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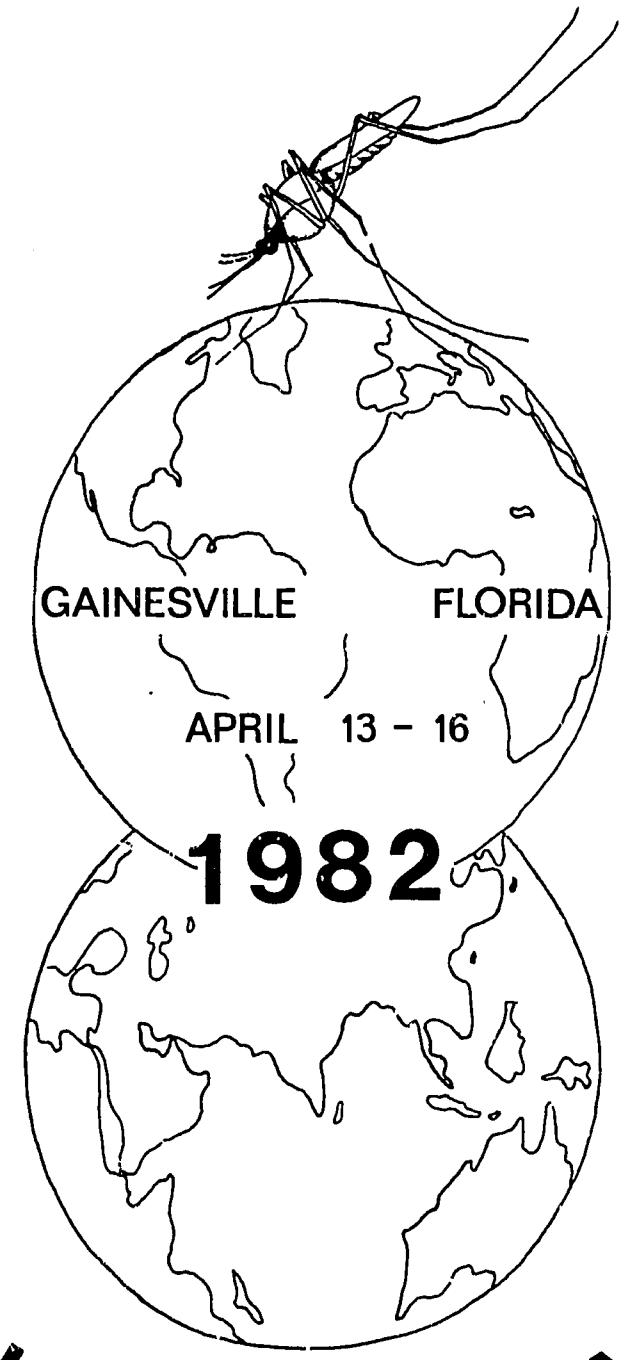
WORKSHOP ON VECTOR CONTROL



USAID : USDA

Comprehensive Vector Control - Current Status

and Research Needs

Workshop sponsored by the United States

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The Insects Affecting Man and Animals Research Laboratory

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Attachment 1 Workshop Agenda

Attachment 2 Working Groups

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Attachment 4 Working Papers (Title and Author)

3.1 "Adult Mosquito Control by Residual Spraying," R. E. Fontaine
3.2 "Larvicides and Their Formulations in Vector Control Programs," M. S. Mulla
3.3 "Space Spraying in Control of Malaria Vectors and Mosquito Vectors of Arboviral Diseases: Summary Report," R. J. Tonn
4. "Water and Weed Management and Source Reduction," F. E. Gartrell
5. "Current Status of Surveillance, Attractants, and Repellents in Vector Control," B. F. Eldridge
6. "A New Approach to Environmental Problems," H. I. Scudder
6. Excerpt From "Malaria Control Manual," H. I. Scudder and F. C. Roberts
7.1 "Genetic Mechanisms," R. Baker
7.2 "Sterile Insect Release," D. A. Dame
8.1 "Parasites, Pathogens, and Predators of Mosquitoes," H. C. Chapman
8.2 "*Toxorhynchites* - A Biological Control Agent of Container-Breeding Mosquitoes," D. A. Focks
9.1 "Malaria Models and Vector Control: The Garki Project and Beyond," L. Molineaux
9.2 "Models and Computer Simulations Relating Vector Control to Vector Density and Malaria," D. E. Weidhaas and D. G. Haile
10.1 "Current Status and Research Needs: A View From Africa," W. L. Kilama
10.3 "Situation of Malaria in the Americas," M. Van Severén
10.4 "Comprehensive Vector Control," C. P. Pant and N. G. Gratz
10.5 "Current Vector Control Methods and Research Needs in Malaria in South East Asia," I. A. H. Ismail
10.6 "Problem Oriented Research on Malaria Vectors in Indonesia, Progress and Future Needs," Y. H. Bang
10.7 "Malaria in the Americas: A Commentary," R. J. Tonn
10.8 "Vector Control at Community Level," J. Mouchet

1. INTRODUCTION

Diseases transmitted to humans by insects are still a major health problem throughout the world. One of the approaches to control or elimination of the diseases transmitted by insects is the control of the vectors. Progress in disease control through vector control can be considered to have reached a plateau following the development and use of highly effective insecticides. The high cost/benefit ratio obtained by the use of insecticides led to a reliance on these tools. However, insecticide resistance, economic considerations, and environmental concerns are now problems and have led to the need for reviewing the approach to operational vector control. Research has been expanding into other methods of control over the past 10 to 20 years and is providing and will provide new methods and technology for control. Currently there is a need to review the progress on research in all areas of vector biology and control and determine both research needs for and operational feasibility of various approaches to control. There is a further need to determine the potential of combining different methods of vector control into comprehensive vector control strategies currently or in the future.

Recognizing this need, the Agency for International Development requested that a meeting be held to review this subject. The Insects Affecting Man and Animals Research Laboratory, ARS, USDA, in Gainesville, Florida, accepted the responsibility for organizing and hosting this meeting in cooperation with the Office of Health, AID. From April 13 through 16, 1982, a meeting was held in Gainesville, Florida, with both scientific and operational experts from various parts of the world. The meeting was restricted in size with individuals selected for their knowledge and experience in various aspects of vector biology and control. The meeting was designed to concentrate on mosquitoes, with primary emphasis on those which transmit malaria.

Attachment 1 is the agenda of the meeting. Attachment 2 lists the working groups organized for the meeting and Attachment 3 provides a list of the participants at the meeting. The main body of the report comprises general statements and recommendations prepared by the working groups and agreed to in general by the participants.

Some of the participants were requested to prepare working papers for the meeting to serve as summary statements and provide starting materials for discussions. These working papers are appended to the end of this report for information only (Attachment 4) and should not be cited or necessarily considered as representative of the opinion of the participants of the meeting.

2. PURPOSE OF THE MEETING

The meeting was convened to bring together a group of specialists in vector biology and control who could review the current status of knowledge in the area of vector biology and control worldwide, and at the same time provide recommendations to AID for research that would support ongoing programs and lead to the development of new and comprehensive approaches to control. Although the document prepared by the group is intended primarily for internal use of AID, it can be made available to interested individuals and agencies.

Several points were brought out in the discussions at the meeting and are included here since they are general in nature and apply to all of the sections of the report.

A system of data storage and retrieval is needed for AID and other agencies that would make information readily available on: (a) vector control or research projects in existence in all parts of the world indicating location, funds, objectives, personnel, and duration; (b) institutions available for training or research in medical entomology and vector control; and (c) maintenance and updating of a World Directory of vector control and research specialists.

Increasing research capabilities and conducting vector control depends on training for individuals. Training activities are extremely important and need to be developed particularly for vector control activities. There is still a need for supervision of overseas projects in vector research and control. There is also a need for continued interagency coordination.

In the future, USAID may wish to consider convening working groups to consider specific areas of importance within the general area reviewed in this report.

Research and operational fund support is limited and it will be necessary to accomplish as much as possible by cooperative research. New vector control methods, particularly nonpesticidal approaches, will depend upon institutions rather than industry for their development. New approaches to control may be more costly to develop but in the long run may be equally cost effective. When possible, new technology should be tested by conducting limited operations within the framework of an established program.

Operational programs require careful monitoring and flexibility in conduct to assure optimum results from resources available. Improved and more efficient monitoring methods are needed to plan and evaluate programs and deal with the problem of resistance, vector density, and disease level.

3. INSECTICIDES

3.1. Residual Sprays

3.1.1. General Status

Residual spraying, especially in dwellings, was the sole method of malaria control for many years, and in some places produced results that achieved or approached eradication. Throughout most of the area where malaria control programs are in place, it still remains the main line of defense, although in other places problems such as exophily or exophagy of the vectors, or inappropriate types of housing, virtually preclude its use. Even where residual sprays remain the most effective method of control, widespread difficulties are being encountered, primarily because of the development of insecticide resistance and the refractory behavior of certain vectors. When alternate insecticides are introduced to control the resistant strains, resistance to them may develop also, and cross-resistance may occur. The new compounds are usually quite expensive, and recently there has been a serious reduction in the number of new compounds available for evaluation. It is therefore crucial to develop ways to preserve the usefulness of the compounds we now have, to delay the development of resistance, and to find ways to obtain the maximum effectiveness with the least amount of the new, more expensive, materials.

There is an additional problem in the potential for improper use of new materials and methods, as when ULV (ultralow volume) formulations are misused as residual sprays, increasing the expense and hazards.

3.1.2. Recommendations

The following recommendations and the priority rank that has been assigned to each are based largely on consideration of the aforementioned widespread difficulties that are being encountered in the use of residual sprays. Some of the recommendations presuppose an adequate state of knowledge of the ecology and ethology of the target populations. In this regard, it is considered highly desirable that an annotated bibliography of all malaria vectors be prepared. The bibliography should include information on the susceptibility and habits of the different malaria vectors as they affect their exposure to residual spray applications; where pronounced exophily or exophagy occurs, additional (or alternative) control measures would need to be included in malaria control programs.

3.1.2.1. Laboratory Research

The first priority in laboratory research is still the evaluation of new compounds. The chemical industry has a dominant role in the synthesis, development, toxicological testing, and registration of new insecticides. Although the number of new compounds has decreased in recent years, it is still of primary importance to assure that all new compounds that become available be evaluated for their effectiveness in

vector control. Compounds synthesized previously should also be reexamined to determine which insecticides are minimally affected by existing resistance mechanisms.

Promising compounds should be studied to determine the potential of the principal vector species to develop resistance to them, the mechanisms of such resistance, the consequent cross-resistance spectra, and the genetic dominance of resistance.

The second priority in laboratory research is the development of improved formulations. The following recommendations apply to space sprays and larvicides as well as to residual sprays. Research is needed to (a) optimize insecticide toxicity on various types of surfaces and environments, including water, and (b) to provide, through microencapsulation, UV (ultraviolet) shields or other means, the capability of controlling the rate of insecticide release and of chemical decay according to desired specifications.

A third priority consists of studies of insecticide usage strategies aimed at inhibiting the development of resistance. Possible subjects for research include the following: (a) studies with admixtures of chemicals to provide for: the development of criteria for choice of chemicals for use in mixtures; research on the role of synergistic combinations; search for negatively correlated cross-resistance, and its validation through laboratory selections of representative populations; (b) studies to develop criteria for the use of specific chemicals in rotation, and their validation through laboratory selection experiments; and (c) studies on the order of use of specific chemicals to develop criteria for selection and testing of the most appropriate sequences under laboratory conditions. Promising results from this research must subsequently be tested under field conditions (see 3.1.2.2).

Insecticide repellency studies constitute a fourth priority. The repellency of existing and future compounds should be examined, and the consequences of repellency on the extent of man-vector contact should be evaluated.

Improved diagnostic techniques for early detection of resistance in field populations are also needed. Bioassay tests at discriminating dosages (dosages that distinguish between susceptible and heterozygous resistant individuals) are useful but they lack certainty where resistance occurs at a low frequency. There is need for more sensitive, simple biochemical marker tests to detect unequivocally the presence of specific resistance genes in populations. A recently developed esterase test for organophosphorus resistance in *Culex quinquefasciatus* shows promise.

3.1.2.2. Field Research

The first four of the following recommendations concern application procedures aimed at reducing insecticide costs. All are of equal importance and first priority; the other recommendations are listed in descending order of priority.

(a) Evaluations are needed on the effectiveness of partial coverage of wall surfaces and/or selective spraying of structures (human habitations, animal shelters, etc.). Such research requires the availability of chemicals possessing vapor or particulate action, and/or knowledge of peculiarities in the resting and biting habits of the target population.

(b) Studies on reduced rates of insecticide application should be undertaken to determine the cost effectiveness of different rates of application as related to the desired length of protection.

(c) The effectiveness of seasonal application of insecticides should be determined, since the need for insecticide deposits may be limited to periods of transmission activity of the vector. In certain areas, agricultural insecticides may so strongly reduce mosquito density that residual house spraying may be temporarily postponed.

(d) Consideration should be given to the possibility of assigning spray priorities to certain localities. Horizontal stratification of country according to disease transmission potential may permit spray activities to be concentrated where need is highest.

(e) Field tests should be made to follow up any promising results obtained in laboratory tests under 3.1.2.1. on the use of admixtures of insecticides, rotation of insecticides, or optimal sequence of use of insecticides to delay the development of resistance, or to follow up on promising results of such studies which are already available.

Each study should include at the minimum the collection of information on: effect on resistance and cross-resistance, control efficacy, operator and resident safety, economics, and logistics.

(f) Sociological and/or other research on means of improving the acceptability of house spraying to residents is needed. Acceptability studies might emphasize the following: deodorized insecticide formulations; employment of local people on spray teams; means of enhancing community involvement; and reduction of visible spray residues on walls.

(g) There is a need to replace the use of human baits by other means of assessing vector population density and biting rates. Research on alternatives might include the use of animals, light traps, attractants, or other means (see also Section 5).

3.2. Larvicides and IGR's

3.2.1. General Status

There are many choices available to those who wish to use larvicides: oils, IGR's (insect growth regulators), synthetic

organic compounds, monolayer films, and microbial insecticides. These materials are formulated in many ways, such as emulsifiable concentrates, wettable powders, granules, and slow release formulations.

Because of the diversity of larvicides and their formulations, their uses will be dictated by the ecological conditions of the breeding places and biological characteristics of the vector species.

It should be pointed out that best results in terms of vector control programs are obtained when mosquito larvicides are employed in conjunction with other control strategies. Source reduction and habitat management should precede the use of larvicides in area-wide mosquito control programs. No single strategy will yield the desired results in a large and sustained vector control program. Similarly, biological control measures should be exploited whenever possible and supplemented with larvicidal applications if and when necessary.

Larvicides provide many more choices for the selection of safe and environmentally acceptable compounds than adulticides, and in some cases they are more efficient and economical to use. Among the many groups of insecticides there are some compounds that are developed only for mosquito control, which reduces the chance that resistance will develop in mosquito populations from agricultural uses.

Some of the conditions under which larvicides may be especially suitable and yield satisfactory results include the following: when the seasonal activity of the mosquito vectors is of limited duration; where breeding sources are confined and accessible for treatment, and residual sprays are not accepted; where exophily of the vector makes residual house sprays ineffective; and to supplement the manipulation of larvivorous fish until the predators have increased to sufficient levels to effect adequate control of larvae.

3.2.2. Recommendations

Chemical larvicides offer a wide range of options for the control of mosquitoes and other vectors in the aquatic stages. To further develop larvicides and larvicidal formulations for use in global vector control programs, and to provide training in their uses, the following research is recommended.

(a) All promising larvicides should be screened and evaluated against larvae and pupae of major disease vectors. Standardized testing techniques for assessing the activity of quick- and slow-acting compounds and methods for assessing novel modes of action should be developed under laboratory conditions.

(b) Research on the development of suitable and effective formulations should be stressed. The efficacy of different types

of formulations such as granules, slow-release preparations, wettable powders (WP), emulsifiable concentrates (EC), and microencapsulated formulations should be evaluated in the laboratory. Priority should be given to the development of formulations to reduce the frequency of application and accompanying labor costs.

(c) Promising larvicides and their formulations should be extensively evaluated under simulated field conditions and further evaluated in small-scale field trials for the assessment of efficacy, suitability, and longevity of formulations. Special emphasis should be placed on field entomological observations.

(d) Those larvicides and formulations which show promise in small-scale field trials should be subjected to large-scale field trials under a variety of conditions. Epidemiological and entomological observations in the trial area should be carried out, including assessment of the possible development of resistance, and additional observations on possible toxic effects to the applicators and acceptability by people in the trial area should be made.

(e) Impact on nontarget organisms and wildlife should be studied under laboratory and field conditions. Since larvicidal formulations are to be applied repeatedly to aquatic habitats, it is essential that adequate information on their impact be obtained during the course of their evaluation in vector control programs.

(f) There are many aquatic plants and plant products which induce high mortality in the immature stages of mosquitoes. Research is needed to identify such plants and plant products and to develop ways in which such options can be exploited in vector control programs.

(g) The research recommended in Section 3.1.2.1. on strategies to retard the development of resistance in the use of residual sprays is also applicable to larvicides.

3.3. Space Sprays

3.3.1. General Status

Space spraying has been used successfully in some situations against vectors of malaria, yellow fever, and dengue as well as other arboviruses. Present usage consists of ULV (ultralow volume) sprays and thermal fogs. Aerosols of diluted insecticides and dusts are used to a lesser extent. Space sprays are applied both from the ground and from the air.

Because space sprays can be applied rapidly to large areas, they are particularly attractive for use during outbreaks of mosquito-borne diseases, especially viral diseases. The use of space sprays against malaria or endemic viral diseases during periods of low level transmission may have some utility in some

situations. However, serious questions remain about just how effective space sprays are in reducing transmission of disease. One problem of major importance is the determination of the time of application. Space sprays (aerial ULV) are frequently used for the control of arboviral epidemics. However, spraying operations are often begun too late in the epidemic to have an impact. This is an epidemiological problem which deals with our inability to recognize the developing epidemic early enough to mount a large-scale space spray effort.

Equipment used to generate space sprays falls into two main categories, namely, ULV sprayers and thermal foggers. Each has its advantages and disadvantages. The thermal foggers produce smaller droplets and are advantageous when penetration into dense foliage or into buildings is desired. The dense fogs produced can be undesirable, particularly when applied in populated areas. Another disadvantage is the requirement that the pesticides must be diluted in costly petroleum solvents prior to use in this type of equipment. ULV sprayers produce an aerosol using liquid insecticides in highly concentrated form. ULV sprays are barely visible to the naked eye.

Thermal foggers may be hand carried or truck mounted. ULV sprayers may be mounted on trucks or aircraft or may be hand carried or mounted on the backs of spraymen (back pack sprayers). Most back pack sprayers and small hand-held sprayers have serious deficiencies. Some disadvantages are (a) excessive weight, (b) high noise levels, (c) high vibration, (d) short service life, (e) nonuniform droplet size, and (f) safety problems.

3.3.1.1. Insecticides Used as Space Sprays

The following compounds have been used experimentally or in large-scale vector control programs: organophosphorus compounds--malathion, fenitrothion, naled, dichlorvos, iodofenphos (jodfenphos), chlorpyrifos, and pirimiphos-methyl; carbamates--propoxur, bendiocarb; pyrethroids--pyrethrum, resmethrin, permethrin, and deltamethrin. Of the above compounds, only malathion, naled, and pyrethrum (and resmethrin in several states) are registered for aerial ULV in the USA.

3.3.1.2. Formulations Used in Space Sprays

As mentioned above, one of the advantages of ULV sprays is the use of concentrated pesticides, without the need for the extra weight and expense of diluents. However, there may be some advantages to using diluted products. Recent work suggests a probable improvement in penetration using increased volumes for ULV application. Also, solid pesticides must be dissolved in solvents prior to use. Some products are so toxic to insects that only a few grams per acre need to be used, and with these compounds solvents (diluents) must be used to provide adequate volumes of spray for dispersal.

3.3.2. Recommendations

Recommendations for research on the use of space sprays in order of suggested priority are as follows:

(a) Additional evaluation is needed on the effectiveness of space sprays in reducing a vector population in its natural habitat and on the impact of such a reduction on the disease.

(b) The advantages and disadvantages of space spray methods and equipment should be compared under different conditions of climate, topography, and environmental factors such as vegetation and buildings.

(c) The quality of operational space spray applications should be evaluated in developing countries where equipment has not been tested for droplet size and distribution, where the flow rate may not have been determined since the equipment was first used, and where training and guidelines for use are considered less than adequate. The evaluation should include determination of droplet size and distribution, flow rates, dosage actually applied, and time of day of application.

(d) Simpler, less expensive equipment that can be more easily repaired in remote areas should be developed. Investigations should include the possibility of mounting ULV units on farm tractors or on trailers pulled by the tractors, and/or utilizing the power take-off of the tractor to replace the engine of the ULV unit.

(e) Research should be conducted on pesticidal chemicals and formulations other than those listed above to determine their effectiveness. In particular, the use of other carbamates and newer synthetic pyrethroids should be pursued. Research should also be conducted on the formulation of pesticides for ULV application to determine the most effective and economical products and the optimum volume of spray for field use. Attention should be paid to safety aspects of space spray application, taking into consideration the exposure of workmen and the environment to toxic chemicals.

(f) New equipment and methodology should be developed for indoor use. Currently available power units for ULV or thermal fog generators are not appropriate for indoor use.

(g) Suggested additional studies include (1) determination of the value of space spray applications to reduce malaria transmission among migratory human populations, and (2) determination of the accumulative effects of space spray applications in reducing adult or larval vector populations or in development of resistance to the insecticide being used.

4. SOURCE REDUCTION, WATER AND WEED (HABITAT) MANAGEMENT

4.1. General Status

Although these broad categories of vector control have been available for many years, they have not been utilized as widely or as well as possible.

Training in and promotion of the use of these methodologies should be given a high priority. It is highly recommended that all vector control directors give serious consideration to the utilization of source reduction as a basic part of their control measures.

Demonstration projects should be funded in tropical areas to show the efficacy of those methodologies and to formulate specific applications.

An increased level of research is urgently needed in both water and weed management.

4.2. Recommendations

Research, training, and other activities that are needed to improve and extend the use of source reduction technology, water management, and weed management are summarized in the following paragraphs.

4.2.1. Source Reduction

(a) It is important to determine which vector species are amenable to source reduction techniques.

(b) Literature on source reduction and its effectiveness and economics is available and well documented. Because many of these publications are no longer widely available they should be collated and reprinted to make them more available for use in current programs.

(c) Training in source reduction methodology is required in order for vector control programs to utilize it. Commonly the people without such specific training view source reduction only as the use of rather massive equipment in large projects, and tend to reject it out-of-hand as neither economic nor manageable, yet source reduction in many cases can be done with minor equipment, even with hand equipment and ordinary labor.

(d) Major problems in source reduction are compounded by the requirement for environmental assessments and environmental impact statements, which tend to inhibit or actually to prevent source reduction programs. Further research should be implemented on major ecosystems and their nontarget organisms (for example, to show the effects of source reduction on tidal lagoons, mangrove swamps, and major freshwater and saltwater aedine habitats).

(e) The scope of any major source reduction project should always be limited by the documented extent and severity of the vector problem. Very careful collection and analysis of epidemiological and entomological data should be made before, during, and after the conduct of source reduction projects in order to provide the basis for the evaluation of the effectiveness of such projects.

(f) The planning, construction, and operation/maintenance of all multi-use water projects should involve review by vector control specialists in order to minimize or prevent the development of new vector sources by these projects. There should be

a person well trained in source reduction methodology to maintain liaison with those donor agencies (such as AID, UNDP, international banks, etc.) planning and funding projects of potential concern to vector control. Liaison must further be maintained with the contractors and ultimate users during construction and operation of any such project.

(g) Vector control programs should be involved in the planning, construction, and operation/maintenance of all projects that incidentally change the rate of water movement either by blocking its drainage or changing its flow pattern (for example, highway construction and storm water management).

(h) Data derivable from remote sensing (LANDSAT) should be exploited to determine the nature and extent of larger areas eligible for source reduction and for the evaluation of past and present projects.

4.2.2. Water Management

(a) Investigation should be carried out in tropical countries to determine whether or not impoundments create vector problems. If so, research should be done on the problems.

(b) Research should be done in tropical countries to determine if the Tennessee Valley Authority (TVA) four-phase water level and shore line management systems are feasible under those conditions.

(c) Joint research projects should be established with agricultural experts to develop methods of mosquito control which are compatible with the specific crop or culture (for example, rice, fish, shrimp, etc.).

(d) Major research is required on irrigation distribution systems from a source reduction standpoint.

4.2.3. Weed Management

(a) An urgent need exists for research on plant-associated vector problems. Each situation may require a separate investigation.

(b) Once a plant-vector association is established, methods must be developed to eliminate the problem without causing or creating additional or secondary problems.

5. SURVEILLANCE, ATTRACTANTS, AND REPELLENTS

5.1. General Status

Surveillance is a critical component of any vector-borne disease study or control operation. Chemical attractants can play a part in surveillance, and can also be used in connection with protection and control. Vector repellents have the potential to offer protection from disease.

The worsening situation for control of malaria in most endemic areas of the world has occurred at a time of diminishing support for studies of vector taxonomy and ecology, as well as

routine entomological surveillance. Consequently, large and expensive control programs have been initiated, or simply perpetuated year after year, and sometimes terminated, often without an entomological assessment of program effectiveness. Certainly we must realize that a precursor to any entomological assessment or field study is a clear understanding of the taxonomy of the target organism(s). This need can be met only if there is continual and increased support for biosystematic research.

The basic methods for collecting critical surveillance data and for conducting vector ecology studies are available and there should be priority support and funding for the field application of these methods. However, there is a need to improve the established surveillance techniques, to improve analysis and interpretation of data, and to develop and introduce new and innovative surveillance methods, e.g., development of a trap baited with a chemical attractive to anopheline mosquitoes. An examination of the uses of chemical attractants in surveillance, or repellents to provide protection from vector species, reveals a very basic lack of information on the physiological/biochemical mechanisms of attractancy and repellency in mosquitoes.

Another area of research that has received limited attention concerns the search for materials, other than repellents, which have a beneficial mode of action through the modification of vector behavior. Such materials might be effectively used to reduce the incidence of disease transmission.

5.2. Recommendations

The following recommendations are presented in descending order of priority.

