections before and after spraying.

Table 5. Decreases in entomological indicators after the first indoor residual spraying campaign, 1948–1949

Indicator	*An. gambiae* s.l.	*An. funestus*
Vector density (% decrease)		
Zone I: DDT kerosene	94.6%	99.2%
Zone II: DDT wettable powder	92.2%	97.7%
Zone III: benzene hexachloride wettable powder	92.9%	99.7%
All zones	91.8%	98.1%
Vector prevalence per house		
Unsprayed zones	0.0009	0.0026
Before IRS	0.3	1.98
After IRS	0.025	0.037

From reference *20*

The *moustiquiers* visited each catching station once a month (*47*) and sent all larvae and adult mosquitoes caught to the central health headquarters for dissection and identification (*38*). The Entomological Research Unit collected the information and conducted research on the history, behaviour and vectorial status of the mosquitoes (*48*). The chemical branch of the campaign routinely tested mosquitoes for susceptibility to insecticides (*47*). By 1952, the entomology laboratory was well established and could dissect and examine sporozoites and undertake more routine day and night catches (*39*). Entomological surveillance played a major role in this era and in future years in guiding vector control interventions and identifying transmission foci.

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA PARASITES

Passive case detection

To encourage passive case detection, circulars were sent by elimination campaign staff to all public and private doctors, with a request for notification of all malaria cases and for blood slides from all suspected malaria cases. Owners and managers of sugar estates were also asked to notify and screen cases from their health clinics (*38*). Until 1950, the focus of all surveillance activities was strengthening passive case detection at health facilities.

In 1948, the Medical and Health Department introduced regular notification of all 'fresh' cases of malaria treated at dispensaries and hospitals. Before then, clinicians had made little difference between new cases and relapses. Between 1948 and 1950, the country experienced an 87% reduction in the number of notified cases in all districts. Clinicians took blood slides from 38% of notified cases before treatment during these years, but only 3% of the slides were found to be positive (*47*). It is possible that many of the notifications were cases of fever and other illnesses, but not malaria.

Active case detection

A mobile 'malaria squad' was formed at the end of 1950 to detect cases actively as notifications by passive case detection decreased. Until the squad was disbanded in March 1952, its main duties were case investigation and contact screening (*56*). When a positive case was detected, either passively or by the mobile squad, the squad visited the patient's residence to take a case history and a blood slide from everyone living with the patient and from close neighbours, searched houses in the surrounding area for vectors and investigated nearby breeding sites

Table 6. Results of mobile malaria squad activities, 1 February 1951–31 March 1952

District	No. of people examined	Fresh cases	Relapse cases	Total positivity rate (%)	Date last positive case identified
A	275	1	1	0.7	30 April 1951
B	191	0	2	1	30 April 1951
C	176	1	3	2.3	29 June 1951
D	126	2	4	4.8	19 April 1951
E	506	7	11	3.4	25 September 1951
F (Savanne)	153	0	0	0	–
F (Black River)	2 733	27	35	2.3	23 March 1952

From reference *37*

Table 7. Positivity rates of slides collected in 1949–1953

Year	Active case detection			Passive case detection	
	No. of slides examined	Total positive	Positivity rate (%)	No. of reported cases	Positivity rate[a] (%)
1949	19 086	742	3.89	23 746	3.1
1950	23 515	129	0.55	6 021	2.1
1951	45 236	175	0.39	1 255	13.9
1952	43 611	47	0.11	97	48.5
1953	28 750	37	0.13	180	20.6

From reference *57*

[a] No. of laboratory-confirmed positives / total no. of reported case

for larvae (*47*). A small team was established in 1952 to visit incoming ships to monitor vectors and screen passengers arriving from malaria-endemic countries for parasites (*39*).

Table 6 gives the results obtained by the mobile malaria squad in the early 1950s; activities slowed in 1952 when it was observed that the squad was detecting very few cases. Table 7 gives the positivity rates for slides collected during passive and active case detection among incoming travellers, contacts of cases and in some sporadic fever surveys.

Parasite prevalence surveys

The results of the first and second prevalence surveys among children under 16 years of age in 1948 and 1949 were similar to those in 1942 and 1943; villages representative of the previous surveys were included (Table 8). By 1952, spleen rates, the traditional malariometric indicator, had been replaced by parasite rates as the main indicator of changes in malaria transmission. In the surveys in 1950 and 1951, while the parasite rates in children over 2 years of age had not altered significantly, those in children under 2 years had decreased to zero (Table 9). These surveys provided evidence that transmission had been reduced dramatically. Similarly, in the 1953 survey of infants, positive cases were found only in Black River, which had the highest transmission and was the last stronghold of *An. funestus* (*56*).

Table 8. Spleen rates and parasite rates in surveys conducted in 1942–1952

Year	No. of children examined	Spleen rate (%)	Parasite rate (%)
1942–1943	No data	57	39
1948[a]	3 585	34.8	9.5
1949 (after first IRS campaign)	12 105	15.3	2.4
1950 (after second IRS campaign)	14 526	2.8	0.36
1951 (after third IRS campaign)	17 294	2	0.14
1952	14 507	Not conducted	0.05

From references *20*, *26*, *52* and *58*
IRS, indoor residual spraying
[a] Survey performed in December, when the lowest numbers of the year are usually recorded

Table 9. Results of parasite prevalence surveys among children, 1948–1951

Age group (years)	Parasite rate (%)			
	1948	1949	1950	1951
0–1	8.36	3.62	1.01	0
2–5	9.54	4.84	0.78	0.62
6–10	10.05	1.96	0.25	0.25
≥ 11	7.39	1.41	0.07	0.03
All	9.5	2.4	0.37	0.14

From reference *59*

By the early-1950s, all the parasite surveys yielded negative results (*47*): 2 years of extensive intervention had rapidly and effectively eliminated much of the malaria burden.

Surveys were also conducted every 3 months to monitor parasite rates in children born after each IRS round. Districts C, D and E (Figure 7) were considered to be suitable for gauging the impact of IRS, as there had been fewer interventions in those areas before the campaign, and morbidity and parasite rates were high. An

arrangement was made with hospitals and clinics to notify births to the malaria team's central headquarters (*38*). Routine surveys of infants continued until 1954 (*53*).

Reporting

Campaign staff reported daily, weekly and monthly on coverage of interventions and on scientific monitoring, including recurrent parasitological and entomological prevalence surveys (Annex 4) (*20*).

The Government changed the reporting system at the time the elimination campaign began, with a new malaria case definition: parasitologically positive for malaria by microscopy. Therefore, it was not possible to ascertain the true decrease in incidence due to the interventions, as the reported malaria incidence would have declined regardless of the intervention. Consequently, statistics such as morbidity, mortality, live birth rate, stillbirth rate, standardized death rate and infant mortality were often used as proxy indicators for malaria incidence, prevalence and deaths (*38*). Significant reductions due to the interventions can nevertheless be seen from the data. While prevalence was a more accurate indicator before 1948, incidence data became more precise after 1952, when parasitological confirmation was required for every suspected malaria case. This was the same year in which malaria became a notifiable disease (*46*).

Diagnosis and treatment

From July 1949, blood slides were taken before treatment from all cases notified as malaria by health facilities in order to estimate incidence and to determine the relative prevalence of parasite species. Microscopists found *P. falciparum*, *P. vivax* and *P. malariae* in almost equal proportions (*20*).

By 1952, field officers were conducting follow-up visits for all malaria cases and administering Paludrine tablets, which were taken daily for 2–3 weeks combined with mepacrine (antiprotozoal quinacrine) on the first day. Health officers and the mobile malaria squad visited patients the first, third and sixth month after treatment to take blood slides in order to monitor treatment outcome and detect relapse (*26*).

In 1954, the health authorities decided that, after initial treatment by the malaria survey officer, treatment would be continued by sanitary inspectors, who dispensed Daraprim (pyrimethamine) tablets at weekly intervals for the first 2 weeks and fortnightly for the following 4 months and took blood slides to monitor parasitaemia and relapse (*48*).

IMPACT OF CONTROL EFFORTS AND THE ELIMINATION CAMPAIGN

From the time malaria became endemic in Mauritius until 1945, the average number of malaria-attributed deaths was 3 000 annually, representing approximately 25% of all deaths (*60*). The annual number of malaria deaths decreased from 3 000 to 1 700 between 1946 and 1947, largely because of the initial control activities (*36*). Mortality from malaria decreased again, from 1 500 to less than 500 deaths, between 1948 and 1950 during the malaria elimination campaign (Figure 10). The incidence rate also dropped markedly between 1948 and 1951 during the elimination campaign, from 105 cases per 1 000 population at risk to 2.6 cases.

Although the country was experiencing a higher birth rate during 1948–1951, there were significant decreases in infant and all-cause mortality. The total death rates were more indicative of trends in malaria mortality, as they showed both the direct and the indirect effects of the disease. The mean mortality rate between 1934 and 1948 was 29.4 per 1 000 population, while that in 1949 was 16.6 and that in 1950 was 13.9 (Figure 11). Similarly, the mean infant mortality rate dropped from 150 per 1 000 live births between 1934 and 1948 to 91 and 76 in 1949 and 1950, respectively, even though the birth rate increased from 34.5 to 51 per 1 000 population between 1934 and 1950 (*47*).

Microscopy results for 1949 indicate that, on average, 55% of malaria cases were due to *P. vivax*, 19% to *P. falciparum* and 26% to *P. malariae* (*20*), although the proportion of cases due to *P. falciparum* increased to 26% and that due to *P. malariae* decreased to about 15% during the campaign. It is possible that the blood slides did not represent the overall malaria burden, as microscopy was not standard protocol until 1952. *P. falciparum* dominated during peaks in the number of malaria cases between January and March, while *P. vivax* persisted throughout the cooler months (*26*).

Figure 10. Malaria-attributed deaths, 1932–1961
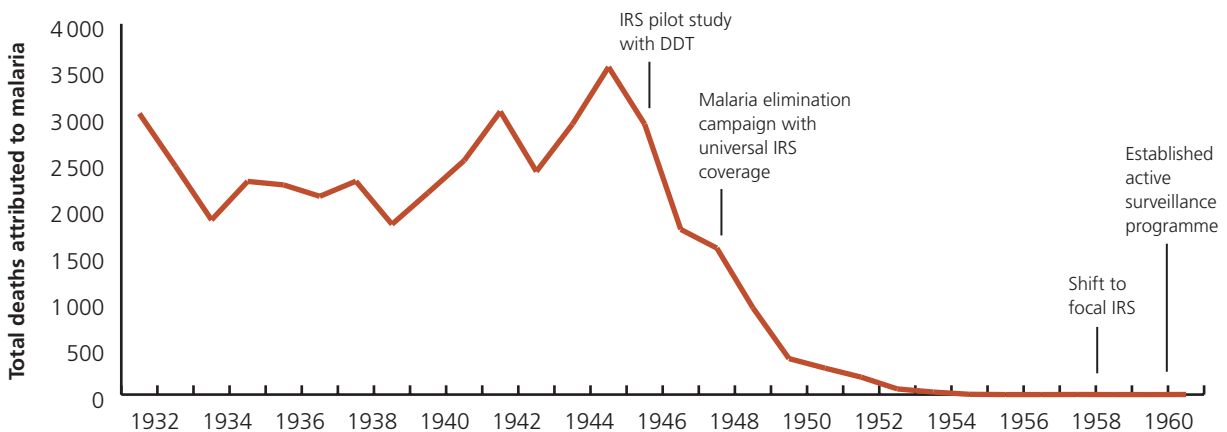
From references *40*, *61* and *62*. IRS, indoor residual spraying

Figure 11. Mean monthly all-cause mortality rates (deaths per 1 000 population), 1934–1948 and 1949

Mean mortality rate, 1934–1948

Mortality rate, 1949
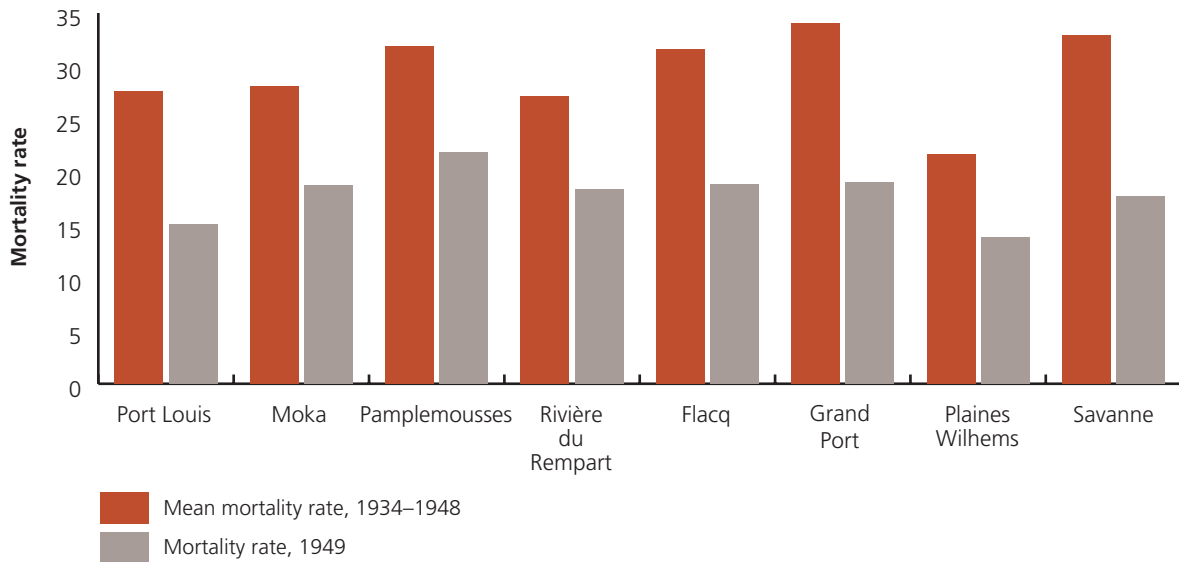
From reference *20*. See Figure 2 for districts.

REACHING ZERO LOCAL CASES, 1952–1968

After the disappearance of *An. funestus* in 1952, malaria followed a seasonal transmission pattern. With a smaller team, focal IRS and larviciding, a functional malaria laboratory and a relatively strong passive surveillance system, elimination campaign officers decided to start a 'control scheme'. In addition to the previous activities, the scheme integrated entomological monitoring, environmental management and parasitological surveys, with special attention to immigrants and the military (*26*). The Government provided prophylaxis free of charge to travellers (chloroquine and pyrimethamine) and radical treatment for all positive cases (primaquine and chloroquine).

By 1955, the campaign staff had been reduced by 64% (from 614 to 224), and it was reduced by another 39% at the end of the year. The field workforce consisted of field workers, drivers and labourers for residual spraying, and five microscopists were maintained in the malaria-dedicated laboratory. IRS teams continued to conduct focal spraying in former high-burden areas, in any area of ongoing transmission and biannually at the airport and seaport (*57*). The airport sanitary staff began disinfection of each arriving airplane around this time (*48*).

The WHO Malaria Eradication Programme was established in Mauritius in 1960 to improve proactive case detection and increase focal IRS in coastal areas (*63*). The Programme established new surveillance sectors with dedicated staff. Proactive case detection included routine surveys and a screening programme for travellers arriving from malaria-endemic countries. While the elimination campaign and subsequent activities included blood surveys, the programme launched in the 1960s focused on fever surveys, which eventually replaced traditional malariometric surveys. More cases were detected in fever surveys, showing that they could select populations with a higher probability of detecting malaria cases (Table 10).

Between 1952 and 1967, Mauritius experienced only sporadic local cases (Figure 12). The brief surge in 1960 and 1961 was probably due to intensified surveillance, during which additional cases were detected. Furthermore, major cyclones in February 1960 and 1962 might have increased mosquito density and local transmission. The last indigenous malaria case was reported in 1968 (*66–68*).

Table 10. Results of surveillance, indicating higher positivity rates from fever surveys

Year	Population	Total no. of smears	ABER (%)	Malariometric surveys			Fever surveys		
				No. of smears examined	No. of positive cases	% positivity	No. of smears examined	No. of positive cases	% positivity
1957	587 872	57 401	9.8	56 591	47	0.08	810	47	5.8
1958	603 466	64 122	10.6	62 180	18	0.02	1 942	70	3.6
1959	621 197	66 451	10.7	63 514	28	0.04	2 937	132	4.5
1960	638 691	40 692	6.4	9 109	7	0.07	31 583	1 172	3.7
1961	662 368	40 225	6.1	7 596	2	0.02	32 629	953	2.9
1962	681 619	49 394	7.2	7 579	1	0.01	41 815	225	0.5

From reference *64*. ABER, annual blood examination rate

Figure 12. Reported numbers of confirmed malaria cases, 1952–1968
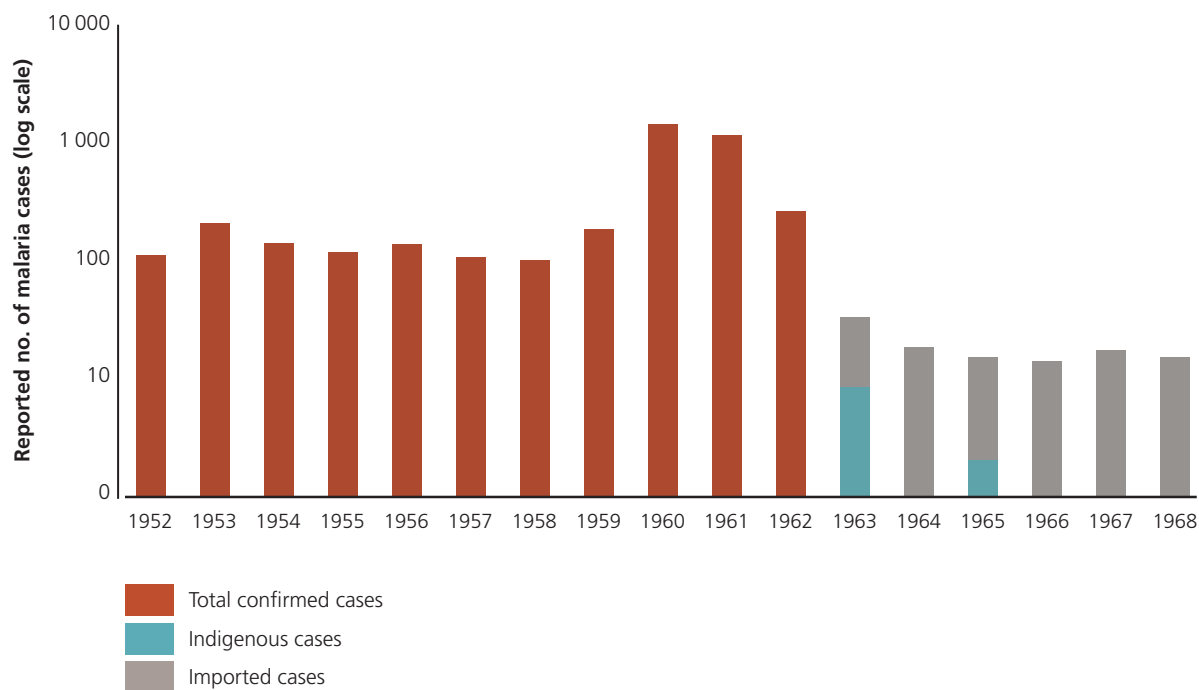
From reference *65*

Programme to prevent reintroduction (1969–1974)

After the last indigenous case was detected in 1968, the island entered the maintenance phase, and, as of June that year, the Malaria Unit was integrated into the general public health services as a branch of the Preventive Division, and the malaria laboratory was integrated into the Central Laboratory (*69*). Field workers and the spraying section were integrated into the general public health services in each health district, and medical officers of public health were immediately responsible for malaria control in their respective districts (*70*).

