ARTICLES

A REVIEW OF THE WORLD HEALTH ORGANIZATION VECTOR BIOLOGY AND CONTROL PROGRAM[1]

C. P. PANT, R. E. FONTAINE[2] AND N. G. GRATZ

Division of Vector Biology and Control, World Health Organization, Geneva, Switzerland.

ABSTRACT. The incidence and prevalence of vector-borne diseases have risen dramatically in most developing countries in all regions of the world. In the past decade, malaria has shown the greatest resurgence. Other resurging diseases include schistosomiasis, African trypanosomiasis, filariasis, onchocerciasis, dengue, plague, mosquito-borne encephalitis, relapsing fever and leishmaniasis. Insecticides continue to provide the major weapon against most vector diseases, but the problem of vector resistance, the escalating cost of insecticides and the restriction placed on their use have severely handicapped many vector control programs.

In meeting the vector control needs of member nations of the WHO, the WHO Division of Vector Biology and Control provides advisory services, technical assistance, training and conducts and supports vector research and development on an international scale.

Integrated vector control approaches involving water management, biological control, genetic control, and other non-pesticidal methods are receiving increasing priority, but the urgent need for effective insecticides is expected to continue for an indefinite period.

Since the beginning of this century vector control for the prevention and suppression of diseases transmitted by insects and other arthropods continues to be a basic and necessary public health measure.

The World Health Organization from the onset of its formation 30 years ago has been deeply involved in vector disease control devoting a large percentage of its limited resources to vector research, development, training and to providing assistance in a wide variety of health fields to the member nations of WHO. The achievements are widely recognized, but in recent years insecticide resistance, the escalating cost of pesticides, and the constraints imposed in the name of environmental protection have impeded the efforts of many developing countries to conduct successful vector control operations and have also severely restricted the use of available methods of vector control.

To remedy this situation, the World Health Organization, through its Division of Vector Biology and Control, is communicating and collaborating with research scientists, insecticide and equipment manufacturers, and vector control strategists. As a service to member nations, VBC functions as an international center for the collection, analysis, collation and dissemination of scientific and technical information, including new developments in the field of vector control.

The enormity of the vector control problem today is evident from reports of widespread prevalence and incidence of vector-borne diseases among which the following are noteworthy:

Malaria leads the list with hundreds of millions of people in the world at risk and infected.

Schistosomiasis is reported to infect several hundred million people in the world.

African trypanosomiasis infects millions of people and many more are at risk in tropical Africa.

American trypanosomiasis reports show millions of people at risk and infected.

[1]Invitational paper presented by R. E. Fontaine at the New Orleans meeting, April, 1977.

[2]Present address, Department of Entomology, University of California, Davis, CA 95616.

***Wuchereria* and *Brugia* Filariasis** infections run into hundreds of millions of cases.

Onchocerciasis infections range between 20–25 million people and a much larger number are at risk.

Yellow fever, dengue and dengue haemorrhagic fever are epidemic in many countries with hundreds of millions of people at risk.

The encephalitides comprising **Japanese, Venezuelan equine, Western equine and Eastern equine encephalitis** cover a wide geographical area with several millions of people at risk.

Plague continues to persist as scattered foci in many countries with hundreds of thousands of people at risk and several hundred human cases reported annually.

Louse-borne typhus, relapsing fever, and leishmaniasis show a focal distribution frequently erupting into major outbreaks.

THE PRESENT STATUS AND PROBLEMS OF CONTROL

Insecticides applied in appropriate formulations continue to provide the principal weapon against most of the above vector diseases. Following World War II, the prevailing belief was that most of the major diseases could be effectively controlled by DDT and other synthetic organic chemicals. As a consequence, widespread vector control programs were implemented including the launching of the global malaria eradication campaign—the largest disease control endeavor in the history of public health. However, during the concurrent period, the application of the same and similar pesticides for agricultural pest control increased enormously frequently covering and overlapping the same areas as vector control programs. The end result of the combined selection pressure on the vector insect population was development of physiological resistance to insecticides. The following are examples of outstanding vector resistance problems:

ANOPHELINES. As late as 1975, the twenty-second report of the WHO Expert Committee on insecticides (1976) noted resistance to insecticides in 42 species of anophelines as compared to 38 in 1968. Resistance to dieldrin was detected in 41 species, 24 to DDT, and 21 of the latter showed double resistance. In 3 species, multiple resistance was detected involving organophosphorus and carbamate insecticides.