(a) Research should be conducted to improve conventional surveillance techniques and hardware, with particular emphasis on malaria vectors. Examples of problems and approaches to improvements are as follows: (1) attempts should be made to develop new or improved trapping methods, in combination with effective chemical attractants adequate to replace the current use of human bait; (2) existing age-grading techniques are difficult and labor intensive and should be simplified and improved; (3) application of new serological methods for host blood meal identification should be evaluated; and (4) improved field techniques for the mass isolation and identification of malaria sporozoite infectons in mosquito salivary glands should be developed.

(b) More research is needed on vector biology and the application of new knowledge to design and to interpret surveillance techniques.

(c) The level of support for biosystematic research to delineate vector species complexes should be expanded. These studies should include a multidisciplinary approach, e.g.,

classical taxonomic, cytogenetic, and chemical studies. Consideration should also be given to developing techniques for the rapid identification of vector species by use of serologic or electrophoretic methods.

(d) The physiology of avidity in haematophagous arthropods needs additional study. Since 1970, less than five efforts have been conducted in this area and none are underway at present. Until the physiological processes of host attraction are understood, our understanding of structure-activity relationships of host emanations to attractancy or repellency will be very shallow. Such an understanding requires both physiological and chemical research on host attraction.

Variations between mosquito species in response to different hosts, based on empirical evaluations, indicate that mixtures of sensors are involved in the response. Thus, different mixtures of materials are likely to be active in different mosquito species.

(e) Research is needed on new methods of use of existing insect repellent materials, or new formulations, to reduce cost, increase persistence, increase effectiveness, and improve user acceptability. For example, an innovative method that requires additional research is the concept of area protection with treated netting.

(f) Additional chemicals (including thos of plant origin) should be screened for insect repellency action. This screening should also include tests to identify materials, not necessarily repellents, that suppress, inhibit, or interrupt hematophagous behavior of arthropods.

(g) The application of microcomputer technology to surveillance data collection, storage, and analysis should be investigated. Computer simulation and mathematical models of various components of vector-borne disease systems will play increasing roles in disease prediction, prevention, and control. These models are dependent upon valid surveillance data input. Microcomputers have great potential for data compilation, storage, and analysis and can provide not only ease of handling data, but also data of higher quality. Even simple programs can be used as parts of decision support systems and can have direct application to field control situations.

(h) The use of various remote sensing techniques such as radar, LANDSAT satellite imagery, and conventional aerial photography for vector habitat surveillance and analysis should be explored. These areas of research offer tremendous potential for development of practical techniques for surveillance of vector breeding over large areas. Such surveillance should be especially

valuable in areas where transportation facilities (roads, etc.) are poorly developed, and where ecological changes result from drought, dam construction, and other factors. The primary advantage of remote sensing, however, is high cost effectiveness, once the research investment has been made.

(i) Research on the identification of chemical attractants is urgently needed. Carbon dioxide has been shown to be attractive to mosquitoes when released in large quantities from traps, and plant and flower-produced attractants for several species of mosquitoes have been demonstrated. None of the latter have been identified and made available for use and no projects are presently underway. Surveillance and control methods could be greatly assisted by deployment of a practical chemically-based material that would attract blood-seeking mosquitoes to a trap. Such a material can only be obtained through sustained basic chemical research on human- or animal-generated skin, body, or excretory emanations, including isolation, identification, synthesis, and formulation efforts. One research effort is presently being conducted on the chemistry of animal-generated attractants for avid mosquitoes. Since 1968, only one effort has been conducted on human-generated emanations, while less than five efforts looked at mosquitoes from the sensory physiology viewpoint. None are now being conducted.

(j) An intensive search should be made to identify semiochemicals (signalling agents) in mosquitoes. Demonstrations of the existence of semiochemicals in adult mosquitoes of four species have appeared in the literature, but none since 1975. No chemicals have been identified, and no work is presently underway. Materials useful in survey and control may be identified through basic research. This situation is very different from that in agricultural insects, where behaviorally active chemicals have been isolated, identified, and synthesized for almost 300 species, and some practical applications are in current use.

6. ENVIRONMENTAL PROBLEMS[1]

For this broad topic one is referred to the current "Regulation 16"[2] which directs the development of environmental examinations, assessments, and impact statements, to be set forth in the Malaria Manual and Guidebook by Scudder and Roberts, 1982.

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[1] See the two supplementary statements by Scudder presented at this meeting and the proposal to use flow-charted algorithms to guide management through environmental problem areas.

[2] Federal Register 45 (207). October 23, 1980. Rules and Regulations, 22 CFR Part 216 Environmental Procedures (for ICA, Agency for International Development).

7. GENETIC CONTROL AND STERILE INSECT TECHNIQUE

7.1. General Status

The successful genetic control campaign waged against the screwworm over the past 20 years provides a model and an incentive for the development of similar autocidal control techniques for other insect pests, especially the most important vectors of disease.

There are essentially two choices available for genetic control. For the sterile insect technique (SIT), the rationale for control is in the use of inundative releases of males sterilized by ionizing radiation or chemosterilants. This method has been tested in field experiments against a few species of mosquitoes, but no operational programs have ever been attempted. The other option involves the assembly of genetic control systems composed of heritable chromosomal aberrations and lethals or desirable traits, e.g., lack of vector competence and insecticide susceptibility. A few small-scale experiments have been conducted, but these had only limited objectives such as measuring competitiveness of the type bearing a chromosome aberration.

The synthesis of genetic control methods has been characterized by many entomologists as too complex and sophisticated for the practical purpose of vector control. Actually, there are precedents in the literature for almost every genetic mechanism that has been proposed for genetic control. The technology and methodology for the synthesis of genetic mechanisms already exist, but there is not sufficient support for this type of research. A sustained effort will be required to fully evaluate the possiblility of a genetic control system for any species, and the cost of developing and implementing genetic control may appear to be higher than the investment required for a pesticide, for which industry bears the brunt of the expense. However, limited resources should not impede the goal of choosing a few important vectors to serve for the development of genetic control methods. The species chosen should be amenable to control by this method in accordance with theoretical considerations.

7.2. Recommendations

In the recommendations listed below, an effort was made to present an orderly progression of how the steps in the development of a genetic control system would be done. Most of the recommendations are directed toward the use of heritable chromosomal aberrations; however, many of the items are applicable to a refinement of SIT. The present status of research on SIT and the genetic mechanisms for the control of vectors, as summarized by R. H. Baker and D. A. Dame, is included in Attachment 4.

(a) Initiation or continuation of studies on the cryptic genetic variability in vectors is needed, using the available

technology (e.g., isozymes, chromosomes, biometrics, cuticular hydrocarbons, etc.) to identify species complexes and to select species for genetic control studies. Several complexes are known for anopheline mosquitoes, and similar situations undoubtedly exist for other species.

(b) Additional studies on the formal genetics and cytogenetics of selected species are recommended to provide the chromosome and linkage maps that are necessary for the synthesis of genetic control mechanisms and the analysis of populations.

(c) Evaluation of the genetic changes that occur during the process of colonization of a species should be investigated by the use of isozyme and chromosome analysis. A better understanding of colonization may improve the general fitness of released insects.

(d) Additional research is needed on the induction and isolation of heritable genetic control mechanisms (e.g., homozygous translocations, compound chromosomes, and conditional lethals) as well as on nonheritable mechanisms (e.g., dominant lethality).

(e) The inheritance of innocuous traits (e.g., lack of vector competence and capacity, diapause, pesticide susceptibility, and autogeny) should be determined, and genetic engineering research should be conducted to transfer the genes transmitting such traits into genetic control systems.

(f) Genetic control systems or strains for SIT should be improved through selective breeding schemes, which should include the improvement of the performance of genetically-altered mosquitoes under field conditions.

(g) Investigations of the cryptic variability in predators and parasites and evaluation of the effect of polymorphism on the efficiency of these biological control agents are needed.

(h) Genetic systems for the efficient separation of male and female mosquitoes for SIT are urgently needed.

(i) Evaluations of SIT for the control of *Anopheles albimanus*, *An. gambiae*, and *An. culicifacies* should be made as a part of an operational program or in a large-scale, integrated management trial in an isolated area.

(j) The environmental impact of chemosterilant residues inside sterilized mosquitoes should be determined, and the search for nonhazardous compounds should be continued.

(k) International centers should be established to preserve special genetic stocks and to provide training in rearing mosquitoes and genetic techniques.

8. BIOLOGICAL CONTROL

8.1. General Status

Comprehensive vector control utilizes all means available for the interruption of transmission of disease agents in such a way that the different techniques complement rather than conflict with each other. Chemical control is usually the easiest, cheapest, and most readily effective method of vector control when it can be used, but unless it provides complete interruption of disease transmission and eradication of the etiological agent, chemical control is repetitive, expensive in the long run, and almost certainly will lead eventually to insecticide resistance. In some instances, as where vectors are exophilic and breeding places are scattered, chemical control may not be possible. It is therefore important to identify natural sources of mortality in vector populations and to explore alternative natural control factors which might be used to augment normal mortality to decrease the size or longevity of vector populations.

Biological control is a method which is usually so host-specific that it will not adversely affect the environment. It is labor intensive rather than capital intensive, which is particularly advantageous in developing countries. Many of the parasites and predators can be produced locally, which avoids problems in monetary balances. The cost/benefit and cost effectiveness may be very high. In addition, the development of resistance to biological control agents is less apt to become a serious operational problem than resistance to insecticides.

No single biocontrol agent is likely to have widespread applicability relative to vector species and habitats. Therefore, the efficacy of a biocontrol agent cannot be decided on the basis of a single test, however large, in one environment against one vector species. Because of a variety of biological physical, and chemical factors, an organism might either have a temporary larvicidal effect or cycle and persist to exert more permanent control in a restricted habitat range. In light of our incomplete knowledge of the limiting factors, potential biocontrol agents need to be evaluated against as wide a variety of susceptible vectors in as many different habitats as possible.

There have been notable successes with biological and conventional techniques without prior extensive knowledge of the biology, ecology, or dynamics of the systems involved. It can be argued that these successes were in some way responsible for the attitude that an appreciation of basic biologies was not essential to vector control. However, it is becoming increasingly apparent that present efforts in all areas are hampered by an inadequate foundation of basic information. It is clear that the type of

information required for biological control is fundamentally different from that required for conventional suppression strategies. If biocontrol is to play a role in the suppression of disease, a great deal of basic research is required. A research philosophy relying substantially on serendipity and the wholesale screening of biologicals will not be as fruitful ultimately as one employing a mixed and more balanced strategy that includes basic research.

Many mosquito pathogens have not reached the stage of field testing because basic questions are unanswered. For example, knowledge is needed as to how horizontal transmission of some types of microsporidia is accomplished before their biocontrol potential can be evaluated. New techniques for the evaluation of the results of field applications are needed for those biocontrol agents which exert their effect over the whole lifespan of the vector. The activity of even those pathogens which have already been proven to be efficacious might be enhanced with a more thorough knowledge of the dynamics of filter feeding in vector *Nematocera*.

8.2. Recommendations

The following recommendations for research on biological control methods have been grouped into two categories: general recommendations dealing with broad areas of research and specific recommendations concerning a few of the more important species.

8.2.1. General Recommendations

(a) Biocontrol agents contribute to suppression of mosquito populations throughout the world. Every locality has specific situations unique to the area. Generally the search for biocontrol agents has been insufficient, and additional exploration should be supported. When fish predators are considered, emphasis should be on the feasibility of using native species, particularly those that offer promise for food or bait.

(b) A major limiting factor in the commercial production of biological control agents is the present general inability to mass produce them. With present technology, living organisms (hosts or prey) are required for the mass culture of most of these agents. A few of the promising biocontrol agents can be produced in vitro, and for the most part those are the ones that have reached the level of commercial production. Therefore, much more research is needed on the development of technology for production of other promising agents such as nematodes, fungi, and fish.

(c) Formulation of biocontrol agents can make the difference between success and failure. For instance, bacterial and microsporidian spores must remain in the larval feeding zone long enough for the mosquitoes to acquire a lethal dose. Different formulations are required to penetrate vegetative canopies and reach larval breeding sites.

Short shelflife is one of the most important potential deterrents to the marketability of biocontrol agents. It is imperative that these products remain viable at relatively high tropical temperatures for extended time periods. Research is desperately needed to resolve these problem areas of formulation and shelflife.

(d) Two strategies for biological control are inundative and inoculative releases. These involve quite different approaches and are appropriate to different vectors and biocontrol agents.

The concept of inoculative release is based on the establishment, persistence, and cycling of the agents in the habitat where control is desired. Knowledge of the various parameters that permit or influence cycling will provide background on the feasibility of using certain agents in specific habitats, determining optimal application times and rates, and may enable enhancement of the cycling phenomenon through formulation.

8.2.2. Specific Recommendations

(a) Large-scale trials of the efficacy of *Bti* (*Bacillus thuringiensis israelensis*) in interrupting disease transmission should be carried out. Such tests should be done with such species as *Anopheles albimanus*, *An. culicifacies*, *An. sundaicus*, or *An. sacharovi*.

(b) The question of whether, to what extent, and under what conditions, cycling of *Bacillus sphaericus* takes place after application should be examined, since the persistence of the organism in the field depends on such cycling.

(c) Carefully designed field trials with various species of *Toxorhynchites* in various habitats should be conducted with the intention of providing information on the mechanisms responsible for the level of suppression obtained.

(d) One factor limiting the utility of *Romanomermis culicivorax* is its inability to cycle in the field under some conditions. This limitation appears to be related to water quality and substrate. It is strongly suggested that research be funded that would characterize potential breeding sites in such a way that probable cycling could be predicted before this agent is used in a suppression effort.

9. POPULATION DYNAMICS AND COMPUTER SIMULATIONS

Modelling is a useful and powerful tool that has application in many fields of biological science. All models include assumptions that attempt to represent a segment of the real world. In most cases increased realism is obtained by increasing model complexity. In any use of models the structure and complexity will depend upon the objectives and ultimate use of the

model. Models provide insight into the behavior and interactions between different components in a system. As such, models are useful research, planning, and training tools.

Modelling research and use of models have had and will continue to have a great impact on understanding disease-vector interactions and development of comprehensive control strategies. Recent improvements in vector-disease models and availability of low-cost computer systems will increase the potential usefulness of modelling systems in field research and operational programs.

9.1. General Status

Modelling of malaria transmission and of vector population dynamics already has a long history, and is currently an active field of investigation (see working papers by Molineaux and by Weidhaas and Haile, Appendix 4).

9.1.1. Models of Vector Population Dynamics

The current emphasis on vector control includes the potential of combining various methods of control into comprehensive control. The complexity of the problem has resulted in the development of models which interact the effect of control methods with the dynamics of populations by following density trends with or without control. The existing models are largely theoretical, but based on a large body of data on the biology, ecology, and life history of vectors. The models have been adapted to computer methodology. Vector models are all based on the life history of the vector involved, but have generally been developed along three main approaches: (a) quantification or computer simulations of descriptive life cycles; (b) mathematical models; or (c) a combination of both general approaches. To date these models have been useful in synthesizing biological and control data, studying the relationship of control to the dynamics of the population and planning research and field experiments. One vector model has been extended to include a model of falciparum malaria in the human and vector population.

Currently, the major accomplishments of these models and computer simulation techniques have been the synthesis of existing data into reasonably quantified models describing the problem theoretically. Such models have improved planning of research and field experiments for control. For example, vector models were used to plan two sterile male release experiments with *Anopheles albimanus* in El Salvador and then to analyze the results of these programs. Theoretical models have been used to study the potential of biological control agents, genetic mechanisms, and attractants as well as the use of insecticide treatments.

There is a need to improve the existing models and simulation techniques and to verify their validity in conjunction with ongoing or new field trials. Such needs include: (a) the development of additional quantitative data on the biological and population parameters which control population dynamics; and

(b) the inclusion of environmental factors (e.g., rain, temperature, humidity, and water level) which also affect population dynamics. There is also a need to develop field methods for measuring the various population parameters to be used in these models. For example, simpler methods of estimating total or absolute numbers of the different stages of the vector, the survival of the various stages under natural conditions and the development times of the various stages and forms are needed.

9.1.2. Models of Malaria Transmission

Malaria transmission models started with Ross as early as 1911, and have been reviewed by Bruce-Chwatt. The evolution of malaria models may be illustrated through three examples.

Ross' model divides the human population into negatives and positives and allows transfers in both directions; superinfection has no effect (the recovery rate is constant) and there is no immunity; he identified the factors that determine transmission as (a) the vector's density, (b) the rate of contact with man and longevity, (c) the incubation period in the vector, and (d) the number of positives. The first four factors are the components of a contact rate later called vectorial capacity. The best known malaria model is Macdonald's, which is Ross' model with some changes, not all fortunate. He assumes that superinfection delays recovery; his formula for this, which makes multiple infections queue before being disposed of, may have gone beyond his intention. He took into account that not all parasitemias are infective, and defined the important concept of basic reproduction rate, which includes the vectorial capacity plus the duration of infectivity. The Garki model of Dietz et al. has seven human states, and takes into account the acquisiton and the parasitological effects of immunity.

Modelling the interface between human and vector populations involves at least three decisions. The first concerns superinfection in the vector; in some models (Macdonald) it does not increase infectivity, in others (Garki) it does; numerically this is probably unimportant. The second decision concerns man-vector contact; past malaria models have assumed uniform contact. The third decision concerns the effect of infection on the vector; past malaria models have assumed that it has none.

Malaria transmission models and vector population models seem to originate in two ways. Some modellers start with a system of equations and give high priority to mathematical analysis with the purpose of making the assumptions explicit, removing ambiguities and contradictions, and possibly, reaching some general laws (e.g., the existence and definition of critical levels). Other modellers start with a straightforward translation of what is presumably known about the biological aspects of the problem into a computer simulation model, and study the model's behavior. It appears that both approaches have something to contribute.

The usefulness of a model could presumably be measured by three criteria: (a) insights provided into the problem; (b) ability to simulate realistically the epidemiology of malaria, making the model more valid for planning and/or teaching; and (c) actual utilization in planning control programs.

The examples cited above may illustrate these criteria. Ross' model provided three important insights, namely the existence of a threshhold (e.g., a critical vector density) below which malaria could not maintain itself, the tendency of malaria to return to the same level after temporary disturbances, and the nonlinear relationship between the entomological situation (e.g., vector density) and the endemic level (the practical implication for control, namely that the same effective vector control may interrupt transmission in one situation, but have almost no impact in another, was clearly drawn only in 1961 by Moshkovsky). The Garki model of Dietz et al. is reasonably realistic in simulating some important aspects of the epidemiology of malaria (see the working paper by Molineaux and the relevant references). Macdonald's model contributed significantly to the decision to embark on global malaria eradication (some implicit assumptions about the uniformity of the vector's behavior in terms of exposure to residual insecticides, and about the uniformity of human behavior in terms of participation in mass drug administration, may have contributed to generate an exaggerated optimism concerning the possibility of eradication).

9.2. Recommendations

The first of the following recommendations is broad in scope and takes first priority; the other three concern different aspects of computer modelling in vector control and are of equal secondary priority.

(a) Projects are needed to include the use and development of disease-vector models in conjunction with operational control programs. This will provide support for planning and operation of the control programs as well as the opportunity to improve and validate modelling procedures and to collect more adequate data for model input.

(b) Models must be developed to simulate vector population dynamics and the effects of important control measures that are currently in use or that are under investigation.

(c) Continued development is needed to provide malaria transmission models that will realistically simulate (1) drug resistance and the effects of alternative drug policies, (2) natural immunity and administration of potential vaccines, (3) morbidity and mortality rates, and (4) serological data.

(d) New and more precise field methods to measure key vector population parameters must be developed.

Attachment 1

WORKSHOP ON VECTOR CONTROL

SPONSORED BY AID
HOSTED BY USDA, GAINESVILLE, FL

April 13 - 16, 1982

AGENDA

April 13 - Tuesday			
8:30 - 8:45	1.0	Welcome and announcements	D. Weidhaas
8:45 - 9:15	2.0	Introductory remarks and status of mosquito-borne disease control	E. Smith
9:15 - 10:15	3.0	Pesticides - status and needs	
9:15 - 9:35	3.1	Residual spraying	R. Fontaine
9:35 - 9:55	3.2	Larvicides and IGR's	M. Mulla
9:55 -10:15	3.3	Space sprays	R. Tonn
10:15 - 11:00	********** COFFEE **********		
11:00 - 11:20	4.0	Water and weed management and source reduction	J. Shisler
11:20 - 11:40	5.0	Surveillance, attractants and repellents	B. Eldridge
11:40 - 12:00	6.0	Environmental problems	H. Scudder
12:00 - 1:30	********** LUNCH **********		
1:30 - 2:10	7.0	Genetic control and SIT	
1:30 - 1:50	7.1	Genetic mechanisms	R. Baker
1:50 - 2:10	7.2	Sterile insect release	D. Dame
2:10 - 2:50	8.0	Biological control	
2:10 - 2:30	8.1	Parasites, pathogens and predators	H. Chapman
2:30 - 2:50	8.2	*Toxorhynchites*	D. Focks
2:50 - 3:20	********** COFFEE **********		
3:20 - 4:00	9.0	Population dynamics and models	
3:20 - 3:40	9.1	Malaria models from the Garki project	L. Molyneaux
3:40 - 4:00	9.2	Vector models related to malaria control	D. Weidhaas
4:00 - 5:00		GENERAL DISCUSSION	

April 14 - Wednesday

8:30 - 12:00	10.0	World-wide view - regions, operations and international organizations		
8:30 - 8:50	10.1	Africa	-------	W. Kilama
8:50 - 9:10	10.2	Asia	-------	S. Tattaniak
9:10 - 9:30	10.3	Americas	-------	J. Van Severen
9:30 - 10:00	********** COFFEE **********			
10:00 - 10:20	10.4	World Health Organization	-------	C. Pant
10:20 - 10:40	10.5	World Health Organization	-------	I. Ismail
10:40 - 11:00	10.6	World Health Organization	-------	Y. Bang
11:00 - 11:20	10.7	PAHO	-------	R. Tonn
11:20 - 11:40	10.8	ORSTOM	-------	J. Mouchet
12:00 - 1:45	********** LUNCH **********			
1:45 - 3:00		OPEN DISCUSSION		
3:00 - 3:30		COFFEE		
3:30 - 5:30		WORK GROUPS		

April 15 - Thursday

8:30 - 10:30	WORK GROUPS
10:30 - 11:00	COFFEE
11:00 - 1:00	OPEN DISCUSSION
1:00 - 3:00	LUNCH
3:00 - 5:30	WORK GROUPS - FINAL DRAFTS
	BANQUET

April 16 - Friday

8:30 - 9:30	Vouchers for travel expenses
9:30 - 11:00	TOUR OF USDA LABORATORY
11:00 - 12:00	Review Report
12:00 - 1:30	LUNCH - Fish fry - USDA Laboratory
1:30 - 3:30	REVIEW REPORT

Attachment 2

Working Groups

Section	Title	Chairman	Participants
3.1	Residual Sprays	G. Georghiou	Y. Bang, R. Fontaine, C. Pant, W. Kilama, R. Roberts
3.2	Larvicides and IGR's	J. Mulrennan	R. Beaudoin, D. Dame, I. Ismail, M. Mulla, S. Tattaniak, R. Taylor
3.3	Space Sprays	D. Eliason	J. Lamdin, J. Mouchet, R. Tonn, V. Valenzuela, J. Miles
4.0 & 6.0	Water and Weed Management and Source Reduction Environmental Problems	J. Shisler	G. Carmichael, H. Scudder, E. Smith, J. Van Severen
5.0	Surveillance, Attractants, and Repellents	D. Roberts	D. Carlson, B. Eldridge, S. Pinichpongse, J. Reinert, C. Schreck, R. Bram
7.0	Genetic Control and SIT	J. Seawright	R. Baker, L. Hilburn, S. Narang, B. Smittle
8.0	Biological Control	R. Barr	D. Bailey, H. Chapman, D. Focks, G. Gerberg, L. Lacey, M. Meisch, A. Undeen
9.0	Population Dynamics and Models	D. Haile	D. Kline, L. Molineaux, D. Weidhaas, M. Young

ATTACHMENT 3

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ATTACHMENT 4

Working Papers

ADULT MOSQUITO CONTROL BY RESIDUAL SPRAYING

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I. Background

Indoor residual spraying is undoubtedly the most effective single malaria control method ever devised. Also, it can be usefully employed for the control of vectors of such mosquito-borne diseases as filariasis, dengue, yellow fever, and encephalitis. When conditions for its use are favorable, it offers possibilities for achieving a rapid solution to complex malaria problems. However, the solution is usually temporary unless reinforced by other vector control measures involving prevention and control of breeding places. Experience in the malaria eradication program has made it abundantly clear that malaria may resurge to previous and even higher levels of prevalence after the withdrawal of spraying.

A. The concept of residual spraying for malaria control emerged from findings in South Africa and India in the 1930s that daily indoor spraying with pyrethrum greatly reduced the incidence of malaria in rural villages. Although effective, the method was impractical and costly for large scale use because of the need for almost daily spraying. To obtain a cost-effective, practical result, an insecticide was needed with a long-lasting residual effect against indoor resting malaria vectors. The advent of DDT in World War II met the need. It was demonstrated by repeated experiments in the mid-1940s that a single DDT spraying of walls and ceilings at a low dosage rate of 1 and 2 g/m^2 provided complete control of resting *Anopheles* mosquitoes for 3 to 6 months and longer.

B. The rationale of residual spraying for malaria control was based on the observation that malaria vectors tended to invade human habitations in search of blood meals and to rest on walls, ceilings, and other indoor surfaces before and after feeding. Thus, when these mosquito resting places were treated with an effective residual insecticide, resting mosquitoes absorbed a lethal dose and died before taking another blood meal. In addition to relieving mosquito annoyance in sprayed habitations, DDT spraying reduced malaria rates and frequently interrupted malaria transmission when the spraying was systematically and thoroughly executed over a large area. Other prerequisites of successful control included: habitations suitably constructed for residual spraying, a strong preference for indoor resting by local malaria vectors and a consistent pattern of indoor activity and sleeping by the people after sundown.