The main objective of the strategy was to "prevent the reintroduction of malaria in Mauritius by detecting promptly imported cases so as to prevent the re-establishment of transmission" (*66*). Ongoing activities during prevention of reintroduction included IRS at ports of entry, prophylaxis for travellers, surveillance of incoming passengers, education about malaria and information for medical personnel on malaria case management (*67*). The specific objectives and activities of the strategy, as described in the 1968 annual report of the Medical and Health Department, are given in Annex 5.

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA PARASITES

Passive and active case detection

By 1969, Mauritius was implementing passive and active case detection, including proactive and reactive case detection (*70*). Proactive case detection involved screening travellers from malaria-endemic areas and 'special groups', such as migrant workers, Mauritian labourers, pilgrims returning from work or religious events, and military personnel. Reactive case detection included case investigation and screening of contacts and neighbours of passively detected imported malaria cases and provision of presumptive treatment for fever cases pending laboratory confirmation. Districts were subdivided into sectors similar to those mentioned earlier, to which surveillance staff were distributed for active case detection, with a total of 50 officers. Surveillance staff also conducted mass blood surveys every 3 months in areas of former high transmission and every 6 months in areas of former low transmission. Presumptive treatment was given to 5 587 people after surveys in 1969 (*67*).

The names and addresses of passengers arriving at the seaport or airport from malaria-endemic areas were documented on health cards upon their arrival in Mauritius, so that field surveillance officers could screen them for malaria (*71*). Surveillance officers were expected to monitor such incoming passengers for 6 weeks or make one visit immediately upon their arrival and three visits every 2 weeks subsequently. Most passengers arriving from malaria-endemic areas were visited once by surveillance officers to inquire about symptoms and to take a blood slide if the officer suspected malaria. About one quarter were monitored for the full surveillance period, although that proportion appeared to decline by 1970 (Table 11).

Table 11. Proactive case detection among incoming passengers from malaria-endemic areas, 1968–1970

Year	No. of passengers	Percentage visited[a]			
		At least once	At least twice	At least three times	All four times
1968	17 993	84%	48%	29%	23%
1969	20 411	93%	40%	31%	27%
1970	No data	78%	26%	19%	16%

From reference *72*

[a] Numbers not available

Table 12. Results obtained with different surveillance methods, 1969 and 1970

Method of case detection	1969			1970		
	No. slides collected	No. positive	Positivity rate (%)	No. slides collected	No. positive	Positivity rate (%)
Passive	5 385	4	0.07	2 974	1	0.03
Proactive	6 689	10	0.15	3 754	8	0.21
Reactive	17 352	4	0.02	12 587	5	0.04

From references *67* and *72*

Table 12 gives the results of passive and active case detection in 2 years during prevention of reintroduction. All the positive cases were imported, mostly from Africa (the Congo, Madagascar, Malawi and the United Republic of Tanzania) and Asia (India and Pakistan) (*72*). On average, proactive case detection yielded the highest positivity rate (0.17%), with 0.06% from passive case detection and 0.04% from reactive case detection. The households and individuals under surveillance were located or living in formerly high-risk areas on the island.

Overall, the annual blood examination rate was 4.6% in 1968, declining to 3.9% in 1969 and 2.4% in 1970. Programme staff reported at the time that cooperation from general practitioners to test suspected malaria cases was poor, especially those in private clinics, as was cooperation from aircraft crews in distributing health cards to passengers to be completed upon disembarkation in Mauritius (*70*).

Diagnosis, treatment and prophylaxis

All Mauritians travelling to malaria-endemic countries with the intention of returning were encouraged to take prophylaxis (chloroquine and pyrimethamine), which was distributed free of charge by the Government of Mauritius. Between 1968 and 1970, an average of 1 247 individuals received prophylaxis for travel each year. The mass media 'invited' Mauritians traveling to malaria-endemic countries to visit Port Louis health centres for advice and prophylaxis (*72*). For any person presenting with fever, the treatment policy authorized, pending laboratory confirmation, initial presumptive treatment

with chloroquine (600 mg) and pyrimethamine (50 mg), supervised by a surveillance officer (*63*). Radical treatment for *P. vivax* consisted of chloroquine for 3 days at doses of 600 mg, 600 mg, and 300 mg and 15 mg of primaquine per day for 14 days, while *P. falciparum* was treated with chloroquine for 3 days (*63*). Health officers supervised every treatment dose.

Throughout the period of prevention of reintroduction, 4 malaria-dedicated microscopists in the malaria laboratory read all slides from all surveillance activities and conducted quality assurance, re-examining approximately 14% of all negative slides and all positive slides (*72*).

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA VECTORS

The IRS operation involved 46 spray personnel in two teams who conducted IRS and larviciding at the ports every 3 months and in the vicinity of every positive malaria case (*70*). Although no entomologist was employed after 1967, entomology assistants continued to monitor sentinel sites, to conduct night catches and to test for susceptibility to DDT and Abate (the organophosphate larvicide temephos) (*71*). Larval surveys continued to find only *An. gambiae* s.l., primarily along the coast into the coastal plains, and entomological teams continued to map breeding sites (Figure 13) and conduct surveys around positive imported malaria cases and ports of entry. The team noted in the 1972 annual report (*66*) that record numbers of *An. gambiae* s.l. were collected in households.

Figure 13. *Anopheles* **breeding sites, 1968**

PORT LOUIS
1. Edith Cavell Street
2. Line Barracks
3. Guy Rozemont square
4. Bourgeois stream
5. Taylor Smith
6. Albion Dock
7. Mauritius Dock
8. Fort George
9. Pleasure Ground
10. Bain des Dames

PLAINES WILHEMS
11. Phoenix
12. Cité St. Jean

PAMPLEMOUSSES
13. Pamplemousses
14. Khoyratty
15. Tombeau Bay
16. Tombeau Bridge
17. Pointe aux Piments
18. Triolet

RIVIERE DU REMPART
19. Grand'Baie
20. Cap Malheureux
21. Pavé
22. St. François
23. Poudre d'Or

FLACQ
24. Providence

GRAND PORT
25. Ste Hélène (Plaisance)
26. Plaine Magnien
27. Carreau Esnouf
28. Anse Jonchée
29. Bambous Virieux

BLACK RIVER
30. Belle Vue
31. Petite Rivière
32. Gros Cailloux
33. Wolmar
34. Tamarin
35. Baie du Cap

From reference *70*

CERTIFICATION OF MALARIA ELIMINATION

A serological survey with indirect fluorescent antibody testing of nearly 6 000 inhabitants of all ages, with emphasis on children under 5 years, was conducted in 1970 as part of the application for WHO malaria elimination certification (*73*). The survey was carried out in Black River, a district that had had the highest burden in the past and where transmission persisted longest. The study team also hoped that the survey would help to understand the trend in decreasing immunity, which is relevant to the risk for reintroduction. The near-absence of positive serology results in children under the age of 5 years (0.6%) confirmed the near-absence of transmission during recent years (Table 13). These survey findings and zero reported indigenous cases led to WHO certification of elimination in 1973.

Table 13. Serological survey results in Black River, 1970

Age (years)	Population	Population examined		Positive sera	
		No.	%	No.	%
< 5	3 039	1 081	36	7	0.6
5–19	8 892	4 137	47	376	9
30–45	6 792	540	8	167	31
> 45	3 619	56	2	43	77

From reference *73*

Outbreaks and their initial control (1975–1981)

RESURGENCE

The main anopheline species in Mauritius in 1973 were *An. gambiae* s.l., *An. maculipalpis* (very rare) and *An. coutani* (non-malaria vector). Chromosome studies of adult and larval *An. gambiae* s.l. sent to the Ross Institute in London around 1975 indicated that all the *An. gambiae* s.l. belonged to subtype B (now called *An. arabiensis*) (*27*).

No local transmission was detected between 1968 and 1975, when the first local *P. vivax* case was found in April 1975 in a harbour area of Roche Bois in the suburbs of Port Louis (*27*). Forty-one cases followed in an outbreak

of local transmission in the same area, where many migrant workers were staying to assist in reconstruction of the island after a devastating cyclone that year (*4, 74*). The number of foci (defined as localities in which at least one local case had been detected (*69*) increased sharply from 8 in 1975 to 77 in 1980 (*27*) after a large cyclone in 1979 (*2*). As the epidemic intensified in the late 1970s, many cases were asymptomatic, and concern was minimal as *P. vivax* did not appear to be virulent to communities (*2*). The malaria epidemic in the 1980s was characterized by local *P. vivax* transmission and only imported *P. falciparum* malaria (with the exception of one local *P. falciparum* case in 1986), whereas previous epidemics were largely due to *P. falciparum* (*74*).

The main *P. vivax* foci during previous epidemics, in the districts of Flacq, Pamplemousses and Grand Port (*69*), were still the primary active foci in the 1980s, accounting for 82% of all cases in 1982 (*74*). In 1982, all districts were malarious, except for the upper part of Plaines Wilhems on the central plateau (*69*) (Figure 14).

INITIAL INTERVENTIONS TO CONTROL THE OUTBREAK BEFORE THE SECOND ELIMINATION CAMPAIGN

The Ministry of Health responded to the resurgence by intensifying interventions and increasing the number of staff for initial control efforts. Geographical reconnaissance was immediately undertaken to identify and target all transmission foci with remedial action. Malaria personnel rapidly re-established island-wide fever and mass blood surveys, presumptive and radical treatment and case and focus investigations. Entomological surveys, routine island-wide larviciding with temephos (Abate 50EC) and thermal fogging with an organophosphate, 5% diethyl(dimethoxythiophosphorylthio)succinate (malathion) were also conducted, alongside health education and small environmental management projects. Larvivorous fish were used in selected areas, and small-scale mass drug administration with chloroquine was conducted in three villages in high-transmission areas (Pamplemousses, Black River, and Flacq) (*5*). All activities were augmented in response to any positive case, with the addition of IRS with DDT within 500 m of a positive case and blood surveys of all contacts.

Figure 14. Map of malaria transmission, 1982

TR: Triolet
BA: Bon Accueil
MI: Mont Ida
BR: Boulet Rouge
WL: Wolmar
VC: Vacoas
QB: Quatre Bornes
PL: Port Louis

✕ Locality with indigenous malaria cases

⊙ Locality where no transmission had been detected.

-·-·- District Boundary.

▦ Towns.

▤ Height more than 400 metres above sea level.

▲ Highest Peak, 827 metres.

-2 0 2 4 6 8 km
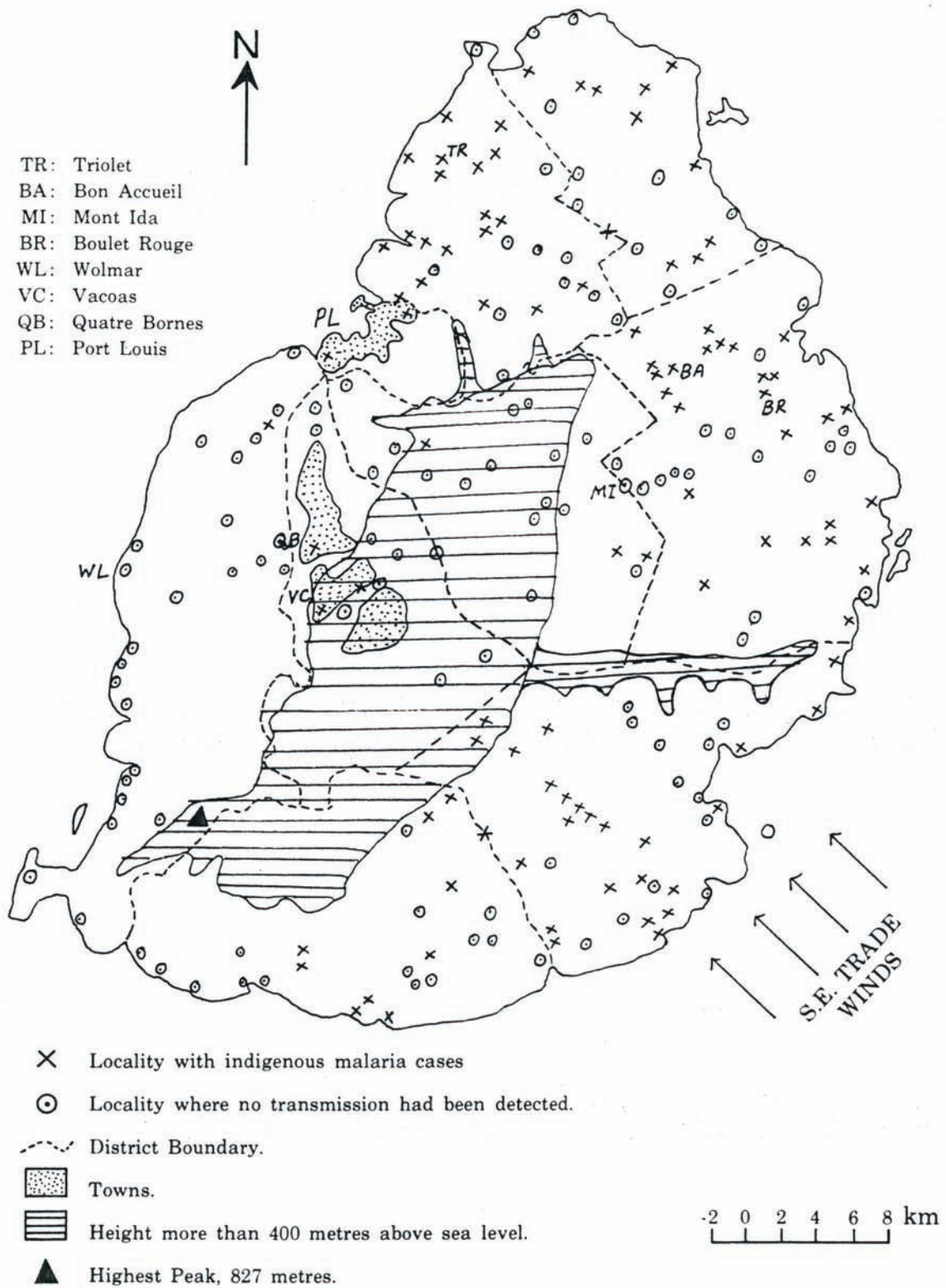
From reference *4*

Figure 15. Malaria focus classification and management, 1979–1982

Chart showing number of foci by district (Flacq, Grand Port, Pamplemousses, Rivière du Rempart, Savanne, Plaines Wilhems, Port Louis, Moka, Black River) categorized by AR, AN > 3 cases, and AN ≤ 3 cases.
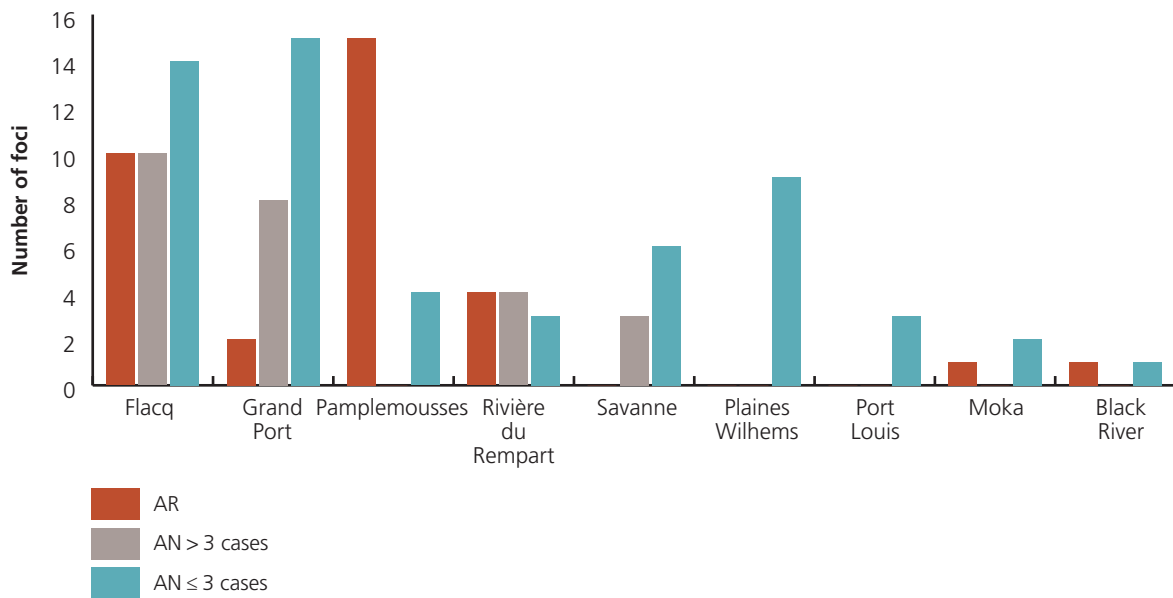
From references *74* and *75*

AR, active residual foci; AN > 3 cases, active new foci with more than three cases; AN ≤ 3, active new foci with three or fewer cases. AR and AN > 3 cases under spraying operations, in addition to fogging, anti-larval measures and surveillance; AN ≤ 3 under fogging, anti-larval measures and surveillance

Transmission foci were identified from the number of cases in a particular locality and categorized by the number of cases detected. Interventions were then targeted according to the size and location of the focus (Figure 15). The responses to active foci included IRS, fogging, larviciding and surveillance, while non-active foci received larviciding, fogging and surveillance only. The aim of this strategy was 100% coverage of the foci with appropriate interventions. A contemporary epidemiological analysis of foci identified in these years is shown in Figure 16.

Active and passive case detection

The Mauritius surveillance programme was intensified after the resurgence leading up to the second elimination campaign. An additional method of case detection, called 'active passive case detection' (referred to as 'enhanced passive case detection' in this document), was used, partly because of the lack of cooperation from public and private health care workers in screening people for malaria. The new method involved surveillance officers, instead of health workers, who visited health facilities to take blood slides from people presenting with fever.