CULICINES. Resistance to organochlorine insecticides in 1975 involved 41 species with 35 resistant to DDT, 26 to dieldrin, 49 to organophosphorus and carbamates with multiple resistance reported in 17 species.

OTHER VECTOR INSECTS. *Musca domestica* resistance to insecticides is widespread. The body louse, *Pediculus humanus* is resistant to DDT, dieldrin, HCH (= benzene hexachloride) and to OP compounds in many countries. The bedbug, *Cimex lectularius* is resistant almost everywhere to DDT, dieldrin, HCH and OP compounds. Triatominae bugs are resistant to dieldrin/HCH in Venezuela, the human flea, *Pulex irritans* to DDT and dieldrin/HCH in many countries, and the Oriental rat flea *Xenopsylla cheopis* to DDT, dieldrin/HCH and OP in many countries at risk to plague.

Lately, vector resistance to insect growth regulators, chemosterilants and to the pathogen, *Bacillus thuringiensis* was recorded.

Resistance of domestic rodents (*Rattus norvegicus, R. rattus* and *Mus musculus*) to the anti-coagulant rodenticide, Warfarin, has been reported from Europe.

IMPACT OF INSECTICIDE RESISTANCE ON CONTROL OF VECTORS AND RESERVOIRS OF VECTOR DISEASE. The World Health Organization has monitored the emergence and spread of resistance for ca. 15 yr on a global scale. Field workers have collaborated in the detection and measurement of the degree and spectrum of resistance using standardized test-kits and insecticide impregnated papers. This information has been supplemented by inquiries, questionnaires, field investigations and spot surveys. The resistance

problems which have resulted in serious disruption of disease control programs and a significant increase in direct and indirect costs of operations are summarized below.

MALARIA VECTORS

In the African Region, the *An. gambiae* sibling species are resistant to DDT and/or dieldrin in parts of a number of countries of West Africa, including Upper Volta, Togo, Senegal, Southern Nigeria, Camerouns and Guinea.

In the American Region, *An. albimanus*, the principal malaria vector in Central America, is multi-resistant in several countries to the organochlorine, OP and carbamate compounds. The areas most seriously affected are associated with crop spraying in extensive agricultural districts along the Pacific Coast of El Salvador, Guatemala, Honduras and Nicaragua. Malaria rates are high in these areas and exhaustive efforts to stop transmission over a long period have not met with success. In Mexico, *An. pseudopunctipennis* is resistant to DDT.

In the Eastern Mediterranean Region, *An. culicifacies* became resistant to DDT in Afghanistan causing control failures in 1970 and was replaced by malathion. The malaria control program in Iran and Iraq has been hampered by pronounced *An. stephensi* resistance to DDT which was replaced by malathion in Iran. Pakistan experienced a gradual deterioration in the malaria eradication program starting in 1966 and the situation became critical after 1970. In part, this was attributed to resistance of *An. culicifacies* and *An. stephensi* to DDT and later to HCH and dieldrin. In Egypt, the main vector, *An. pharoensis* is resistant to DDT and dieldrin. Sudan reported resistance of the *An. gambiae* complex to DDT and HCH (Gezeira district) after malaria outbreaks in 1974–75 and malathion spraying was adopted.

In the European Region, resistance of *An. sacharovi* to DDT was recorded in Turkey as early as 1958. By 1967 double resistance to DDT and dieldrin had appeared and the incidence of malaria began to rise in 1968 due to mosquito control failures. In some areas (e.g. Chuker plains) resistance to propoxur, fenitrothion, and fenthion has appeared.