C. The creation of the world malaria eradication campaign under the auspices of WHO in the late 1950s basically emerged from three events: (1) the disappearance of endemic malaria in the United States, Peurto Rico, and Italy where DDT house spraying was employed extensively in conjunction with other methods (larval control), (2) the disappearance of endemic malaria from several mainland tropical areas after a few seasons of residual spraying, and (3) the appearance of mosquito resistance to DDT in some malaria control programs.

Resistance posed a serious threat because the indefinite continuation of a malaria control strategy by DDT spraying would predictably intensify and

spread until the insecticide was rendered ineffective for malaria control. An eradication program would conceivably avert this possibility since it would be limited in time and planned and coordinated to complete the spraying phase in a four year continuous coverage operation.

D. Although the malaria eradication campaign evolved into one of the greatest public health endeavors of all times, the eradication objective could not be sustained in most developing countries. The eradication objective was, therefore, changed to control in 1975.

Administrative, managerial, and financial difficulties were major obstacles to the eradication effort, but the residual spraying strategy also encountered difficulties in many situations. Significant problems included:

(1) Extradomiciliary transmission due to exophilic and exophagic behavior of many malaria vectors and/or their opportunistic capability of feeding and resting outdoors and indoors. When combined with a traditional pattern of outdoor activity of people after sundown, including outdoor sleeping, residual spraying had little effect.

(2) Mosquito resistance to DDT and other residual insecticides.

(3) Insufficient knowledge of the ecology, habits, and behavior of many malaria vector species as a basis for planning and predicting the need for supplementary and complementary vector control activities.

(4) Reports on spray operations indicated a tendency to overspray and to overextend spraying into non-transmission areas resulting in excessive expenditures. This problem stemmed from the use of case detection as the criteria for spraying without backup entomological data on the occurrence and distribution of vector populations.

(5) Adherence to rigid residual spraying criteria in carrying out spray cycles, spray rounds, dosage rates, house spraying coverage, without proper evaluation of entomological, epidemiological, and socioeconomic factors contributed to excessive cost and misplacement of resources.

II. *Residual Spraying in Malaria Control*

There is still a world-wide attack on malaria, but the recommended strategy has been revised to adoption of an integrated strategy involving a combination of methods: chemical, biological, cultural, and physical operations directed against adult and immature stages.

A. *Planning a residual spray program*

Geographical reconnaisance, training, and other preparatory activities are necessary for proper planning and organization of the spraying and for determining the total technical, manpower, material, and budget requirements of the program.

B. *Insecticides for residual spraying*

Residual type insecticides are contact poisons which kill adult mosquitoes resting on sprayed surfaces. The toxic effect results from absorption through pores and nerve endings. Some insecticides produce a combined contact and fumigant or vapor effect, although the effective lethal period of vapor disappears long before the contact effect. Criteria governing the effectiveness of residual insecticides are as follows:

(1) a high biological activity against the vector mosquito lasting 3 months after application.

(2) producing a high vector mortality after one-half to one hour exposure.

(3) low toxicity to man and animals.

(4) good storage, mixing, and application characteristics.

(5) low application costs.

INSECTICIDES USED IN RESIDUAL SPRAYING

Insecticide	Class	Relative Cost	Hazard	Insecticidal Action	Dosage[a] Rate (g/m^2)	Estimated[a] Effectiveness (months)
DDT	Organochlorine	Low	Slight	Contact	1-2	6-12
Dieldrin[b]	Organochlorine	Low	High	Contact	0.25-0.50	6-12
Lindane	Organochlorine	High	Moderate	Contact & fumigant	0.25-0.50	3-6
Malathion	Organophosphorus	Moderate	Slight	Contact	1-2	2-3
Fenitrothion	Organophosphorus	High	Moderate	Contact & fumigant	1-2	3-6
Propoxur	Carbamate	High	Moderate	Contact & fumigant	1-2	2-3
Landrin	Carbamate	High	Moderate	Contact & fumigant	1-2	2-4
Chlorphoxim	Organophosphorus	High	Moderate	Contact & fumigant	1-2	3-4
Pirimiphos-methyl	Organophosphorus	High	Moderate	Contact & fumigant	1-2	3-4

a Dosage rate and period of estimated effectiveness depends on a number of variables such as vector susceptibiltiy, climatic conditions, type surface, and build-up effect of retreatments. If a build-up effect is confirmed after the second round, the dosage rate may be reduced or the intervals between spray cycles increased.

b Because of the hazard to man and domestic animals, the use of Dieldrin has been banned by most countries. Experience has shown that after a period of use, spray operators develop toxic symptoms even when veils, caps, and gloves were worn in addition to hats and overalls. Dieldrin should not be used for indoor spraying without full justification and unless strict precautionary measures and medical supervision are ensured.

C. *Spray application*

Although residual insecticides may be applied by a variety of spraying equipment, the hand operated, 3 gallon capacity, compression sprayer continues to be the most effective and commonly used method. The five factors governing the application of a uniform dosage rate are:

--the insecticide concentration or percentage of insecticides in the liquid;

--the air pressure in the sprayer;

--the nozzle tip aperture size;

--the distance from the nozzle tip to the surface being sprayed;

--the speed of application over the surface.

The ultra-low volume (ULV) cold fogger machine may have promise for indoor residual treatments offering the advantage of rapid coverage and the standard compression sprayer. However, the heavy rebound of spray droplets from ceilings and walls may limit the use of ULV for this purpose.

A malaria control program offers opportunities for a much more flexible approach to residual spraying than was allowed under the rigid spraying protocols governing malaria eradication. For example, spray coverage, dosage rates, spray cycles, spray rounds could be adjusted to fit the epidemiological condition governing malaria transmission rather than pursuing a standard pattern of spraying without regard for entomological and epidemiological factors. Using a flexible approach would provide opportunities for realizing economies in material, labor, and transport without loss of effective control. A few examples of such opportunities would include:

(1) *Spray coverage*, the concept of laying a protective barrier of sprayed houses around the perimeter of a village or town to intercept the influx of malaria vectors from outlying rural areas. There is evidence to show that the peripheral treatment would obviate the need for spraying the inner area of the town or village. Treatment of buildings or rooms not used as sleeping places such as kitchens, grain stores, unoccupied houses, shops, schools, churches, and auditoriums, could be omitted from spraying coverage.

(2) *Focal coverage*. Malaria tends to assume a focal distribution associated with the distribution of vector mosquito breeding. Identification and delimination of these areas for spraying coverage could conceivably reduce the spraying workload.

(3) *Selective spraying* implies spraying parts of walls, ceilings, and mosquito resting places rather than treating the entire house according to traditional eradication procedures. There is entomological evidence that partial spraying is effective.

(4) *Dosage rates* could be adjusted to the variables of transmission. Areas of short seasonal transmission could receive a lower dosage rate than areas of long seasonal activity. After the initial

spray round, subsequent rounds could be sprayed at a lower dosage rate taking advantage of the build-up effect.

D. *Safety precautions*

The insecticides recommended for residual spraying are very toxic to mosquitoes and many other insects but need not be hazardous to man if precautions are taken. However, human toxicity is almost certain to arise if small amounts of the material are accidentally taken orally or if skin surfaces are contaminated for several hours. Therefore, special care must be taken to protect spray personnel and the public from possible ill-effects due to unnecessary exposure or accidental ingestion.

E. *Health education*

Experience has shown that residual spraying cannot be forced upon the public. People need to be convinced that spraying will give protection from vector diseases and mosquito annoyance. The education should aim to develop an attitude of cooperation and collaboration of the people with the residual spraying effort.

F. *Mosquito resistance*

Procedures for avoiding the development of mosquito resistance to the residual insecticide should be included in the operational plan.

III. *Entomological Assessment of Residual Spraying*

Residual spraying is an insect control operation and should be planned with the objective of achieving maximum control of the target insect (the malaria mosquito or other disease vector) for the longest possible period with the least expenditure of effort and cost. The most effective and economical programmes are those planned and evaluated on the basis of sound entomological data on the ecology, behavior, habits, host preferences, mosquito susceptibility to the insecticide under varying conditions, and environmental stresses. These are the mosquito factors that govern decisions on proper selection of the insecticides, spray cycles, rounds, spray coverage, and dosage rates. Assumptions and generalizations on mosquito bheavior can lead to inefficient and wasteful operations.

In the pre-spraying phase of residual spraying, the entomological data provides a basis for decisions on the selection of the insecticide, the dosage rate, the spray cycles, spray rounds, and the geographical boundaries of spraying.

After the first and subsequent spray rounds, entomology asesses the (1) impact of the spraying on the vector population; (2) the duration of insecticidal effect; (3) the need for alteration in the spray cycles and rounds; (4) the need to change the dosage rate; (5) the need to change insecticides because of incipient resistance or other problems; (6) changes in mosquito behavior induced by insecticidal exposure; (7) non-target control effects on other household insects such as bedbugs, roaches, fleas, and flies; and (8) harmful effects on beneficial insects (honey bees, silkworms).

In summary, the systematic collection and interpretation of entomological data will not only provide an ongoing evaluation of the progress of control but can lead to improvements and economies in the program. As the operation progresses, the assessment may show that lower dosage rates, fewer cycles, or fewer houses need spraying. to achieve the vector control objective. With many insecticides, spray residues may build up sufficiently after several cycles to allow an increase in the interval between cycles or a decrease in the dosage rate. As insecticides, labor and transport are costly items, economies realized could be substantial and usefully employed for extension of the vector disease control effort.

IV. Suggestions for Research

1. If not already available an updated annotated bibliography dealing with the biology, ecology, and ethology of all mosquito vectors of malaria and other diseases vunerable to control by residual spray should be compiled. The bibliography would not only provide an essential reference for planning residual spray programs but would also reveal voids in the knowledge of mosquito vector biology for future study.

2. Examine the efficacy of partial indoor coverage of residual sprays (alternating sprayed and unsprayed swaths on inside walls, spraying lower half of walls, and similar treatment combinations) compared with complete treatment.

3. Investigate and recommend methods of avoiding mosquito resistance to insecticides in residual spray programs, i.e. joint, rotational and sequential use of insecticides, selecting an insecticide not used extensively for local agricultural pest control, not using the same insecticide for both larval and adult control and other procedures.

4. Investigate the feasibility of training and utilizing local village people to perform house spraying operations under supervision instead of relying exclusively on spray operators employed by the organization.

5. Assess the potential for ULV residual spraying application.

6. Investigate the efficacy of house spraying around the periphery of villages and towns surrounded by mosquito sources and malaria transmission as a protective barrier against the influx of malaria infective mosquitoes into the unsprayed central area.

7. Investigate an appropriate role for residual spraying in the development of an integrated malaria control plan.

LARVICIDES AND THEIR FORMULATIONS IN VECTOR CONTROL PROGRAMS

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Larvicides and larvicidal formulations play an important role in the control and eradication of vector-borne diseases. Larvicides constitute those chemical control agents which primarily induce mortality in the larval stages of disease vectors, but could also have biological activity against the pupal stage. Some of the larvicidal compounds possess delayed action properties, inducing mortality and aberrations in the adult stage resulting from treated larvae or pupae. The ensuing write-up deals with larvicides that have potential for being used in area-wide control programs of mosquitoes.

It should be pointed out that best results in terms of vector control programs are obtained when mosquito larvicides are employed in conjunction with other control strategies. Source reduction and habitat management should precede the use of larvicides in area-wide mosquito control programs. Similarly, biological control measures should be exploited whenever possible and supplemented with larvicidal applications if and when necessary. Larvicidal measures are suitable and deemed to yield satisfactory results under some of the following conditions:

1) The seasonal dynamics of mosquito vectors are limited to only a few months of the year.
2) Breeding sources are confined and easily accessible for treatment, such as those in urban areas and arid zones.

3) Larvicidal measures are relied upon in areas where residual sprays are not acceptable for aesthetic reasons in affluent segments of townships.

4) Exophagy and exophily of the vectors where residual house sprays are not effective, require larvicidal measures.

5) To supplement the manipulation of larvivorous fish until the predators build to sufficient levels to effect adequate control of larvae.

Current Status:

At the present time, larvicides and larvicidal formulations are experiencing greater use in mosquito control programs. Diverse groups of compounds are available which manifest high level of larvicidal activity. Some of the major groups of compounds with proven larvicidal activity are as follows:

1) Petroleum hydrocarbon larvicides, which include a variety of parafinic, isoparafinic and aromatic hydrocarbons. Most of the larvicidal petroleum oil larvicides contain small amounts of cationic or nonionic surface active agents which materially increase spreading properties and biological activity of the hydrocarbon fractions.

2) Organophosphate insecticides. This group contains some of the most effective larvicides currently employed. These compounds now have been used for more than three decades in mosquito control programs.

3) Organocarbamate insecticides. This group of insecticides in general is not too effective against mosquito larvae. Nevertheless, these are some compounds which show high activity against mosquito larvae.

4) Synthetic pyrethroids. Recently, a moderate number of photostable pyrethroids have become available for experimentation against insects. Most of these compounds have very high level of activity against mosquito larvae.

5) Insect growth regulators. Diverse groups of compounds have been recently studied and found to have high level of activity against mosquitoes. One of the juvenile hormone type of compounds (methoprene) is currently used in area-wide control of mosquitoes. Compounds in the urea-type IGRs are also highly effective against mosquitoes. There are also some IGRs in the carbamate, triazine and other groups of compounds which show good activity against mosquitoes.

6) Microbial insecticides. Recently, two microbial insecticides have been found to show promise for the control of mosquito larvae. *Bacillus thuringiensis* Ser. H-14 formulations have already been cleared for use in mosquito control programs. *B. sphaericus* and other microbial strains are currently being investigated for possible use in mosquito control programs.

7) Monolayer organic films. In addition to petroleum oil larvicides which form films on water surface, there are a number of synthetic surface active agents which form monolayer films on water surface. Among these compounds, aliphatic amine and polyoxyethylene stearyl alcohol have been shown to result in good control of mosquito larvae and pupae.

These compounds producing monolayer films on water surface offer additional tools for mosquito control in situations where mosquitoes have acquired resistance to other groups of larvicides.

Future Research Needs:

From the foregoing it is quite clear that chemical larvicides offer a wide range of options for the control of mosquito vectors in the immature stages. To develop larvicides and larvicidal formulations in global vector control programs, systematic research on the evaluation and development of mosquito larvicides should be implemented as follows:

1) All promising larvicides should be screened and evaluated against larvae and pupae of major malaria vectors. Specific testing techniques for assessing quick-acting and slow-acting compounds and other novel modes of action should be developed under laboratory conditions.

2) Research on the development of suitable and effective formulations should be initiated. The efficacy of different types of formulations such as granules, slow-release, WP, EC, microencapsulated, and other formulations should be evaluated in the laboratory.

3) Promising larvicides and their formulations should be extensively evaluated under simulated field conditions and further evaluated in small-scale field trials, to assess the efficacy and suitability of formulations.

4) Finally, those larvicides and formulations which show promise in small-scale field trials should be subjected to large-scale field operational trials under a variety of conditions using a variety of application techniques. It is at this stage that the practicability of larvicidal treatments in a given region should be determined.

5) Impact on nontarget organisms and wildlife should be studied under laboratory and field conditions. Since larvicides and

larvicidal formulations are to be applied repeatedly to aquatic habitats, it is essential that adequate information on the impact of these larvicides is obtained during the course of their evaluation for vector control.

6) Another important area of research that needs impetus is the relationship between plants and their natural products to the development and survival of mosquitoes. There are many aquatic plants and plant products (both planktonic and macrophytes) which induce high mortality in the immature stages of mosquitoes. Research is needed to identify such plants and plant products and to develop ways in which such options can be exploited in vector control programs.

It should be pointed out again that larvicidal techniques as other control measures will produce best results when supplemented by other vector control measures. No single strategy will yield the desired results in an area-wide and sustained vector control program. Combination of larvicides, source reduction and encouragement of biological control agents will likely produce promising results.

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SPACE SPRAYING IN CONTROL OF MALARIA VECTORS AND MOSQUITO VECTORS OF ARBOVIRAL DISEASES: SUMMARY REPORT

Space spraying for vector control includes three general types of application equipment:

1. Thermal foggers (portable or vehicle mounted)
2. Mist blowers (portable, vehicle mounted, or aircraft)
3. Aerosol (ULV) equipment (portable, vehicle mounted or aircraft)

Although used primarily for emergency control in arboviral epidemics, space spraying is increasingly being used in mosquito and pest insect abatement. In *Aedes aegypti* eradication/control operations, it has largely replaced indoor residual spraying.

All three types of equipment have been used in Asia against the vectors of dengue - dengue haemorrhagic fever. Early experiments done by WHO and SEARO in Thailand demonstrated the value of the equipment, and later investigations in Malaysia, Indonesia, Korea (Japanese B. Encephalitis), Ethiopia, Tanzania, Nigeria, and the Americas confirmed that space spraying is a worthwhile tool against arboviral vectors. Needless to say the efficacy of the different equipment varied.

Thermal fogging has been used against *Anopheles aconitus* in Central Java and both, thermal fogging and ULV, have been used against peri-urban malaria vectors in countries such as India. Thermal fogging is routinely used around houses with malaria cases in parts of Venezuela, while mist blowers

have been used experimentally in eastern Nigeria and Guyana against some Anopheles species. Some residual action was noted with the mist blowers. Residual action had been also observed against Aedes aegypti in various Asian studies and larval mortalities were noted in forest populations of Aedes aegypti following aerial ULV applications in Tanzania.

Since the dengue 1 epidemic in the Americas which began in 1977, there has been an increasing demand for space spraying in many countries. Some operations have been effective while others have been limited to inefficient use of equipment, especially portable. Since 1977, training courses have been given to increase the efficacy of applications.

The World Health Organization has suggested using space spray for emergency control where there is a necessity of rapid adult control, when the vector is exophilic and/or exophagic and where indoor residual spraying is not practical as well as in urban situations, where the economics are against residual control or in situations where malaria and other vectors have widely distributed immature populations.

Two other uses have been suggested. 1. In routine Aedes aegypti eradication programs in the Americas as a supplement to larviciding. 2. In malaria programs where the human population is migratory and residual spray operations are too slow to permit adequate coverage.

Each of the three types of equipment has drawbacks and limitations. Field staff in general have listed the following as difficulties.

1. The cost of equipment, insecticides and maintenance curtails use in many developing countries. Vehicle mounted equipment may cause shortages of vehicles in other essential areas. (There are solutions to this problem).

2. Lack of trained staff to operate and maintain the equipment. Frequently repairable equipment end in junk piles or engineers-technicians must be brought to the country as consultants at great expense.
3. Lack of adequate supervision and planning of operations produce incomplete coverage or cycles too extended to be effective. Supervision might improve operation performance, safety and reduce expenses.
4. Public relations appears to be a problem in some countries where public cooperation in opening doors and windows during treatments has been poor or where environmentalists are active.
5. Frequently there is insufficient information about the vector to assess the impact of the operation. In case of emergencies, few evaluations are done and even in experimental work, there is a lack of standard comparable evaluations. Lastly, control operations are usually planned in a way that any one operation factor can not be evaluated.
6. Difficulties pertaining to equipment are:
   a) obtaining target dosages and uniform coverage;
   b) nozzle wear and design;
   c) compensation for climatic conditions;
   d) uniform and critical droplet size and machine output variations;
   e) lack of instruction and parts manuals in native language;
   f) availability of space parts and local mechanics;
   g) equipment is too expensive and sophisticated;

h) weight, size, noise, carbonization of engine.

i) insecticide contamination of non target areas.

j) standard oil/gasoline mixtures, especially in portable aerosol applicators.

k) lack of commercial ULV aerial equipment for large aircraft.

A number of suggestions for research have been made which are worth considering:

1. Studying the impact of space spraying as the only application method on different vector species. (This suggestion may require development or refinement of some evaluations techniques.)
2. Evaluation of indoor space spraying by itself as compared to including patio spraying or possible application from the streets. (This would involve development of improved scheduling of applications and would be confined to Aedes aegypti.)
3. Defining the advantages and disadvantages of equipment types under various climatic, environmental and housing conditions.
4. Several investigators have pointed out that the residual action of ULV is an indication of overtreatment. Consequently, dosages should be defined, the ULV solutions vs concentrations situation resolved and economic merits of all methodology determined.
5. Droplet size is still a confusing topic. Research is needed to determine optimal droplet size to obtain ideal mortality of different vectors and to develop better nozzles to insure uniform size as well as to simplify methods of determining MMD and VMD in the field.
6. Defining the impact of space spraying on environment.
7. Determining the role of space spraying in public health in producing

insecticide resistance in target vectors.

8. For *Aedes aegypti* control, a need exists to improve insecticide distribution into target areas, e.g. angle of nozzle, climatic conditions, operation planning.

9. Development of improved equipment, especially portable ULV and mist blowers to reduce:

   a) engine carbonization

   b) noise

   c) heat

   d) weight

   e) wear on nozzles, breakage of plastic tubing, and switch leakage

   f) safety (toxicological)

   g) clumsiness in operation

Acknowledge

Information for the above report was obtained through a questionnaire distributed to WHO and PAHO personnel with field experience in space spray application.

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WATER AND WEED MANAGEMENT AND SOURCE REDUCTION

Introduction

Water and weed management and source reduction measures for mosquito control can be classified generally into two broad categories: (1) environmental modification and (2) environmental manipulation. Environmental modification consists of measures involving permanent or long lasting physical changes aimed at preventing, eliminating or reducing habitats of target species. This category includes drainage, filling, land leveling, controlled flooding or dewatering, and transformation of reservoir margins. Although these measures are of a permanent nature, proper operation and adequate maintenance are essential for their proper functioning. Regulation of water levels in reservoirs, stream flushing, water salinity changes, vegetation removal or control, shading and exposure to sunlight are examples of environmental manipulation measures.

The two categories of control measures are not mutually exclusive. For example, the effectiveness of water level regulation for reservoir mosquito control depends in large measure upon conditions in the reservoir margins particularly with regard to proper drainage and types of vegetation present. Further, to serve their intended purpose, shoreline transformations require controlled water level operating regimes.

For purposes of this statement, the introduction of chemical or biologicalagents into the habitat for mosquito or vegetation control are not considered to be source reduction measures, although strictly speaking they might well be.

Current Status

The principles underlying the varioue types of source reduction measures are well established and are based upon consideration of water/vegetation interrelationships as well as direct effects upon mosquito production. Also there is a vast amount of documented experience as to their overall effectiveness. The techniques and methodologies involved are adaptable to a wide range of diverse situations associated with the production of the various malaria vectors and other mosquitos. The various types of control measures may be utilized singly or in combination to deal with mosquito production from natural and man-made habitats and for planning and incorporation of mosquito control features in water resource and land development projects.

Drainage, filling and other source reduction measures, supplemented by oil or Paris green based larviciding were the principal methods employed for malaria control until the late 1940s when residual pesticides became available. Since that time, for malaria control reliance has been placed almost entirely on chemical insecticides. AT present source reduction measures are not widely used in malaria control programs.

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Chemical methods generally are preferred for malaria control and other vector control operations as well because, comparatively, they are relatively simple to apply and, at least for the short term, are less costly. However, vector resistance to chemical insecticides has developed, insecticide costs have increased greatly and there is increasing public objection to applications of insecticides in the ambient environment. Because of these developments, interest has been renewed within the past few years in the use of source control measures in mosquito control programs, including malaria control programs. This renewed interest is projected to reduce reliance upon chemical control measures and to lead to integration of source control as a primary and essential part of mosquito control and vector disease control programs. This is expected to result in the development of control strategies for given situations that are more effective, longer lasting, safer to man and the environment, and in the long term more economical.

While man-made mosquito problems frequently are given prominent attention, it must be recognized also that activities such as drainage and land reclamation for agricultural purposes, filling associated with land development schemes, and community sanitation and drainage can make substantial contribution to mosquito control when they are properly designed and executed. Likewise mosquito habitats are eliminated where they are subjected to permanent deep flooding by dam and reservoir construction.

Research Needs

In a field as broad and complex as vector control considered on a worldwide basis there are doubtless many limitations of presently applicable knowledge that provide much room for needed research. However, basic information on the ecology of the principal target species and related habitats is adequate in most situations for problem definition. The principal need is for research to adapt existing control technologies and to develop new ones to solve problems encountered frequently in instituting and maintaining control programs. This is in addition to the need for applied research in most operations programs to improve effectiveness, reduce costs, or both. The specific suggested areas of research which follow are concerned principally with mosquito control.

Mitigation of Environmental Impacts - Natural wetlands are subject to undesirable effects from source reduction measures for mosquito control. Drainage and filling projects eliminate aquatic habitats for other organisms in addition to mosquitos. Further, any manipulation of water in a wetland for mosquito control or otherwise is certain to have an ecological impact. Some progress has been made toward development of techniques to mitigate these impacts for tideland and stream channelization projects, but continued research is needed to develop practical alternatives to drainage and filling of natural wetlands for mosquito control. In consideration of environmental impacts the trend in source control measures is to minimize the impacts by manipulating water and modifying habitats as little as possible without jeopardizing the achievement of mosquito control goals.

Aquatic Vegetation Control - Aquatic weeds are major contributors to mosquito control problems and control of fresh water snails involved in transmission of bilharzia. In addition, they interfere with many uses of water resources. They can interfere with navigation, fishing, water supply and recreational activties. In irrigation schemes, they can significantly increase water loss, block pump inlets and other irrigation channels. In some situations turbine inlets to hydro-electric plants have been blocked.

Approaches to aquatic plant control fall generally into four categories: (1) herbicides, (2) biological methods that use living organisms to attack the weeds, (3) manipulation of the natural environment to harm them or displace them with less objectionable species, and (4) physical methods that shred the weeds or harvest them from the waterways. In general, the various types of control methods can complement each other and should not be considered competitive. Also, control methods must take into account the beneficial purposes of plants which are vital to a healthy aquatic environment.

Research to activate these various approaches to plant control has been conducted by mosquito control and other interests and is continuing. Only chemical control and physical control methods have provided practical means for large scale weed control efforts. However, both are expensive and results are temporary and only moderately effective. Further, the herbicides used are non-specific and are subject to the usual array of restraints that must be exercised whenever toxic chemicals are introduced into the aquatic environment.

For mosquito control and other purposes, there is need for continuation and expansion of research in aquatic weed control to reduce costs and increase effectiveness of chemical and physical methods and to accelerate field testing of various biological methods and environmental manipulation that have and are currently under study and investigation. Of special interest to mosquito control are methods directed to control of floating mat and deep rooted emergent types of plants which generally are not amenable to control by water level management or habitat modification.