In 1975, the active case detection system was struggling, as it lacked uniformity and personnel, according to reports from the time (*5*). The population was underserved, with one surveillance field worker per 15 000 people, there were challenges in following-up incoming passengers, and the annual blood examination rate was 2.1%. Until a change in the programme in 1982, it took 9 days for blood slides collected in the field to be delivered to the malaria laboratory (while newspapers published in Port Louis reached the entire island within 3 h) (*74*). Enhanced passive case detection was also inconsistent, as the time spent by surveillance officers in health facilities varied from 1 to 10 h every week. Passive case detection by the country's well-distributed health system was inadequate, as, despite the dissemination of circulars and health education materials, few fever patients were tested for malaria (*5*). This method contributed 1–2% of all slides for screening at the malaria laboratory between 1975 and 1987 (*5, 6, 69, 76*).

Active case detection was intensified in 1979, and surveillance officers received 1 week of retraining. Mapping of known residences on the island was also updated (*5*). Proactive case detection at the island's airport, seaport and

Figure 16. Epidemiological analysis of foci identified in 1979–1982

EPIDEMIOLOGICAL ANALYSIS OF MALARIA FOCI (1979-82)

From reference *74*

harbour disinfection station included screening all incoming vessels and passengers (*77*). All passengers arriving at the airport, approximately 168 000 per year on 3 100 aircraft, were required to present health disembarkation forms to health inspectors that included information on recent travel, destination of stay in Mauritius and whether they had fever. On average, 32 000 passengers a year throughout the late 1970s and early 1980s were put under malaria surveillance (*78*), representing about 340 passengers per year for each surveillance officer (*69*).

In 1981, the Ministry of Health and Quality of Life, with WHO intercountry teams of consultants, devised a plan of action for 1982–1988 that included strengthening passive and active case detection systems (*69*). As of 1981, 102 surveillance field workers were deployed throughout the island (an increase from 53 in 1975) to visit incoming passengers from malaria-endemic countries and conduct fever and mass blood surveys. These activites were designed to identify additional infections in the community and guide targeting of interventions, including small-scale mass drug administration. In addition, approximately 100 health inspectors posted at health offices in every district were responsible for screening passengers at the seaport and airport, conducting environmental inspections, supporting surveillance and responding to positive cases (*79*).

Vector control and entomological surveillance
During the 1974 sugar boom, houses were built of concrete without appropriate water drainage, particularly from rooftops (*2*). There was little community cooperation in cleaning the rooftops and, as noted by the entomologist during the campaign, rooftop breeding

probably contributed to the density of *An. gambiae* s.l. and possibly the increase in local malaria transmission (*4*). Consideration was given to legislating drainage of rooftops, although this never came to fruition (*75*).

Focal spraying began in 1975, with two rounds in 1975 and 1976 during the transmission season (December–May) around Roche Bois, the focus of the first outbreak of local malaria (*69*). Two rounds of spraying were usually done each year, avoiding weeks in late December when Mauritian households traditionally washed their walls and cleaned their homes in preparation for the New Year. Biannual IRS was extended to a significant number of additional foci throughout the island in 1980 as transmission increased (*74*). The focal spraying unit consisted of 21 staff, who also conducted island-wide fogging and biannual DDT spraying at the seaport and airport (*78*). Technical-grade DDT, the form typically used in IRS programmes, was used on 40% of high-standard houses and 75% wettable powder DDT on the remaining houses and animal sheds (*69*).

Fogging operations with 5% malathion also began in 1975 at the outset of the epidemic but were stopped in 1981 because of ineffective implementation of this relatively costly activity, the chief problem being that fogging was conducted in the morning when the temperature was already too hot resulting in premature evaporation of the fog (*69*).

Labourers undertook environmental management projects, although these projects were arbitrarily chosen at central level and correlated poorly with entomological surveillance, according to reports (*69*). Furthermore, the annual increase in breeding places due to recurrent cyclones made source reduction difficult (*2*). Despite this, sanitary engineers conducted drainage and cleaning projects, with the goal of building drains and filling marshes in 1983 (*74*).

Diagnosis and treatment
Six laboratory technicians performed microscopy at the country's re-established malaria-dedicated laboratory (*5*). Despite the large number of blood slides sent in each day by field workers and health facilities, the 2–3-day lag

between receipt, reading of slides and communication of the results to the field was satisfactory. There was, however, no quality assurance until 1984, when 12% of negative slides were re-examined, with one positive *P. vivax* result (*69*).

The treatment policy continued to authorize, pending laboratory confirmation, initial presumptive treatment with chloroquine (300 mg) and primaquine (15 mg) (*69*), although it was reported that not all fever cases were given antimalaria agents (*75*). Radical treatment for *P. vivax* usually included chloroquine for 3 days at doses of 600 mg, 600 mg and 300 mg and 15 mg of primaquine per day for 14 days (*2*), while *P. falciparum* malaria was treated with chloroquine (as above for 3 days) and a single dose of pyrimethmine (25 mg) (*69*). Treatment follow-up included examination of slides taken after the full course of treatment and for 4 consecutive months for both parasite species, then three times a year for 3 years for *P. vivax* and three times a year for 2 years for *P. falciparum* (*2*).

Governance and legal framework
Government officials and health staff began to realize the gravity of the situation at the beginning of 1983, according to WHO consultants supporting the country's elimination efforts (*6*). That year, the Minister of Health and Quality of Life took an active role, mobilizing health awareness and education throughout the country (*74*). High-level officials occasionally visited vector control or environmental management operations, and these events were widely publicized.

The Prevention of Malaria Act was revised in 1981 to change its coercive approach to a more motivational approach, stressing the importance of health education (*75*). In the 1981 revision, although power to enter and inspect all dwellings for mosquito breeding places was maintained, community education and mobilization were strongly emphasized. As communities were generally unaware of this legislation, public health personnel were encouraged to enforce the policies throughout the campaign. Small punitive measures were maintained, and households were fined Rs300–Rs500 (US$ 66–110, 2008 US$) if they did not cooperate with spraying and environmental projects (personal communication from S. Sohun, 6 June 2009).

A malaria action committee was formed in 1984 by the Chief Medical Officer to ensure that all the proposed activities were carried out, giving priority to larval source reduction with the cooperation of other ministries and private agricultural authorities (75).

Programme organization

Although malaria was integrated into general public health services in 1968, the Malaria Control Unit was re-established in the late 1970s in response to the epidemic and was responsible for programme implementation (69), including vector control, ensuring ample supplies, logistic support and manpower, active case detection, training spraymen and field workers, health education, monitoring, surveys, treatment and follow-up (27). The Malaria Control Unit regularly distributed supplies to private clinics, including slides, slide boxes and malaria surveillance forms. Private health facilities sent back all slides and forms to the public malaria laboratory for diagnosis (69).

There was an average of 638 staff in the years before reintroduction (1973–1975), and the number nearly doubled after reintroduction, to an average of 1 256 in 1976 and 1977 in order to confront the resurgence adequately (71). WHO provided training fellowships for health inspectors during the 1970s (80), and the principal and senior health inspectors at the Malaria Unit went to WHO for training between 1982 and 1983 (81).

Second malaria elimination campaign (1982–1988)

The second elimination campaign was officially launched in 1982, with implementation of the plan of action drawn up by the Ministry of Health and Quality of Life with technical assistance from WHO. The plan included a strategy for reaching zero indigenous cases, with emphasis on focus classification, management and elimination.

Transmission fluctuated seasonally over time but was generally highest between January and May, with small peaks in September 1982 and 1983 (82). Similar seasonality had been seen earlier when transmission of malaria changed from stable to unstable around 1952. The months of higher transmission, April and May, coincided with months with a significant amount of rain (Figure 17), especially in 1982 during the peak of the epidemic, when Flacq, the main foci throughout, received almost 1000 mm of rain in February, leading to a major outbreak, with 329 cases, representing 50% of all indigenous cases detected that year (74).

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA PARASITES

Active and passive case detection

In 1984, the malaria programme restructured active case detection, so that every district was divided into sectors with approximately 7 314 inhabitants or 1 271 households per sector (75) and assigned field workers. The number of field workers almost doubled between 1975 and 1981 and increased by 70% between 1981 and 1986 in response to programme requirements and recommendations by external technical advisors (69).

Most blood slides were collected during proactive case detection (Figure 18), which identified an average of 50% of positive cases, while passive, enhanced passive case detection and reactive case detection contributed the other 50%, but with significantly fewer slides. The annual blood examination rate increased throughout the campaign, from 2.1% in 1975 to a peak of 9.8% in 1983 to 8% towards the end of the campaign in 1987 (Figures 19 and 20).

Diagnosis, treatment and mass drug administration

In 1984, 53% of the positive slides collected in the field were delivered to the malaria laboratory within 24 h and 73% within 48 h. The laboratory was more efficient, examining 69% of the positive smears the same day and 90% within 24 h (75). Malaria treatment, including presumptive treatment for any fever case presenting at a health facility or during fever surveys, pending the result of the blood slide examination, remained consistent with the protocol in place before the campaign.

Mass drug administration with chloroquine (600 mg depending on weight and age) to 35 905 individuals in seven districts and 38 villages that reported indigenous malaria was conducted in January and February 1984 (2).

Figure 17. Climate indicators and malaria transmission, 1979–1985

COMPARATIVE GRAPH SHOWING MONTHLY POSITIVES AND CLIMATIC CONDITIONS
_1979-1985_
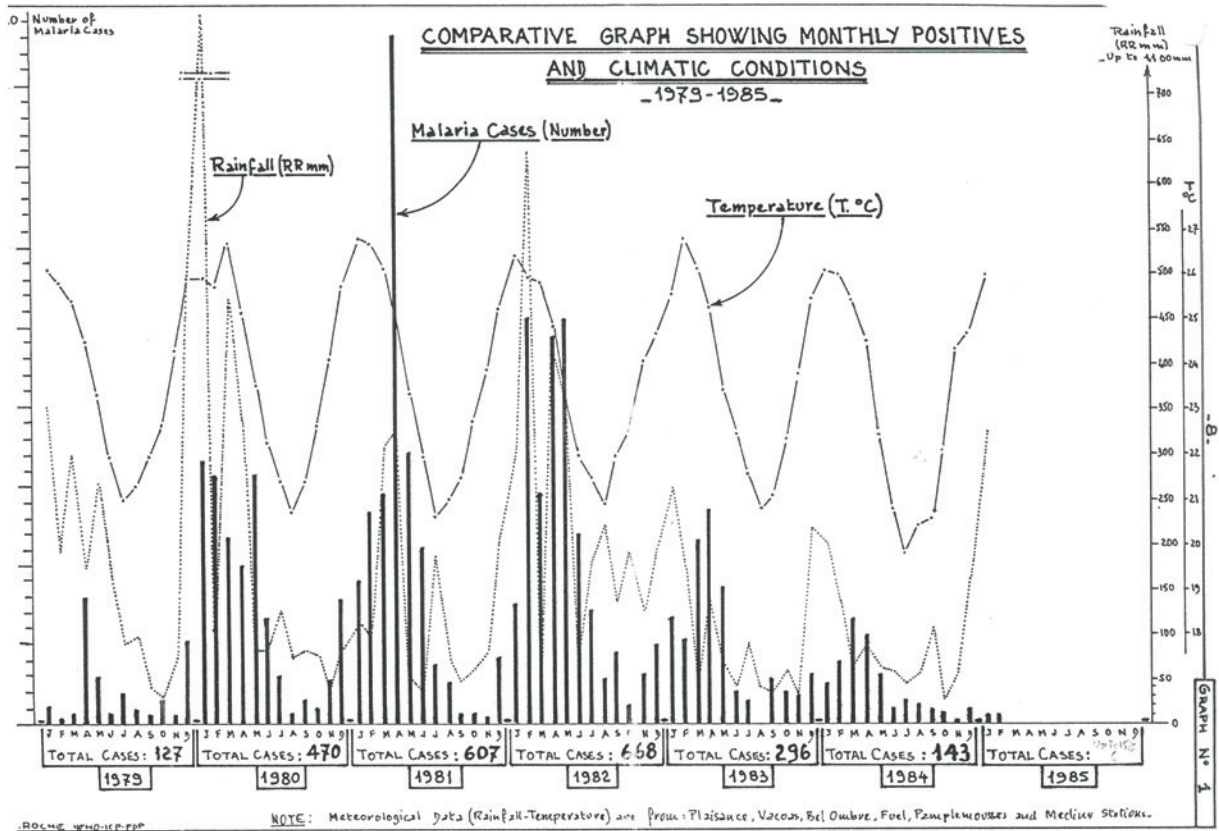
From reference *75*

Figure 18. Numbers of blood slides taken, by type of surveillance, 1975–1987
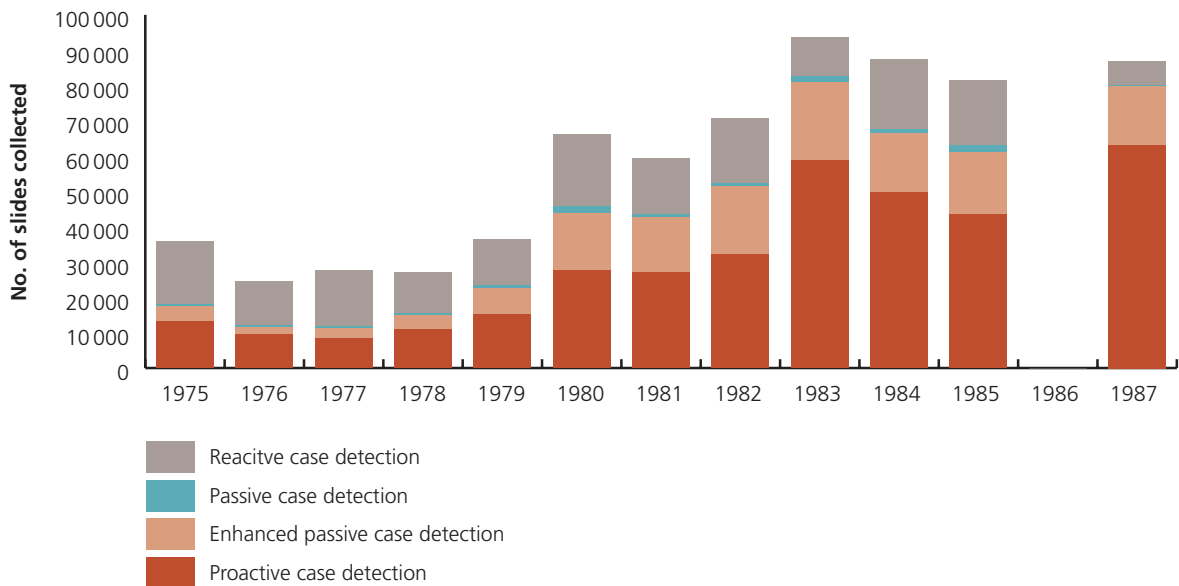
From references *5, 6, 69, 75* and *76*
No data available for 1986

Figure 19. Relations between the numbers of slides positive for malaria parasites and the annual blood examination rate (ABER), 1975–1987
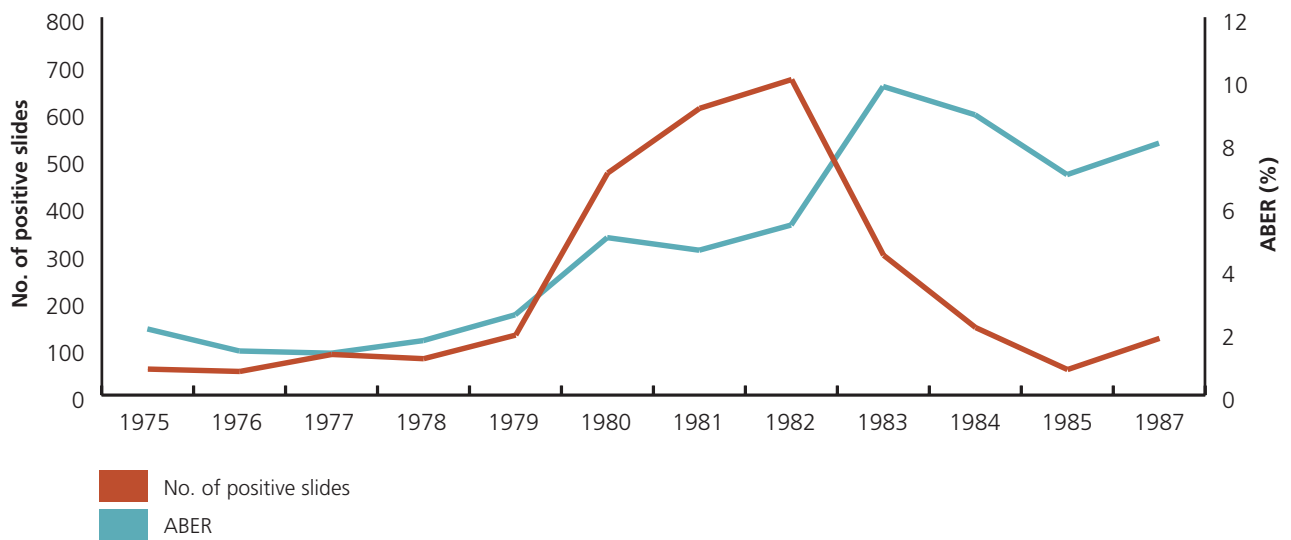
From references *5, 6, 69, 75* and *76*
No data available for 1986

The inhabitants of 100 houses situated around a positive case were also given chemoprophylaxis as part of this campaign (*75*). Small-scale drug administration was also conducted in 1979, although the details were not reported (*5*).

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA VECTORS

Between 1982 and 1988, the Medical Entomology Division had 22 personnel, including one scientific officer, one assistant entomologist, mosquito catchers, field workers and laboratory personnel (*27*), an increase of 13 personnel between 1976 and 1982 (*69*). The number of full-time salaried spraymen increased from 17 in 1979 to 51 in 1982 (*74*), and approximately 200 temporary labourers participated in twice yearly IRS campaigns between 1983 and 1986. In 1986, 500 personnel were required for the spray campaigns (*6*), whereas there had been 750 personnel in 1981 (*69*).

Vector control

The plan of action recommended an island-wide spraying campaign, but, as resources and funding were insufficient, IRS was conducted only in areas with established transmission (*74*). Therefore, in 1982, at the height of the epidemic, just over half the population was protected by IRS; the remaining population was not covered by IRS but was included in larval control and surveillance activities (*69*).

Pamplemousses in the north and Flacq and Grand Port in the east had the highest transmission during the epidemic, while most imported cases were detected in Plaines Wilhems and Port Louis (Figure 21) (*74, 75*). Justifiably, the IRS campaigns included these areas.

By 1986, the population of the island was receiving three sets of interventions, according to the numbers of recent and former foci of indigenous cases. Approximately 5% of the population was under IRS, larviciding and surveillance and 5% under larviciding and surveillance alone, while the remaining 90% (population of 910 677) was under surveillance only, with no vector control measures (Figure 22) (*6*).