In the Southeast Asia Region, a low level of DDT resistance was detected in *An. culicifacies* in India as early as 1959. After 1965–1966, DDT and HCH spraying failed to control malaria and there were malaria epidemics within the area covered by the eradication program. In 1966, these compounds were replaced by malathion which according to recent reports is also on the resistant list.

Resistance to DDT in Indonesia appeared in *An. aconitus* in Eastern and Central Java in 1962–63. In Sri Lanka, *An. culicifacies* resistance to DDT since 1972 has created further difficulties for the control program.

In the Western Pacific Region, some instances of malaria vector resistance to dieldrin were detected, but control has not been seriously hampered as DDT is reported to be still effective against the malaria vectors.

As the above information suggests, the scope of the resistance problem is extensive and growing. Globally, approximately 256 million people live in areas where resistance is posing serious problems, and this may be an underestimate.

The operational implications of vector resistance in malaria programs are usually very serious as the cost of replacing one insecticide with another may be prohibitive for most countries. For example, the replacement of DDT by malathion or propoxur may cost 3 to 8 times as much, not including the costs associated with higher toxicity to man and revision of dosage rates and spray cycles.

IMPACT OF RESISTANCE ON OTHER DISEASE VECTORS. *Ae. aegypti* resistance to DDT in the Americas has interfered with the eradication of the species from that region. In Southeast Asia, control of haemorrhagic dengue has been impeded by resistance to the chlorinated hydrocarbons leaving little or no alternative but to adopt the more expensive OP compounds.

Culex quinquefasciatus (=*fatigans*) is generally resistant to the organochlorine insecticides and OP insecticides are being routinely used in urban control programs. In the USA, France and Ryukyu islands, multiple resistance to OP insecticides has appeared, and replacement by other insecticides will be difficult and costly.

Resistance of body lice to chlorinated hydrocarbons and malathion has complicated the control of typhus in Burundi. In South Viet-Nam, flea resistance to the organochlorine compounds necessitated replacement by organophosphorus insecticides, but some resistance to malathion has already been detected.

Resistance of the rat flea, *Xenopsylla cheopis*, to DDT was reported from several areas of the world.

OTHER VECTOR CONTROL PROBLEMS FACED BY MEMBER NATIONS OF WHO. Although problems of vector resistance to insecticides seriously concern the member nations of WHO, this represents only one of a host of other important control needs being dealt with by the WHO Division of Vector Biology and Control. A few examples follow:

(1) Safety measures for spraymen, the inhabitants of treated areas, and protection of the environment from contamination.
(2) Advice on suitable formulations of insecticides for vector control.
(3) Pesticide specifications for purchase and use in large quantities by member nations.
(4) Development of specifications for and evaluation of vector control equipment and advisory services on equipment use and purchase.
(5) Advice on alternative methods of vector control such as biological and environmental measures.
(6) Identifying cost factors in vector control as a basis for improving program efficiency.
(7) Vector control training and dissemination of information on new vector control methods, monitoring resistance and susceptibility of vectors to insecticides.

WHO VECTOR BIOLOGY AND CONTROL PROGRAM

It should be noted that the development of effective control measures must be done against a background of thorough knowledge of the ecology and biology of the vectors concerned, and this forms an essential component of all WHO supported research.