Reservoir Projects - No two dam and reservoir projects are exactly alike. For a specific project the potential mosquito problem is determined by the climate of the region in which the project is located, the size and topography of the reservoir basin, the condition of the area to be flooded with regard to drainage and vegetation, and the expected water level schedules to be followed to meet project requirements.

Water level management and other measures that have been developed for control of mosquitos associated with reservoirs are based almost solely on experience with reservoirs in the temperate zone of North America. Hundreds of reservoirs have been constructed and operated without consideration of or provisions for mosquito control. A recent review of dam construction throughout the world revealed that 14 massive man-made lakes exceeding 1.5 million acre-feet have been impounded in tropical countries, many of which are in endemic areas of malaria and/or schistosomiasis. Many other such projects are planned or are under construction.

Experience has demonstrated that climate is an important governing factor in defining anopheline production potential and the associated malaria transmission problem. There has been considerable speculation on the matter but no definitive studies of the extent to which temperate zone reservoir mosquito control experience may be transferable to or adapted for application to reservoirs in tropical regions. Accordingly, it is proposed that comprehensive case studies be made of several selected large reservoirs in tropical regions to determine the feasibility of mosquito control and to identify conditions under which a reservoir mosquito control program would be warranted. The studies should include projections for long term uses of the reservoir and development of adjacent shorelands.

Irrigation Schemes - Man-made rather than natural habitats are usually responsible for excessive mosquito populations associated with irrigation systems. The sources of these mosquitos are most often caused by faulty irrigation, drainage and management practices. They are often associated with both engineering and agricultural practices and thus are amenable to correction or prevention through proper planning, design and operating practices. Irrigation systems and practices designed to attain maximum application efficiency and to minimize water losses or wastage also tend to prevent or control the creation of habitats favorable for the propagation of mosquitos.

Large scale demonstration projects are needed to evaluate the economics and mutual benefits to agricultural production and mosquito control of irrigation system design and operation to attain maximum application efficiency and minimum water losses and wastage. The effects on mosquito production of alternative ways of meeting irrigation requirements also could be investigated.

Tidal Lagoons - Tidal lagoons in South Java and similar lagoons in other tropical regions present an important malaria mosquito problem for which environmental management measures may be the most practical means for control. The lagoons are characterized by heavy inflow of fresh water during the rainy season. During the dry season inflow of fresh water is limited and the outflow to the ocean and tidal fluctuations are restricted due to a buildup of sand deposits or "sills" at the outlet to the ocean from the lagoon. The production of the malaria vector occurs in the dry season and is apparently associated with changes in salinity of water in the lagoon. Other factors possibly involved are seasonal changes in tidal fluctuations, internal drainage, water temperatures, and lagoon ecology. Salinity control as an environmental management technique does not appear to be practical because of the major engineering works that likely would be required to handle the high fresh water inflows during the rainy season and provide the desired level of salinity control during the transition period from rainy to dry season conditions.

A research and demonstration project should be undertaken to develop practical means for dealing with this problem. The project should include (1) comprehensive field studies of one or more lagoons to define the problem and to identify possible methods for control, (2) selection of a method or methods of control for demonstration, (3) engineering design and cost studies of method or methods selected, (4) final design and installation of required structures or other works, and (5) evaluation of effectiveness.

WORKING PAPER

Current Status of Surveillance, Attractants, and Repellents in Vector Control

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The three areas which comprise this review are all areas in which research and development efforts have been moderate in recent years, and in which there have been few significant breakthroughs. There is considerable raw material for significant progress in the form of developments in fields other than vector control, but comprehensive research efforts will be needed to adapt these developments to vector control applications.

Surveillance

Surveillance methodology available before 1976 for mosquitos has been critically reviewed by Service in his comprehensive book on field sampling methods. In addition to covering all traditional methods such as adult trapping and larval dipping, he thoroughly discusses mark-release-recapture techniques and life table analyses.

Research on mark-release-recapture techniques has continued since the appearance of Service's book, and a considerable body of information has accumulated on methods of marking and on analysis and interpretation of results. Some excellent studies have recently been described which involve the use of mark-release-recapture techniques for estimation of anopheline populations.

For collections of aquatic stages of arthropod vectors, the trend has been toward area samplers such as the Enfield sampler in place of traditional dipping. Mark-release-recapture methods have also been used in this context.

Research continues on refinement of traditional trapping techniques, and better traps of all types continue to appear. A vastly improved miniature light trap for small flying Diptera has been developed, and should be available commerically soon.

Several trends seem evident in the research mentioned above. Greater awareness by entomologists of advanced statistical procedures is one, as well as the availability of better statistical procedures. The recent explosion of microcomputer technology, and the availability of inexpensive hardware and software, will push the use of improved sampling techniques and data analysis even further. However, few programs are presently available which are specifically tailored to analysis of vector surveillance data.

The availability of remote sensing data and photographs is a recent development. There have been a limited number of attempts to adapt remote sensing techniques to vector surveillance, but these attempts have only scratched the surface. This is an area that would seem to have enormous potential for vector surveillance, especially if the areas of remote sensing imagery, computer analysis, and descriptive phytoecology can be combined.

Even fewer attempts have been made to utilize radar for vector surveillance. Research on aerobiology was stimulated by the International Biological Program (IBP) and this brought together, among others, biologists and atmospheric scientists with their methodologies. One of the offshoots of this was the use of radar to track airborne insects, but this has not been exploited to any degree by vector biologists.

Considerable improvement in surveillance techniques has resulted from parallel studies on reproductive biology of disease vectors. Much remains to be done in this area, however. Surveillance techniques involving tests for parity are difficult to interpret without a detailed understanding of the vector's biology. This understanding is also necessary to the interpretation of results of techniques such as CO_2 trapping, which samples only a segment of the vector population.

The potential exists, then, for further improvement of surveillance hardware, better sampling designs, improved and easier data collection and analysis using computers. Remote sensing techniques, including perhaps even radar, will be part of the future. All this should make practical mathematical vector-disease-host models commmon and useful.

Attractants

Little research has been done on attractants for control or surveillance of arthropod vectors, with most of the research being limited to three areas: 1) attractants for use as baits in conjunction with pesticides for control of house flies; 2) attractants as baits for trapping or killing wasps and other stinging Hymenoptera, and 3) oviposition attractants to trap mosquitoes. Although attractants are the object of intensive research for the purpose of surveillance and control of agricultural pests, research on attractants for vectors of human and animal disease is, in comparison, at a very low level. Some research has been conducted on household pests and on stored product pests. Cockroach pheromones were discovered almost 30 years ago, but have never seen general use for control or surveillance. A 1981 book: Semiochemicals, Their Role in Pest Control, does not even mention arthropod vectors of human or animal disease. Sonenshine and his colleagues are doing some research on tick pheromones, but there are few other examples. The level of activity is so high in the area of semiochecmicals that it seems inevitable that disease vectors will be included in such studies.

Repellents

Research and development activities have been much more active in the repellent area than in the attractant area. Several laboratories have been conducting research on various aspects of repellent development. Although there have been no developments of earthshaking magnitude, there has been measurable progress in several areas. Testing methodology has improved both in the laboratory and in the field. Part of this improvement is based on the same factors which have caused improvement in surveillance methodology (see above). Another factor has been the attempt by several laboratories to equate their results with those of other laboratories. A critical analysis of testing methodology was recently made by Schreck in the Annual Review of Entomology.

The testing of new chemical compounds for mosquito repellency has continued in several laboratories although the number of new compounds available for testing has been reduced in recent years. Although no compounds haveemerged which are likely to replace the diethyl toluamide formulations which have now been with us for more than 30 years, chemists feel that they have gained some ground in understanding the relationship between structure and activity. Given the present poor state of our understanding of insect physiology, especially the physiology of host attraction in haematophagous insects, it is doubtful that our knowledge of structure-activity relationships is very deep. The physiology of blood avidity in insects continues to be a gaping hole in repellent research. The demonstration that blood avidity in Culex pipiens is under juvenile hormone (JH) control is one recent advance, but much more needs to be learned. Electrophysiological studies on mosquito antennae and other structures have been largely emperical, and few attempts have been made to relate them to mosquito behavior. Morphological studies have been done on various sensilla of several mosquito species which will be useful eventually to our total understanding of attraction physiology. We are far from being able to tell a complete story for any vector species, however.

Although the search for new repellent compounds has not been an unqualified success, the use of existing repellents in new ways has yielded promising results. The use of repellent-treated netting in tent barriers and jackets has been shown to have considerable practical value. The concept of area repellents rather than topically-applied skin repellents has recieved considerable attention recently. Naphthelene, essential oils, pyrethroids, and deet have all shown promise in this context.

Efforts have continued on improved formulations of existing repellents to improve duration of effectiveness, resistance to wash-off and other characteristics. Few of these improvements have reached the point of practical use.

It would seem that practical improvements in repellent use will continue to be forthcoming. Spectacular breakthrough in repellent development will probably only follow spectacular breakthroughs in our understanding of haematopagous vector physiology, however.

Recommendations

1. Further research on application of microcomputer technology to surveillance data collection, storage, and analysis.

2. Further research on mathematical models of vector/pathogen/host systems using improved surveillance data systems.

3. Further research on the use of various remote sensing techniques such as radar, LANDSAT Satellite imagery, and conventional aerial photography for vector habitat surveillance.

4. Continued research on improved conventional surveillance tecniques and hardware.

5. Continued research on vector biology, and the application of new knowledge to design and interpreation of surveillance techniques.

6. Expanded research on semiochemicals of arthropod disease vectors.

7. Continued research on conventional chemical attractants.

8. Expanded research on physiology of avidity in haematophagous arthropods.

9. Continued screening of chemicals for insect repellency.

10. Continued research on new methods of use of existing insect repellent materials.

A New Approach to Environmental Problems in Vector Control

- Harvey I. Scudder, Ph. D.[1]

Environmental problems, regardless of their nature and specifics, must first be addressed with the following concepts in mind, if one is to deal with them equitably in the long run:

1. Recognition that the environment is vulnerable to our actions, even to our presence, has only recently developed in the overall conscience of mankind. This has led to a proliferation of controls over all kinds of environmental interventions, including vector control, often with unfortunate results, characterized by stop-gap measures and often a failure to understand the dynamics of a given ecology.

   What is really needed is management knowledge and the ability to apply it, so that we can become truly the husbandmen of our environment. Agriculture, as an example, owes its successes to comparable advances which moved it from a culture of hunter-gatherers to husbandmen with management expertise and skills.

2. Research must be done to provide this management expertise, so we may have the concepts, the data, and the abilities to manage the dynamics of the environments we invade, in order to insure desirable and stable systems in which, for example, vector-borne disease is not a factor. We need a new discipline of applied ecology, which can become a part of all planning, operations, and maintenance, and be economically justifiable on a cost/risk/benefit basis in the long run. Within this new body of knowledge, we can then control a given disease vector, and at the same time, know <u>what else we are doing</u> ! In the less complex realm of agriculture, integrated pest management (IPM) seeks to and seems capable of achieving these ends.

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1. Scientist Director (Retired), U. S. Public Health Service; and Professor of Microbiology, Emeritus, California State University, Hayward, in Hayward, CA.

Abstract of presentation to the AID's "Comprehensive Vector Control Workshop", to be held in Gainesville, FL, April 13-16, 1982.

3. Costs of control within a context of environmental management must be rigorously and carefully studied, in order that they may be clearly identified and quantitated; only then may they be justified in contrast to our usual short term, often drastic interventions with their long term implications for which costs must also be identified and computed. We must also identify and compute the probable costs of the unstable environmental systems we create by our short term solutions, out of which may arise the potential for surprise responses to our intrusions.

4. There must be public acceptance of the most economic level of control, even though this may mean some disease, some discomfort, some nuisance. Beyond such a point, some prophylactic measures of control may be economically feasible, or may need to be individually elected and carried out. We must thereby limit the economic burden to society at large.

5. Education of the general public to a point of understanding environmental responsibility must be achieved, in order that non-technical persons will not only be able and willing to support environmental decisions, but will help in their management. This education must be begun at the earliest elementary level, and continue throughout all higher education as a civic responsibility. Again, the parallel with health education is applicable, since this is really one's health ecology.

6. Effective restraints must be agreed upon in order to limit the progressive elimination of species and habitats, locally to internationally. Because of man's needs for food and living space, these must be tempered until population growth can be brought under control or substitute technologies can alleviate aspects of the problem.

7. Political problems which make the solutions to environmental management so difficult must be urgently studied. Part of this aspect would be greatly aided by environmental education, but part requires more attention to the economics of long term solutions, instead of the crisis vis-a-vis heroic effort.

How does one secure support for a preventive measure or program, which would avoid the crisis: or , support for a maintenance phase, when the problem has little or no visibility ?

With these foregoing concepts on a working basis, an internal document has been produced for the Agency for International Development, entitled:

"Decision Support Manual & Guidebook for Malaria Control Programs"

The Manual has been built around a decision support system of flow-charted algorithms, backed up by a four-part Guidebook of the literature considered essential to making the decisions set forth in the algorithms. Together the Manual & Guidebook make up a Programmatic Environmental Assessment of Malaria Programs. Testing of this new approach under field conditions and in training programs by AID is in the planning stages. Computer adaptation of the decision support system is envisioned, and ultimately, a telecommunications network to furnish the technical support and continuing update which the program should require.

This new approach to vector control with a built-in environmental assessment and monitoring system should have applicability to other environmental programs. Also it should provide a basis for simulation modelling.

HIS/a
10 Mar 82

Excerpt from: Scudder, Harvey I.; and Roberts, Fred C. 1981. Malaria Control Manual. Environmental & Health Sciences Associates, Dublin, CA.

SECTION 1.3 ECOLOGICAL PARAMETERS

If we are to manage our environment successfully, we must know in advance what impacts our actions may have, and be able to make appropriate decisions on cost/risk/benefit basis. We must know the nature of these impacts in sufficient detail; where, how, and why they would occur; and have both the information and time sufficient for both the analyses and the making of rational choices.

Finally we must monitor the environment in relation to our decisions carefully and in depth in all the essential aspects, to both verify the validity of our projections and decisions and to safeguard against unforeseen consequences.

The immediate question is, obviously, what do we measure? What are these essential parameters which would tell us what we need to know, in order to make an environmental assessment and follow it up with a reasonable monitoring program? Even if we do all of this, how can we be sure that those who follow us in our structure will continue to acknowledge the responsibility and carry out the commitment?

"There is no simple set of ecology parameters for an EA. Similarly, there is no simple way of using ecology parameters to determine all which one needs to know about the ecological impacts of a control project.

Consistent with the need to consider ecological impacts at several levels, three principal components of ecology have been selected for the EA: species and populations, habitats and communities, and ecosystems. Within these components, parameters have been selected which best represent the concerns for ecology which should be integrated into environmental analyses during project planning phases."[1]

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1. Whitman, et al. 1971 p. 12 (adapted).

1.31 - Species and Populations

The kinds and numbers of living things are the most likely parameters to reflect changes in the environment as integrations of both biotic and abiotic factors. Parameters based upon species and populations would vary with the many features of seasonal, climatic, and population dynamics, quite apart from those induced by a control program's impacts, so assessments and monitoring of these require a great amount of interpretation.

Species which are common in the various ecological situations or habitats under study may be selected for census as index species, and if these are diverse enough in the niches they occupy, may do well as sentinels, indicating by their numbers and population trends what is occurring, either positive or negative. They need to be selected to represent each recognized niche or subhabitat, aquatic or terrestrial, for activity during each season, and for a degree of convenience in census by informed biologists so that accurate data may be obtained.

Specialized parameters include the assessment and monitoring of rare and/or endangered species. Literature, or the identity and range of such forms may be available, but in undeveloped countries (even in developed countries!) they may not have been studied, or documented for the area under consideration. A careful survey is needed to reveal such forms, particularly if major habitat changes or habitat elimination is part of a control program. One must be sensitive to the possibility that a form common in an area under study may be rare elsewhere, and that extinction could occur if its very localized but prime habitat is under impact. Assessments involving such questions may require assistance from specialists outside the control program.

Population parameters of index species, determined by census techniques, should reveal the direct effects of seasonal variations, different annual variations, natural catastrophes, or impacts of chemicals or other habitat alterations. These overt effects and the deduction of population trends may be very difficult to interpret. Data from years prior to the beginning of the control program, at least from one prior year, would be most helpful.

Program impacts may result from such actions as the introduction of the mosquito fish Gambusia, or of Tilapia which may cause drastic shifts in the species and populations of other fish, other aquatic animals, and plants.

1.33 - Habitats and Communities

A major part of any environmental assessment is a careful analysis of the different kinds of habitat included in the impact or control area, inclusive of subhabitats or niches, and the determination of how each might be affected, as well as the extent to which secondary effects might occur outside the area of direct impact. (For example, damming a river would have an effect downstream as well, but draining the swamp might not.)

If a portion of a habitat must be sacrified, one must know what aliquot it represents of that kind of habitat in a region, and hence be the basis for estimating the magnitude, and hence importance, of the impact.

Such an assessment opens the need to consider mitigations, under which replacements in a nearby or adjacent area may be proposed to reduce the regional impact. Even if the aliquot damaged or destroyed is small, a policy of mitigation may be advisable. This may range from reserving an area of comparable habitat for perpetuity (if that can be done), or restoration of a formerly damaged or destroyed area to a level where it can once again function as the same kind of habitat it once was.

Effects on communities[1] follow alteration of a habitat, and major shifts in their species composition and populations will result.

Species diversity is a frequently used parameter for assessing communities, on the assumption that the number of different kinds of living things qualifies the complexity of trophic levels and broadly quantifies the overall energy exchange occurring in a habitat. Changes in this parameter may be used as a signal that investigation is needed, to explain what is occurring. For example, a body of water may become eutrophic, as in the instance of a surfeit of nutrients added by a sewer outfall, or oligotrophic, as the result of acid rain. In each instance there would be major changes in species diversity as well as in the index species and their populations.

1.36 - Ecosystems

Programs of source reduction have the greatest possibility of changing entire ecosystems.[2] Major drainage works or an impoundage may result in the disappearance of a marsh or swamp with profound changes in the ecosystems encompassed by these actions. Changes from natural to agricultural or residential uses of land areas may occur, and the nearly complete loss of native species of plants and animals would follow.

An impoundage, for example, creates a new ecosystem which would change the malaria vector picture entirely, but not necessarily for the better. If large populations of water weeds, such as Salvinia or Eichhornia come in, a worse problem may be created, of if the impoundage is not properly designed and contoured, the shoreline may develop a wealth of Anopheles habitats. The impoundage may damage the entire biota of a region, and may even produce

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1. The assemblage of different species of living things which associate with each other.

2. The complexes of plant and animal species and their populations which associate with each other in a given area, together with all the physical and chemical factors which condition the various habitats.

changes in the climate. Forecasting such possibilities and making the best decisions about them requires expert engineering and biological knowledge and design. Outside assistance by specialists in such problems is highly recommended, because very profound errors are in evidence on most continents today.

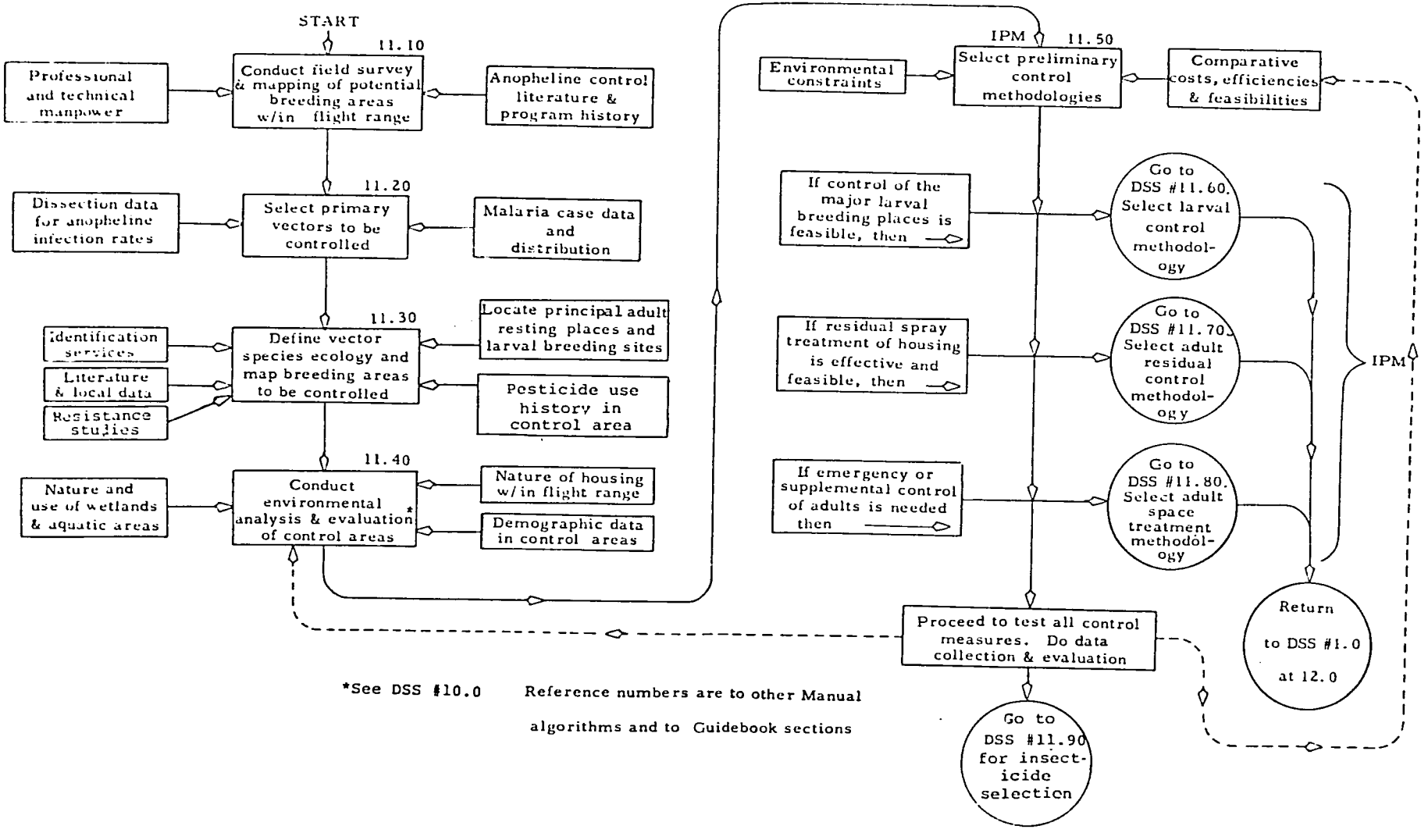
1.38 - Procedure

The Manual and the Guidebook have been built around a core of environmental assessment policies and procedures for malaria programs, and the details are embodied in various chapters, of which Chapter 10 presents the legal base and Chapter 11 the control program. Environmental assessment and monitoring policy and procedures are set forth specifically in these Chapters, with cross-reference to monitoring in operations Chapters 17 and 19.

The reader should consult these major references which are given in the bibliography: Southwood, 1978; Pudoc, 1979; Ricklefs, 1979; Price, 1975.