Figure 20. Surveillance output (annual blood examination rate), 1985
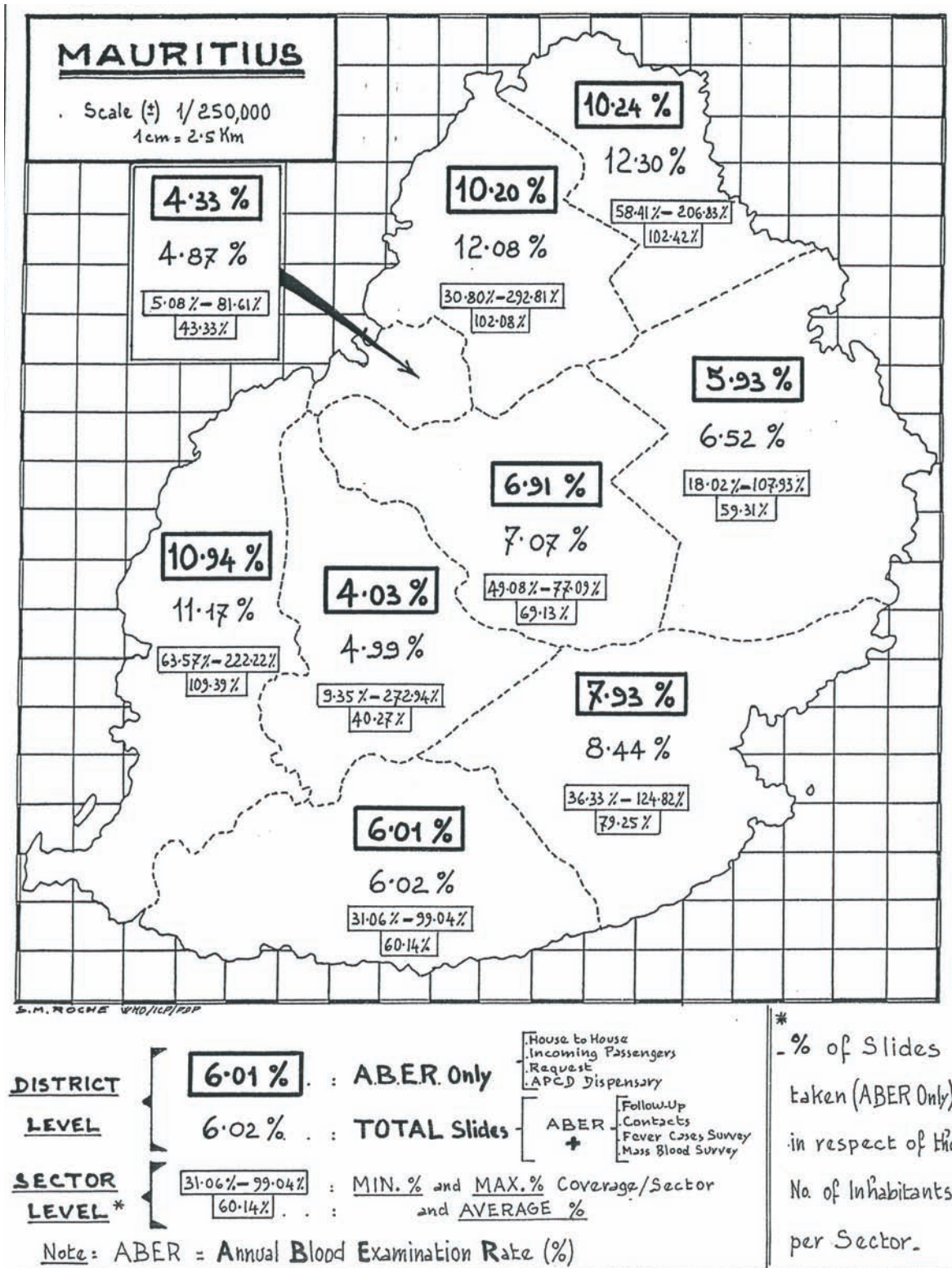
From reference 6

Figure 21. Numbers of cases and coverage with indoor residual spraying (IRS), by district, 1979–1985

Legend:
- Local cases
- Imported cases
- Number of inhabitants proteced by IRS in 1982
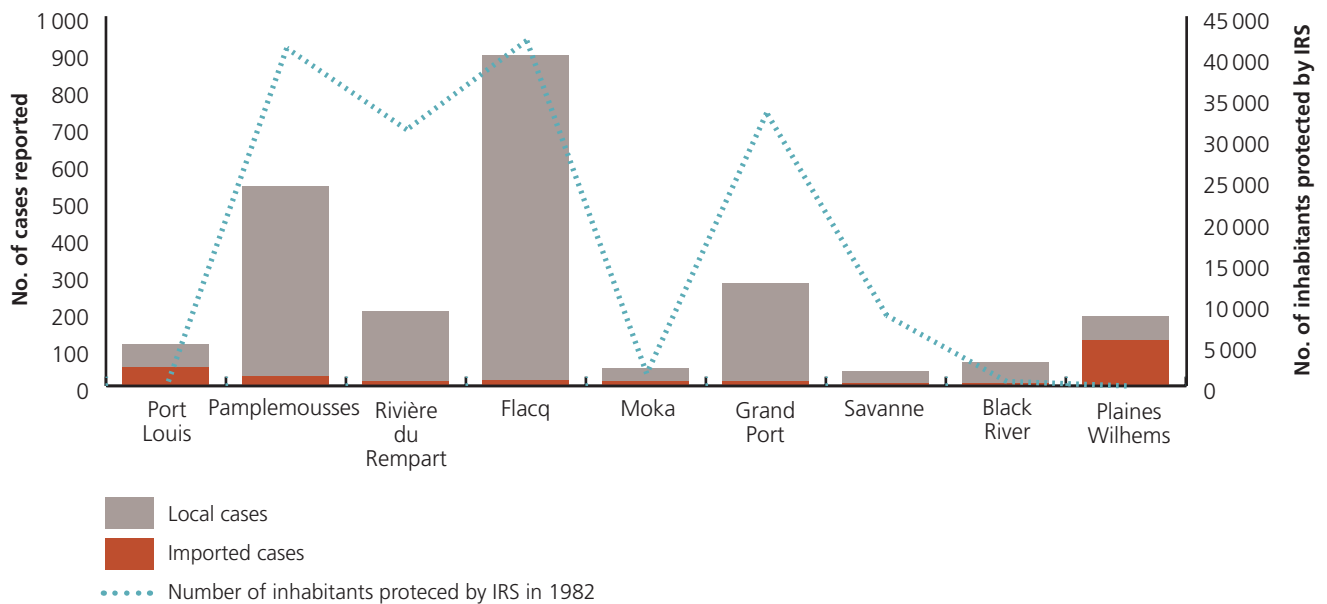
From references *74* and *75*

The total population protected by IRS during the campaign is shown in Figure 23. Although coverage of the total population was generally low, coverage of transmission foci with IRS was consistently over 65% and usually above 80% (*6*).

Larviciding with liquid and pellet forms of temephos was conducted primarily in transmission areas where IRS operations were not carried out or where coverage was poor (*69*). In 1985, larviciding and environmental management teams visited 37 965 houses, 3 930 (10%) of which were found to have potential breeding places in or around them. The teams eliminated 1 603 (4%) breeding places and treated 15 832 (42%) potential sites with temephos; 1 202 larviciders and 275 assistants conducted 38 rounds of inspection throughout the island (*6*). Several difficulties in the larviciding operations were described in reports from the campaign: antilarval measures were accompanied by very little entomological monitoring; the teams of larviciders often used oil instead of temephos, a much less effective method; and the teams were disorganized and did not map breeding places (*74*).

Lebistes spp. (guppies) and Tilapia spp., both larvivorous fish, were used occasionally during the malaria campaign (*27*). These fish were reported to have been useful in irrigation ponds and deeper rooftop pools where temephos was less effective, although data were not collected to demonstrate this (*4*).

Fogging was re-established in 1982 because of its potential usefulness against the unique outdoor biting behaviour of *An. gambiae* s.l. in Mauritius, and operations were conducted in the evening (*27*). By 1984 and 1985, fogging was conducted only in Port Louis in areas of malaria outbreaks (*75*).

Entomological surveillance

In 1985, after the peak of the campaign, reduced densities of *An. gamibae* s.l. were found. For example, of 244 rooftops examined in 1985, 14 (5.7%) had *An. gambiae* s.l. larvae, a decrease of 20% from 1983. During pyrethrum spray-catches inside houses, the density of *An. gambiae* s.l. per room had decreased from 0.07 in 1982 to 0.008 by 1987. Generally, except for one or two localities in Black River, *An. gambiae* s.l. were not found in large numbers

Figure 22. Map showing operations areas for residual spraying and larviciding, by focus, 1986

MAURITIUS
Scale (±) 1/250,000
1cm = 2.5 Km

N
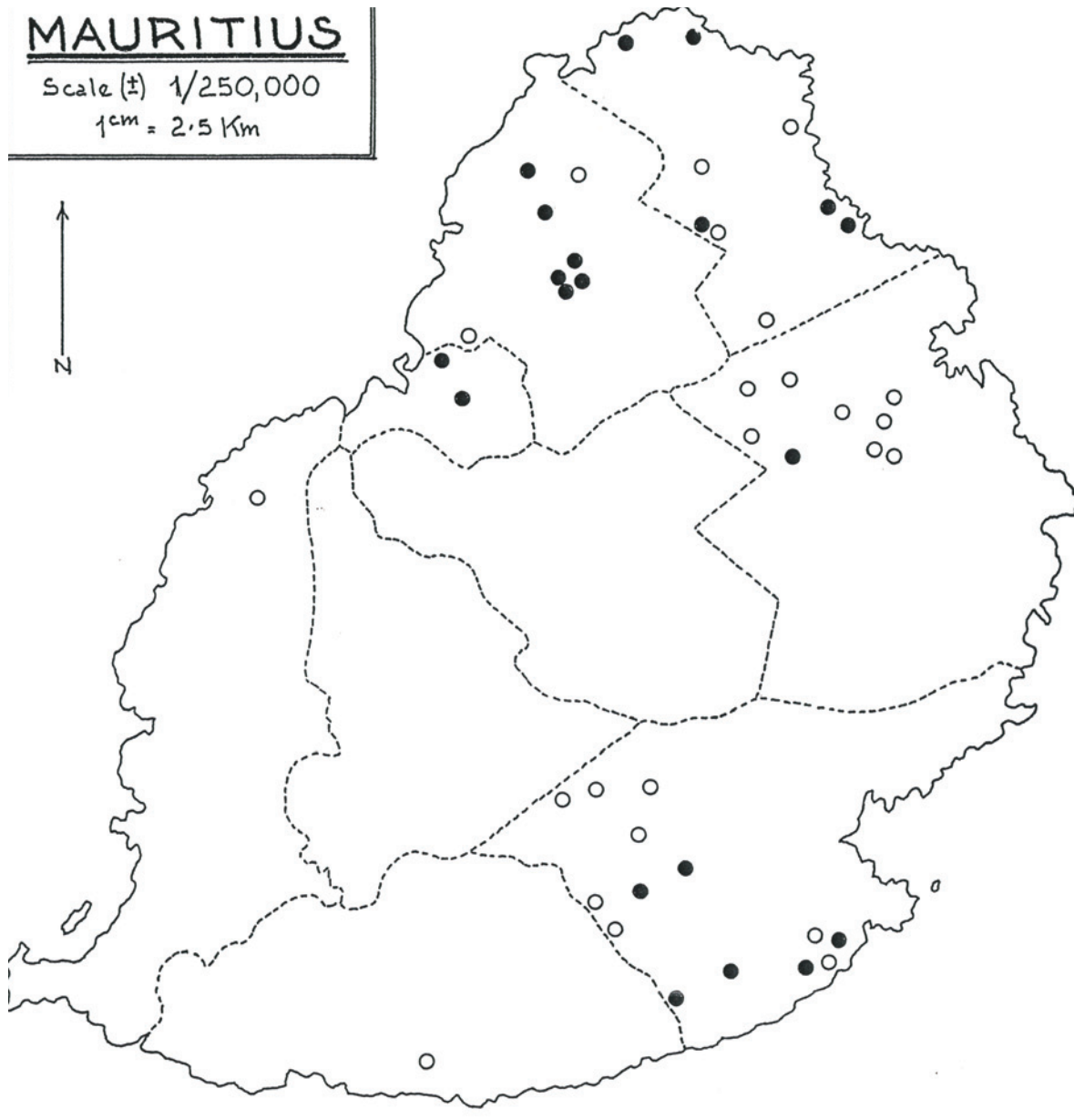
Legend:

Symbols	Operations	No Inhabitants protected
●	SPRAYING AND LARVICIDING	48,361 Inhabitants
○	LARVICIDING ONLY	50,202 Inhabitants

From reference 6

Figure 23. Proportions of the population protected by indoor residual spraying (IRS) out of the total island population, 1980–1987
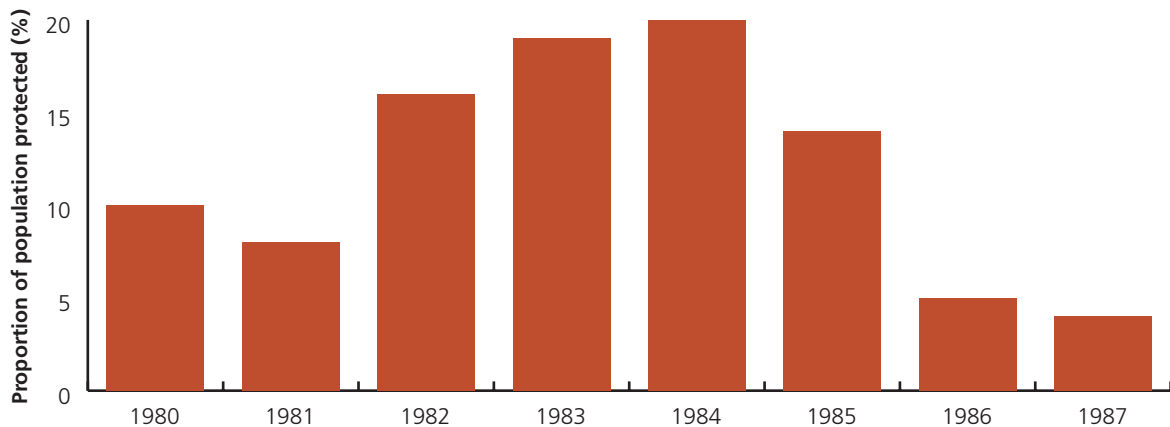
From references *6*, *74* and *75*

(*27*). In the opinion of the entomologist during the campaign, the control and elimination of breeding sites for *An. gambiae* s.l. had a greater impact on malaria transmission in Mauritius than any other vector control intervention (*4*).

INFORMATION, EDUCATION AND COMMUNICATION

The malaria programme gained the cooperation of the Mauritius Broadcasting Corporation in 1984 to diffuse a health education campaign in order to overcome community resistance to IRS (*75*). The health education included pamphlets, posters, talks on the radio, at social centres and at schools and films on malaria transmission and prevention (*2*).

Health officials talked frequently with communities about environmental hygiene, asking households to remove resting or breeding places in and around their houses. The malaria programme relied heavily on community involvement to eliminate standing pools of water and to use larvivorous fish in their irrigation ponds (personal communication, S. Sohun, 6 June 2009).

FINANCING

Between fiscal years 1983–1984 and 1986–1987, overall health service spending per capita was approximately US$ 45 (2008 US$). Government financial constraints

affected performance overall, according to Government officials and technical advisors on the campaign, but the Government was able to provide the funds and additional staff needed for the first year of the malaria elimination campaign. The total budget for the Preventive Division was Rs21 million or US$ 4.2 million (2008 US$), and the budget for the first year of the campaign was Rs18,9 million (US$ 3.8 million) (*74*). Funding probably came from other Government pools, in addition to the Preventive Division, but no documentation to that effect was found.

Impact of the second elimination campaign

The resurgence of malaria was due largely to local *P. vivax* transmission, which reached a peak of 623 cases in 1982. Only one local *P. falciparum* case was reported between 1981 and 1988. After the first 3 years of the campaign, the epidemiology of malaria changed, with a marked decrease in local transmission and an increase in the number of imported *P. falciparum* cases, from 27 in 1985 to 123 in 1988. On average, *63%* of all cases during the resurgence were in males (*7*).

After the elimination campaign had contained the resurgence in 1988, subsequent small local *P. vivax* outbreaks occurred in 1992 and 1996; the last indigenous case of malaria was reported in 1997 (Figure 24).

Figure 24. Numbers of malaria cases reported, by origin of infection, 1973–2008
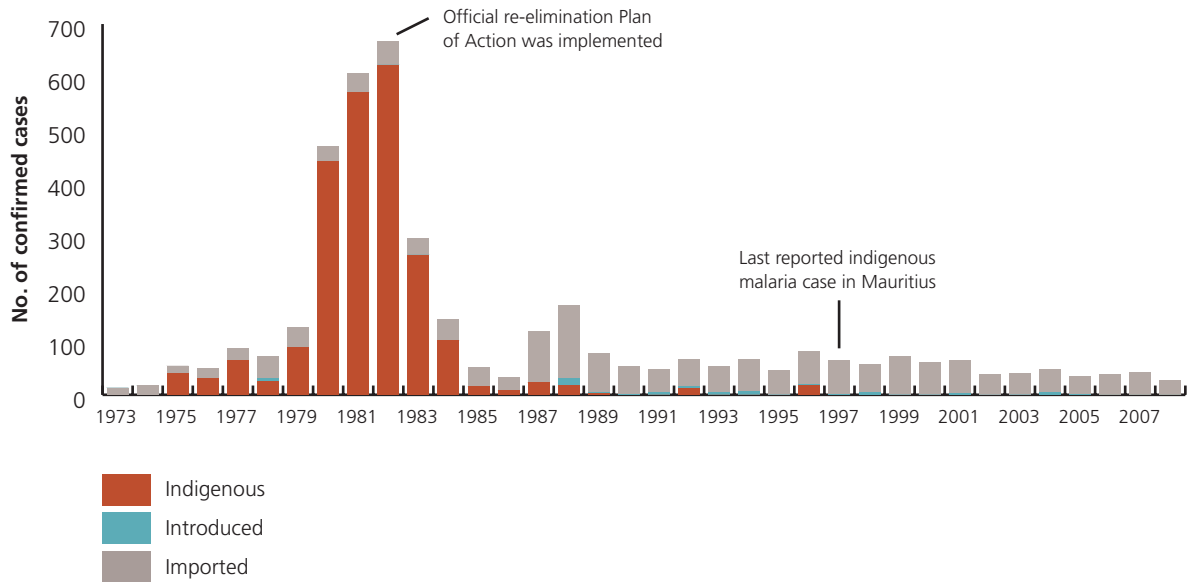
From references *22, 24* and *65*

Programme to prevent reintroduction (1998–2008)

IMPORTED AND INTRODUCED MALARIA

Between 1998 and 2008, an average of 48 imported and introduced malaria cases were reported every year, or 3.9 cases per 100 000 population (*83*). *P. vivax* and *P. falciparum* each contributed approximately 50% to the case total (Figure 25). This importation rate may be compared with 2.2 imported cases per 100 000 population in the United Kingdom in 2008 (*18*), corresponding to 1 370 cases (*85*), and 0.524 imported cases per 100 000 population in the United States in 2006 (*18*), corresponding to 1 564 cases (*86*).