EVALUATION AND TESTING OF NEW INSECTICIDES. When faced by the challenge of vector resistance to DDT, the World Health Organization in 1960 established a program for the evaluation and testing of new insecticides (Wright 1971). About 60 insecticide manufacturers, universities, research institutes cooperate in the scheme by submitting promising compounds for evaluation, and the studies are carried out by collaborating laboratories and WHO research units as follows:

Laboratories:

(1) Department of Entomology, University of Illinois at Urbana-Champaign, Urbana, Ill., USA (Prof. Metcalf).
(2) Center for Disease Control, U. S. Public Health Service, Atlanta, USA (Dr. Taylor).
(3) Entomology Research Division, Agricultural Research Service, US Department of Agriculture (Dr. Weidhaas).
(4) Tropical Pesticides Research Unit, Porton Down, Wilts, U. K. (Dr. Hadaway).
(5) Toxicology Research Unit, Medical Research Council, U. K. Carshalton, Surrey (Dr. Aldridge).
(6) ORSTOM/OCCGE Team Centre Muraz, Bobo Dioulasso, Upper Volta (Dr. Brengues).
(7) University of California, Riverside (Dr. Georghiou).

WHO Field Research Units.

(1) ACRU I (*Anopheles* Control Research Unit No. I), Kaduna, Nigeria.
(2) VRCRU (Vector & Rodent Control Research Unit), Jakarta & Semarang, Indonesia.

(3) RCDU (Rodent Control Demonstration Unit), Rangoon, Burma.
(4) AVRU (Arbovirus Vector Research Unit), Enugu, Nigeria.
(5) CDVRU (AMRO-0902) Chagas' Disease Vector Research Unit, Maracay, Venezuela.

To date, more than 2,000 insecticides have been tested, but the number of new compounds has lately dwindled to a very small number. The process of testing and evaluation involves 7 stages, beginning with laboratory screening and ending with large scale field trials. Each testing stage advances to more exacting criteria of effectiveness and safety. The first 3 stages involve laboratory testing followed by 4 stages of field evaluation. The few compounds qualifying for the final stage 7 trial are subjected to large scale comprehensive entomological, epidemiological, and toxicological evaluation in areas of natural vector populations and endemic vector diseases. Insecticides fulfilling the exacting criteria of the final stage are considered by the WHO Expert Committee for use in vector control programs.

The Organization has recently proposed a scheme for the evaluation of biological control agents, analogous to the insecticide testing program. This will ensure that proper consideration for human safety and environmental protection is given at an early stage. The evaluation of pesticide equipment is proceeding along similar lines.

PESTICIDES RECOMMENDED FOR CONTROL OF MALARIA VECTORS. Malathion (OMS-1) was recommended for use in areas of vector resistance to DDT and is presently being applied in many programs (Najera et al. 1967).

Fenitrothion was successful for malaria control in East Africa where *An. gambiae* and *An. funestus* are the primary vectors (Fontaine and Pant 1977).

Other OP compounds which have shown promise in advanced field trials are Dichlorvos (OMS-14) (Foll and Pant 1966), dicapthon (OMS-214) (Pant et al. 1969). Chlorphoxim (OMS-1197) was effective in field trials, but recommendation for use must await further epidemiological evaluation based on unpublished reports of WHO/ACRU-I, Kaduna, Nigeria.

Propoxur (OMS-33) has performed well against malaria vectors, but the high cost severely limits it use for most malaria control programs (Wright et al. 1969). The carbamates showing promise in field trials include Landrin (OMS-597) (Rishikesh et al. 1975, unpublished) and Mobam (OMS-708) (Pant et al. 1969).

PESTICIDES FOR THE CONTROL OF OTHER DISEASE VECTORS. Tsetse fly, the vector of trypanosomiasis, is being controlled by DDT, dieldrin and endosulfan, but new insecticides and techniques are now being evaluated in Upper Volta including ULV applications of some synthetic pyrethroids (OMS-1998, and OMS-1821), the OP compounds (OMS-1825, and OMS-595), fenthion (OMS-2), and endosulfan (OMS-570).

Aedes aegypti, the vector of yellow fever and dengue-haemorrhagic fever has been successfully controlled by temephos (OMS-786) used as a 1% sand granule formulation for larviciding in Southeast Asia (Bang and Pant 1972). Because of the low mammalian toxicity of temephos, it can be safely used in areas where larvae breed in drinking water containers. However, in the event of epidemics of these virus diseases when adult control of *Ae. aegypti* is urgent, aerial and ground ULV application of malathion or fenitrothion is the method of choice (Lofgren et al. 1970) (Pant et al. 1971, 1973, 1974).