D.S.S. #11.0

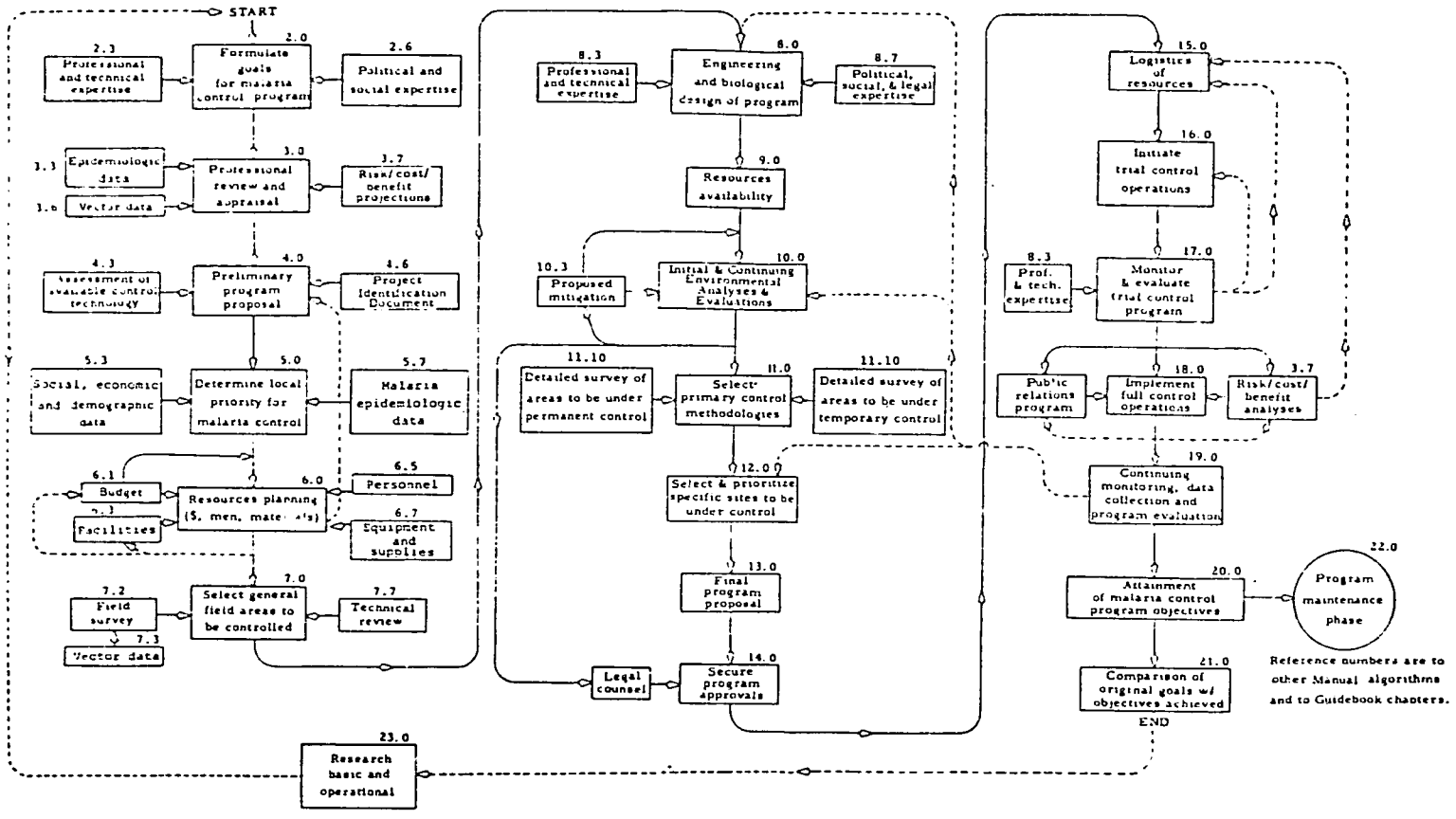
Select Primary Anopheline Control Methodologies (IPM Approach)



*See DSS #10.0 Reference numbers are to other Manual algorithms and to Guidebook sections

D.S.S. #1.0

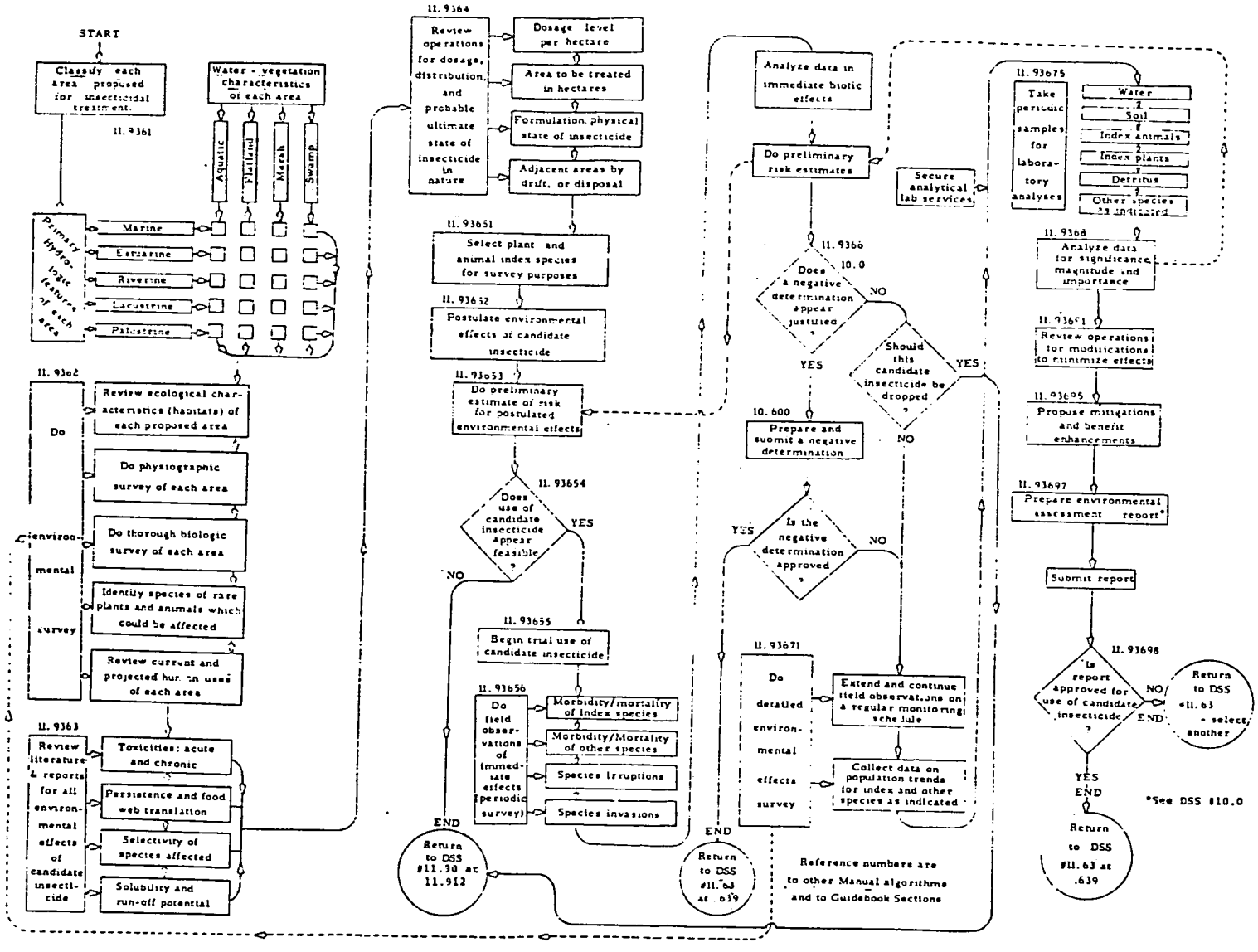
Generalized Decision Support System for Malaria Control (Vector Program)



Reference numbers are to other Manual algorithms and to Guidebook chapters.

D.S.S. #11.936

Assess the Environmental Effects of a Candidate Insecticide on Natural Aquatic and Wetlands Areas



Genetic Mechanisms - R. Baker

The genetic variability and reproductive potential of mosquito vectors suggest that there is no perfect control method, except for physical changes in the environment, to which the pest cannot evolve resistance. This has been evident with chemicals and will probably be true for biological, hormonal and other control agents. However, the methods of control and their application may delay resistance. A mixture or number of methods of control applied over a long time period probably will delay resistance compared to using the single best method for a short period. Perhaps in some vector species, genetic mechanisms can be utilized in an integrated pest management program with other control measures or during periods with reduced populations caused by temporal or seasonal fluctuations.

Over 20 years have passed since the prospects of utilizing genetics as a mechanism for the control of insects, especially mosquitoes, were identified. In the 1950's and 60's the Sterile Insect Release Method (SIRM), was applied to various insects including mosquitoes. While successful in the screwworm program, the SIRM program in mosquitoes (*Anopheles albimanus*, *An. quadrimaculatus*, *Aedes aegypti* and *Culex pipiens*) has had mixed results. However, its efficacy has not been fully tested. Other genetic mechanisms for insect and disease control have been proposed and tested by a few investigators in a few laboratories. These mechanisms include sex ratio distortion, meiotic drive, hybrid sterility, cytoplasmic incompatibility, lethal genes, conditional lethals, heterozygous and homozygous translocations, double heterozygous translocations, pseudohomozygous translocations, compound chromosomes and refractory genes. Some of these genetic mechanisms were first discovered in mosquitoes and *Drosphila* as the result of previous basic genetic studies before the concepts of genetic control had evolved. This suggests that future basic genetic and ecological research on vector species may identify other possible mechanisms for control since each species has unique attributes. Some of these genetic mechanisms proposed appear restricted to a few species (e.g.

cytoplasmic incompatibility in some culicines) while other mechanisms (e.g. translocations) may have potential in all species.

Unfortunately, although considerable attention has been given to the theoretical concepts of genetic mechanisms, the intensive genetic and ecological eperimental evaluation needed in the laboratory and field has been delayed or lacking. This is especially the case for the anophelines compared to the culicines. Many more field releases to measure population suppression and mating competitiveness with different genetic mechanisms other than the SIRM have been carried out with four culicine mosquitoes (Ae. aegypti, Cx. quinquefasciatus, Cx. tarsalis and Cx. tritaeniorhynchus) in various countries (Burma, India, Pakistan, Kenya, France and the United States) compared to only two anophelines (An. culicifacies species A in Pakistan and An. gambiae in Upper Volta). One of the reasons for the slow progress in anopheline research was the initial lack of interest during the period of anticipated success of the malaria eradication program. Further progress in developing genetic mechanisms requires intensive scientific interest and long-term and sustained research funding not dependent on the results of a few field experiments.

Other reasons for the lack of interest in anopheline genetics are the difficulties in colonization, maintenance, and manipulation. However, when an effort is made, most vector malaria species can be colonized, although some species more readily than others. Increased success has occurred by having the wild caught females forced to oviposit in confined tubes or vials instead of mass oviposition containers. Moreover, artificial copulation techniques are successful for most anophelines and can be utilized to initiate research programs. However, the effects of colonization may have altered the competitive mating behavior, selected an assortive mating behavior, or affected other genetic and ecological attributes when re-introduced into the field. This probably is one of the most important factors in the failure of genetic control attempts. Mass rearing techniques for mosquitoes are available and with each field release new improvements in efficiency have been developed.

Genetic sex sorting mechanisms for SIRM have been used in field experiments in An. albimanus, An. culicifacies, and Cx. tritaeniorhynchus. Similar systems were first produced in An. gambiae and An. arabiensis and probably can be synthesized for most anopheline vector species especially if a chemical resistant gene is available which can be translocated to the Y or male producing chromosome. In Cx. tritaeniorhynchus, dominant and recessive temperature sensitive lethals have been induced on the sex determining chromosomes to produce genetic sex sorting systems. A similar heterozygous Y-autosomal translocation system in males has been suggested for introducing insecticide susceptibility into field resistant populations.

Basic studies have been done by a few investigators for a few anopheline species. Mutants, linkage maps and chromosome aberrations are available for An. albimanus, An. culicifacies species A, An. gambiae, and An. stephensi.

Besides the SIRM, translocations offer the current best prospects for genetic control of Anopheles. These aberrations are self-propagating from generation to generation, may reduce the overall reproductive potential of a population through partial sterility, can incorporate such desirable alleles as susceptibility to insecticides or pathogens, refractoriness to malaria or filaria parasites, and can be mass produced to replace a target population. Homozygous translocations have been produced in two species (An. albimanus and An. culicifacies species A), but none have been applied in field population replacement experiments. However, An. culicifacies species A males carrying a complex chromosomal aberration (a heterozygous translocation and pericentric inversion), have shown promising mating competitiveness in field releases. However, this study and other releases point to the necessity of acquiring ecological data on the time of mating, age of mating, flight distance of males and females, and resting habits as well as methodology of mass rearing for release.

Anopheline species do possess excellent banded polytene chromosomes both in larvae and adult females which have been utilized in basic and applied studies. These chromosomes along with isozyme analysis and crossing studies have discovered or defined

sibling species in many of the important vector complexes (e.g. An. gambiae, An. maculipennis, An. culicifacies, An. hyrcanus, An. punctulatus, An. albitarsis, An. nuneztovari, and others). Moreover, these chromosomes, besides suggesting possible evolutionary relationships among anopheline species, are in some cases the only method of taxonomically identifying vector species and populations. Recent evidence suggests various adaptive values are found in inversion polymorphisms in Anopheles which can relate to the blood host (man versus livestock), resting sites (indoors versus outdoors), and vulnerability to residual insecticides.

In either suppression, eradication or replacement of vector populations, the vectorability of possible immigrant or the induced population is of concern. Unfortunately, most of the genetic studies on refractoriness have involved laboratory models and not the natural relationship of human vectors to human parasites. Five mosquito vectors have involved malarial parasites, three of these have included anophelines (An. stephensi, An. gambiae and An. atroparvus) to either avian or murine malaria. The genetics of refractoriness in these species has been variable ranging from autosomal dominant and intermediate dominant to polygenetic inheritance. However, recent success in infecting An. stephensi and An. freeborni with Plasmodium falciparum cell cultures should stimulate research on the genetics of refractoriness. In addition to these studies, other investigations have suggested that certain phenotypes in field and laboratory anopheline populations have fewer malaria infections than "wild-types". The relationship of refractoriness to morphological characters and variation in the field needs investigation.

Recommendations for Future Research

1. Colonization amd maintenance of wild-type strains of the major malaria vectors for laboratory and field experiments.
2. Evaluation of the genetic and laboratory environmental factors occurring during the process of colonization and mass rearing which reduce mating competitiveness, dispersal, and general fitness in SIRM and genetic replacement programs.
3. Initiation of basic genetic (including biochemical analyses) and cytogenetic

studies on vector species to include isolation of mutants, linkage relationships, detection and identification of sibling species and measurements of genetic variability within and between vector populations in nature.

4. Identification and development of genetic control mechanisms with special emphasis placed on balancer and marker strains to isolate compound chromosomes, homozygous translocations and conditional lethals (including insecticide susceptibility) useful to bioregulate vector populations at various life stages and under different seasonal environments.
5. Development of genetic systems to efficiently separate sexes for the SIRM.
6. Investigation of the cryptic genetic variations in the bionomics and vectorial capacity within and between vector populations to include the intensity of man-vector contact, exophilic resting habits, daily survivorship, gonotrophic cycle durations and the time required for the completion of sporogony. An important aspect of this research is to characterize malaria vectors for biochemical and chromosomal polymorphisms.
7. Determination and isolation of the genetic factors affecting vector competence and transmission of malaria parasites for vector population replacement.
8. Study the interrelationships between the genetic variation found in predator and parasite populations and the genetic variation in mosquito vector populations in order to improve the use of these agents in vector control strategies and to delay resistance.
9. Assessment in the field of presently available and potential genetic mechanisms for vector population replacement or suppression with special emphasis on bionomics, mating behavior, and population dynamics.
10. Establishment of international reference centers to maintain wild-type, genetic and important chromosomal aberrations (e.g. for sex sorting mechanisms, balancers, compound chromosomes, insecticide and parasite-preditor bioassays) of vector species, and to provide training in mosquito rearing, maintenance, and genetic techniques.

WORKSHOP ON VECTOR CONTROL

7.2 Sterile Insect Release

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Rationale for Use of Sterile Mosquitoes

Of several genetic methods proposed for the control of mosquitoes, the induction of dominant lethality has perhaps received more attention than any other during the last two decades. Dominant lethality can be induced by either radiation or chemicals as chromosomal damage that affects the development and maturation of the progeny of exposed parents. This differs from sterility resulting from inability to mate, infecundity (reduced production of gametes), sperm inactivation, or aspermia in which differentiated sperm are not produced, the sperm supply is exhausted, or the continuous production of sperm is inhibited. It is due to this difference that dominant lethality provides a potentially useful means of controlling or eliminating populations of mosquitoes that are physically isolated from other populations of the same species, because the introduction of dominant lethals can inhibit the reproductive success of the target population. In this sense the technique has been called the sterile insect technique (SIT) and includes both the release of sterile insects and the sterilization of natural populations directly without the release of sterile insects.

The release of sterile mosquitoes is a rather sophisticated procedure involving the initial colonization of the relevant species, large-scale rearing of viable and competitive insects for release, followed by sterilization, packaging, transport, and release at the optimum time and place. Continuous releases over a number of generations are required to obtain ultimate elimination of the target population; the duration of the release period is determined by the initial size of the target population and by the ratio achieved of effective sterile males to the indigenous (wild) males. Thus, in order to obtain practical sterile:wild ratios, the target population would normally be suppressed by other control techniques prior to the release of the sterile insects.

The use of insecticides for prior suppression would be suitable since they provide maximum effect when the population density is high, i.e., an insecticidal application kills more target insects when the density is high than when it is low. On the other hand the sterile insects can be used more economically when the target population density is low. Thus, the use of conventional control methods is entirely compatible with SIT and the two methods are complementary. Furthermore, since the sterility method is directed toward the adult portion of the target population, alternative methods that are directed toward the immature stages are suitable adjuncts both before a release program and during its progress, e.g., larvicides, IGRs, predators such as other invertebrates or fish, or mosquito pathogens. Indeed, the complexity of controlling indigenous insect populations often dictates the use of several integrated suppression measures.

Although SIT is usually considered as a method of eliminating an isolated population of a pest species, it can also be useful as a tool to keep a low density population in check or to maintain a barrier zone for protection of an uninfested area. In either case SIT is normally considered useful only for large-scale operations partly because of the considerable effort required to perfect the technique for practical usage, especially the development of mass rearing, sterilization, and distribution technology, but also because of the staff and physical plant required to conduct such a program. In view of the long dispersal range of many mosquitoes, SIT programs must be undertaken in well isolated areas or on

sufficiently large scale to avoid the infiltration of enough fertile females and males to significantly affect the ratio of sterile to fertile mosquitoes in the release area.

Another factor influencing adoption of SIT for the control of a vector species is that the method is selective and provides control of only the target species. If more than one vector were significantly contributing to the transmission of a disease, it might be necessary to release sterile insects for each implicated species in order to obtain the desired control of disease transmission with SIT. While this seems a serious disadvantage, the capability of limiting the impact to the target species can be a major advantage from the environmental viewpoint when a single species has been incriminated as a vector.

Characteristics of Likely Mosquito Species and Situations for SIT

SIT can be considered only for a few of the more important mosquitoes, i.e., those that are of major interest from an economic, medical or veterinary standpoint. The rather large initial outlay of personnel resources required to develop and test the methodology for each target species and the expense of conducting operational programs over large areas tend to exclude species of minor importance from consideration. Nevertheless, the method has received considerable attention because it offers a potentially useful means of coping with control problems that have become extremely complex and unmanageable by conventional methods, e.g., insecticide resistant populations.

Prerequisites for Consideration of SIT for Mosquito Control Operations

Adequate operational control can be anticipated only if certain minimum prerequisites are met. Foremost among these is the ability to colonize and mass-rear the relevant species. While this objective may seem readily attainable, a major increase in efficiency is required when production of a colonized mosquito species is converted from laboratory scale rearing to factory production of a million or more insects for release daily. Not only must the released sterile insects be able to overwhelm the suppressed natural population numerically, but they also must be of high quality and have maximum vigor and competitiveness. Also, since the females are bloodfeeders and possibly could become vectors if released in numbers, an efficient method of separating the sexes prior to release should be available.

An adequate sterilization technique is essential to provide a release insect with a high level of dominant lethality without serious deleterious effects on viability or vigor and without affecting the competitiveness of the resulting sperm. If radiation is used for the sterilization process suitable irradiators capable of processing millions of insects daily are required; fortunately, hazards from this radiation source will be minimal and of course there is no residual radioactivity in the resulting sterile insects. Should chemosterilants be used, in addition to the avoidance of undesirable side effects on the insects and on personnel, care should be taken to minimize sterilant residues and thus avoid undesirable affects on the environment and nontarget organisms.

The relative change in density from one generation to another (rate of increase, RI) profoundly influences the numerical requirement for sterile insects. In some instances RI is density-dependent, i.e., RI is different when the population level is high than when the density is low. Since RI plays such an important role in determining the impact of a sterile male release program, it is essential to have detailed information on the density and the seasonal fluctuations of the target populations prior to the initiation of releases.

Mating behavior of the target population is closely related to the efficiency of a release program because the released insects must encounter virgin females in the population when the latter are ready to mate. If this interaction is inadequate then the females will mate only with wild males, which naturally will be in the proper place at the

right time. Thus, released insects must be positioned in the right place and should be distributed in proportion to the distribution of the indigenous population to provide their maximum effect. Furthermore, the dispersal and migratory behavior of the released insects should be similar to that of the target population to assure that they remain in the proper habitat and seek their mates at the time when the females are available for mating. Otherwise, assortative mating may result in fewer sterile matings than expected for the ratio of sterile males in the release area.

Multiple mating behavior, however, has no harmful impact on the ultimate success of a release program as long as both the sterile male and its sperm are competitive. This seems to be one of the least understood facets of SIT, for even experienced biologists reason that if females mate more than once the effect of released sterile males will be diminished. However, a female that mates two or more times will encounter the same ratio of sterile males:wild males on each occasion, and random chance will determine the type of mate that is successful each time. Therefore, on a population basis the number of sterile matings that occur with each copulation will be a reflection of the proportion of effective sterile males in the population; if the effective sterile:wild ratio is 9:1, 9 out of every 10 pairings will be with sterile males for the first, second, and all subsequent matings. Multiple mating behavior could in some circumstances enhance the release effort, because females already in the population that have had a fertile mating prior to the first sterile releases will be susceptible to a sterile mating. Also, if mated females infiltrate into a release area they will be subject to mating with sterile males during subsequent matings.

The dispersal activity of the indigenous mosquito population, e.g., the migration of females already fertile and ready to oviposit after arrival within the release area, can exert a seemingly disproportional influence on control levels because each may deposit eggs that cannot be affected by the sterile males in the area. The influence of migration is such that if only a small percentage of a population are immigrants, enough normal progeny may be produced to reduce the ratio of released sterile males to normal males below the effective level.

Progress With Techniques

Large-scale production of mosquitoes has been achieved on numerous occasions, e.g, with *Aedes aegypti*, *Culex fatigans*, *Culex quinquefasciatus* and *Anopheles albimanus*. The escalation from a healthy self-sustaining colony to one capable of producing hundreds of thousands of release individuals daily requires the development of standardized methods that must continue to be efficient in the event of variations in nutrition, environmental control, water quality, personnel quantity and quality, and labor relations, to mention just a few of the daily factors that play a role. Colonization is a somewhat hazardous process because it represents a period of indefinite length when existing conditions may favor the selection of individuals that can survive in confinement and the elimination of those that cannot. This factor played a dominant role in the first field releases of sterile mosquitoes (*Anopheles quadrimaculatus*). To overcome these problems the development of hybrid vigor has been investigated with promising results. Also, several workers have suggested that a colony might be invigorated by regular periodic introduction of wild stocks directly from the field; others favor the complete replacement of existing stock with new wild stock because this assures that the wild genome is brought in, while the former technique merely assumes that it has been incorporated. However, to keep this discussion in balanced perspective, sterile mosquito releases have revealed that colonized insects are not necessarily unfit and a high degree of competitiveness has been observed in sterile male mosquitoes released into the natural environment.

Satisfactory methods have been evolved for removing most females from releases by separating the sexes of *Culex* and *Aedes spp.* in the pupal stage using mechnical separators that take advantage of the size differential between the sexes in those species with relatively firm bodies. These techniques normally provide >99% separation, leaving 1%

or less of the release lot as females. However, *Anopheles spp.* have a greater overlap between the size ranges of male and female pupae and also have a soft body that reduces the efficiency of sexual separation by mechanical means. *An. albimanus* sexed in this manner routinely consist of ca 85% males and 15% females. Clearly, this level of efficiency is inadequate for *Anopheles* if millions of mosquitoes are to be released daily, since this would result in the liberation of thousands of potential vectors daily. Fortunately, genetic methods to sex mosquitoes have been developed, e.g., induction of a heat-sensitive lethal factor in *Culex tritaeniorhynchus* and insecticide resistance in the male sex chromosome of *An. albimanus* and *An. gambiae*.

The creation of dominant lethality in mosquitoes to be released has been achieved by exposure to gamma radiation in the pupal or adult stage or to chemosterilants in the larval, pupal, or adult stages. While there is some flexibility in the choice of sterilization method, irradiation of young pupae has resulted in undesirable reductions in competitiveness; exposure of adults >24 hr old has sometimes improved competitiveness. Chemosterilization of the larval stage may result in lack of permanency of sterility or in reduced matings, but chemosterilants have been used effectively for pupal exposures, providing virtually complete sterility in the resulting adults. Generally speaking, the chemosterilization of mosquitoes has provided sterile mosquitoes that are hardier and more vigorous than those treated with gamma irradiation. But, chemosterilants may present greater hazards in handling than irradiated mosquitoes because the successful mosquito sterilants have generally been alkylating agents, which are known mutagens. Thus they may present a hazard to man during the treatment process and a potential hazard to nontarget organisms if they persist as residues in released insects. However, in *An. albimanus*, *Cx. quinquefasciatus* and *Cx. fatigans* the sterilant residues were very low (<1 ng/mg) in young adults and became less than the detectable level at 48 hr. Because these alkylating agents are highly reactive and thus become bound in the host tissues, it seems unlikely that released insects would present a meaningful hazard to nontarget organisms; nevertheless, some effects have been reported in spiders allowed to feed heavily on treated mosquitoes in laboratory cages.

The efficiency of released sterile mosquitoes depends in part upon the type of handling they receive after sterilization. The effects of pupal storage, cage maintenance, packaging, transportation, distribution, and release method can all reduce the efficiency of otherwise competitive insects. For example, post-sterilization losses with *An. albimanus* have been minimized by taking the mosquitoes to the field as pupae to avoid significant losses that occurred with adult sexing techniques. On the other hand, some workers have reported better results when adults were released because they could shelter the insects from excessive mortality resulting from environmental hazards caused by premature releases, the chemosterilant residues could be minimized by holding prior to release, and in the case of irradiation, somatic damage could be reduced by waiting until the adult stage for treatment.

Results of Field Releases of Sterile Mosquitoes

The preceding sections may have given the impression that there are so many obstacles to placing viable sterile insects in the field that the prospects of success seem rather hopeless. Fortunately, this is not the case. Even though many factors may reduce the effectiveness of released insects, the final elimination or continuous suppression of very low level populations may be accomplished more economically by SIT than by any other known method, even if the released insects are below normal in competitiveness.

Effective sterile releases have been conducted on a research basis with both *Culex* and *Anopheles spp.* A great deal of cumulative research experience, however, preceded these events and provided the guidelines for the discussion presented in the earlier portions of this document.

Releases of *An. quadrimaculatus* were conducted in 1959-1960 in a semi-isolated area on the shore of Lake Okeechobee, in Florida. The insects were reared in Orlando, where they were irradiated as pupae, packaged and transported daily to the release site. After prolonged releases without significant induction of sterility into the natural population, a search for the factors that thwarted success revealed that the basic cause of failure in the release program had been behavioral deficiencies due to selection during colonization.

In 1971, a study was conducted with *An. albimanus* colonized from its native habitat, reared, chemosterilized and released in an isolated breeding location in El Salvador. Over a period of 5 months the release of 4.3 million sterile males reduced the indigenous population below the level of detection. Along with the released males were the sterile females that could not be separated from the males with the mechanical sexing system utilized; they comprised 14% of the total release. In 1976 another release program was initiated with *An. albimanus*, this time with the goal of releasing 500,000 sterile males daily; the sexing system was modified to include pupal and adult sexing. However, the losses encountered in this dual sexing system were so extensive that only 40% of the reared males were released in the field, and they were much reduced in competitiveness. However, the development and introduction of the MACHO strain, which could be sexed by exposure to propoxur in the egg stage, reared essentially without females, and released as pupae provided a viable adult that competed well in the field. In combination with methoprene as a larvicide (IGR), the daily releases of over 1 million sterile males (and ca 5000 females) caused a measurable level of control, but total control was prevented by the immigration of substantial numbers of females across the 4 km buffer zone bordering the release zone.