Between 2005 and 2008, 82% of imported cases were in foreigners (Figure 25), 70% of whom came to Mauritius as expatriate migrant workers. Of all imported cases, 84% arrived from Comoros, India, Madagascar and Mozambique, with 63% from India alone (Figure 26) (*87*).

While no malaria-related deaths were reported between 1962 and 1989 (*61*), seven were reported between 1990 and 2007 (*62*).

Except for the peak in 1987 and 1988, the number of imported cases has remained stable over time, with the same if not fewer cases in the 1970s and 1980s than more recently. This trend implies that vigilance is critical as long as the importation risk remains the same. Of significant concern to the Ministry of Health and Quality of Life are the introduced cases—those resulting from first-degree local transmission from imported cases. Between 1998 and 2008, there were 10 introduced cases, 50% of which were *P. vivax* and 50% *P. falciparum*. Of these cases, 7 occurred among females, and 1 case occurred in a child under 5 years. Detection of these cases led to a rapid response, with screening of contacts by the Communicable Disease Control Unit and vector control activities by the Vector Biology and Control Division, in accordance with the case response system described below. As introduced cases could lead to onwards secondary indigenous transmission, effective surveillance and prompt response to imported and introduced cases remains a priority for Mauritius.

Figure 25. Numbers of malaria cases, by origin of infection, nationality and parasite species, 1998–2008

Legend (top chart): Introduced | Imported

Legend (middle chart): Foreigner | Mauritian

Legend (bottom chart): Unidentified | Mixed | *Pf* | *Pv*
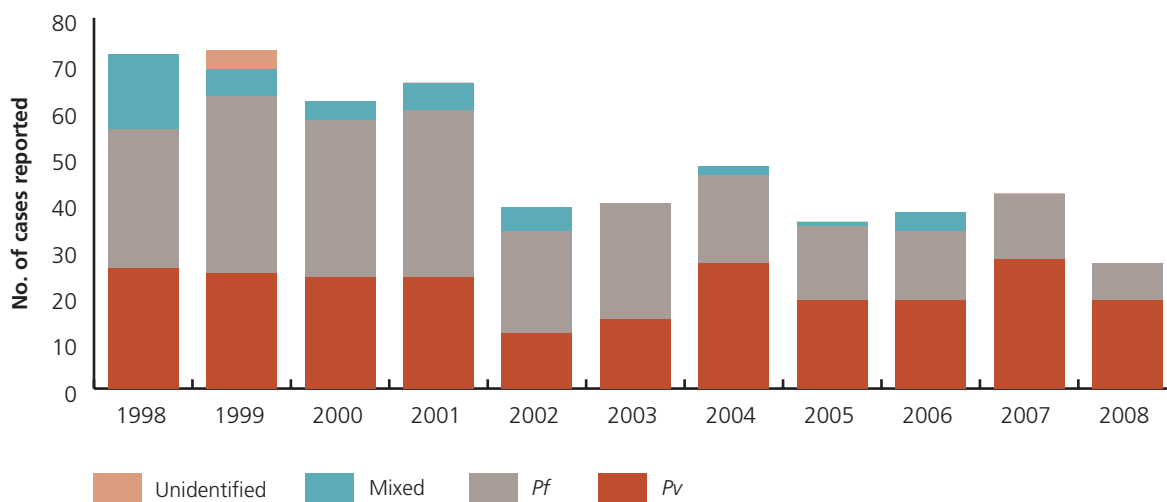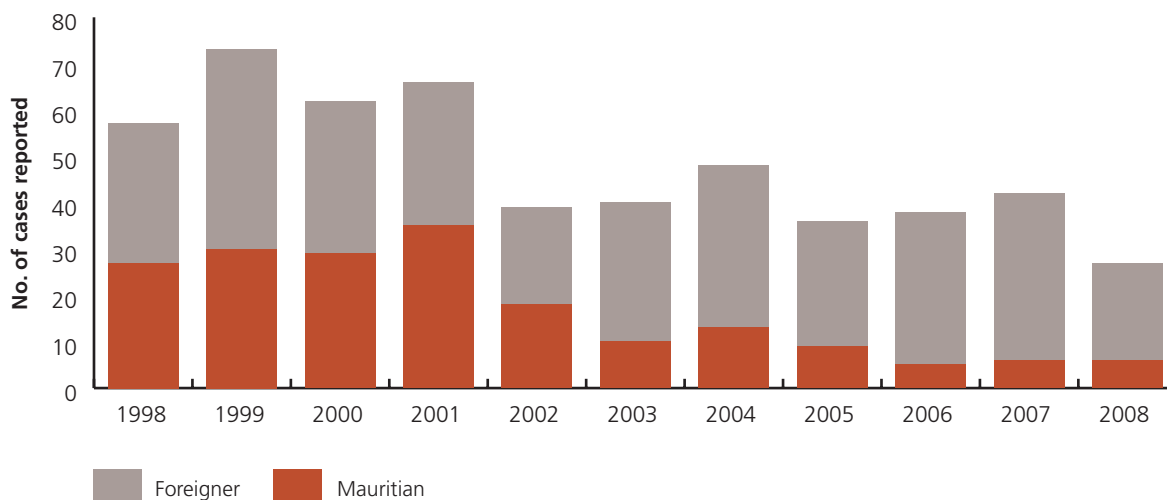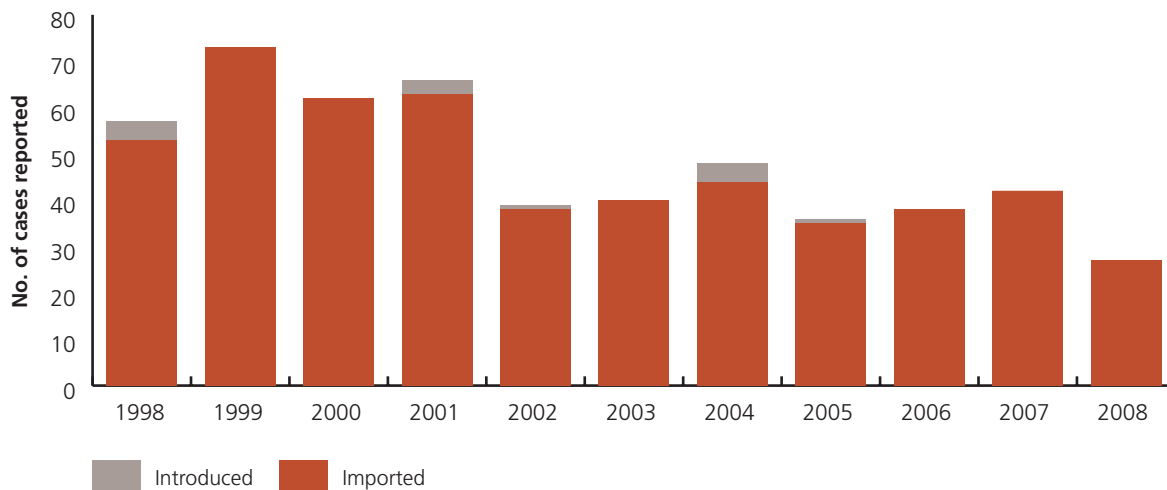
From references *22* and *84*. Pf, *Plasmodium falciparum*; Pv, *P. vivax*

Figure 26. Country of origin of imported malaria cases, 2005–2008
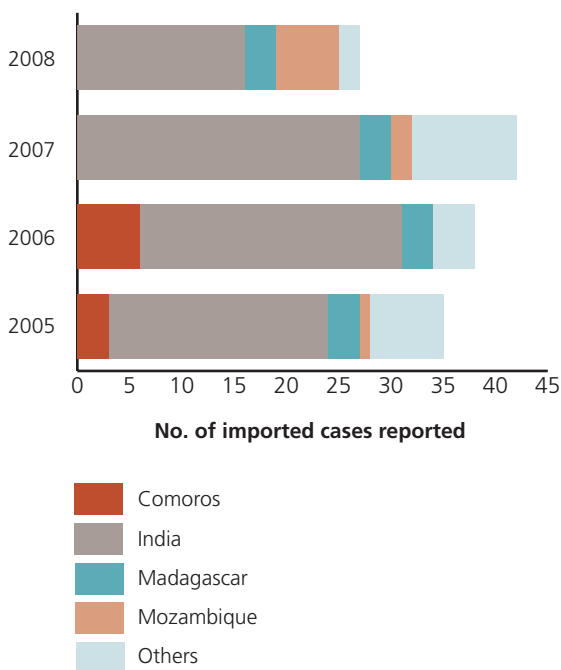
From reference *87*

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA PARASITES

Passive case detection

Mauritius has a strong passive case detection system, with a large network of hospitals and primary health care centres throughout the island that are responsible for reporting all notifiable diseases, including malaria.

The entire surveillance system depends heavily on passive case detection: in 2008, 48% of malaria cases were detected by this method, while 26% of cases were detected by proactive passenger screening and 26% by reactive case detection (*88*). In 2007, the proportions were 43%, 24% and 33%, respectively (*89*). All slides collected are sent to the public malaria diagnostic testing laboratory.

Proactive case detection by passenger screening

Mauritius' proactive case detection system depends on passenger screening, in virtually the same programme implemented since the 1960s. All passengers arriving or transiting from a malaria-endemic country and all pas-

sengers who are febrile and/or have been to a malaria-endemic country in the previous 6 months are put under surveillance (personal communication, C. Jeelal, 18 March 2009). Before November 2008, slides were taken from all passengers complaining of fever at the port of entry in order to exclude malaria. At present, passengers who are febrile are referred to a public or private hospital near the port of entry.

A team of health inspectors based at the Airport Health Office screens passengers for avian influenza, chikungunya, cholera, dengue and malaria. Health inspectors screened all visitors at the airport health desk until November 2008, when the Government changed the screening process to relieve tourists from standing in long queues. Health officials now depend on the information that passengers provide on the health declaration form (Figure 27), which elicits information on countries in Asia, Africa and South America that were recently visited, physical address in Mauritius and whether the passenger has fever. The forms are sent to one of the 13 health office with the surveillance card (Figure 28), and any passenger who fulfils the malaria surveillance criteria described above is contacted by a health surveillance officer within 48 h of arrival. The officer visits the passenger, and, if the passenger stayed in a malaria-endemic country for 12 days or longer or has fever, the officer immediately takes a blood smear for examination at the laboratory. If the passenger was in the endemic country for fewer than 12 days, a blood smear is taken on the second visit, 14 days after the date of arrival (*90, 91*).

Passenger screening continues for 42 days, with visits every 14 days after the first visit. The period of 42 days is based on the average transmission cycle, the incubation period of malaria infection and the possibility of delayed detection if the individual is on prophylaxis, which may initially diminish parasitaemia and therefore symptoms. On average, between 2005 and 2008, 79% of passengers were contacted by a visit or a phone call; 21% left the country before contact or were untraceable; 60% were contacted a second time and 44% a third time; and 38% of passengers were under surveillance for the full 42-day period (*90*).

Figure 27. Health declaration form for arrivals in Mauritius

	D/J	M/M	Y/A

- Flight Number _____ Date of arrival : [ ] [ ] [ ]
  No. de Vol — *Date d'Arrivée :*

- Surname:Mr/Mrs/Miss _____
  Nom:Mons/Mme/Mlle

- Other Name: _____
  Prénom

- Permanent Address _____
  Adresse Permanente

- Nationality _____
  Nationalité

Resident	Non Resident	Tick as
Résident	*Non Résident*	appropriate
		Cochez la case appropriée

- Address in Mauritius _____
  Adresse à Maurice

- Telephone No. in Mauritius _____
  No. de téléphone à Maurice

- Port of original embarkation _____
  Port d'embarquement

- Proposed length of stay in Mauritius _____
  Durée du séjour à Maurice

Which country have you visited during the last six months?
Quel pays avez vous visité les 6 derniers mois?

Specify country & length of stay : _____

Nom du pays et durée du séjour _____

If you are suffering from any of the following, please tick as appropriate.
Si vous souffrez d'un/des symptôme(s) ci-dessous, veuillez cocher la/les case(s) appropriée(s).

	Yes / Oui	No / Non
Fever / *Fièvre*	☐	☐
Cough / *Toux*	☐	☐
Sore Throat / *Mal de Gorge*	☐	☐
Respiratory Distress / *Problème Respiratoire*	☐	☐
Joint Pain / *Douleur articulaire*	☐	☐
Rash / *Eruption Cutanée*	☐	☐

Declaration

I declare that the information I have given is true and complete. I understand that I shall commit an offence if I fail to fill in the card or knowingly give false information.

Je déclare qu'à ma connaissance toutes les informations fournies sont exactes et complètes. Je suis conscient que le fait de ne pas remplir cette fiche ou toute fausse déclaration de ma part pourrait entraîner des poursuites pénales.

Signature: _____ Date: _____

For office use	

Figure 28. Surveillance card for passenger screening

MALARIA		HEALTH
CHOLERA		SURVEILLANCE
OTHER		

Serial No. : AD 6658 | RES ✓ |
Origin : India | NR |
Flight No. : _____ | EXP |
Date : 18.6 |

NAME/S
1. _____
2. _____
3. _____
4. _____

Address of stay

_____

_____

Phone/Mobile No. _____

As foreign migrant workers pose the greatest threat to maintenance of malaria-free status, as many originate from areas endemic for *P. vivax*, additional efforts are made to track them (personal communication, C. Jeelal, 18 March 2009). Health surveillance officers visit communities of migrant workers weekly for up to 3 years (the maximum duration of a work permit for expatriate workers) to screen for new or relapsed infections.

Of 191 212 passengers under surveillance for malaria in 2008, 52 837 Mauritians and 95 805 foreigners were visited by health surveillance officers, who took blood smears from 45.67% and 12.95% of each population, respectively, for a total of 36 538 slides that year, from which 7 positive cases were detected (*88*).

Reactive case detection

Reactive case detection in Mauritius includes investigation of any malaria case to document travel history and classify it as imported, introduced or indigenous. Reactive case detection also includes monitoring for treatment efficacy and screening of contacts in fever surveys within a 500-m radius of any malaria case to identify additional infections, as described below.

Diagnosis and treatment

Mauritius provides free universal access to diagnostic testing and treatment for malaria and other vector-borne diseases. The malaria-dedicated laboratory receives slides from both public health institutions and private doctors and reads all slides within 24 h. Emergency service laboratory technicians are available to read slides in the event of an urgent case after normal working hours (personal communication, JGS Yew Fong Lam, 20 February 2009).

When the malaria laboratory identifies a case during normal working hours, it immediately contacts the Communicable Diseases Control Unit, the Vector Biology and Control Division and the relevant health office. After hours, the laboratory telephones the Regional Public Health Superintendent on call, who immediately initiates the appropriate treatment.

All positive cases in both public and private health facilities are treated free of charge. The health officers in the 13 health offices throughout the country conduct all the necessary follow-up. *P. vivax* cases are treated with chloroquine for 3 days (600 mg, 600 mg and 300 mg) and primaquine (15 mg for 14 days) or mefloquine (1 000 mg immediately) for chloroquine-resistant malaria. *P. falciparum* cases are treated with a six-dose regimen of artemether-lumefantrine (Coartem) twice a day for 3 days (*92*). If gametocytes are present, *P. falciparum* cases also receive a single dose of primaquine (45 mg).

Blood smears are taken daily by health surveillance officers from patients during and at the end of treatment to confirm the success of the treatment and to monitor resistance to the drugs. For *P. vivax* cases, health surveillance officers take blood slides every 3 months for 9 months after the first 42-day surveillance period, for a total follow-up of almost 1 year. For *P. falciparum* cases, health officers take weekly blood slides for 4 weeks, then a monthly blood slide for 3 months, with a final slide after 3 more months, for a total 7-month follow-up (*92*). This protocol is successful primarily for Mauritian residents returning from abroad (approximately 23% of cases in 2005–2008 (*87*)), as foreigners often leave the country before extended follow-up is completed.

For the management of severe cases, intravenous quinine is given for 7 days. In mixed infections, *P. falciparum* is treated first, then *P. vivax*, according to the protocol (*92*).

Chemoprophylaxis

The International Vaccination Centre distributes free malaria prophylaxis to travellers to malaria-endemic countries. The Centre provides mefloquine or doxycycline for travellers going to chloroquine-resistant areas and proguanil and chloroquine for those going to areas with chloroquine-sensitive malaria (personal communication, F. Khodabaccus, 6 March 2009). In recent years, about 12 000 individuals received prophylaxis annually (*93*), with 331 928 tablets distributed in 2000 and 463 722 in 2008 (*87, 94*). Individuals visit the Vaccination Centre after a recommendation from a travel agent, word of mouth or direct inquiries.

INTERVENTIONS TO IDENTIFY AND CONTROL MALARIA VECTORS

Vector control

Mauritius' integrated vector control strategy includes IRS and larviciding at the seaport and airport, regular larviciding of other breeding sites, environmental management and community mobilization (personal communication, A. Bheecarry, 27 April 2009). Every 6 months, all buildings in and around the seaport and airport are sprayed, including the cargo areas. All airport buildings were sprayed with DDT until 2011, when pyrethroids replaced DDT. A larviciding team visits the airport weekly to treat breeding places in and around the airport with temephos (Abate 50EC) (personal communication, C. Jeelall, 18 March 2009). Crews on airplanes returning from malaria-endemic countries are required to spray the cabin with Permethrin 2% before landing.

A 100-person workforce conducts routine larviciding in areas surrounding all positive cases, in formerly malaria-prone regions and around residences of migrant workers from malaria-endemic countries (87). Larviciding teams attempt to treat all identified breeding sites fortnightly (personal communication, A. Bheecarry, 27 April 2009).

Health inspectors conduct frequent household visits to detect and remove breeding sites as part of a larval source reduction strategy.

Entomological surveillance

Two teams of health surveillance officers and spray operators from the Vector Biology and Control Division carry out daily surveys to assess adult mosquito and larval incidence and conduct larviciding of previously marked areas in which adult and/or larval *An. gambiae* s.l. have been found.

Between 2004 and 2007, an average of 10 of 100 potential breeding sites were positive for mosquito larvae, and one of the 10 sites was positive for anopheline mosquitoes (95). Most of the larvae found are Culex, and about 20% are Aedes larvae. *An. gambiae* s.l. is found in all types of habitat, including its favourite habitats of open pools, small ponds, river and canal edges and, most importantly,

rainwater collected on flat concrete roofs of buildings, as rooftop breeding continues to be a key source of *Anopheles* larvae.

The results of tests with standard WHO pre-impregnated papers for the susceptibility of adult *An. gambiae* s.l. mosquitoes to insecticides indicate that this species continues to be susceptible to most of the insecticides used frequently in Mauritius, including DDT, despite widespread use of this insecticide in 1946–1990 and its limited use until 2011.