Culex quinquefasciatus (= *fatigans*), the vector of Bancroftian filariasis, has been effectively controlled by larviciding with fenthion (OMS-2) in Rangoon City on a routine basis since 1967 (Graham et al. 1972). This was the insecticide of choice after extensive field trials showed that residual spraying for adult control was ineffective (DeMeillon et al. 1967), that oiling for larval control was uneconomical (Pal and Gratz 1968, Gratz 1976, Mathis et al. 1969), and that the use of dieldrin and DDT induced resistance (Brown 1971, Rosen 1967).

The WHO Research Unit at Dar-es-

Salaam demonstrated that 1% chloropyrifos (OMS-971) applied to pit latrines and sewage drains at 1 ppm., was more effective than fenthion and gave control of *Cx. quinquefasciatus* (= *fatigans*) up to 3 months after treatment. However, based on confirmation of *Cx. pipiens* resistance to OP compounds in California, France and Japan, testing of new insecticides is continuing. Presently, the WHO Vector and Rodent Control Research Unit in Jakarta is examining the new insect growth regulators, notably methoprene (OMS-1697), and Dimilin (OMS-1804) (Nelson et al. 1976, unpublished, Self et al. 1976, unpublished).

VECTORS OF JAPANESE ENCEPHALITIS. The WHO Japanese Encephalitis Vector Research Unit operated in Seoul, Korea from 1969 to 1974 and in Taiwan from 1970 to 1972. In addition to studies on the ecology and biology of *Cx. tritaeniorhynchus* and other suspected vectors of Japanese encephalitis, the Unit developed methods of emergency control using large scale aerial ULV insecticide treatment. Malathion, fenitrothion and naled applied by helicopter or fixed wing aircraft were found to be effective. It was also shown that ground application of ULV insecticide could be carried out in urban areas.

The control of *Simulium* vectors of onchocerciasis, is being evaluated in the Volta River Basin of West Africa (WHO, unpublished). This gigantic program, being coordinated by WHO, covers seven countries (700,000 km²) with a population of 10 million people. Temephos (OMS-786 Abate) applied as an emulsion concentrate has been provisionally selected on the basis of safety to man and non-target organisms and biodegradability. Both fixed and rotary wing aircraft have been perfected for application of the insecticide.

Triatomid vectors of Chagas' Disease are vulnerable to control by propoxur (OMS-33) according to studies by the WHO Chagas Disease Vector Research Unit at Maracay, Venezuela. It shows promise as a replacement for HCH and dieldrin whose effectiveness has been mitigated by resistance (Gonzalez-Valdivieso 1971, unpublished).

Flea vectors of plague and rodent reservoirs are presently the object of basic and applied studies on ecology and control by WHO in Indonesia and Rangoon, Burma (Turner 1974).

ALTERNATIVE METHODS OF VECTOR CONTROL. In recognition of the need for integrated vector control, WHO is placing increasing emphasis on non-chemical methods such as water management, biological and genetic control and environmental manipulation.

In the WHO biological control evaluation and testing scheme, various biologic agents are being screened for efficacy and safety by collaborating laboratories and institutes, and by the WHO field research units located at Kaduna, Nigeria and Jakarta, Indonesia. The efficacy of *Poecilia* and *Gambusia* mosquitofish is being assessed in China (Taiwan), at Bangkok and Rangoon primarily for the control of *Culex*. Predaceous larvae, *Toxorhynchites* sp., have been evaluated for the control of *Aedes* in Dar-es-Salaam and Bangkok. The microsporidian, *Nosema*, for *Anopheles* control in Nigeria has been investigated, and the efficacy of the mermithid nematode, genus *Romanomermis* has been evaluated against *Culex* species in Bangkok and Taiwan. Studies on *Coelomomyces* and *Lagenidium* fungi are being supported.