In 1960-1961, laboratory-reared *Ae. aegypti* were sterilized by gamma irradiation in the pupal stage and flown to Pensacola, Florida, where they were released 24 hr post-irradiation. Care was taken to prevent losses in insect viability in these studies, but subsequent investigations revealed that *Ae. aegypti* is extremely intolerant to gamma radiation and males with reduced competitiveness result from such exposures. Thus, in this instance the strain of mosquito was carefully colonized from local genome, but the sterilization treatment was deleterious to the released insect. However, chemosterilized males have since been found to be competitive in the field in Florida and India. This species might be an excellent candidate for SIT because of its behavioral characteristic of low dispersal, but further practical studies have not been conducted.

Cx. quinquefasciatus and *Cx. fatigans* have received more attention as a target for SIT than any other mosquito, perhaps because of the relative ease in rearing these species. Although some early experimental releases (India, Kenya) were unsuccessful, in 1970 a natural population of *Cx. quinquefasciatus* mosquitoes was eliminated experimentally by sterile insect releases in Florida. Further releases were conducted in India with irradiated males and chemosterilized males, which were found to be capable of dispersing amongst the natural population and inducing sterility into females, but immigration of fertile females from outside the experimental areas thwarted control.

In these field studies, the released insects were determined to have the following levels of competitiveness: *An. albimanus*, 25-50% in the 1972 program, 80% with the MACHO male in 1979; *Ae. aegypti*, quite low in 1961, but highly competitive in 1976 and 1977; *Cx. quinquefasciatus* and *fatigans* ranged from ca 25-50% depending upon the nature of the treatment. Although some of these competitiveness rates seem low, they reflect not only the competitiveness per se but some also include the efficiency-related factor of placement of the sterile males in relation to the mating grounds of the indigenous population. At 50% competitiveness, 2 sterile males are required to compete with 1 wild male; at 25%, 4 sterile males are needed. With easily reared species like *Ae. aegypti* and *Cx. quinquefasciatus* and *fatigans* (ca $40/million in 1971 in India) a weakness in competitiveness might be overcome economically simply by releasing proportionally more sterile insects. However, with a more difficult insect to rear like *An. albimanus* (ca $156/million in

El Salvador in 1979) it is fortunate that the competitiveness is so high.

Outlook for SIT for Mosquito Control

Conducting the necessary research to evaluate these techniques is time-consuming and expensive, but the potential usefulness of SIT as a supplement to conventional control methods in selected situations seems readily apparent. SIT is compatible with a variety of other methods and it complements insecticidal usage by being highly efficient at low population densities, while pesticides are most efficient at high population densities. For species of major importance, especially species that are difficult to control by conventional methods, SIT could play a more significant role in the future than is generally believed. For lesser species, it is unlikely that the development cost would be justified.

A matter of major importance that is often not adequately considered is that SIT provides a system of further suppression or continuous management that has maximum efficiency when the target pest population is low. For many insects, if a critical level of density of the target population occurs naturally or can be achieved by conventional methods in an isolated ecosystem, SIT may become more effective and more economically and ecologically desirable than any other available method for final elimination or for preventing resurgence of damaging or hazardous populations. The level of density when this would be the case will depend on the species and the circumstances.

At the present time the use of SIT for mosquito control is in the research phase. No operational programs have been conducted. For several species, extensive information has been generated and operational programs could be considered after further limited research. However, for most species, a considerable amount of laboratory and field study would be required prior to determining the feasibility of SIT.

Research Requirements

1. Development of more efficient methods of dispersing sterile mosquitoes.

2. Analysis of the potential costs and benefits of SIT in relation to alternative systems of vector control.

3. Development of guidelines to determine which species are of sufficient importance to warrant developmental research on SIT.

4. Studies on the impact on nontarget organisms of the minute amount of sterilant residues found in recently exposed mosquitoes.

5. Continuation of the search for effective nonhazardous sterilants.

6. Studies on the population dynamics, dispersal behavior and migrational capabilities of mosquitoes being considered for SIT.

PARASITES, PATHOGENS, AND PREDATORS OF MOSQUITOES

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8.1 This summary statement will contain some of the latest information on the above subject and should be helpful in deciding where we are and what our needs are in the near future.

Parasites

8.2 The only parasite group that shows considerable promise in mosquito control, particularly with malarial vectors, is the mermithid nematodes.

8.2.1 Mermithid nematodes - The sole aquatic mermithid that can be and is mass produced is *Romanomermis culicivorax*. While it can infect over 70 mosquito species, it is usually most effective against *Anopheles* as was shown in the El Salvador project. This nema may or may not recycle and become established after releases. Recent research that might enhance its attractiveness to industry is: (1) a material (fluroform - used in holding cut flower stalks in arrangements) can be used in shipping rather than sand which should reduce shipping charges by 4 fold; (2) this material also can almost eliminate the loss of nema eggs during shipment; (3) the use of water, instead of coarse sand for the culture pan, could enable eggs of a known age to be shipped, all of which should hatch at the first flooding, rather than a third or so that presently hatch in sand cultures; (4) eggs can be stored in water for 21 weeks, thereby stockpiling them for the mosquito breeding season; and (5) studies on deep freezing preparasites and hopefully eggs by Bailey et al at Insects Affecting Man Research Laboratory, could also have an impact on our ability to lengthen the storage time.

Pathogens

8.3 Most of my time devoted to pathogens should probably be spent on *Bacillus thuringiensis* H-14 (*B.t.i.*) because of recent advances and control efforts.

8.3.1 *Bacillus thuringiensis* H-14 - The importance of this bacterium was certainly emphasized when the 5th meeting of the Scientific Working Group on Biological Control of Vectors in Geneva in October, 1981, was entirely devoted to bacterial control agents. *B.t.* H-14 has been used successfully against numerous mosquito species, including anophelines, in a variety of habitats. Two industrial products are presently available (Bactimos^R and Teknar^R). Since present formulations remain in the larval feeding zone for only a short time period, they must be applied inundatively as a microbial pesticide with no possibility of recycling.

8.2.2 *Bacillus sphaericus* (1593) -This bacterium stands a good chance of being the next biocontrol agent produced by industry. Disadvantages are that *B.t.i.* is so successful and already being marketed, and *sphaericus* is more fastidious in its mass culture requirements. *B. sphaericus* may be slightly more toxic against *Culex* species and there is a possibility that it may recycle in areas with high organic content.

8.3.3 Fungi - Considerable research is presently being funded on *Culicinomyces clavosporus*, *Lagenidium giganteum*, *Tolypocladium cylindrosporum*, and to a lesser extent, species of *Coelomomyces*. All but the latter species can be produced both by in vivo and in vitro means. Although *Culicinomyces clavosporus* has been mass produced in Australia, improvement is needed in conidial yields, higher temperature tolerance of conidia, and its recylcing ability. *Tolypocladium* has not yet been mass produced but strains of it show good infectivity against a variety of species in diverse habitats and also exhibits an ability to persist or recycle at least in some environments. While recycling occurs with *Lagenidium giganteum*, the responsible factors are unknown. Present disadvantages are its restriction to fresh water habitats and the lack of mass production technology. The complicated life cycle of *Coelomomyces* (the need of a microcrustacean as an intermediate host) has cast a shadow on the potential of this fungus. To treat inoculatively, requires the presence of both the host and intermediate host. To treat inundatively, requires the ability to mass produce the infected intermediate host or to find a species of the fungus that at some time does not require the presence of a intermediate host to ultimately infect the mosquito host.

8.3.4 Microspora - Research studies on the Microsporidia is being done at the USDA - ARS laboratories in Gainesville and Lake Charles, and by Dr. Barr's group in Los Angeles. Studies involve the search for alternate hosts, life cycles, spore germination, laboratory transmission, and biocontrol potential.

Asexual Microsporidia - The most common monomorphic species are *Nosema algerae* and *Vavraia culicis*. Many laboratory strains of these two species no longer cause high larval mortality. Both can be mass produced using large lepidopterous larvae as the in vivo host. Since spores of *N. algerae* stay at the surface or general feeding zone of mosquito larvae for a short time, improvements in formulation are needed. Dr. Barr isolated a strain of *V. culicis* from *Culiseta incidens* which is highly lethal to that host as well as other mosquito species in the laboratory. Barr's group has found 4 possibly different strains of *V. culicis* in California. Both *N. algerae* and *V. culicis* have been produced to some extent by in vitro means

Microsporidia with sexual cycles - These dimorphic microsporidian species are usually very common in most species including anophelines. Transovarial transmission is quite common. Larval mortality in males or in both sexes can be high although the resulting uninucleate spores are not known to be infective. Per os transmission takes place at some time in the field, but the factors making this even possible are unknown. Two exceptions, *Hazardia milleri* found in *Culex quinquefasciatus* in Texas and Louisiana and a *Thelohania* sp. found in *Aedes aegypti* in Thailand, are easily transmitted per os. This per os laboratory transmission and resultant mortality with *H. milleri* varies from low to high, although the reasons are unknown. This pathogen is presently producing mortalities in excess of 80% at Lake Charles.

The life cycle of the *Thelohania* sp. in *Ae. aegypti* is being studied and present indications are that females can be infected that produce eggs and the resultant infected larvae die, thus releasing infective haploid spores. *Toxorynchites amboinensis* larvae can be infected and the possibility exists that searching infected females could be used to deposit eggs in vector habitats that would result both in predatory larvae and ultimately as a foci of infective haploid spores.

8.3.5 Viruses - Although iridoviruses, cytoplasmic polyhedrosis viruses, desonucleosis viruses, and baculoviruses have been isolated from and studied in mosquitoes, only the latter virus has shown some potential. Some continuing research needs to be done with the viruses, otherwise we will know no more about them ten years from now. Possibly studies involving larval selection of food particle size might cast some light on the optimum size for the maximum intake of virions, with or without bait (attractants).

Predators

8.4 The effect of many invertebrate and fish predators on mosquito populations is not fully known but generally appreciated. Their effect on the aquatic stages of mosquitoes in waters of a more permanent nature is usually greater; also, their predation is often greater against culicines as opposed to anophelines. Our inability to colonize or mass produce most of these predators is the most serious drawback in their use. However, the protection of existing natural predator populations should be of paramount importance in mosquito control operations.

8.4.1 Invertebrate predators - Probably the most important include predatory mosquitoes, water bugs and beetles, odonatans, flatworms (planaria and microtubellarians), *Hydra*, and crustaceans, including microcrustaceans.

8.4.2 Fish - Quite a number of species of fish have been used since early in the 1900's against pest and vector mosquito species in a variety of habitats. The most commonly used species are *Gambusia affinis*, *Poecilia reticulata*, and *Tilapia* spp. with the first two species having been distributed almost worldwide. Fish use in vector control is being widely studied. Major parameters in fish studies should include finding their minimum effective density, tolerance to various environmenta conditions and chemical pesticides, their mass production potential, and the ecological impact of such releases, particularly with exotic species. Combined releases of plant eating and larvivorous fish species may be useful in controlling vector populations, with the herbivorous species (often Carp) also serving as a food reward to entice participation in such releases. The early correct identification of fish species is absolutely essential.

Toxorhynchites - A Biological Control Agent of Container-Breeding Mosquitoes

Toxorhynchites is a genus of large non-biting mosquitoes that are predaceous during the larval stage on certain mosquitoes and other aquatic organisms that inhabit natural and artificial containers, such as leaf axils, treeholes, drums, water cisterns, and discarded tires, cans, and bottles. A number of factors have recently reawakened interest in the genus as a potential biocontrol agent of mosquitoes produced in such habitats. Dengue haemorrhagic fever (DHF) continues to be an important vector-borne disease of Southeast Asia and the Western Pacific as does filariasis in Southeast Asia and the South Pacific. Dengue remains endemic throughout much of the Caribbean and Central America with the first significant outbreak of DHF in this hemisphere occurring in Cuba during 1981. And finally, yellow fever persists in Africa and Central and South America producing sporadic outbreaks in spite of the availability of vaccine. A second reason for interest in the genus *Toxorhynchites* stems from the difficulty or impossibility of controlling container-breeding mosquitoes. Traditional source reduction, so successful in eliminating *Aedes aegypti* in the past, is labor intensive and, is now often considered prohibitively expensive. Chemical control programs directed against urban container-breeders are also increasingly expensive and frequently ineffective. And, it should be appreciated that there are no practical techniques for the control of mosquitoes breeding in natural containers such as *Aedes triseriatus* from rot cavities or *Aedes albopictus* from banana leaf axils.

The early attempts to use *Toxorhynchites* as a biological control agent cannot be considered successes; the preliminary efforts were hindered by a lack of knowledge of the basic biology and dynamics of the systems involved. The classical biocontrol strategy employing inoculative releases did not dramatically eliminate the prey species, but rather resulted in equalibriums being established between the prey and predator. An additional, compounding factor reducing their effectiveness was the use of species of predator whose ovipositional preferences, and hence larval habitat, did not coincide sufficiently with those of the prey.

Work conducted since 1970 has clearly demonstrated that *Toxorhynchites* can control container-breeding mosquitoes under some conditions. On St. Maarten in the Caribbean where water storage vessels, e.g., cisterns and drums, are a principal source of *Ae. aegypti*, a house index of 0 was maintained for ca 6 weeks following a single introduction of *Toxorhynchites brevipalpis* eggs into containers. A single release of 62 gravid females of the sylvan subspecies *Toxorhynchites rutilus rutilus* in a 7 ha Indiana woodlot resulted in oviposition in all of the rot cavities present; the introduction resulted in recycling of the predator and a season-long reduction in the emergence of *Aedes triseriatus* of 35%. Researchers in New Orleans, Louisiana found that this subspecies was too strictly orientated towards trees while searching for oviposition sites, and thus, failed to locate more than 10 or 20% of the artificial containers found at ground level. They found, however, that *Toxorhynchites amboinensis* females would oviposit in virtually every type and color of container found in substandard neighborhoods, irrespective of the containers' location or association with vegetation. Weekly releases of this species during a 2.5 month period reduced the emergence of *Ae. aegypti* and *Culex quinquefasciatus* by 67%. Workers in Florida and East Africa observed natural infestations of *Tx. r. rutilus* and *Tx. brevipalpis*, respectively, reduce *Ae. aegypti* breeding in automobile tires to near zero levels; in both instances, the investigators believed that inoculative releases conducted early in the breeding season would have produced season-long control. A final recent example of the efficacy of *Toxorhynchites* is the work in French Polynesia by a team of French scientists, whose liberations of gravid females of *Tx. amboinensis* on a number of islands are reported to have provided effective control of the vector species. These researchers are presently attempting to eradicate *Ae. aegypti*

breeding in tires and drums from several villages on the island of Tuamotus.

Future research directed towards developing control strategies employing this genus should emphasize 2 areas. The oviposition site preferences of more species need to be investigated in depth through field studies as successful biological control programs will require finding the proper match between the prefered oviposition sites of the most suitable species of *Toxorhynchites* and the target mosquito prey. Priority should be given to studies designed to identify promising species and produce quantitative data on their effectiveness for control of vectors of yellow fever, filariasis, dengue, DHF, and some forms of encephalomylitus. The second area requiring extensive work concerns mass-production techniques. The cost of current methods employing mosquito larvae as prey are not prohibitively high when the target species are treehole-breeders as extensive overlap in oviposition site preferences, stability of the habitat, and recycling permit low release rates. Urban mosquito control, however, based on estimates from French Polynesia and New Orleans, may require regular liberations of as much as ca 10X the rate necessary for sylvan control. Alternate species of prey that do not require a blood meal, such as tubifex worms, should be investigated as substitutes for the prey mosquitoes currently being used for predator production. When designing rearing methods, an attempt should be made to strike an economical balance between technology, etc., and labor intensiveness that is appropriate for the intended area of use.

MALARIA MODELS AND VECTOR CONTROL: THE GARKI PROJECT AND BEYOND [a]

L. Molineaux

What, if anything, can planners of malaria control expect from mathematical or simulation models, with respect to vector control? Probably assistance in answering the following two questions: 1/. what changes in the malaria situation are to be expected from defined changes in the entomological situation? 2/. what changes in the entomological situation are to be expected from the application of defined vector control measures? The first question is addressed by malaria transmission models, the second by vector population models.

This brief and selective presentation will be divided into two parts: 1. the contributions of the Garki project in this area; 2. some outstanding problems and suggestions for further work.

1. Contributions from the Garki Project[1]

1.1 Plasmodium falciparum transmission model

The project included among its objectives the construction and validation of a model of the transmission of *Plasmodium falciparum*[2]

The model's driving input variable is the vectorial capacity. It was calculated following Garrett-Jones' formula ($ma^2p^n/-\log_e p$) on the basis of: 1/. the man-biting rate (ma) estimated by all-night collections on human baits; 2/. the man-biting habit (a), being quotient of the proportion of blood-meals taken on man, (estimated by the precipitin test) by the interval between blood-meals (estimated on the basis of the distribution of resting females according to abdominal (Sella) stages and of the condition of the ovariolar sacs of biting females); 3/. the vector's probability of surviving one day (p), estimated on the basis of its age-composition, according to a combination of Christophers' and Detinova's methods; and 4/. the incubation period in the vector (n), calculated from the temperature by the method of Moshkovsky. Fig. 1 shows the estimated man-biting rates and calculated vectorial capacities, during one year of baseline observations, in the two villages that were extreme with respect to these variables.

The model distributes the human population into 7 states, in order to take into account the incubation period, as well as immunity and its effect on infectivity, the recovery rate and the detectability of parasitaemia; 7 equations describe the movements between the states as well as the effects of birth, death, and superinfection.

The model's principal output variable is the prevalence of patent *P.falciparum* parasitaemia, as a function of time (e.g. season) and, if the situation is stable from year to year, as a function of age as well. The model was fitted to the data from one year of baseline observations in the

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[a] Invited paper presented at the meeting "Comprehensive Vector Control - Current Status and Research Needs", Gainesville, Florida, April 13-16, 1982.

two villages already referred to; certain parameters (e.g. the rate of acquiring "immunity") were estimated through the fitting process. Fig. 2 shows the resulting fit between the observed P.falciparum rates and those put out by the model, by village, age and season. The model appears to describe rather realistically the effect of age on the prevalence of P.f. and on the amplitude of the seasonal variation.

The next step was to test the model by using as input vectorial capacities calculated on the basis of entomological data from different situations, without changing the other parameters, and to compare the prevalence put out by the model to the prevalence actually observed. This was done with data collected in Garki itself after residual spraying propoxur, as well as with data collected in Kisumu, Kenya, before and after residual spraying of fenitrothion (3). Fig. 3 shows the comparison between the observed prevalence of P.falciparum and that put out by the model, in the untreated control area and in the sprayed area. Here also the model behaves rather realistically.

The model, and the fitted parameter values can be used to describe the relationship (at equilibrium) between prevalence of P.falciparum and vectorial capacity. This relationship is shown in Fig. 4. The two main characteristics of the relationship are: 1/. the existence of a (nonzero) critical vectorial capacity below which malaria cannot maintain itself; 2/. the sensitivity of malaria to small changes if the vectorial capacity is close to the critical level, in contrast with the insensitivity of malaria to large changes in the vectorial capacity when the latter is much larger than the critical level. Qualitatively, the same characteristics were already demonstrated by the first (and simplest) of all malaria models namely the model of Ross. The Garki model introduced more realism with respect to the quantitative and dynamic relationship between measurable parasite rates and vectorial capacities.

The implications of Fig. 4 for planning vector control in a given malaria situation are that it is desirable to know: 1/. the baseline vectorial capacity; 2/. the reduction in vectorial capacity that can be expected from application of various vector control strategies. Unfortunately, these things are not easy to measure. The following section looks at some contributions from Garki in this respect, but much remains to be done (see below, outstanding problems and suggestions for further work).

1.2 Mosquito behaviour and insecticidal impact

The impact of propoxur on the man-biting density of A.gambiae s.l. varied significantly between villages, and the relative effectiveness of propoxur was a stable characteristic of the village from one year to the next (4). The phenomenon was not related to spraying coverage, nor to distance from unsprayed villages, but it was correlated with the pre-spraying ratio between the man-biting density (estimated by night-biting collection (NBC)) and the indoor resting density (estimated by pyrethrum spray collections (PSC)) as shown in Fig. 5. The ratio may be interpreted as an index of exophilic behaviour. The difference in vector behaviour between the villages could be due to genetic and/or environmental changes.

There was no correlation with the relative abundance of the two species of the gambiae complex present in the area (A and B, i.e. A.gambiae s.s. and A. arabiensis), but Coluzzi found that the frequency of certain chromosomal inversions within each of the two species was significantly correlated with the variation in effectiveness of propoxur between villages and also with the method of collection and hence with behaviour (5). Possible implications of these findings are: 1/. resting behaviour may vary between individuals even within a local population of a true species; 2/. intraspecific genetic differences between neighbouring villages may be relatively stable, i.e. there may be relatively little exchange between the gene pools. What is the predictive value of a simple index like the NBC/PSC ratio? This was explored with the Kisumu data and it was found that the fact that fenitrothion was much more effective in Kisumu than propoxur had been in Garki was largely predictable on the basis of the much lower prespraying NBC/PSC ratio in Kisumu (4).

If the resting behaviour of the individual vector is stable, this has implications for the interpretation of insecticide trials. After application of a resitual insecticide, it is usual to observe a reduction in number and in average age. The latter is usually interpreted under the (implicit) assumption of uniform behaviour and exposure (typically a new p is calculated by taking the appropriate root of the new proportion parous). It is easy to show that this is the most optimistic interpretation of the findings, with respect to the expected reduction in vectorial capacity (6). Fig. 6 compares the calculated reduction of vectorial capacity corresponding to a given reduction in proportion parous, under the usual (implicit) hypothesis of uniform behaviour and under the contrasting hypothesis that the vector population is a mixture of completely endophilic and completely exophilic individuals. Reality is likely to lie between these two extremes. In testing the Garki model under the impact of propoxur, both hypotheses were tried, and the hypothesis of non-uniform exposure yielded a much more realistic parasitological output (6). In addition to this rather indirect evidence, Coluzzi's findings provide a direct proof of genetically determined heterogeneity of resting behaviour.

Some entomological observations were continued for about three years after the last application of propoxur. Some of the findings suggested persistent behavioural selection, but it was not possible to disentangle possible persistent selection from the persistent direct effect of propoxur, demonstrated by a high mortality in the contact bioassay tests early in the wet season as much as 3 years after the last application of propoxur (this was the last observation made). Incidentally, this raises a problem concerning the evaluation of several insecticides in relatively rapid succession in the same village.

2. Some outstanding problems and suggestions for further work

There is work required on the human and parasitologic components of malaria models, especially if we want the models to be of use in exploring questions regarding other species (P.vivax), vaccination and drug resistance, but here we consider only the vector component of malaria transmission models. Vector population models may be equally or more important, but they form the subject of Dr Weidhaas' presentation.

The practical measurement of the vectorial capacity is a problem, and work and/or guidelines are required on collection methods (e.g. substitutes for the collection on human baits), sampling design, method of examination (alternativ methods of age-grading), methods of statistical analysis.

Vector survival is both the most crucial and problematic component of the vectorial capacity. The usual formula assumes exponential survival and no effect of the infection of the vector. Both assumptions are in contradiction with certain observations (7, 8) but the importance of this for malaria models is largely unexplored. Whatever the survival function adopted, the evaluation of its parameters from census data is a problem in itself (9).

The question of heterogeneity of resting behaviour merits further field and/or laboratory work. A related question concerns the possible heterogeneity with respect to host choice; this affects the computation of the vectorial capacity and of what can be expected from manipulations of the man-vector contact, e.g. through zooprophylaxis, or from attempts to affect the vectors through chemicals introduced into animal host populations.

What precedes refers mostly to what may be called the direct measurement of the vectorial capacity. Indirect methods exist, but their practical use requires some development. If we know the quantitative relationship between the vectorial capacity and some of the dependent variables, we can use the latter to estimate the vectorial capacity. Fig. 4 suggests that at low levels of vectorial capacity, very difficult to measure directly, parasitologic (and serologic) methods are sensitive, whereas they are insensitive at high levels of vectorial capacity, easier to measure directly. The entomological inoculation rate (number of sporozoite-positive bites/man/time unit) increases with the vectorial capacity even at very high levels but the quantitative relationship is not well known. If a reliable method were developed for the detection of antisporozoite antibodies, it might remain discriminatory beyond the level of vectorial capacity at which parasitology and the other immuno diagnostic methods reach a ceiling.

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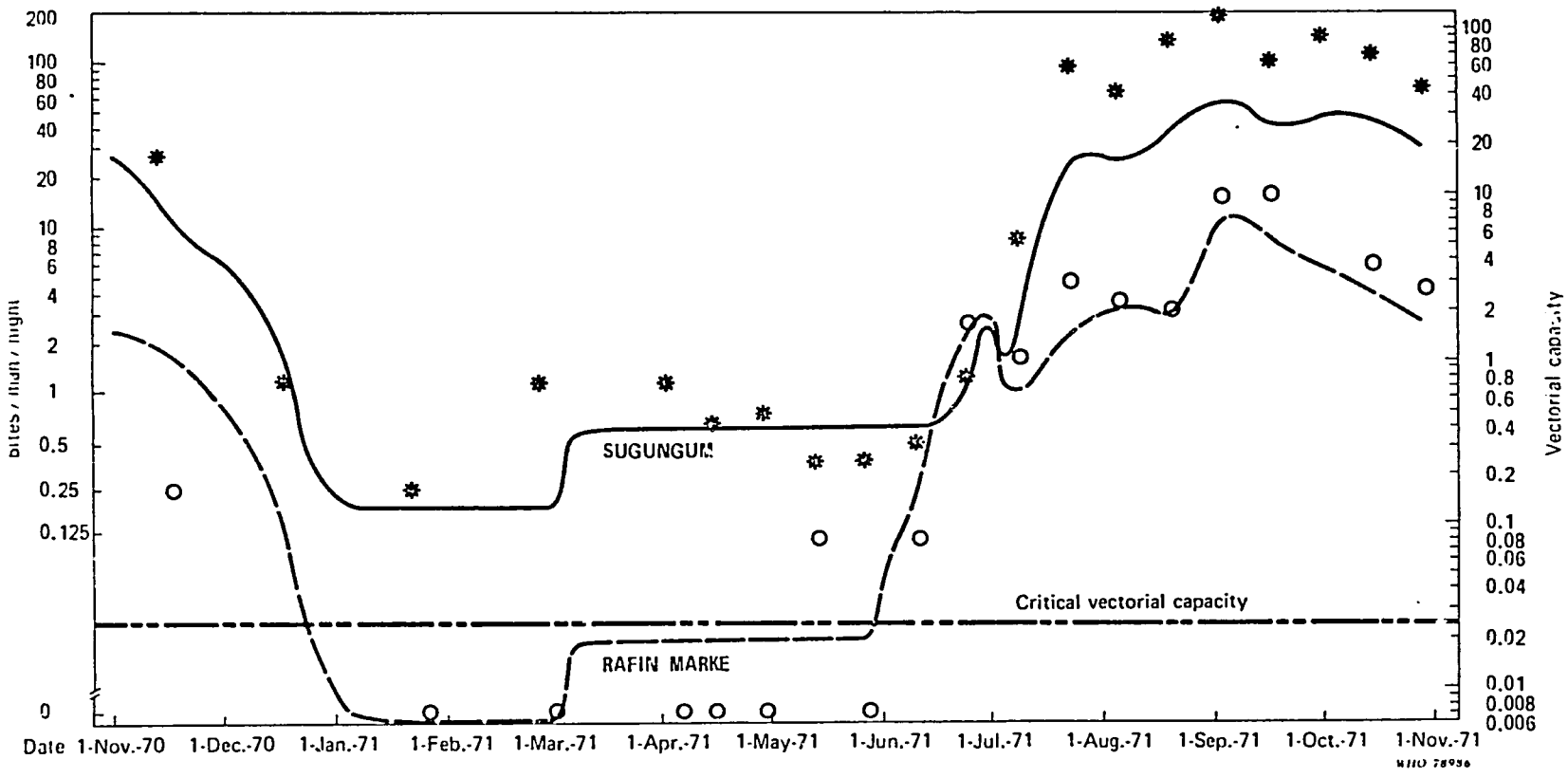


Fig. 1. Observed man-biting rates (asterisks and circles) and estimated vectorial capacities (solid and broken lines) for A. gambiae and A. funestus combined.