Night catches are also performed to determine the presence of the vectors and to evaluate the risk for transmission. Approximately 8–16 night catches are conducted throughout the former transmission season (mid-October to mid-May), with health surveillance officers acting as human bait both outdoors and indoors, in order to assess different mosquito habitats and behaviour (personal communication, A. Bheecarry, 27 April 2009). Sentinel sites have been established throughout the country, and one catch is performed per sentinel site every 1 or 2 years.

Every 2 years, the entomology team conducts a mosquito survey on Rodrigues. To date, no anophelines have been found on the island; thus, no local transmission of malaria has ever occurred.

CASE RESPONSE SYSTEM

The response to a positive case is illustrated in Figure 29. Health surveillance officers perform fever surveys at the case's place of residence 18–24 days after the patient first showed symptoms of malaria and at any other residence or place at which the patient stayed for the evening or night 18–24 days after a first stay (92). In the event of an indigenous or introduced case, IRS is repeated for 2 consecutive years within 500 m of the case's residence under strict supervision of public health staff.

Figure 29. Response system to any positive case detected in Mauritius

Positive case detected at malaria laboratory

Notification of CDCU, VBCD and respective health office

RPHS or health staff initiate treatment

HSO or HI conducts all treatment follow-up and monitoring

Parasitological action

Entomological action

Health education in the community about malaria

HSOs or HIs conduct fever survey within 500-m radius

HSOs or HIs take blood smears of any contact with malaria-like symptoms

Conduct survey for 8 weeks

Larviciding within a 500-m radius of case's residence

Environmental inspection and source reduction within 500-m of case

IRS within 500-m of case's residence (only if indigenous or introduced case)

CDCU, Communicable Disease Control Unit; HI, health inspector; HSO, health surveillance officer; IRS, indoor residual spraying; RPHS, regional public health superintendent; VBCD, Vector Biology and Control Division

INFORMATION, EDUCATION AND COMMUNICATION

In 2000, the literacy rate in Mauritius was 84.4% (88.4% male, 80.5% female) (*18*), and access to radio, newspapers and television is widespread. In addition to weekly television and radio programmes, the Ministry of Health and Quality of Life frequently uses the media to 'sensitize' the population, with health education focused on everything from preventing diabetes to understanding a new health policy to removing stagnant water from habitations.

Malaria-related information, education and communication activities include education in schools, community centres, worksites and other institutions. Health programmes on the radio and television describe malaria prevention from time to time. Most of these activities are seasonal and are intensified during the former malaria transmission season.

PROGRAMME ORGANIZATION

In 1968, after the first successful elimination campaign in the mid-1900s, the vertical malaria unit was absorbed into the health system. Since then, malaria control and prevention has operated as a semi-vertical system. In general, public health programmes and their budgets are combined in a pool of public health activities and funds within the Ministry of Health and Quality of Life. Malaria-related activities are also absorbed into general public health activities in the health inspectorate. Health inspectors oversee food safety, sanitation and pollution abatement, with vector control support, environmental management and health education as their chief malaria-related activities. The airport inspectorate team is an exception, as they are mainly concerned with surveillance of incoming vessels and passengers for malaria and other communicable diseases.

While the malaria unit is integrated into the Communicable Diseases Control Unit and malaria-specific entomology into the Vector Biology and Control Division, the two units essentially represent a vertical malaria programme, with 90–100% of their time spent on malaria prevention. The malaria laboratory, although located at

the integrated Central Health Laboratory, also remains an independent section, dedicated to malaria microscopy. A total of 105 staff members are directly involved in malaria control and prevention of reintroduction, with an additional 461 spending 10–50% of their time on the malaria programme. See Annex 6 for an organogram of the basic structure of the malaria programme.

POLICY FRAMEWORK FOR MALARIA CONTROL AND PREVENTION

The Public Health Act 1925, amended in 2002 and 2006, continues to give the health inspectorate the power to enter and inspect all dwellings for mosquito breeding places. If inspectors serve a notice requiring inhabitants to "remove or abate the collection or accumulation of water", the inhabitant must comply within the time given by the health officers (*96*). If an inhabitant fails to comply with the notice, there is a financial penalty. The Act also permits health officers to remove breeding places, even on private property, and requires notification of disease by all medical practitioners to the Sanitary Authority. Inspectors carry identification cards with relevant sections of the Act but rarely have to enforce them, as communities are generally aware of their mandate.

REPORTING AND RESEARCH

The Communicable Diseases Control Unit generates annual reports and monthly malaria bulletins giving the number of confirmed cases and *Plasmodium* species detected during the month, classification (imported, introduced or indigenous), country of origin of infection (if the case is imported), nationality of the case (Mauritian or foreigner) and trends with data from previous years. These bulletins are circulated in health offices and published on the Ministry website.

Reports of surveillance activities, blood slides taken at the seaport and airport and microscopy activities are submitted monthly to the Communicable Diseases Control Unit from health offices, ports of entry and the malaria laboratory. The Unit can therefore monitor routine surveillance, case detection activities and workforce performance.

Since June 2007, the Vector Biology and Control Division has been evaluating the effectiveness of a biolarvicide, Bacillus thuringiensis israeliensis. This bacterium is being used for larviciding in nine small localities (one locality per district) as an alternative to temephos.

The Vector Biology and Control Division collaborates with the Centre for Research and Surveillance of Transmissible Disease in the Indian Ocean (Centre de Recherche et de Veille des Maladies Transmissibles de l'Ocean Indian) and Insecticide Resistance and Wolbachia Infection in the Indian Ocean to investigate the 'sterile insect technique' with use of Wolbachia endosymbionts to sterilize male mosquitoes before their release to mate with feral females.

COST ANALYSIS

Costs for elimination and prevention of reintroduction

Most analyses of elimination and prevention of reintroduction are based on modelled rather than actual costs. Minimal evidence exists concerning the financial costs of a successful elimination campaign, and the Mauritius elimination experience, with its successful history of elimination and good programme financial records, offered a unique opportunity to fill this evidence gap.

The years representative of the various phases of the programme, with cost data, are 1948–1951 (elimination), 1960–1961 (end of elimination), 1982–1988 (elimination), 1990–1991 (end of elimination) and 2008 (prevention of reintroduction). For the purposes of the costing exercise, because the phases were defined by the strategy and the combination of interventions, the costs and capacity for fiscal years 1960–1961 and 1990–1991 are categorized as prevention of reintroduction. All costs are in US$, adjusted to 2008 with Mauritius currency inflation and then converted to US$. The complete method used for costing is described in Annex 7, with references.

As shown in Figure 30, the annual per capita cost of the current programme to prevent reintroduction is US$ 2.06 (2008 US$), or 0.83% of public health expenditure, a significant reduction from the costs during elimination and also lower than the US$ 2.99 per capita spent dur-

Figure 30. Total and per capita malaria elimination programme costs (2008 US$), 1948–2008
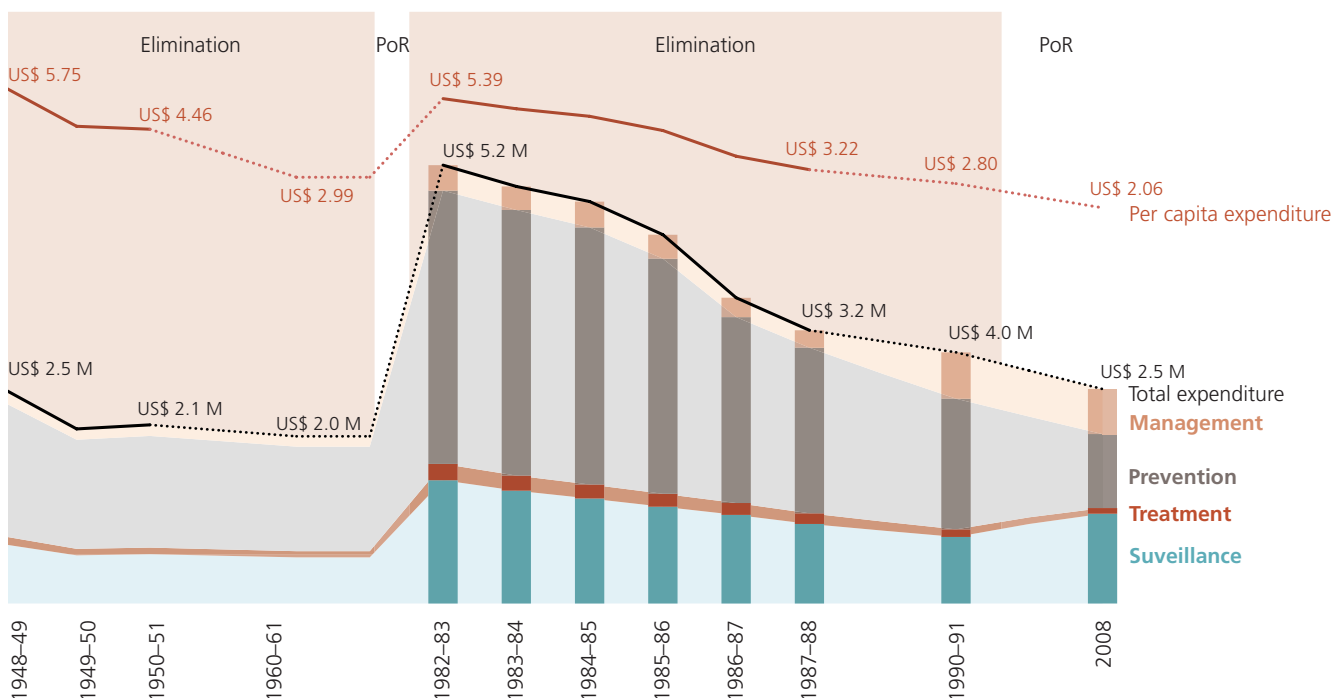
From reference *3*
PoR, prevention of reintroduction; M, million

ing the first prevention of reintroduction period (9% of public health expenditure in 1960). Per capita expenditure was highest during the first year of both elimination campaigns: US$ 5.75 in fiscal year 1948–1949 and US$ 5.39 in 1982–1983. The total annual costs peaked in 1982–1983 and 1984–1985 at approximately US$ 3.5 million and US$ 3.25 million, respectively. The total annual cost of the current programme is US$ 2.6 million.

Figure 30 also shows the strategic shift from prevention activities to surveillance, which is represented by expenditure proportional to each intervention during the recent elimination and current prevention of reintroduction periods. Surveillance accounted for an average 28% of annual expenditure during elimination in the 1980s but now amounts to 42% of total annual costs, while prevention-related costs declined from 63% of total expenditure during elimination to 34% during prevention of reintroduction today.

Figure 31 shows the breakdown of expenditure by broad activity areas of surveillance and prevention. Between elimination and prevention of reintroduction, the proportion of spending on entomological surveillance increased, as did the proportion of spending on prophylaxis for travellers: in 2008, the Government spent nearly US$ 64 000 on prophylaxis free of charge to travellers to malaria-endemic areas.

The per capita costs for passenger screening and vector control, the two main interventions over time, were US$ 1.19 and US$ 1.57 during elimination and are US$ 0.70 and US$ 0.62 during prevention of reintroduction, respectively.

The Mauritius Government has always been the primary funder, although WHO has contributed limited financial and other resources since the 1960s, including equipment (motorcycles for surveillance officers and vehicles), insecticides, environmental projects, technical support and training.

Figure 31. Proportional expenditure for surveillance (A) and prevention (B)
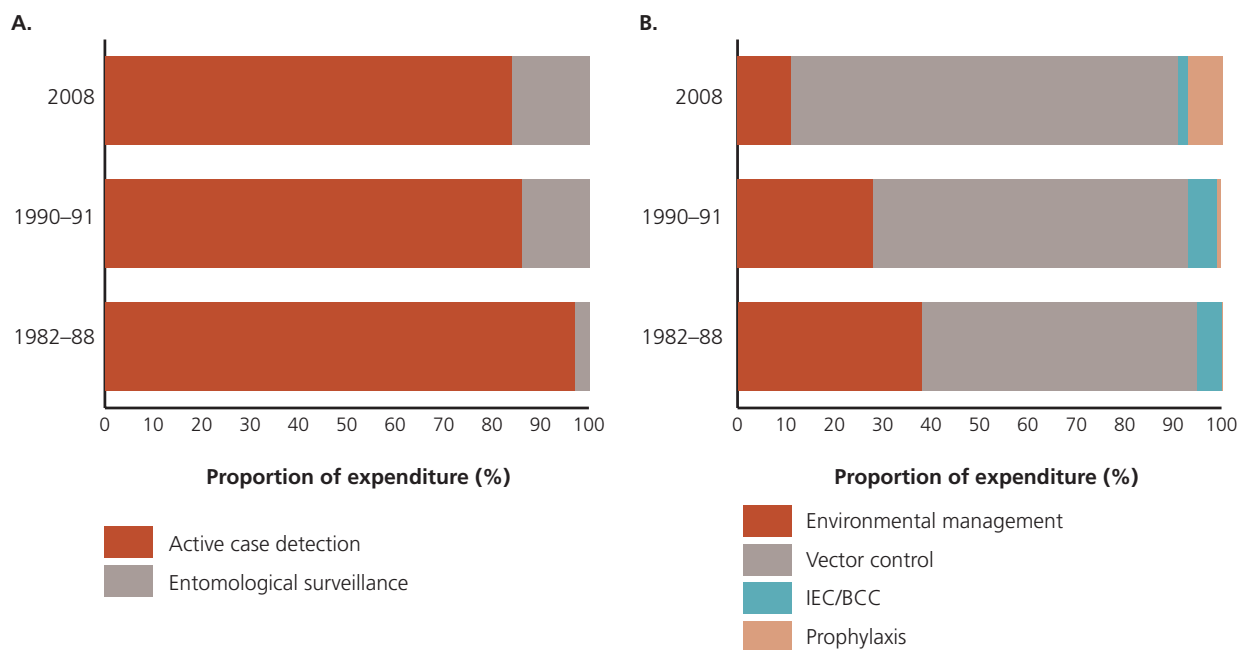
IEC/BCC, information, education and communication / behaviour change communication

Capacity during elimination and prevention of reintroduction

Both elimination and prevention of reintroduction required a substantial operational effort, including a major investment in human resources, although the number of full-time equivalents decreased over time (Table 14).

Despite integration, prevention of reintroduction remains personnel-intensive, with nearly 400 people (274 full-time equivalents) spending some of their time on malaria-related activities, although this is less than was required for either elimination campaign (Table 14). The cost per full-time equivalent is highest during the current prevention of reintroduction, at approximately US$ 9 000, which includes an approximately 100-person surveillance staff and a 100-person vector control staff,

all spending nearly 100% of their time on malaria-related activities. The current programme spends proportionally more on personnel (90% of total expenditure) than in earlier periods, when there was nearly equivalent spending on consumables and personnel (Figure 32).

The proportions of skilled and unskilled labour fluctuated over time (Figure 33). Skilled labour constituted an average of 23% of the workforce during elimination in the 1980s and 61% during prevention of reintroduction in 2008, when the workforce decreased in size but maintained its technical and managerial capacity. The cost for each cadre of the workforce was different, the majority of personnel costs being spent on skilled labour, with the exception of the first elimination campaign, when most expenditure was for unskilled labour (Figure 34).

Table 14. Costs and capacity of workforce during the various elimination and prevention of reintroduction periods, 1948–2008

Expenditure category	Average 1948–1951	Average 1982–1988	1960–1961[a]	1990–1991	2008
	Elimination	Elimination	PoR	PoR	PoR
Personnel	46%	83%	51%	93%	90%
Consumables and equipment	54%	16%	49%	6%	10%
Total workforce	614	1 338	–	534	384
Number of full-time equivalents[b]	614	684	–	465	274
Full-time equivalents per 100 000 population	132	69	–	45	24
Average annual expenditure per full-time equivalent	US$ 1 673	US$ 6 748	–	US$ 6 403	US$ 9 161

From reference *3*. PoR, prevention of reintroduction
[a] While total expenditure for personnel was available for 1960–1961 in technical reports on the elimination programme, exact figures for the total workforce and full-time equivalents were not available.
[b] As it was not possible to calculate full-time equivalents for the first elimination period, the full staff was used, as planning documents for the campaign indicate that most staff were engaged directly in the 3-year campaign.

Figure 32. Proportions of personnel and non-personnel costs, 1948–2008
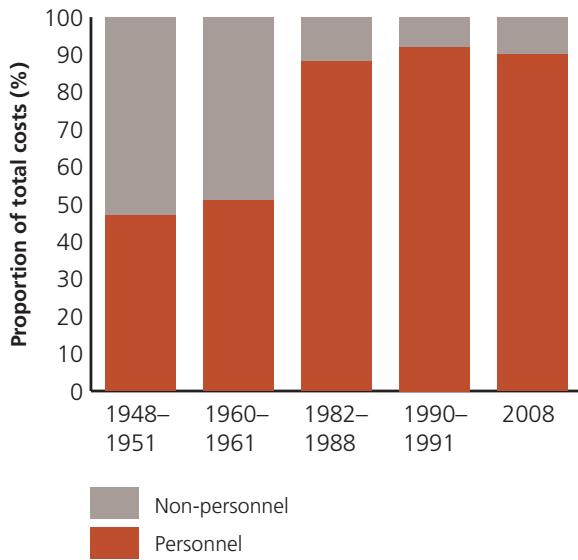
Non-personnel costs include consumables and equipment.

Figure 33. Proportions of personnel by skill level, 1982–2008
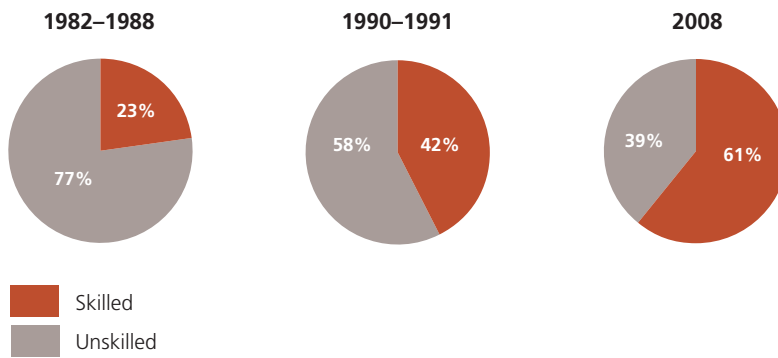
Figure 34. Proportions of personnel costs by skill level, 1948–2008
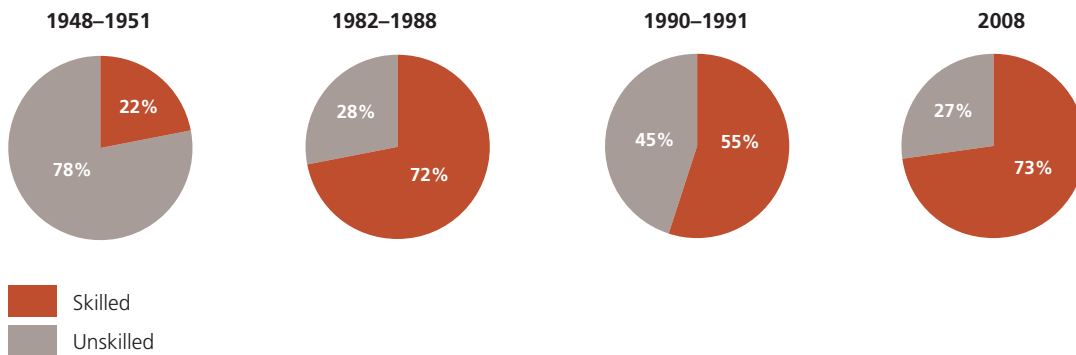
FACTORS THAT CONTRIBUTED TO CHANGING THE MALARIA SITUATION

Receptivity and vulnerability

BEFORE RESURGENCE

According to WHO consultants who reviewed the malaria situation in Mauritius in 1980, the increased density of *An. gambiae* s.l. and the increased prevalence of breeding sites were the results of lax source reduction after the country received elimination certification in 1973 (*5*). Recurrent cyclones also led to a proliferation of breeding sites (*2*). The vector population may have become less susceptible to DDT, or IRS operations had become less effective, because the number of *An. gambiae* s.l. collected in houses increased from 3 in 845 houses (0.4%) in 1967 to 117 in 425 houses in 1972 (28%) (*4*).