In genetic control, WHO supported studies on the effect of field releases of sterile hybrids of *An. gambiae* complex. In small scale WHO trials, the application of genetic principles was demonstrated for the control of *Cx. quinquefasciatus* (= *fatigans*) in Rangoon (Laven 1967). A WHO Research Unit in New Delhi, collaborating with the Indian Council for Medical Research, investigated the possibilities of genetic control of *Cx. quinquefasciatus* (= *fatigans*). Techniques for mass rearing and sterilization were developed and perfected before sterile male releases were attempted (Pal, 1974). However, none of the genetic methods tested to date appears to hold much promise for operational use in the near future. Nevertheless, research

on genetic control is continuing including studies of the tsetse fly.

The World Health Organization has established a special program on research and training involving selected tropical disease. Five of these diseases—malaria, trypanosomiasis, leishmaniasis, filariasis, and schistosomiasis—are carried either by insect vectors or snail intermediate hosts. Although this program includes a large component for development of chemotherapeutic agents and vaccines, a section on operational research will focus on improving methods of vector control giving emphasis to non-chemical methods.

HEADQUARTERS AND REGIONAL SERVICES OF WHO

The Vector Biology and Control Division of WHO at its headquarters in Geneva is staffed by 15 scientists specializing on the ecology and control of disease vectors, on chemistry, on toxicology and safety, on genetics, on vector biology and on vector control operations. The group coordinates the activities of vector control research units and provides consultation and assistance to the member countries. In addition, there are inter-regional research units organized to perform research on specific subjects relevant to the needs of the area. There are presently 6 such units at the following locations:

(1) WHO Vector and Rodent Control Research Unit—Jakarta, Indonesia. Activities involve studies of the ecology and control of anophelines, and culicines, biological control, field trials of new techniques, equipment and assistance to the member countries.

(2) WHO Rodent Control Demonstration Unit—Rangoon, Burma. Activities include ecology and control of reservoirs of disease such as plague and dynamics of plague transmission, trials of rodenticides and testing susceptibility of fleas to insecticides.

(3) Chagas' Disease Vector Research Unit—Maracay, Venezuela. Studies cover ecology and control of Chagas' disease vectors.

(4) Anopheles Control Research Unit—Kaduna, Nigeria. The program covers research on the ecology and control of anophelines, on chemistry and pesticides specifications, trials of new insecticides and equipment and studies of biological control agents.

(5) Arbovirus Vector Research Unit—Enugu, Nigeria. The research includes ecology and control of vectors of yellow fever and reservoirs of Lassa fever.

These specialized Research Units are established in areas where the member countries urgently need and request the assistance of the World Health Organization. When the work program is completed, usually in 5 to 7 years, the units are dissolved.

DISSEMINATION OF PUBLICATION AND REPORTS

WHO collects and disseminates vector control information to member countries through publication of the WHO/VBC series. Up to February 1977, 650 documents on vector control and related topics have been issued. In addition, about 50 monographs and Expert Committee Reports on vector control have been published.

WHO retains a panel of international experts to assist the organization in communicating research results. These specialists participate in the meetings of expert committee and scientific working groups to develop reports and recommendations on health matters of current interest to member countries. In the field of vector biology and control, there are presently 93 members representing 39 countries.

The WHO has stressed standardization of techniques for determining the levels of susceptibility to different insect vectors. Standard kits and impregnated papers are made available at nominal costs. The results are interpreted, stored in a computer,

and special maps showing the distribution of resistance are maintained on a current basis. So far, approximately 8,000 test kits have been supplied for testing about 20 vector species.

With the assistance and advice of collaborating laboratories and scientists, specifications for pesticides and equipment are formulated, and information is distributed on the safe use of pesticides, including the supply of kits for measuring toxicological effects.

