

simple procedure was used for malaria control with spectacular results at low cost in many countries. Progress was so satisfying that many tropical countries were encouraged to consider malaria eradication a feasible worldwide objective.

In 1956 member nations of the WHO in Asia, the Americas, Europe, and North Africa joined in a pact to eradicate malaria in an eight-year program based on uniform operational, evaluative, and administrative procedures recommended by the WHO expert committees on malaria. The scale of the program, involving 76 nations in 1958, and the challenge of the eradication goal were unprecedented in the history of international health.

By 1972 malaria had been eradicated from areas totaling 745 million in population, or 40 percent of the world's at-risk population of 1.8 billion. However, control was not achieved in hard-core malarious areas of other countries because of vector resistance to DDT and other residual insecticides. In some places, the malaria parasite developed resistance to 4-aminoquinoline drugs used for malaria treatment during the latter phases of the eradication program. Moreover, residual spraying was not universally effective against all malaria vectors, because some species preferred outdoor biting, and transmission continued despite adequate house spraying. Eradication programs were further beset by escalating insecticide costs, dwindling political, administrative, and financial support, and lack of community cooperation.

Because reliance had been placed on insecticidal measures to eradicate malaria, research on biological control and other noninsecticidal measures had received low priority. Thus, few proven alternatives were available as replacements, or as supplements, to insecticides on which integrated vector control could be based.

Recognizing these deficiencies, the WHO revised its research priorities, giving increasing support to development of alternative mosquito control measures, particularly in the field of biological control. In 1975 the WHO adopted a research program entitled Biological Control of Vectors (BCV) as a key component of the Special Programme for Research and Training in Tropical Diseases. This special program, assisted and cosponsored by the United Nations Development Program (UNDP) and the World Bank (the Bank), serves as an agent for social and economic progress in developing countries. It is concerned with advancement in: (1) training to upgrade the biomedical research capability in

countries severely affected by tropical disease, and (2) research and development of preventive, diagnostic, therapeutic, and vector control methods against six major tropical diseases, five of which are vector-borne. Malaria is first, followed by schistosomiasis, filariasis and onchocerciasis, trypanosomiasis (African sleeping sickness and South American Chagas disease), leishmaniasis, and leprosy. The main objective is development of drugs, vaccines, diagnostic tests, and methods for biological control of vectors.

The special program has stressed that "tropical diseases, especially those transmitted by insect vectors, are intimately associated with many aspects of human society and the environment." Therefore, research will be directed toward solving practical problems of tropical disease in the countries themselves, including maximum involvement of indigenous workers to increase national competence in disease control research.

Development of training, research planning, implementation, and evaluation in the field of biological control of vectors is the responsibility of Scientific Working Groups (SWG) composed of leading professionals in biological science. A steering committee manages the activities of the SWG. Twenty-five research projects in biological control and one in vector ecology and behavior were funded in 1979. The program is currently supporting research projects in 23 institutions in 11 countries. Research in progress includes screening candidate microorganisms, standardization of larvicidal bacilli, and field trials, all on an annual budget of approximately \$350,000. The program also supports Collaborating Centers to assist the biological control investigations; services include receiving and registering biological control agents, providing materials and instructions, and assisting investigators in developing and facilitating their studies and cooperative activities.

University of California mosquito research scientists are participating in four projects involving laboratory and field studies of the efficacy of fungal and bacteria pathogens. One bioagent under investigation, *Bacillus thuringiensis israelensis* (BTI), has good prospects of becoming an excellent larvicide, based on preliminary experimentation. One of its strongest attributes is the selective lethal effect on mosquitoes, midges, and gnats and the absence of injury to beneficial nontarget organisms in the aquatic environment.

The WHO views biological control research and development as "a long-term

effort of 20 years or more" but foresees that some of the new bioagents, such as BTI and possibly others, will soon be ready for extensive trials within the national health services of cooperating countries.

Mosquito Abatement Districts

In California mosquito control has been traditionally a function of autonomous mosquito abatement districts (MADs) organized by local city and county governments under the authority of the State Mosquito Abatement Districts Act of 1916.

After the first few MADs were formed in 1916, their number and size steadily increased to 56 districts in 1970, the current level. A few county health departments also conduct mosquito control programs in some areas of the state where the district organization has not been adopted.

Today the area under mosquito control covers nearly 32,000 square miles, extending from the northernmost reaches of the state southward to the Mexican border. Within this territory 15.316 million of California's 22 million total population are being directly protected from mosquito annoyance and from the risk of mosquito-borne diseases. The expenditure for this work in fiscal year 1978-79 was \$14,712,816, averaging less than \$1 per person.