Surveys conducted by the Medical Entomology Division in Mauritius in the 1980s drew attention to the propensity of *An. gambiae* s.l. to breed on the flat rooftops of concrete houses, the primary housing structure in Mauritius after 1960 (*4*). Of 5 486 rooftop pools sampled in the early 1980s, 29% contained *An. gambiae* s.l. larvae, 1% contained *Culex* and < 1% contained *Aedes*, both prevalent mosquitoes on the island. Table 15 shows the proportions breeding on rooftops and on the ground in key foci of malaria transmission. Therefore, vector control was directed towards reducing rooftop breeding with temephos and larvivorous fish.

Increased tourism and the arrival of migrant workers, especially from India, heightened the island's vulnerability to imported parasitaemia (*2*). The number of arrivals steadily increased from 1933 but jumped significantly at the beginning of the 1970s and then more than doubled, from 67 994 incoming passengers in 1975 to 166 000 in 1982 (*2*). Most passengers arrived by air, with only about 3% arriving by sea. In 1976, 67% of passengers arrived from Africa, 22% from Europe, 4% from Oceania and 7% from Asia; 79% of those from Asia were from India (*97*), which was confronting a major malaria epidemic at the time (*98*).

Between 1965 and 1985, 55% of all imported cases arrived from Madagascar (28%) and India (27%), with 40% from other African countries and the remaining 5% from Asia (*5, 74, 76*). Despite the increase in arriving passengers over time, the number of imported cases detected remained relatively constant, at an average of 34 cases annually (*24*).

PREVENTION OF REINTRODUCTION, 1998–2008

Although *An. gambiae* s.l. remains present in Mauritius, receptivity may be lower than during previous periods. Between 2004 and 2007, the average year-round incidence of *An. gambiae* s.l. in its preferred resting places (animal

Table 15. Propensity of *Anopheles gambiae* s.l. to breed on rooftops

Year	Focus	Population	Cases in focus/ total cases per year		Pools on roofs			Water at ground level		
			No.	%	Total	Total positive	% positive	Total	Total positive	% positive
1979	Mont Ida	9 000	45/90	50	53	31	58	96	12	13
1980	Triolet	14 000	100/440	23	11	10	91	128	25	20
1981	Bon Accueil	16 000	202/571	35	62	21	51	39	2	5
1982	Bon Accueil	16 000	197/623	32	70	27	39	20	1	5

From reference *4*

sheds and outdoors) was 1.56 and 1.13 per person-hour, respectively (*95*). As early studies showed, adult *An. gambiae* are rarely detected indoors. Owing to its exophilic nature and low human-biting rate, *An. gambiae* s.l. is now considered a relatively poor vector of malaria in Mauritius, especially when compared with the *An. gambiae* s.l. of mainland Africa. Nevertheless, the climate and ubiquitous breeding places, especially with recurring cyclones, help maintain a constant presence of this mosquito.

In 2008, 1 226 428 passengers arrived in or transited through Mauritius (*99*), 3.4% of whom arrived by sea and all the others by air (*100, 101*). Approximately 226 000 Mauritian residents travelled abroad, 60% of them to India, Madagascar, South Africa and the United Arab Emirates. Of non-residents, 89% visited Mauritius for holidays and 4% for business, of whom 64% came from Europe, 23% from Africa and 8% from Asia (*101*). The endemicity of *P. vivax*, *P. falciparum* or both parasite species in many Asian and African countries significantly increases Mauritius' vulnerability to imported malaria (*88*).

Populations most severely affected

While there is limited documentation on the populations affected before 1979, reports indicate that the malaria epidemic became generalized from the mid-1800s through to the end of the elimination campaign in 1951. Between 1979 and 1984, *63%* of all malaria cases were in males, only 7% were in children under 5 years, and 66% of all cases were in people over the age of 20 (*74, 75*).

Owing to its small size and the similar ecological conditions throughout the island, the total population at risk continues to be the entire island of Mauritius, with a population of 1 234 052 at the end of 2008 (*99*). The central plateau is at a higher altitude than the rest of the country and has a lower risk for malaria transmission, although malaria vectors remain present and the area has experienced malaria transmission during epidemics (*38*). The current population at risk also includes Mauritians and residents of Mauritius travelling abroad to malaria-endemic areas with the intention to return to Mauritius. Between 2005 and 2008, 82% of all imported malaria cases were among foreigners and 18% in Mauritian citizens (*87*); 59% were among expatriate workers.

Achievements and setbacks
POTENTIAL RISK FACTORS FOR RESURGENCE

The increase in receptivity and in global travel in the 1960s and 1970s discussed above, combined with a reduced capacity for malaria control and lax interventions probably affected the transmission potential in Mauritius, leading to the resurgence. Internal technical personnel considered that the resurgence was due to an increase in larval breeding sites (*5*) and in the number of travellers (*2*), although the number of imported cases detected remained relatively constant at the beginning of the epidemic (*24*). WHO consultants suggested that certification of malaria elimination contributed to a relaxation of surveillance, environmental management and vector control (*69*). For example, the annual blood examination rate was 16% in 1965 but only 1.4% in 1975 (*69*). The integration of malaria into the preventive health services in 1968 further contributed to weakening the health surveillance mechanism. Poor passive case detection, due to lack of cooperation from health workers in screening for malaria, was frequently cited as an important factor in the resurgence (*5, 69*). If the passive surveillance mechanism had remained strong throughout the prevention of reintroduction phase, the outbreak might have been prevented or interrupted before significant onwards transmission (*69*). A WHO report at the time stated, "passive case detection activity is the backbone of the total health system to maintain the eradication achieved" (*74*).

Moreover, lack of cooperation of communities in cleaning larval breeding areas, especially on rooftops, despite health education and visits from public health officers, was suspected to have resulted in a proliferation in the number of breeding sites (*2*). Technical reports also discussed the possibility that financial constraints affected the recruitment of workers, transport and insecticide procurement, thus weakening the prevention of reintroduction programme and leading to the resurgence (*2*).

No single risk factor for resurgence can be singled out. General weakening of operational structures, technical proficiency, community awareness and financial commitment together created an environment for reintroduction. Success is fragile, as seen in other countries that

have experienced resurgences (*102, 103*): maintaining the gains of malaria control and elimination is critical to avoiding major epidemics in nonimmune populations. The resurgence in Mauritius was relatively moderate, probably because there was some sustained effort to reduce receptivity and vulnerability during the initial prevention of reintroduction period. Yet, the risks for importation and transmission remain high in the country, requiring sustained interventions to prevent reintroduction.

COMPARISON OF THE TWO PERIODS OF PREVENTION OF REINTRODUCTION

A contrast of Mauritius' initial failure to prevent reintroduction and its current success provides a number of important lessons for the effective maintenance of elimination (*3*). Unlike the first programme, the current one succeeded in maintaining elimination, despite large cyclones in 1994 and 2002 that caused huge damage (US$ 81 million (*104*) and US$ 50 million (*105*), respectively) and an increase in the number of travellers arriving from malaria-endemic countries (*106*). Routine island-wide larviciding appears to have contributed to maintaining low anopheline density, and an extensive response system to every imported and introduced case, requiring rapid mobilization of resources and personnel, effectively prevents onward local transmission. Achieving this level of success

requires a substantial operation, including many full-time equivalents and a large, sustained political and financial commitment. In its passenger screening strategy, the current programme succeeds in contacting a larger fraction of travellers from malaria-endemic countries repeatedly, has better operational capacity in districts and has more surveillance officers per 100 000 population than in 1960 (Table 16). The number of full-time personnel for screening passengers declined, however, between 1990 and 2008, potentially limiting the effectiveness of the programme. With a change in policy in 2008, health inspectors also stopped screening fever cases at the airport, although this practice accounted for an average of 11% of all imported malaria cases detected during 2005–2007. Achieving an appropriate balance of interventions and capacity to sustain elimination will remain the country's greatest challenge.

Even though there is no indigenous malaria transmission, Mauritius continues to spend over US$ 2 per capita on its malaria programme. This political and financial commitment is essential for the country's programme for continued prevention of reintroduction. As we learnt from the first programme, this commitment must be sustained, with maintained awareness about malaria in communities and among health workers and interventions to address receptivity and vulnerability.

Table 16. Surveillance indicators for active case detection

Indicator	Average 1982–1988[b]	1960–1961	1990–1991	2008
	Elimination	PoR	PoR	PoR
No. of surveillance officers per incoming passengers from malaria-endemic regions per 1 000 population[a]	5.7	2.4	2.1	0.5
No. of surveillance officers per district	19.4	5.6	15	11.1
No. of surveillance officers per 100 000 population	17.9	6.1	13.0	8.1
% cases detected by passenger screening[b]	47.7	58.0	No data	25.9

From reference *3*. PoR, prevention of reintroduction

[a] Extrapolated from the number of passengers from endemic regions in 2005–2008.

[b] The passenger screening programme began during the first programme to prevent reintroduction in 1960.

LESSONS LEARNED

Financing malaria elimination and prevention of reintroduction

Until malaria eradication is achieved, most countries will continue to face some risk for resurgence of malaria. With its passenger screening programme and other routine interventions to prevent reintroduction, the Mauritius Government appears to have determined to accept very little risk and has committed the financial resources to achieve that. As other countries pursuing elimination of malaria establish programmes to prevent reintroduction, they too will have to determine the level of risk for resurgence that they will accept. While intensive border screening and vector control may be feasible for some countries, poorer countries may not have the same options. The programme in Mauritius has been financed almost entirely from domestic resources, with consistent funding ensured by strong political will; countries that receive substantial external funding may face greater challenges in securing the necessary stable, long-term resources. Achieving elimination and preventing reintroduction will require a change in malaria financing, with the understanding that it is a recurring investment, like routine immunization (*107*). Mauritius is a good example of this reality, with an annual investment of over US$ 2 per capita on malaria prevention.

In addition to mobilizing and sustaining additional resources, countries must also identify opportunities to improve the cost-effectiveness of interventions and identify ways to reduce their expenditure on malaria, especially in light of the recent economic downturn and reduced donor funding for global health and malaria. Improving 'value for money', to obtain the greatest impact, will be one of the greatest challenges for countries pursuing elimination.

Approaches to elimination

Following its decisions to eliminate malaria in the 1940s and again in the 1980s, the Mauritius Government mobilized US$ 2.5 million and US$ 5.2 million, respectively, and deployed personnel to rapidly reduce transmission. This approach indicates that the country's strategy was to inject substantial resources into elimination at the outset and then use fewer resources, targeting interventions to eliminate the remaining foci of local transmission.

The Mauritius case-study illustrates the success of organizing a military-like offensive to attack malaria when the decision to eliminate the disease was made in 1948 and when the country experienced resurgence in 1975. Each time, the campaigns were supported by numerous Government and external technical experts, who generated considerable information to guide interventions and monitor progress. Interventions and staff performance were closely monitored, and their impact was measured continually, including routine prevalence surveys and vector surveillance to determine the effectiveness of interventions and to compare the effectiveness of different activities and insecticides. This united front against malaria, with a strong evidence base to support it, is an important lesson.

The use of geographical reconnaissance throughout the history of malaria control and elimination in Mauritius was an important factor for success. Mapping formed the basis for operations, effective use of resources and the identification of transmission foci. Consistent data collection, analysis and feedback at every level of the health system and the malaria programme led to robust programme implementation.

On the basis of these data, Mauritius effectively focalized interventions. After initial elimination campaigns with widespread coverage with IRS, the malaria programme quickly shifted to focal IRS and other focal interventions, such as larviciding, mass drug administration and active screening of high-risk populations. Not only was this shift probably cost-efficient and cost-saving, but it allowed the malaria programme to eliminate hotspots of transmission systematically. Focus management is an important component of an elimination strategy and has been recommended to countries currently considering or pursuing elimination (*108*).

The emphasis on island-wide environmental management and development projects also deserves notice. While initial deforestation and other environmental changes may have initially led to increased transmission, large-scale cleaning and drainage projects and developments in housing and urban areas resulted in a decrease in malaria transmission before the initial elimination campaign and probably helped to sustain lower transmission levels during the rest of the 1900s. Upgrading housing structures and improving land usage are thus important not just to achieve broader development and disease control goals but also to reduce the malaria burden and transmission potential.

Private sugar companies played an important role in malaria elimination in Mauritius by educating the employees on sugar estates about malaria prevention, and private clinics on the estates actively participated in screening patients for malaria and notifying cases to Government authorities. The private sector has been active in malaria control in mainland Africa, with mining companies supporting malaria control efforts in Ghana, Mozambique and Zambia and oil companies acting as partners in the Government malaria programme in Equatorial Guinea (*109*). Private companies, recognizing that malaria control can be a cost-effective investment, are often willing to join the fight against the disease. Once malaria is no longer perceived as a burden, however, sustaining investment from the private sector becomes difficult, as evidenced by the lack of support from sugar companies in Mauritius after the first elimination campaign. Main-

taining investment in malaria from the private sector and governments remains a major challenge for countries pursuing elimination.

The Mauritius experience also offers lessons on legislation on malaria control and elimination. The use of legal frameworks, including the Public Health Act 1925 and the Prevention of Malaria Act 1981, to enforce environmental management and vector control, proved useful in achieving coverage with effective interventions. Simply having the legal framework in place was apparently sufficient to ensure the participation of communities in malaria prevention, as the malaria programme rarely had to enforce the legislation.

Approaches to prevention of reintroduction

As the parasites and vectors of malaria were initially imported into Mauritius in the 1800s, it is natural that the country's priority today is to protect its ports of entry and travellers from malaria. The aim of targeting ports of entry with IRS and larviciding and incoming planes from malaria-endemic countries with disinfectant is to reduce the importation of vectors, and the aim of giving travellers prophylaxis and rigorously screening arrivals from endemic countries is to reduce the importation of parasites. Activities to minimize the risk for importation are at the core of the country's current strategy to sustain elimination, and this is a key lesson for countries pursuing elimination and planning the prevention of reintroduction.

Mainland countries with porous borders may find it difficult to reduce the risk for importation and should explore locally appropriate interventions. Apart from a few examples of effective screening at borders (*110*) and at ports of entry (*111*), there is a general dearth of evidence about effective border interventions for mainland countries.

The Mauritius experience shows that all countries, mainland or insular, that are pursuing elimination should target and monitor high-risk populations once they are in the country. In the passenger screening programme, surveillance officers proactively screen migrant groups

arriving from malaria-endemic countries. Mauritius' reactive case detection and response system closely monitors positive cases to ensure successful treatment and screens contacts and neighbours to identify additional infections in order to prevent local transmission. The strategy for preventing reintroduction also includes routine island-wide larviciding based on entomological surveillance to maintain low levels of anopheline breeding and therefore diminish receptivity. As sporadic introduced cases have been reported in the country during the past decade, on-going vigilance is critical to prevent indigenous transmission from those cases.

Factors for success

One intervention or one strategy alone was not responsible for the elimination of malaria in Mauritius. Throughout the history of malaria in the country, it was met with a combination of effective interventions. Most traditional malaria control programmes, especially in sub-Saharan Africa, are based on vector control with distribution of insecticide-treated bednets and IRS. Recently, there has been a global drive to confirm cases with a diagnostic tool and to record and report the result (*112*). Malaria

control programmes should have a comprehensive strategy incorporating a stratified approach to the risk for malaria transmission, identification of foci, alternative vector control interventions, active surveillance including measures to reduce the risk for parasite importation, and innovative information, education and communication to maintain knowledge about malaria in communities. The Mauritius experience indicates that a localized, comprehensive strategy is a critical factor for achieving elimination; one intervention alone cannot achieve it. The strength and composition of the strategy must, however, be accompanied by the necessary financial and political commitment.

Overall, Mauritius' experience demonstrates that it is possible to eliminate malaria and to prevent its reintroduction in a situation of relatively high receptivity and vulnerability, but that interventions to reduce both must be sustained. While each country that is pursuing and achieving malaria elimination has its own context, this case-study and the case-study series can provide useful information for activities at country, regional and global levels.

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ANNEX 1: CASE-STUDY METHODS

Existing frameworks for malaria elimination (*1, 2*) were used to conceptualize this case-study. A systematic literature review was conducted to identify all the available information on the history of malaria epidemiology, control and elimination in Mauritius. The PubMed (United States National Library of Medicine), OVID (Ovid Technologies, Inc.) and Google Scholar databases were searched with the keywords 'malaria' and 'Mauritius' and 'eradication' or 'elimination'. Relevant citations in the resulting publications were also included, as well as published government and WHO reports and digitalized books. In addition, all the grey literature available at the National Archives, the Health Statistics Unit, the Mauritius Institute of Health and the Communicable Disease Control Unit of the Ministry of Health and Quality of Life of the Government of Mauritius was searched for references to malaria, malaria control or malaria elimination. Only publications from 1860, the time of emergence of malaria in Mauritius, were included in the review. All information, statistics and budgets related to malaria in Mauritius were extracted from this subset of reports and publications and compiled for analysis.

Direct observation of ongoing surveillance and vector control activities provided additional insights, and visits to major implementing institutions in Mauritius and the ports of entry allowed closer examination of the passenger screening programme. Further information was collected during approximately 50 interviews conducted with a semi-structured questionnaire with technical experts, policy-makers and operational personnel from past and present malaria programmes and WHO. All individuals were purposively selected on the basis of their professional affiliation in public health; most had current or previous involvement in malaria financing, programme management or implementation. Information was verified by document review and, when possible, from additional individuals with identical rank and responsibility.

Data were collected in Mauritius between February and June 2009. The report thus includes all relevant information through the end of 2008.

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ANNEX 2. MALARIA VECTORS IN MAURITIUS

Anopheles gambiae sensu lato is commonly found throughout the year, along the coastal belt to an altitude of about 600 feet (183 m) above sea level. During the hot, rainy season (December–April), however, *An. gambiae* s.l. appears to breed up to an altitude of about 1 600 feet (488 m). There are records of *An. gambiae* s.l. breeding at 1 850 feet (564 m) in March (*1*).