WHO stimulates and assists research activities. In 1976–1977, contractual technical agreements were signed with 82 individual scientists to support work on a wide range of vector control subjects. Moreover, there are 26 laboratories designated as WHO collaborating centers which cooperate with the organization in solving vector control problems.

It is evident from this summary that WHO is concerned principally with assisting developing countries to solve difficult vector problems. This is possible through the exchange of technical information on an international scale and through collaborative research and research coordination. Vector control has received high priority in the Organization's total health effort as vector-borne diseases are usually the chief health problems in most developing nations. Although the WHO resources are very limited in relation to the size of the problem, there has been no lag in the effort to carry out the program while maintaining the highest standards.

In the field of mosquito control, the American Mosquito Control Association has assisted in the development of mosquito control technology internationally. Additionally, the United States as a member nation of the WHO has participated and contributed to the support of malaria and other vector disease control programs.

As you have undoubtedly concluded from this presentation, there are many challenges to be met and problems to be solved in international vector control. If the past is any guide to the future, the solutions will not come easily, and WHO will need and will welcome the continuing collaboration and support of this Association and its members.

References Cited

Bang, Y. H. and C. P. Pant. 1972. A field trial of Abate larvicide for the control of *Aedes aegypti* in Bangkok, Thailand. Bull. Wld. Hlth. Org. 46:416–425.

Brown. A. W. A. and R. Pal. 1971. Insecticide Resistance in Arthropods. WHO *Monograph Series* 38.

DeMeillon, B., M. Paing. A. Sebastian and Z. H. Khan. 1967. Outdoor resting of *Culex p. fatigans* in Rangoon, Burma. Bull. Wld. Hlth. Org. 36:67–73.

Foll, C. Y. and C. P. Pant. 1966. The conditions of malaria transmission in Katsina Province, Northern Nigeria and effects of dichlorvos applications. Bull. Wld. Hlth. Org. 34:395–404.

Fontaine, R. E. and J. H. Pull. 1977 Malaria control: field testing of a new insecticide. WHO Chronicle 31:102–105.

Graham, J. E., M. H. M. Abdulcader, H. L. Mathis, L. S. Self and A. Sebastian. 1972. Mosquito News. 32(3):399.

Gratz, N. G. 1976. The importance of chemicals in the control of tropical disease. *In Chemie der Pflanzen schultz–und Schadingsbekampfungmittel,* Band 3, Springer Verlag, Berlin.

Laven, H. 1967. Eradication of *Culex p. fatigans* through cytoplasmic incompatibility. Nature, London, 216:383.

Lofgren, C. S., H. R. Ford, R. J. Tonn and S. Jatanasen. 1970. The effectiveness of ultra low volume applications of malathion at a rate of 6 US fluid ounces per acre in controlling *Aedes aegypti* in a large scale test at Nakhon Sawan, Thailand. Bull. Wld. Hlth. Org. 42:15–25.

Najera, J. A., G. R. Shidrawi, F. D. Gibson and J. S. Stafford. 1967. A large scale trial of malathion as an insecticide for anti-malaria work in Southern Uganda. Bull. Wld. Hlth. Org. 36:913–935.

Pal, R. 1974. *The Use of Genetics in Insect Control* ed. R. Pal and M. J. Whitten 1974, Elsevier.

Pal, R. and N. G. Gratz, 1968. Larviciding for mosquito control. Pans Sect. A. 14:447–455.

Pant, C. P., G. P. Joshi, R. Rosen, J. A. Pearson, P. Renaud, M. Ramasamy and M. Vandekar. 1969. A village scale trial of OMS-214 (Dicapthon) for the control of *Anopheles gambiae* and *An. funestus* in Northern Nigeria. Bull Wld. Hlth. Org. 41:311–315.

Pant, C. P., H. L. Mathis, M. J. Nelson and Phanthumachinda Boonlaun. 1974. A large-scale field trial of ultra low volume fenitrothion applied by a portable mist-blower for the control of *Aedes aegypti*. Bull. Wld. Hlth. Org. 51:405–415.