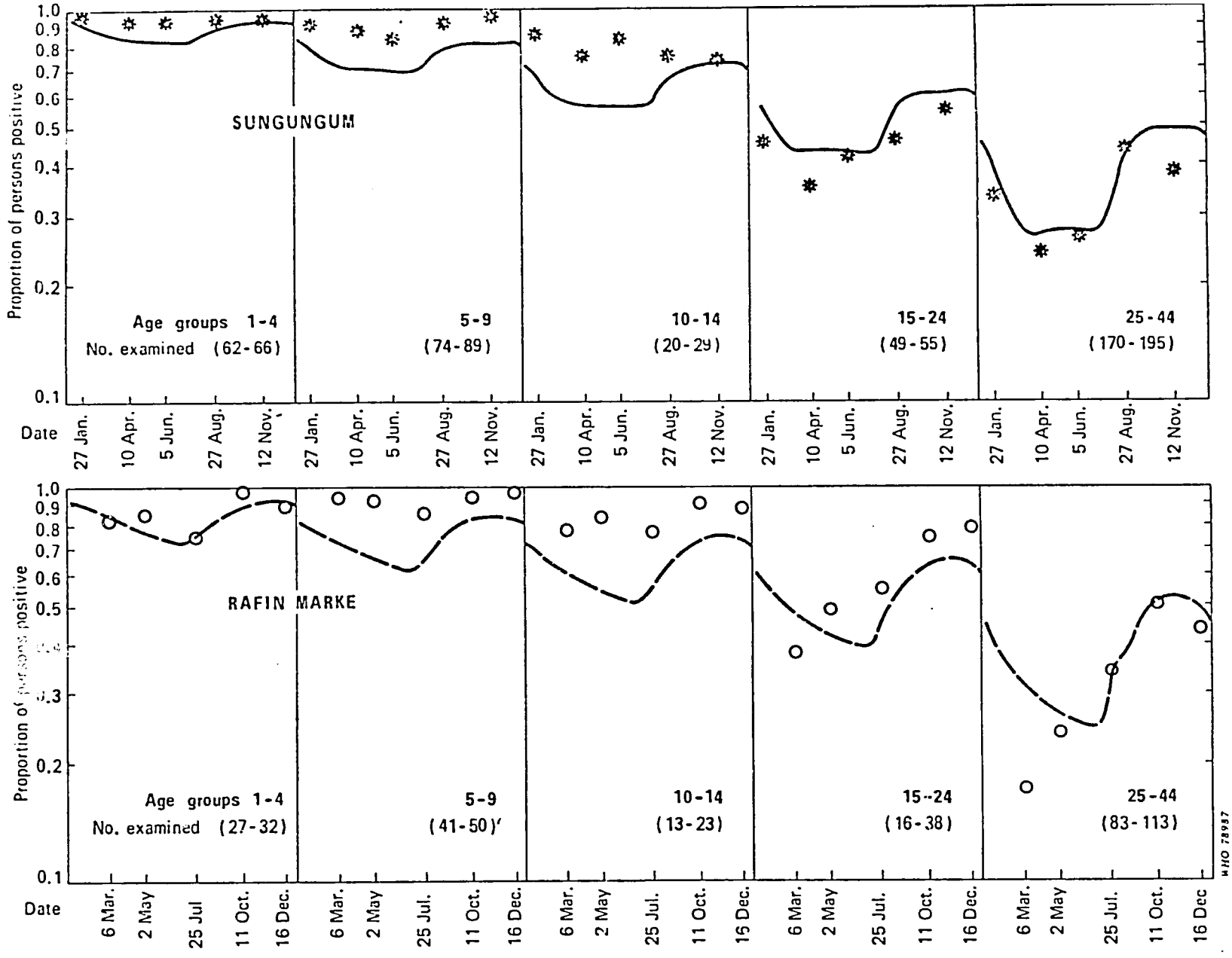
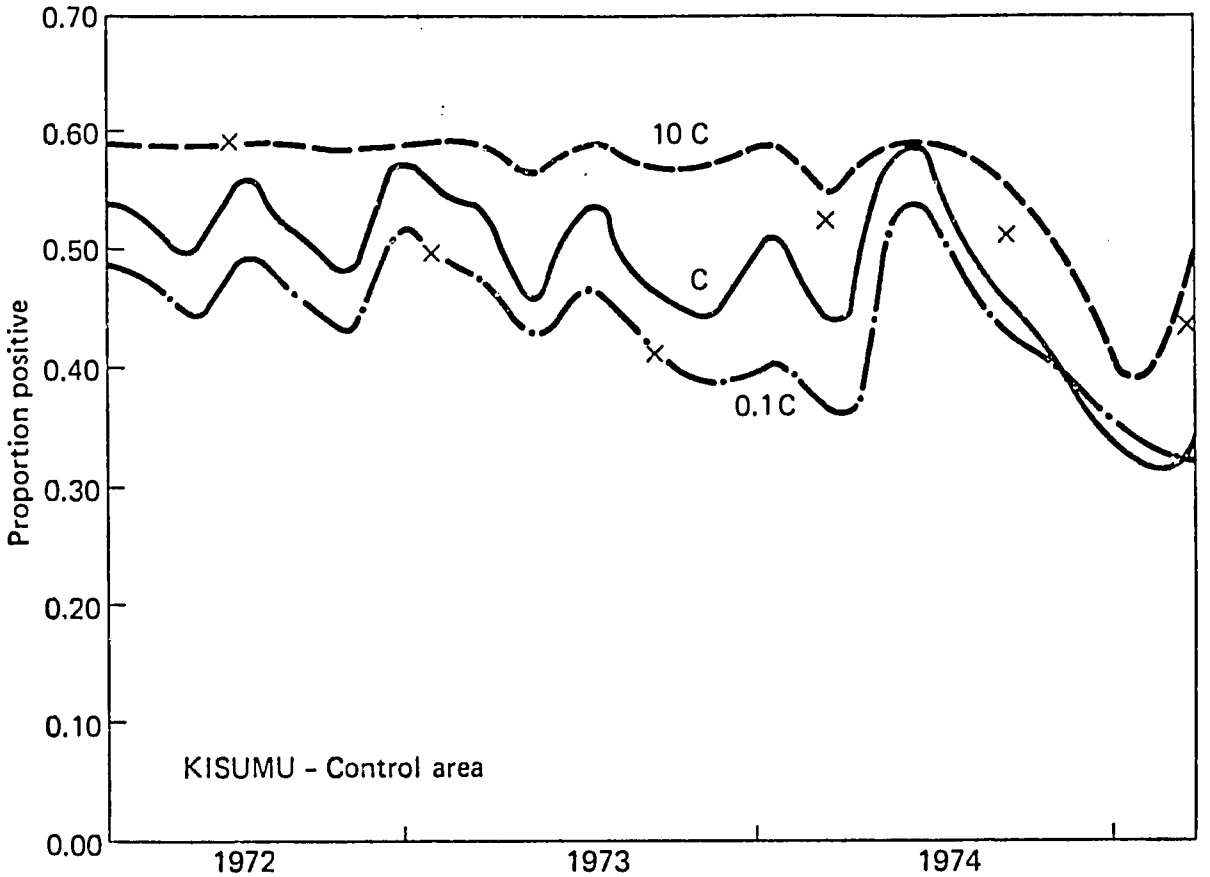


Fig. 2. Comparison of observed (asterisks and circles) and simulated (solid and broken lines) apparent proportions positive.



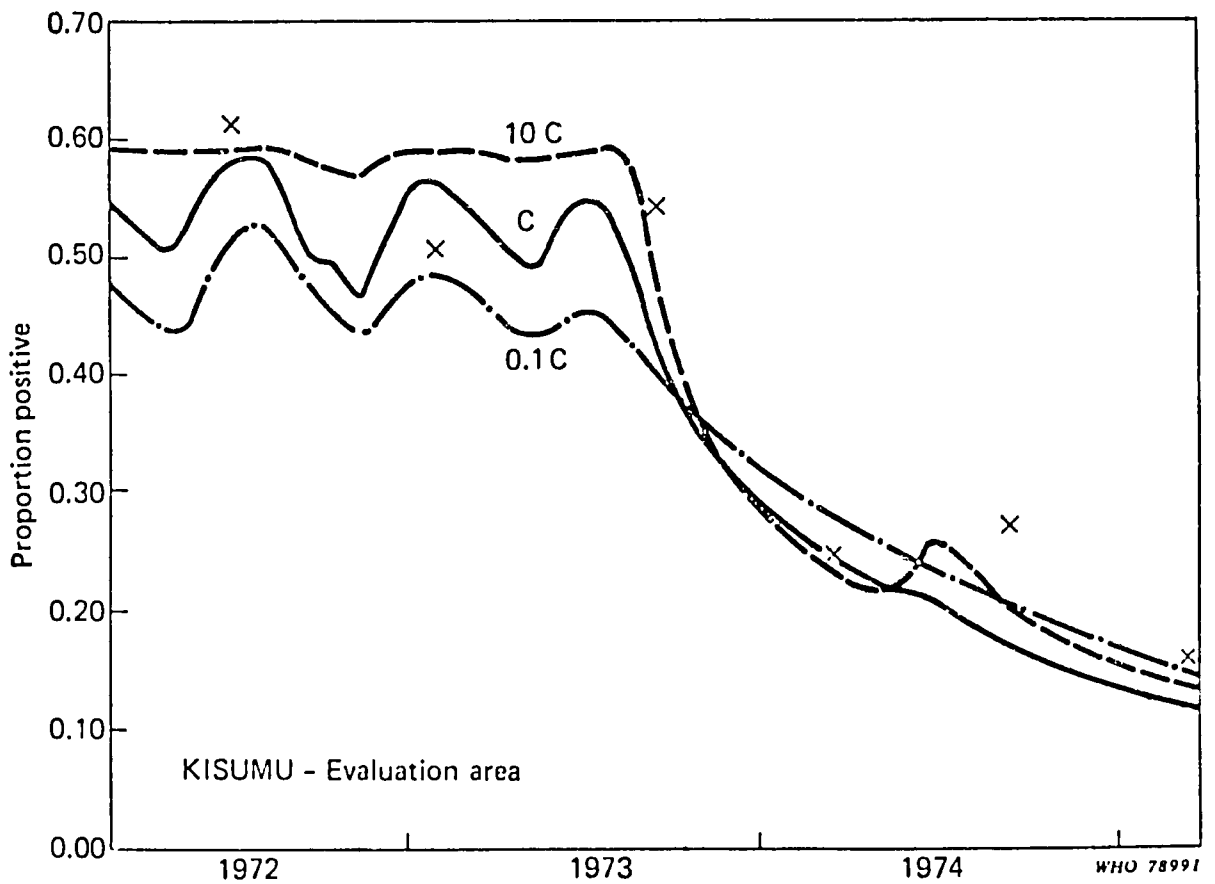


Fig. 3. Kisumu, untreated control (top) and evaluation (fenitrothion in 1973-1974) areas. Prevalence of P.falciparum observed (X) and calculated from the estimated vectorial capacity (C) and from 10C and 0.1C.

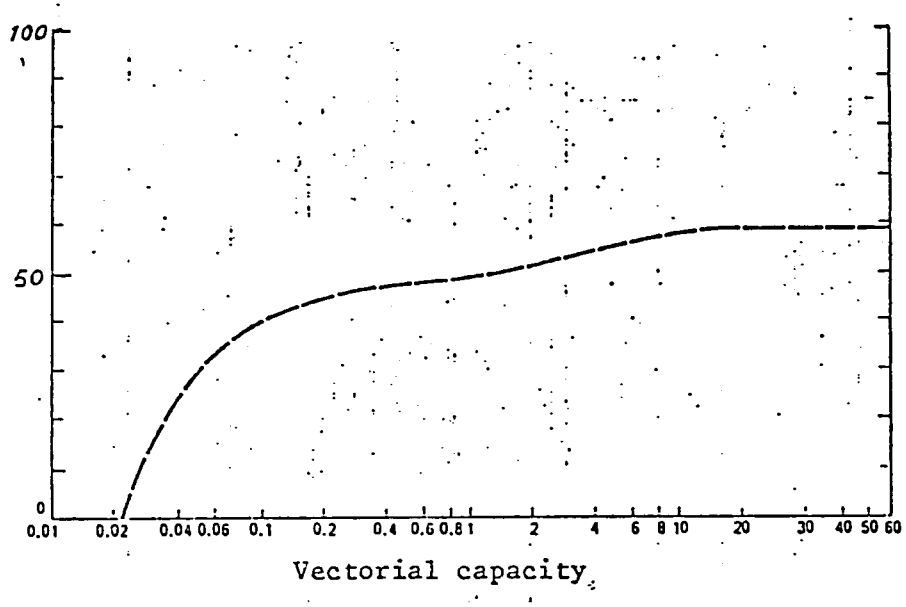


Fig. 4. The relationship between the vectorial capacity and the prevalence of patent P.f. parasitaemia. (From Dietz et al, Bull. WHO, 50, 347-357, 1974)

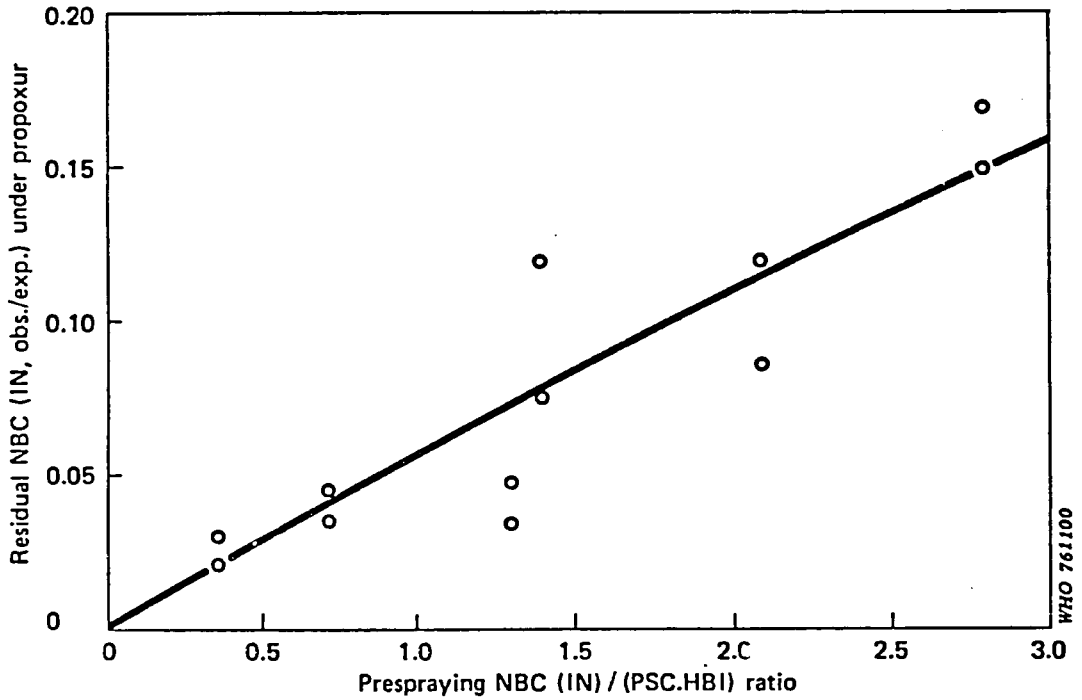


Fig. 5. The prespraying NBC (IN)/(PSC.HBI) ratio of A.gambiae s.l and its residual NBC (IN) under propoxur, by village.

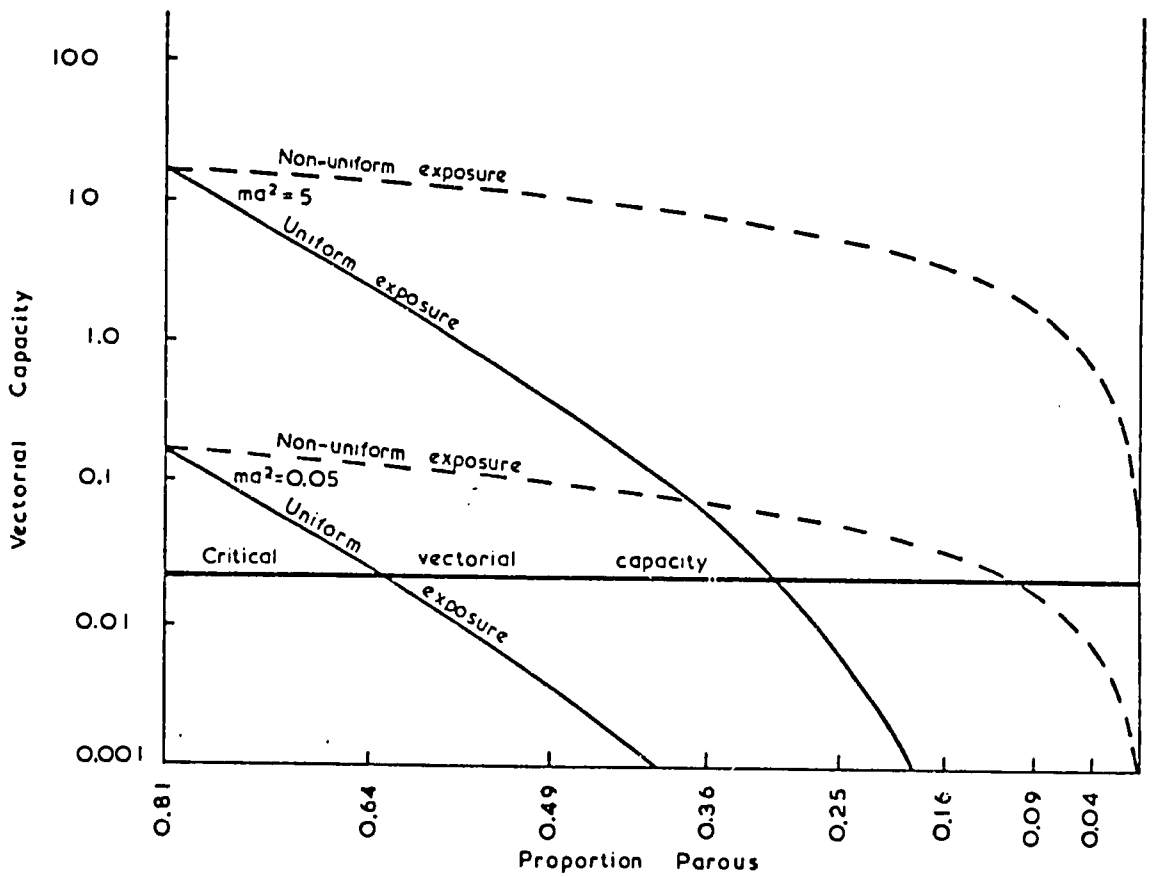


Fig. 6 The reduction in vectorial capacity corresponding to a given reduction in proportion parous, according to the models of uniform and non-uniform exposure at two levels of ma^2 (baseline proportion parous $P_1 = 0.81$; $p_1 = \sqrt{P_1}$; $n = 10$).

Models and Computer Simulations Relating Vector Control to Vector Density and Malaria

D. E. Weidhaas and D. G. Haile

Several important considerations suggest that there is a need to construct quantitative models adaptable to computer simulation that would mimic the density of all stages of mosquito vector populations as they exist in nature and, then, either evaluate or predict the effect of various control methods, applied singly or in combination, on the density of the populations over extended periods of time. First, it seems obvious that with the large number of variables involved it would be impossible to quantitate their interactions without the assistance of a computer to calculate and store the large number of changing values. Then such models and simulations would be excellent training and educational tools. They would highlight the major entomological factors (i.e. life history parameters) influencing density and provide the ability to "mimic" or "reproduce" season-long density trends of mosquito populations with or without the application of control methods. They would help in translating a large body of data on the immediate reductions in density resulting from control applications to the effect on the total population (all stages of the vector) over time. They would allow the development of hypotheses on appropriate timing and combinations of control methods and aid in the planning of field research designed to improve existing control methods or develop new ones. With the possibility of additional methods of control being developed at any time in the future, i.e. biological, attractants, pheromones and genetic, they would provide a means of studying their potential prior to extensive field testing. And, of course, they would provide a means of highlighting missing data and information. Although such models and simulations may not be considered essential to the development of control methods and strategies, they can be an effective tool in planning and development. Furthermore, the combination of complete life history models of vectors with epidemiological models for disease transmission, i.e. the development of the parasite in the vector and the human host, similar to the mathematical models of MacDonald and the Garki Project would permit evaluating the effect of many different control methods not only on the vector but also on the prevalence and incidence of disease.

Models describing insect density, population dynamics, insect control and disease transmission are not new. Most researchers and operational specialists construct visual, descriptive or graphic models for any problem they undertake and then test and quantitate the model through experimentation and experience. Computer technology now permits the process to be much more detailed with the interaction of many variables. For insect control specialists Knipling illustrated about 25 years ago, through mathematical models, the interaction of a control method, i.e. sterile insect releases, on the dynamics of an insect population using only density, growth rate, and the degree of sterility as controlling parameters. He used the generation concept as his unit of time. MacDonald emphasized the applicability of mathematical models in studying malaria transmission by identifying and quantitating major entomological and epidemiological parameters, particularly vectorial capacity.

The development of computer simulations applicable to insect population dynamics, control and disease transmission is a recent development and many types have appeared in the general field of entomology. They all are based on the available data on the life history development of the organisms involved and key parameters controlling their development. They may be primarily "mathematical models" in which transition from one condition or form to another is controlled by a rate equation. Or they may be primarily based on a "life history approach" where transitions from one condition or form to another occur between defined age classes of all stages and types of the insect, disease and host. Or they may be a combination of both of these approaches.

Our interest in computer simulation models has centered on the development of models based on complete life history tables for the insect, disease and host using a minimum of key entomological or epidemiological parameters to control the results of the simulations and we have decided to use this approach for illustration, although other approaches are possible.

Figure 1 illustrates a life history table of an anopheline mosquito, in this case *Anopheles albimanus*, that depicts the structure and function of a vector model. The model divides the insect into its four developmental stages - eggs, larvae, pupae and adults and malaria infected adult mosquitoes and further subdevides these types into daily age classes. Thus, three parameters control the structure of the vector model: (1) development time of the immatures, i.e. eggs, larvae, and pupae; (2) the preoviposition time and (3) the cycle of biting and egg laying. In most cases we keep these parameters constant, but they can be made variable with temperature. Four other parameters are used to quantitate the model, i.e. supply numbers of the individuals in each age class and move them through time on a daily basis: (1) average daily survival of adults; (2) average daily survival of immatures; (3) number of eggs per oviposition; and (4) the sex ratio. Thus, if sufficient data on a vector species is available, it is possible to initialize a simulation, i.e. supply actual numbers for all (or any) of the age classes present on the day a simulation is to begin and then advance all age classes through time on a daily basis. Only a computer can handle all of the calculations involved and store those of interest for future use. To date we have controlled the density of the vector by varying the average daily survivals of the adults and immatures on the basis of existing seasonal density curves or estimated data on survivals.

This approach should be useful to those primarily interested in vector control. Since all stages of the insect are quantitatively followed each day, it is possible to program any control method or combination of methods and evaluate its effect on the density of the population over time. The only requirements are that the effect of the control method be described quantitatively and, if it is naturally-occurring living organism, that its life cycle and the host interactions also be described quantitatively. We have conducted such simulations for adulticide and larvicidal treatments, attractants, sterile insect releases, release of genetically-altered insects, release of biological control agents, including *Toxorhynchites*, a pupal parasite of house flies and a nematode of mosquitoes.

An extension of this vector life history model to the transmission of disease, such as malaria, would permit us not only to study the effect of control on population density, but also to study the relationship of insect population density and control to the prevalence and incidence of disease in much greater detail including the number of new cases (infections) occurring daily. Figures 1 and 2 include an illustration of a model describing the development of *falciparum* malaria in both the vector and the human host. It provides daily age classes of humans and a single class of susceptible humans. Immunity and superinfections are not programmed in this model. For the mosquito, two parameters determine the number of female mosquitos that become infective: (1) development time of the parasites in the mosquito and (2) the average daily survival of the females carrying the parasite. The various stages of the parasite in the daily age classes of infected humans are illustrated in Figure 2. Human-biting female mosquitoes without the parasite (Figure 1) become infected by the malaria parasite in proportion to the number of humans with sexual forms of the parasite capable of giving them to mosquitoes (Figure 2) compared to the total human population. The number of susceptible humans newly infected with malaria is a function of the number of infective females and the proportion of susceptible humans. The model dealing with the development of malaria in the vector and human can be initialized with any level of prevalence of malaria

representing either epidemic or endemic malaria and then be updated daily by computer simulation. Thus, it is possible to conduct simulations of vector densities with or without the application of control practices to determine mosquito biting rates on humans daily over extended periods of time and then run simulations to study daily the prevalence, incidence and new cases of malaria as well as the sporozoite rate by interacting the mosquito biting rate on humans with the malaria development part of the model. Output can be tabular or graphic and in the simplest case could include, on a daily basis, mosquito biting rate on humans, sporozoite rate, % positive blood slides and new cases.