Under laboratory conditions at the Vector Biology and Control Division, young female *An. gambiae* s.l. show a mean lifespan of 16.8 days at a temperature between 21 and 24 °C, although its lifespan may be different under natural field conditions (personal communication, A. Bheecarry, 27 February 2009). As observed during night catches, *An. gambiae* s.l. usually starts feeding between 19:00 and 20:00, slowing at 23:00, peaking again between 02:00 and 03:00, with activity declining between 03:00 and 04:00, increasing again between 04:00 and 05:00 and dropping sharply between 05:00 and 06:00 (personal communication, A. Bheecarry, 27 February 2009).

Throughout the twentieth century, scientists studied the perplexing behaviour of *An. gambiae* Giles in Mauritius. Gebert (*2*) found that *An. gambiae* can breed in saltwater (*An. merus* of the *An. gambiae* family), although circumstantial evidence indicates that only freshwater forms can transmit malaria in the country (*1*). Tonking and Gebert in 1947 observed its marked preference for animal shelters, leading many to conclude that *An. gambiae* survives because of its zoophilic behaviour (*3*). As evidence of this conclusion, despite extensive DDT spraying during the malaria elimination campaign in 1948–1951, large numbers of *An. gambiae* were found in cattle sheds (*4*). Therefore, experts concluded that the behaviour pattern of the Mauritian population of the mosquito was different from that of mainland African *An. gambiae* (*5*). In 1975,

An. gambiae s.l. eggs were sent to the London School of Hygiene and Tropical Medicine for species identification and were identified as *An. arabiensis* (*6*).

Of 7 590 female anophelines dissected over 50 years in Mauritius, only 10 were positive for sporozoites and three for oocysts (*1*); however, the 10 containing sporozoites included some dissected in 1908, when *An. funestus* and *An. gambiae* s.l. were confused. Therefore, it is possible that no sporozoite-positive *An. gambiae* s.l. has ever been found in Mauritius. These results may be biased by the collection method, which favoured the more zoophilic proportion of the anopheline population (*1*).

An. funestus was found to breed in warm coastal districts all year round, causing continuous transmission of malaria, even during winter months (*4*). Conversely, *An. gambiae* s.l. appeared during heavy rainfall in December and January and was largely responsible for the sharp epidemic season of February, March and April. Rainfall during January and February in the decade before the first elimination campaign fluctuated significantly, between 10 and 37 inches (28–94 cm), often vacillating with cyclones. *An. funestus* was remarkable domestic: at times in the early 1900s, before major antimalaria works, investigators found up to 1500 *An. funestus* adults in a single room.

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ANNEX 3. ORGANOGRAM OF STAFF, MALARIA ELIMINATION CAMPAIGN, MAURITIUS, 1948–1951

Diagram I

Officer in Charge

Office Staff

- Entomologist
  - Assistant Entomologist
    - Laboratory Assistants (3)
    - Moustiquiers (20)
      - Assistant Moustiquiers (20)
- Chemist
  - Laboratory Assistants (2)
- Medical Officer
  - Laboratory Assistants (3)
- Labour Supervisor
  - Assistant Supervisor
    - Drivers (20)
      - Assistant Drivers (10)
    - Carpenter
      - Labourers
- Field Organisation
  - (See below)
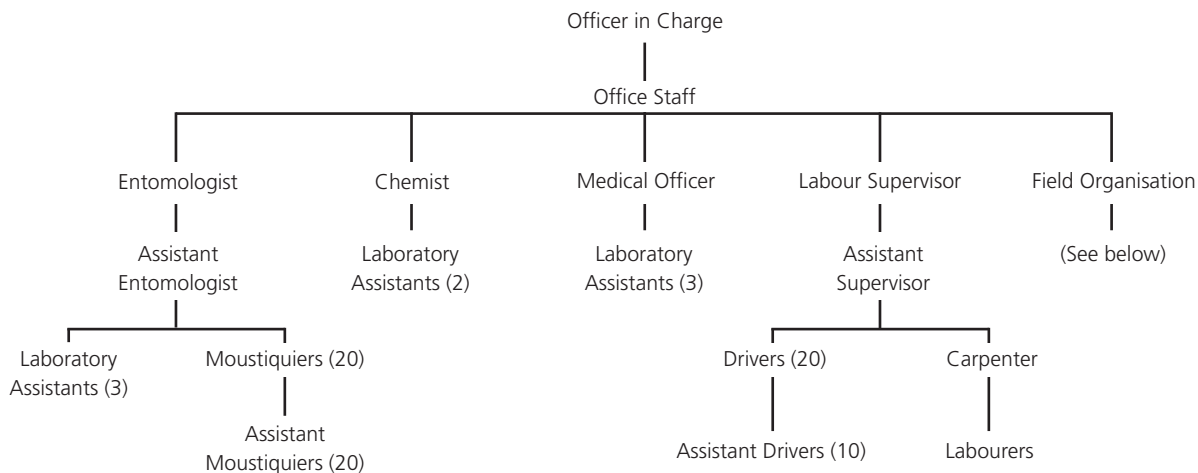
Diagram II

Field Organisation

In each of the six districts, the following team is in charge of work

Field Officer

Assistant Field Officer

- Senior Overseer
  - Junior Overseers (9)
    - Spray Gangs (18) (each of 2 labourers)
- Clerk Time-keeper
  - Store-keeper Mixer
    - Labourers (4)

SCHEMATIC REPRESENTATION OF RETURNS TO CENTRAL HEADQUARTERS

Moustiquiers   *Spleen and Parasite Survey*

Daily Adult   Daily Larval   House and School   Survey of Children born
catches   catches   survey of children   in selected areas after
                                    under 14 years   spraying

District Headquarters   Chemical and Biological
                                                            testing of residual in-
                                                            secticide   (monthly
                                                            mean per district)

Central Headquarters   Port and Airfield control
                                                            to prevent the intro-
                                                            duction of vectors

                                                            Vital statistics.   Malaria
                                                            morbidity and mortali-
                                                            ty, infant mortality etc.

                                                            Meteorological data

                                                            Temperature,   humidity,
                                                            rainfall

Daily spraying returns from   Control figures from the
districts. Total houses. Insec-   French Island, Reunion
ticide used. Average No. of
rooms per gallon. etc.

COSTING—Labour, Transport, Insecticide,
Solvent, Equipment, stores.

ANNEX 5. STRATEGIES FOR PREVENTING REINTRODUCTION OF MALARIA, 1968

The specific objectives and methods for preventing reintroduction, as described in the 1968 annual report of the Medical and Health Department (*1*), are to:

"1. Achieve complete eradication by securing registration with the WHO.

"2. Maintain a network of basic health services to ensure effective implementation into maintenance phase.

"3. Absorb various categories of the trained national personnel from the malaria elimination programme into rural health services after appropriate retraining.

"4. Maintain accurate data in geographical reconnaissance.

"5. Maintain mechanisms for epidemiological and entomological evaluation to prove the efficacy of the malaria eradication techniques.

"6. Eliminate completely any residual foci and residual parasitaemia.

"7. Maintain an efficient system of public relations and health education, including private doctors.

"8. Continue training national personnel in all categories as required for accomplishment of the programme.

"9. Promote the necessary regulations for executing the programme effectively and for prevention of reintroduction of malaria into Mauritius."

The same report described the methods for preventing reintroduction, including:

"1. Maintain system of vigilance.

"2. Prompt detection, notification and treatment of all cases of malaria

"3. Epidemiological investigation of all cases

"4. Appropriate preventive / remedial measures

"5. Continued entomological activities

"6. Retention of nucleus of a malaria staff within the general health services

"7. Adequate funds for maintenance phase activities

"8. Training in malaria of medical and auxiliary personnel and refresher training for staff

"9. Assessment of the results of the methods

  "a. Active case detection, including passengers

  "b. Pasive case detection

  "c. Screening of all blood donors

  "d. Detection, treatment and follow-up of malaria cases and parasite carriers

  "e. Investigation and classification of all malaria cases

  "f. Elimination of any foci of transmission, including spraying operations, mass blood surveys and presumptive mass drug administration

  "g. Adequate measures to prevent reintroduction of malaria

  "h. Health education of the public."

The vigilance system enacted in June 1968 included the following activities to maintain an effective, rapid response to imported cases and sustain low vector density (*2*):

"1. Detection of imported cases or those missed in consolidation or relapsed cases

"2. Presumptive treatment of all suspected cases

"3. Notification and radical treatment of microscopically confirmed malaria cases and their follow-up for a period of one or two years with monthly blood examinations

"4. In receptive areas, implementation of measures to control vectors, even before epidemiologically confirmed cases

"5. Epidemiological investigation of confirmed malaria cases to determine the origin of infection

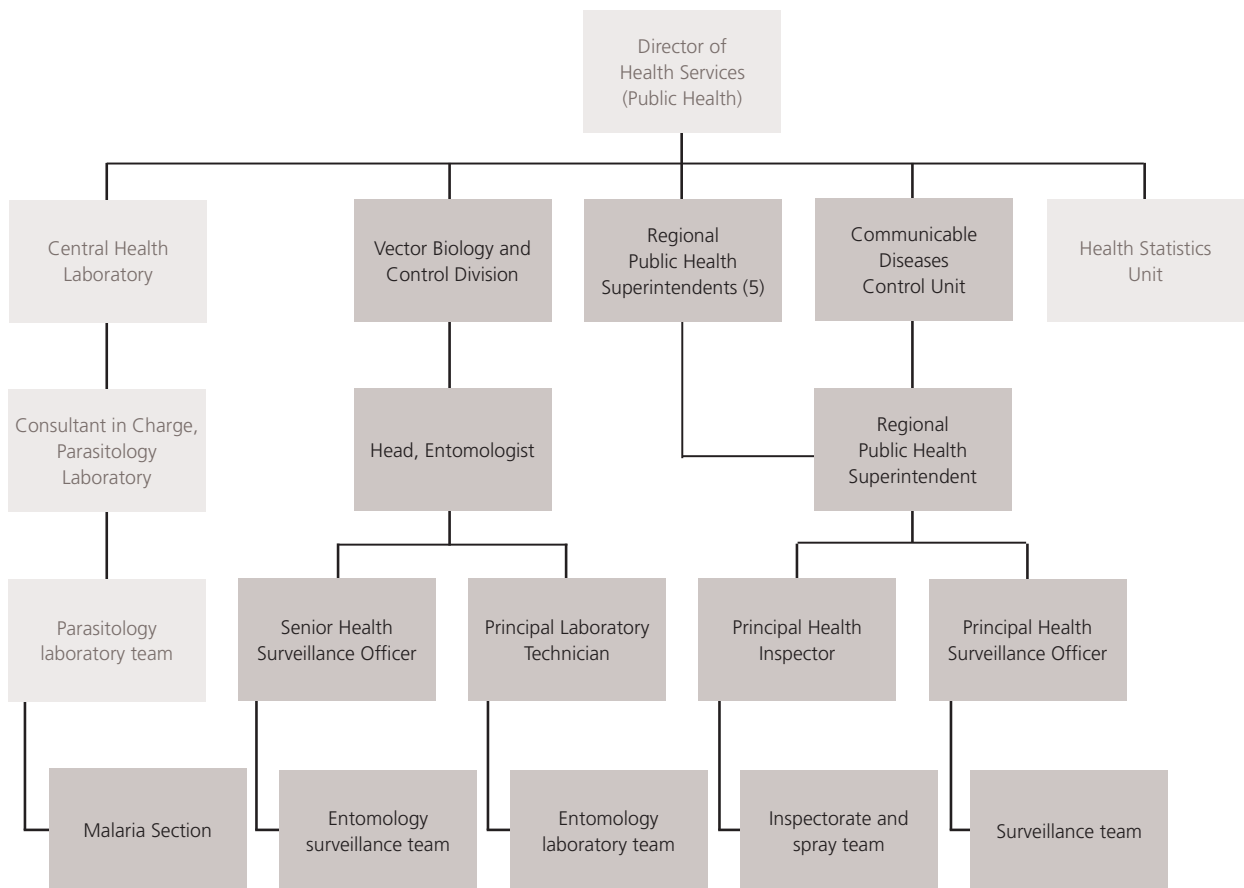"6. Prompt implementation of appropriate remedial measures depending on result of epidemiological investigations

"7. Extensive promotion of public and professional awareness of malaria intensified in vulnerable and receptive areas."

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ANNEX 6. ORGANOGRAM OF PERSONNEL DIRECTLY OR PERIPHERALLY INVOLVED IN THE PROGRAMME FOR PREVENTION OF REINTRODUCTION, 2008

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                          Director of
                          Health Services
                          (Public Health)

  Central Health    Vector Biology and   Regional        Communicable      Health Statistics
  Laboratory        Control Division      Public Health   Diseases          Unit
                                          Superintendents Control Unit
                                          (5)

  Consultant in Charge,  Head, Entomologist            Regional
  Parasitology                                         Public Health
  Laboratory                                           Superintendent

  Parasitology      Senior Health      Principal      Principal Health   Principal Health
  laboratory team   Surveillance       Laboratory     Inspector          Surveillance Officer
                    Officer            Technician

        Malaria       Entomology        Entomology     Inspectorate and   Surveillance team
        Section       surveillance      laboratory     spray team
                      team              team
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ANNEX 7. COSTING METHODS AND REFERENCES

All costs identified from budgets, technical reports and programme reviews were allocated to specific activities in four main intervention categories: surveillance and diagnosis; treatment; prevention; and management. Within each activity, costs were classified as 'personnel', 'consumables', 'capital equipment', 'training' or 'services'.

Comprehensive costing data were available for both elimination campaigns, 1948–1951 and 1982–1988. Costs were also available for 1960–1961, 1990–1991 and 2008. Although local transmission was not interrupted until 1968 and was not reinterrupted until 1998, the interventions and strategies used in 1960–1961 and 1990–1991 were similar to those of the programme to prevent reintroduction. Malaria incidence had reached virtually zero during these years (1, 2), and the strategies in place were continued until re-emergence in 1975 (3) and through the early 1990s (4). Therefore, the costs and capacity for these two years and for 2008 are considered to be representative of the programme to prevent reintroduction and are analysed as such above.

Personnel costs for 1949–1961 were collected from the accounts of the Government of Mauritius and the Mauritius Blue Book of budget salary estimates (5, 6), supplemented by technical reports (7, 8). The same sources for later years omitted substantial expenditures, e.g. for travel and overtime, which contributed 20–50% of personnel costs beyond basic salary (9, 10). Thus, complete personnel costs for the 1980s were extrapolated from fiscal year 1990–1991, for which more complete data were available (9, 11), verified by programme staff employed at the time using an average annual inflation rate between 1982–1983 and 1987–1988 of 4.7% (12) and assuming a constant annual change in salaries. The costs for 2008 were derived from a number of finance and implementing institutions (13).

The analysis included only malaria-specific costs, excluding general health system resources. Thus, the time spent on malaria-related activities per person per grade was estimated, as the malaria programme was integrated into the health system at various times throughout elimination and prevention of reintroduction. Two methods were used to identify all personnel costs: interviews with current and former staff to determine the average number of hours or days spent on malaria each week, and a review of technical reports from the recent elimination campaign.

Costs other than for personnel were derived from reports of actual expenditures and prospective budgets. About 40% of the costs for elimination were actual expenditure reported subsequent to implementation, while the remaining costs were prospective estimates found in programme budgets. All the costing data for the current programme for preventing reintroduction include actual expenditure.

Straight-line amortization was used for capital equipment, and all costs were apportioned among activities on the basis of the judgement of local staff for recent costs and from reports of past programmes. All costs were indexed to the year 2008 with local gross domestic product deflators for Mauritius (14) and then converted to US$ (15, 16).

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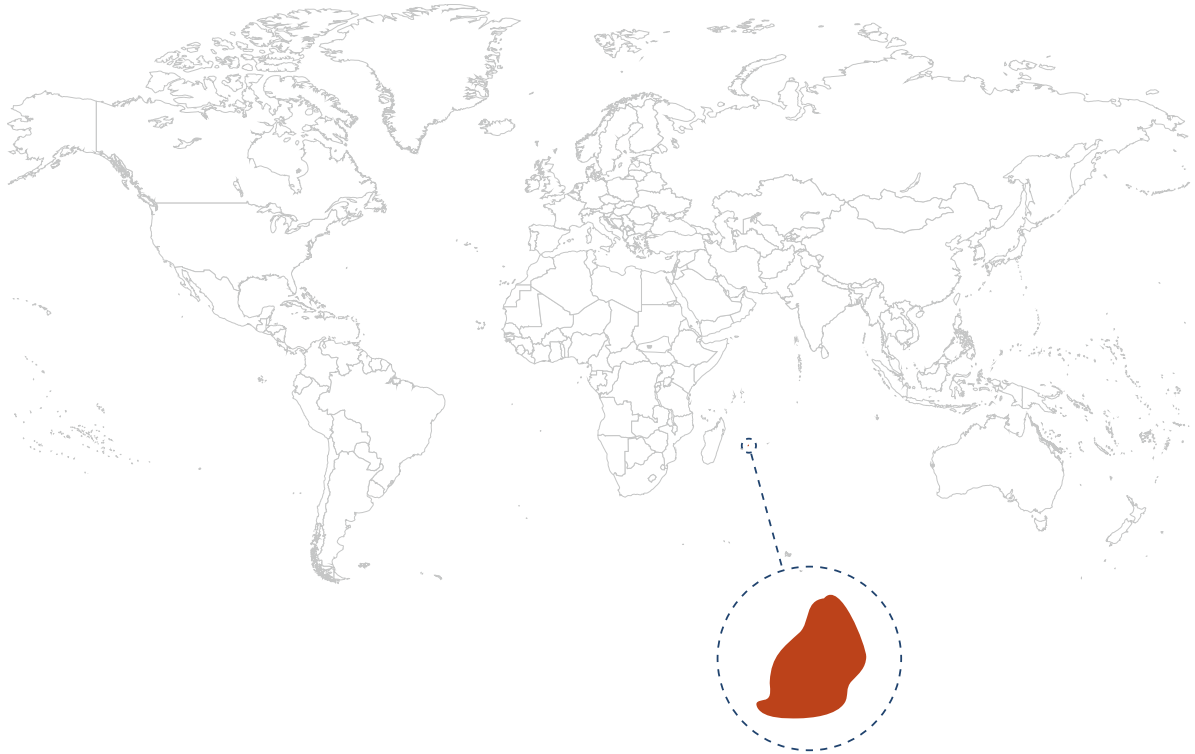
This case-study is part of a series of malaria elimination case-studies conducted by the World Health Organization (WHO) Global Malaria Programme and the University of California, San Francisco (UCSF), Global Health Group. The case-studies series documents the experience gained in eliminating malaria in a range of geographical and transmission settings with the aim of drawing lessons for countries that are embarking upon elimination.

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