Pant, C. P., G. A. Mount, S. Jatanasen and H. L. Mathis. 1971. Ultra low volume ground aerosols of technical malathion for control of *Aedes aegypti*. Bull. Wld. Hlth. Org. 45:805–8171

Pant, C. P., M. J. Nelson and H. L. Mathis. 1973. Sequential application of ultra low volume ground aerosols of fenitrothion for sustained control of *Aedes aegypti*. Bull. Wld. Hlth. Org. 48:455–459.

Pant, C. P., P. Rosen, G. P. Joshi, J. A. Pearson, M. Ramasamy, P. Renaud and M. Vandekar. 1969. A village scale trial of OMS-708 (Mobam) for the control of *Anopheles gambiae* and *Anopheles funestus* in Northern Nigeria. Bull. Wld. Hlth. Org. 41:316–19.

Rosen, P. 1967. The susceptibility of *Culex pipiens fatigans* larvae to insecticides in Rangoon, Burma. Bull. Wld. Hlth. Org. 37:301–310.

Turner, R. N. Martoprawiro and A. Padmowiryono. 1974. Dynamics of plague transmission cycle in Central Java (Ecology of potential flea vectors). Health Studies in Indonesia. Vol. II., No. 2, 1974. (Bulletin Penelitian Kesehatan).

WHO Expert Committee on Insecticides, Twenty-second Report. 1976. Resistance of vectors and reservoirs of disease to pesticides. WHO Tech. Rpt. Ser. 585.

Wright, J. W. 1971. The WHO Program for the evaluation and testing of new insecticides. Bull. Wld. Hlth. Org. 44:11–22.

Wright, J. W., R. F. Fritz, K. S. Hocking, R. Babione, N. G. Gratz, R. Pal, A. R. Stiles and M. Vandekar. 1969. Ortho isopropoxyphenyl methylcarbamate (OMS-33) as a residual spray for control of anopheline mosquitoes. Bull. Wld. Hlth. Org. 40:67–90.

FIELD TRIALS WITH THE MERMITHID NEMATODE, *ROMANOMERMIS CULICIVORAX*, IN CALIFORNIA

B. J. BROWN, E. G. PLATZER AND D. S. HUGHES

Department of Nematology, University of California, Riverside, CA 92521

ABSTRACT. Field tests were conducted with *Romanomermis culicivorax* Ross and Smith, against 4 species of mosquito larvae in 3 natural and 2 artificial sites. Infective nematodes were disseminated at 706 to 25,000 per m^2 surface area. All species of mosquito larvae were infected and the percentage infection was dependent on the mosquito subfamily, application rate, and test site. In mixed mosquito populations anophelines were more susceptible to parasitism than culicines. Infections in culicine mosquitoes did not exceed 62% at the highest exposure rates. Control of mosquito larvae was reduced in sites with dense vegetation or algal mats.

INTRODUCTION

The broad host range of *Romanomermis culicivorax* Ross and Smith (= *Reesimermis nielseni* Tsai & Grundman of authors, in part) suggests it as a promising biological control agent for mosquitoes—at least 52 species of mosquitoes are known to be infected (Petersen 1973). This study was conducted to determine the feasibility of using *R. culicivorax* as a control agent in mosquito producing habitats in California. Field tests were conducted in 2 artificial and 3 natural sites against 4 species of mosquitoes.

MATERIALS AND METHODS

Romanomermis culicivorax was propagated in *Culex pipiens* Linnaeus following the procedures of Petersen and Willis (1972a). Preparasites were introduced into treatment areas with an 8 liter Hudson® sprayer to give a coarse spray (Petersen and Willis 1972 b). In all studies, preparasites were from 3 to 6 hr old at the time of application. Ponds were sampled 48 hr after treatment. Native mosquito larvae were recovered from treated areas with either a 400 ml dipper or a sweep net. Parasitism was determined by dissecting