The increase in mosquito control primarily reflects the enormous expansion of irrigated agriculture in California, accompanied by an unprecedented development of industry, urbanization, and recreation and a doubling of the state's population since 1950. These economic and social forces have complicated the mosquito problem, which is characterized by extreme variability and dynamic change. Regulatory constraints imposed by federal and state environmental protection agencies on mosquito control have further compounded the problem in recent years.

To maintain a control capability of sufficient scope, flexibility, and efficiency in this unstable situation, mosquito abatement districts have consistently supported mosquito research and development. Awareness of the importance of research reached new heights in the late sixties



Tag Day for anti-mosquito fund.
"Buy a tag, mister?"



when, due to various deficiencies of conventional insecticides, the high standards of mosquito control in California threatened to deteriorate. Because mosquito research had been confined almost exclusively to pesticide development, there were few proven alternatives in the fields of biological, genetic, physical, and cultural control.

Faced with this crisis, the MADs supported special state funding for an expanded University of California mosquito research program. In addition, some districts further reinforced the research effort by increasing their own research input, by providing supplementary grants, and by donating equipment, materials, transport, staff, and other forms of assistance in kind to University researchers.

In fiscal year 1977-78 research assistance by MADs was valued at \$195,000. In 1979-80, however, assistance was reduced to \$88,000 because of an average 50 percent statewide reduction in local revenues for all MADs due to enactment of Proposition 13.

Mosquito control trends since the expanded research program began show a marked redirection of strategy and control methodology. Efforts by MADs to develop and integrate biological, cultural, physical, and other nonpesticidal measures into their mosquito programs have produced gratifying results.

The use of conventional organophosphorus pesticides has decreased 65 percent since 1970 from 250,000 pounds of such compounds as ethyl and methyl parathion, Dursban, Baygon, Baytex, and malathion to 87,000 pounds applied in 1978. During the corresponding period, the area receiving larvicide applications was reduced by 55 percent, a change attributed to improved water management practices, reduction of mosquito sources, and substitution of mosquito fish for larvicides. Changes in farming practices, such as conversion of irrigated pastures to row crops, and the encroachment of urban housing tracts upon agricultural land also contributed to the decrease in the use of larvicides.

Another important cause of declining pesticide usage is attributed to a gradual reduction in spraying coverage. Selective and discretionary spraying has largely replaced massive, total-coverage spraying once commonly employed in most control programs. In selective spraying, the pesticide is confined to specific sites of larval activity within an extensive habitat. Discretionary or optional spraying allows operators to judge the degree of larval infestation justifying the need for spraying. Besides conserving insecticide, the selective-discretionary practice spares natural enemies of mosquitoes in the aquatic habitat, lessens the possibility of mosquito resistance, and reduces the cost of labor and materials.

The impact of research on California mosquito control is reflected in the shift from almost complete dependence on conventional pesticides to an integrated control strategy, using biological, physical, cultural, and other nonpesticidal measures whenever feasible. Other factors, such as mosquito resistance to insecticides, the high cost of new insecticides, and regulatory constraints by the federal Environmental Protection Agency, have also influenced the redirection of mosquito control programs. Although not clearly recognized, the evolution in control results from the progressive attitude and resourcefulness of MAD managers in reconstructing their programs to pioneer new and largely unproven methods and to support research and development.

In looking to the future, the prospects for further development of biological control methods and concepts in the MAD programs seem ever more promising, because research will undoubtedly open up new opportunities for improvement in the practical application of such measures.

The California Department of Health Services

The California Department of Health Services maintains a program of vector biology and control. Its Vector Biology and Control Section (VBCS) has statutory authority to assist local mosquito abatement agencies, to conduct surveillance of vectors and vector-borne diseases, to perform emergency vector control, to certify vector control technicians, and to disseminate information to the public.

Types of VBCS actions in support of local vector control agencies include reviewing programs; consulting on physical, biological, and chemical control methods; assisting with specialized vector identification; assisting with pesticide resistance surveillance; representing vector control interests before state and federal regulatory agencies; reviewing environmental impact reports and other planning documents; and training technicians in all aspects of vector prevention and control. Agencies with limited resources place a greater demand upon the VBCS than do agencies with greater resources.

The VBCS is also responsible for administering cooperative agreements with local vector control agencies. This mechanism has been utilized to oversee the use, by local agencies, of pesticides and physical source prevention activities (habitat manipulation). Pesticide use reporting, assurance of compliance with chemical and physical control restrictions, and assurance of personnel competence are elements of the VBCS oversight function.