An example of the use of this model system is included for illustrative purposes. Recently we were trying to decide whether to pursue research on the development of animal treatments for the control of mosquitoes that transmit malaria. The argument supporting this concept was simple. Since malaria control was achieved in the past by placing toxic residues on surfaces inside houses where mosquitoes were predominately endophilic, e.g. 80% went inside houses to contact the treatment, then malaria control should result if toxic residues were maintained on animals where the mosquitoes were predominately zoophilic, e.g. 80% of the blood feeding occurred on domestic animals. We wanted to evaluate this idea further and examine the theoretical requirements, in terms of the percentage of females visiting animals that would have to be killed each day to effect vector and disease control.

We used the simulation model described above to define an annual biomdal density curve for the vector and then followed the prevalence and incidence of malaria over the same period of time. We ran the simulation several times with and without animal treatments as follows:

1. No insecticide or drug treatments to control the vector or the disease were programmed. Prevalence of malaria was followed on a daily basis with final output of incidence. One simulation assumed a starting prevalence of 1.5%; a second, 30%. Eighty percent of blood feeds were considered to be zoophilic with human and animal feeding random.

2. Same as above (#1) except simulations were programmed to kill 10%, 20%, 30%, or 40% of the 80% of the females feeding on animals each day for 360 days.

3. Same as above (#2) except that simulations were programmed for a density-dependent increase in growth potential of the vector when the population was reduced by insecticide treatment.

Table 1 provides a summary of the results of these simulations. Without treatments of any kind to control malaria, our simulations - with the values we chose to define, initialize and run the simulations - showed a final prevalence of 56 and 49% on day 360 and incidence values of 1.1 and 1.4, respectively for initial prevalence values of 1.5 and 30%. Our human population was set at 100,000 individuals so the number of malaria cases was high, i.e. approximately 1 and 1.5 per individual.

Table 1 illustrates that if an animal treatment could be developed which: (1) maintains only 20 to 30 or 40% of the animals completely toxic to female anophelines which feed on them or (2) keeps all of the animals sufficiently toxic to kill 20 to 30 or 40% of the females that feed on them, then malaria control would result and elimination would occur at some time as long as the treatments were continued and malaria was not reintroduced into the area. When no density-dependent regulation of growth potential was programmed, reductions in incidence of malaria ranged from 66 to 99% and no new cases of malaria occurred after day 128 to 346. When density-dependent regulation was programmed, the reductions were, of course, less and times to the last occurrence of a case of malaria were longer.

Our conclusion was that the treatment of domestic cattle is, at least theoretically, possible and represents a method which should be considered for malaria control where domestic animals are maintained and accessible for treatment. Obviously, programming our simulation to kill 50% of the females visiting animals would increase the effectiveness and provide more rapid control of malaria. Combination of the method with the concurrent availability of drugs through active and/or passive case detection as a presumptive treatment offers further promise. Drug treatment to reduce the prevalence of malaria at the same time the vector is killed and controlled should have a dramatic effect. Although we have not yet programmed our simulation to include presumptive treatments of malaria with drugs, we plan to do so. The effect is evident when comparing simulations of 40% kill with starting prevalences of 1.5 and 30% with the density-dependent rens, i.e. a final prevalence of 0.1% and 100% reduction in incidence with the last case occurring on day 249 compared to the values 3.7%, 92% and day 308. Although the approach appears intriguing, its development requires that methods of treating animals to keep them toxic to vectors be developed and that these treatments remain effective for relatively long periods of time, i.e. weeks to months. Further information is needed on the types of animals and husbandry practices.

Thus, it appears that vector and disease models can serve as a tool in planning and developing vector and disease control strategies. Their further development could lead to their use in planning and executing organized vector control programs. However, it appears that their use will be limited to researchers and large organized programs in the near future.

The further development of models and simulation techniques should be pursued and extended to more species and diseases. Inclusion of the effects of climatic factors such as rain, temperature, food and others on developmental cycles would improve the precision of the simulations for specific objectives. Since these types of models and simulations depend upon data obtained in all aspects of vector biology and control, research in biology and control which allows quantitative assessments of key parameters is a prime requirement.

Figure 1. Life history description of an anopheline mosquito such as *Anopheles albimanus*.

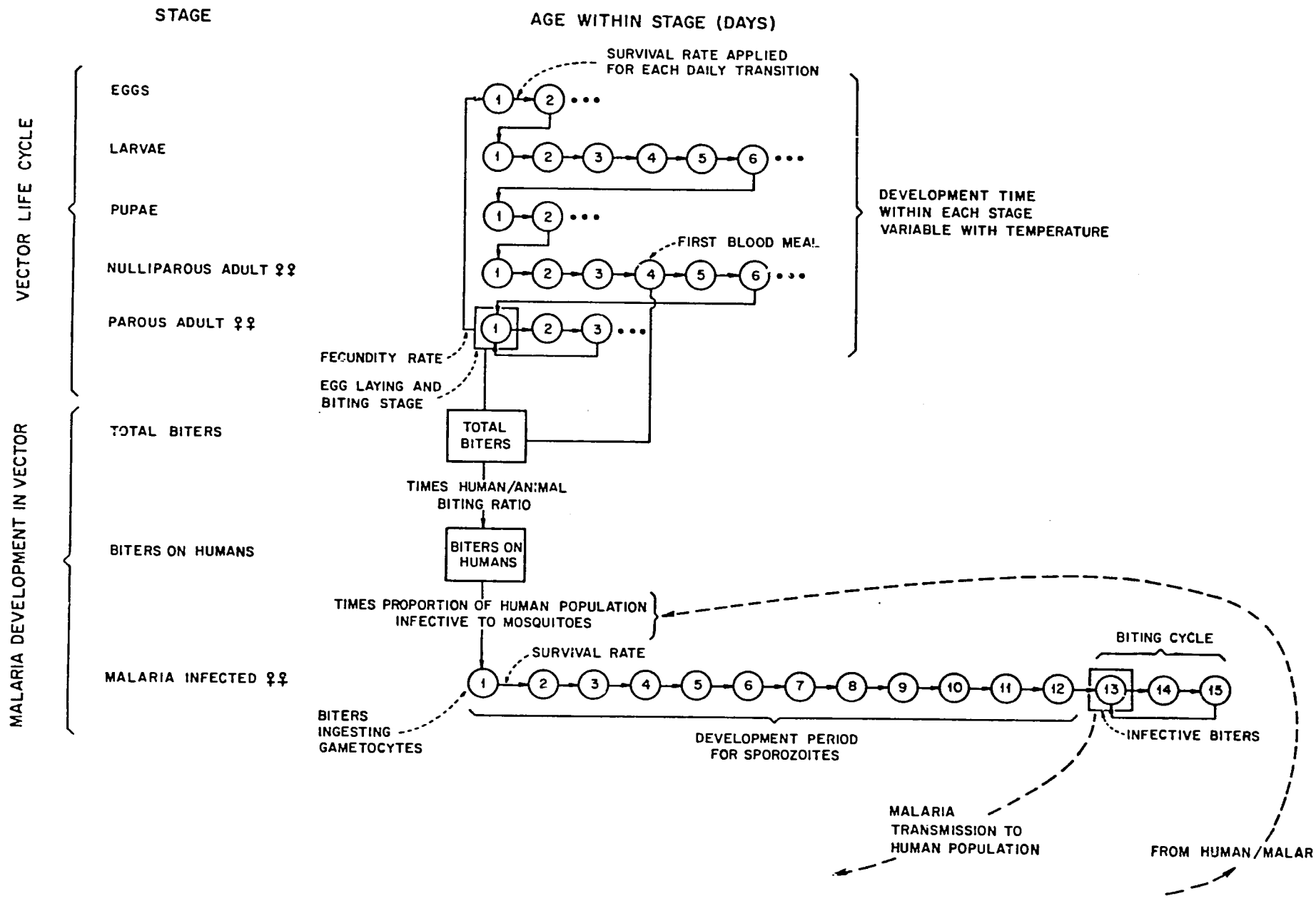


Figure 2. Diagram of development of malaria parasite in the human population.

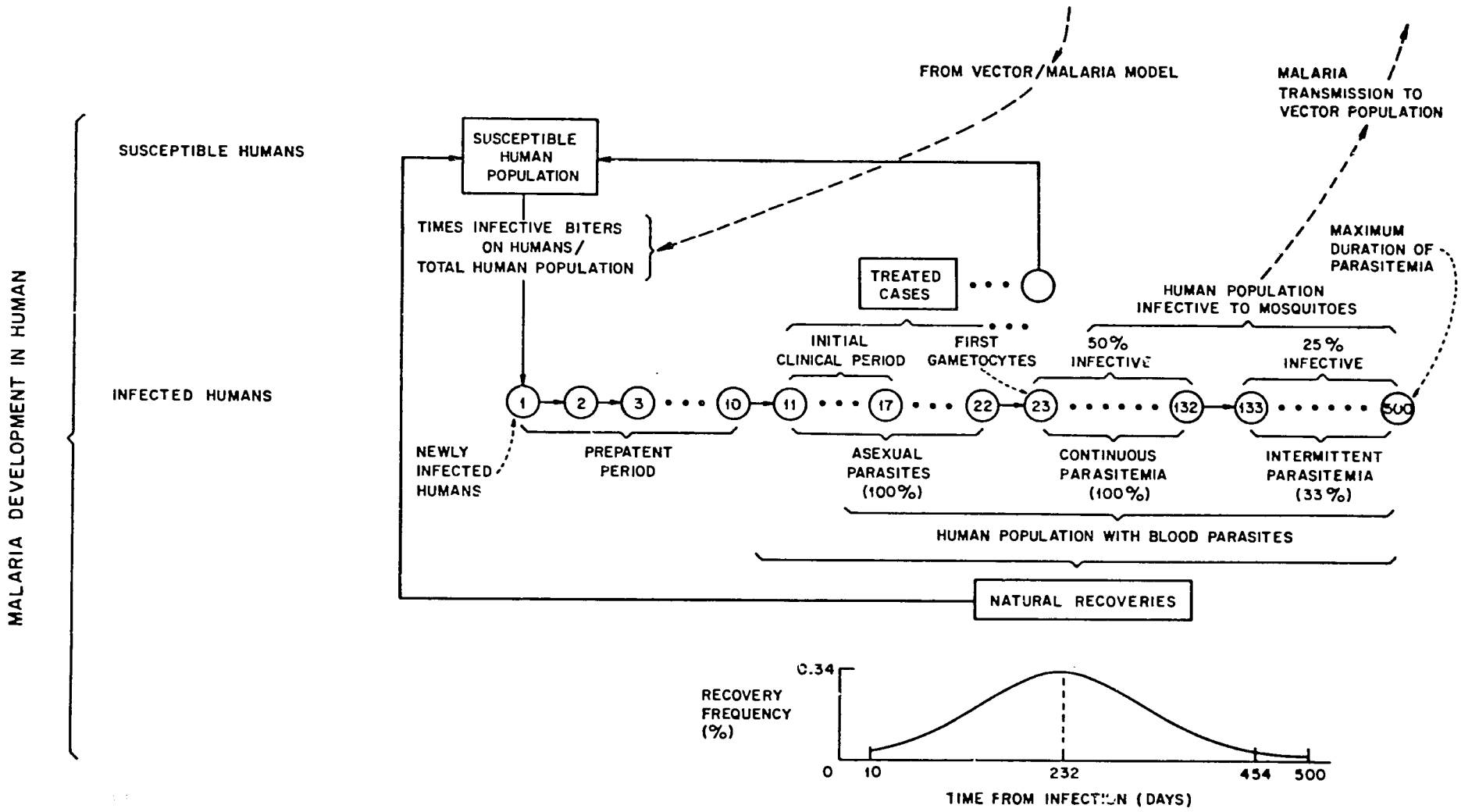


Table 1. Prevalence and incidence of malaria in a theoretical simulation model with and without toxic treatments to domestic animals.

% kill each day of females	Initial prevalence (%)	Final prevalence (%)	Incidence	Last day on which a new malaria case occurred *	%reduction in incidence
		Density-independent simulations			
None	1.5	56.4	1.14	---	--
10	1.5	20.4	.29	---	75
20	1.5	0.8	.02	290	98
30	1.5	0.1	.006	128	99
None	30	49.4	1.41	---	--
10	30	41.3	1.14	---	19
20	30	17.3	.48	346	66
30	30	3.0	.14	286	90
		Density-dependent simulations			
None	1.5	56.4	1.14	---	--
10	1.5	75.1	1.00	---	13
20	1.5	15.3	.21	---	82
30	1.5	1.0	.02	318	98
40	1.5	0.1	.01	249	100
None	30	49.4	1.41	---	--
10	30	44.1	1.28	---	9
20	30	48.5	1.11	---	21
30	30	26.5	.52	---	63
40	30	3.7	.11	308	92

* In simulations over a 360-day period, no figures in this column indicate some new cases of malaria occurred throughout.

10.1

COMPREHENSIVE VECTOR CONTROL

CURRENT STATUS AND RESEARCH NEEDS: A VIEW FROM AFRICA

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1. INTRODUCTION

Without doubt, malaria is among the foremost (if not the foremost) causes of morbidity and mortality in tropical Africa; it accounts for more than 10 per cent of outpatients and the same proportion of inpatients. Mortality in hospitals due to malaria has been estimated at 2.0 per cent, and that outside hospitals may be higher.

The control of malaria in Africa today emphasizes chemotherapy and chemoprophylaxis/chemosuppression in rural areas and larval control in urban areas, although both approaches have their drawbacks.

Although chemotherapy reduces specific mortality and chemoprophylaxis/chemosuppression reduces both specific mortality and morbidity, the latter are facing serious problems associated with drug distribution, noncompliance and more lately resistance to both antifolates and 4-aminoquinolines. Unfortunately, alternatives are yet to be introduced on the market.

2. VECTOR CONTROL

Since antimalarial drugs cannot be fully relied upon in malaria control, vector control deserves a closer look.

Vector larval control is the method often used in urban areas of Africa. This measure is currently running into serious problems which are probably mainly due to the current financial crisis that is gripping nonoil producing African states. Administrative constraints also play a major role in many situations.

Since the discovery of synthetic insecticidal chemicals, lamentably little source reduction is employed in urban areas of Africa.

In African rural areas, malaria vector control is often lacking. The defeatism has its recent roots in the experiences gained from the various malaria pilot control/eradication projects which were undertaken in different epidemiological conditions: malaria eradication was only achieved in islands far from the African continent (Réunion and Mauritius); the results ranged from good in tropical forest areas (e.g. South Cameroon and Madagascar) and in the southern fringes of malaria transmission (South Africa, Swaziland and Zimbabwe), to very poor responce in the lowland savanna. Wherever malaria was unstable in the fringe savanna areas and semideserts, where malaria was hypo- to mesoendemic very good results were obtained (e.g. Sudan and Somalia).

A closer examination of past experience in the lowland (dry) savanna shows a string of failures: malaria transmission could not be interrupted. The most recent reported failure was with the "Garki Project" in Northern Nigeria where residual spraying with proposur, failed to effect reduction in the man-biting An.gambiae s.s. and An.arabiensis populations. This failure was attributed to the exophilic behaviour of a significant part of the vector population. Previous workers in similar situtions had attributed failures to such shortcomings as: insecticide resistance, exito-repelenca, insufficient insecticide dosage, long interval between insecticidal applications, sorption, wearing off of treated surfaces, immigration of either hosts, incomplete coverage and high baseline level of transmission.

From their experience with the Garki Project, Molineux and Gramiccia (1980) concluded that "in rural areas of the Sudan savanna of Africa residual spraying is not to be recommedned as a malaria control method". Even in an area where mass drug administration was combined with proposur domiciliary spraying, interruption of malaria transmission was not achieved, and the authors concluded that "MDA either alone or in combination with residual insecticides is not recommended in the rural areas of the Sudan savanna of Africa." One must also add that intradomiciliary spraying is not recommended for urban areas of Africa.

Further factors that contribute to failures in malaria vector control programmes in Africa include:

a) the shortage of properly trained technical staff to maintain equipment and transport;
b) the lack of properly trained and well motivated managerial personnel to run the control projects all the way from the national to the peripheral level;
c) human practices which may include evening gatherings outside protected human dwellings;
d) poverty both at individual and governmental levels - this is more so in nonoil producing countries, which are facing their worst ecomic crisis;
e) poor transport facilities;
f) failure to fully involve the intended beneficiaries in the entire vector control programme.

3. FUTURE RESEARCH NEEDS FOR VECTOR CONTROL

The future research needs for vector control in Africa are tremendous. Foremost there is the shortage of properly trained personnel to undertake research and control of malaria vectors. The introduction of three WHO/TDR supported courses in medical entomology will in future alleviate this problem if the courses have sufficient theoretical and practical inputs.

Besides the medical entomologists, there is a crying need for sanitary engineers, and sanitarians. These personnel must be well versed not ohly with the application of insecticidal chemicals but also with alternative vector control measures. A further group are programme managers, planners and health educators cum medical sociologists.

On the vector side, research must concentrate on the *Anopheles gambiae* complex. The other species, e.g. *An. funestus* are either easily amenable to control with residual insecticides, or their importance is only secondary. With *Anopheles gambiae* s.l. there is need for example to:

- Study vector bionomics of the sibling species;
- Study the behavioral differences of the species and relate this to role in malaria epidemiology;

- Develop and apply such identification methods as chromosomal and gene enzyme systems and correlate these with morphological characteristics
- Test new (and old) insecticidal compounds, establish diagnostic dosages and predict resistance;
- Undertake field trials of new insecticides;
- Study impact of use of insecticides in agriculture, on *An.gambiae* s.l susceptibility to insecticides;
- Study past experiences with source reduction measures and implement on pilot basis;
- Emphasize studies on biocontrol agents including rearing, culture or production under "laboratory" conditions, and undertake field trials;
- Develop equipment suitable for use by primary health care workers.
- Studies of knowledge, behaviors, attitudes and practices that are essential in eliciting and sustaining community participation in vector control.

SITUATION OF MALARIA IN THE AMERICAS

MARCH - 1982

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SITUATION OF MALARIA IN THE AMERICAS

MARCH - 1982

GENERAL INFORMATION

During many years, the antimalaria programs in the Americas rested on the theory of eradication, following rigid, almost inflexible, guidelines, based on the intradomiciliary application of insecticides of residual action and chemotherapy as a reinforcement, on which they placed their hopes and which became traditional.

A) Application of insecticides of residual action:

As a consequence of the agricultural development, the necesity for the application of pesticides for those purposes arose, causing a high degree of physiological resistance of the vector, in some cases, to almost all the available chemical compounds, which limited the effectivity of the intradomiciliary sprayings in large areas. As an example, we can mention four countries in Central America, known for their high malaria problem, which is located majorly in their respective coast of the Pacific Ocean, where the phenomenon of resistance is higher.

B) Chemotherapy administered in the different plans of treatment.

The abuse, which for many years was made in the eradication programs, with the massive distribution of antimalarials, produced weariness in the population and the consequent rejection of this measure, in addition to the resistance of the parasite to the four amino-quinoleines, detected in several

countries of the Continent. On the other hand, the two measures mentioned previously were applied, and are still being applied, in some programs, in an indiscriminating manner, all along the malarial area, without taking into consideration the local factors which originate the transmission of the illness, nor that the behavior of the malarial phenomenon differs from area to area, and even from village to village. The above is based on the fact that, despite having maintained for many years the strategy of eradication, it has not been possible to obtain the desired objectives and still 58.7 million people live in the zones with transmission of malaria (source: PAHO/WHO). Mention should be made of M.A. Farid's statements in the summary: "THE MALARIA PROGRAMME FROM EUPHORIA TO ANARCHY", from the document "WORLD HEALTH FORUM", which in part says: "many of the Third World countries they launched the biggest eradication programmes, whether in the Eastern or the Western Hemisphere, failed because they did not apply the eradication measures with the needed epidemiological insight and required efficiency. Experts sitting in WHO Headquarters in Geneva, whose job was to coordinate the global programme began to interfere, advising when to stop spraying and how to utilize the malaria funds, failing to leave the matter in the hands of those on the spot who knew about the local malaria situation".

In another part of the summary it also says: "I believe there is no such thing as a single global or regional strategy for malaria control, with WHO advising Member States concerning methodology to be used. This is something that national govern-

ments have to develop themselves, through their own efforts". And in another part it continues: "The countries of the Third World should realize that time is against us and should not waste time awaiting a therapia magna of future or until the WHO coordinate field operational research on malaria bears fruit, but instead they should act and learn by doing". End of quotation.

Actual situation of Malaria in the Americas

Also taken from the PAHO report, dated September 14, 1981, "Situation of the Malaria Programs in the Americas", XXIX Report, we observe that the number of cases continued to increase in 1980 and that in the last five years that increase was of 56% for the countries of the Region. On the other hand, we find that the eight countries considered in group IV, which only represent 18% of the malarial area of the Continent, produce 61% of the total cases and that of those Central America, with four countries, contributes with a high percentage to the problem.

CONCLUSIONS:

Facing the expressed reality, we believe that it is imperative to make a new plan of each of the programs, since it has been demonstrated that with spraying and medication the proposed results are not obtained, specially in those identified in group IV, which permits them to conform to dynamic strategy able to allow them to leave the stalemate in which they find themselves. We also think that it is necessary to establish the bases and objectives of this new strategy and a clear and defined plan of action which can serve

as an operational guide to the different programs, in accordance with their individual characteristics. Within this context, we can consider the following points as important:

1. STRATIFICATION

   We consider that this should be the first step, so that once the problem is identified in time and space, in small epidemiological operational universes, with their ecological and ethological local characteristics, we may proceed to select the measures to be applied in a combined manner.

2. EPIDEMIOLOGICAL INFORMATION

   Proceeding from or taking into consideration the stratification problem, it is necessary to also have the epidemiological information readily and on time, in order to be able to situate the phenomenon in the moment and place where it occurs with more intensity.

3. ENTOMOLOGICAL INFORMATION

   As an important complement we must also have a ready and sufficient entomological information, which together with the epidemiological information, will originate a dynamic epidemiology that will provide sufficient elements of judgement for operational effects.

4. REDUCTION AND/OR ELIMINATION OF BREEDING GROUNDS

   Faced with the technical problems, specially the physiological resistance of some vectors to insecticides and the resistance of certain parasitary strains to "Cloroquine", it is not possi-

ble to continue depending on these two measures. We think that the best weapon we have is the reduction and elimination of breeding grounds through engineering works, which go from the small and simple to the large and complex, in addition to biological and larval control. Naturally, we understand that in order to start or continue the antimalarial actions with this focus, it is necessary to have additional financing, specially for the design and construction of major works, as in the case of estuaries, river basins, etc.

5. DEVELOPMENT WORKS

We believe that the financing Organizations of development works must include within their general budget of the work, a reasonable percentage for development of actions of the health component and, specially, if they are works that will modify the environment for the control of vectors.

6. INTERSECTOR COORDINATION

A maximum effort should be made to obtain an effective and tangible intersectorial coordination, among all the organizations and government secretariats, which in one way or another act within the malarial areas of the different countries.

COMPREHENSIVE VECTOR CONTROL

by

C. P. Pant and N. G. Gratz

Globally about one thousand million people living in the rural areas or urban slums suffer from poverty and malnutrition and are subject to parasitic and infectious diseases. This is reflected in the average life expectancy at birth of about 50-55 years in the developing countries, as compared to about 72 years in the developed world. Infant mortality rate in the developing countries ranges from 100-200 per thousand as compared to 10-20 per 1000 in the developed countries. Problems of health and socioeconomic conditions are closely related and the disparities amongst and within countries are continually growing. Diseases transmitted by vectors, so rampant in the tropical developing world can seriously hamper socioeconomic development. Among the vector-borne diseases, malaria remains the most important with some 850 million people living in endemic areas that lack active control measures; there are an estimated 400 million cases annually. Lymphatic filariasis is a threat to approximately 500 million people with about 50 million infected cases. Schistosomiasis is endemic in about 70 countries and an estimated 200 million people are infected. Onchocerciasis or river blindness infections are about 20 million with 100 million people at risk. African trypanosomiasis, Chagas' disease, plague, yellow fever and other arboviral diseases also give rise to significant morbidity and mortality.

While considering the possibility of implementing effective vector control measures, to control these diseases, it is also interesting to digress a little and examine the GNP *per capita* in the countries affected by these diseases and their health care systems. In most developing countries, the GNP *per capita* ranges from US$ 200-1000 as compared to US$ 5000-10 000 in

most developed countries. Economic problems of unemployment, inflation etc. continue to plague most developing countries and further reduce their capacity of public expenditures including public health and specifically vector control programmes. To compound this difficult situation, the health systems and health services are poorly developed in many of the developing countries. Approximately two-thirds of the population still do not have a reasonable access to health care. Most of the health resources especially curative, are concentrated in the large cities. The proportion of the GNP spent on health is less than one per cent in many developing countries i.e., a few dollars/person/year.

It is within this context that the World Health Organization's main thrust of the Seventh General Programme of Work has been aimed at providing support to the national and international action so that "by 1989 at least 50 per cent of the coutnries severely affected by vector-borne diseases will have acquired means for self-reliant development, implementation and evaluation of vector control strategies involving communities in their self-protection". This is also in line with the global strategy for Health for All by the Year 2000, which aims at redressing some of the problems above and endeavours to make some form of health care available to all the people especially those living in the developing countries as well as in the developed countries.

Within this context, the proceedings of this seminar on comprehensive vector control will be most timely because we are at the cross roads as regards the strategies for vector control in many areas. Some of the techniques used in the past have not always been suited to the socioeconomic conditions of countries most affected by these diseases. There exists a wide gap between technological development and available resources in the tropical rural areas. The availability of several effective, safe and low

cost pesticides coupled with improvements in the technique of application made it possible for many governments to embark on extensive - in many cases nationwide - programmes for the control of vector-borne diseases. Due to several technical and administrative problems, this approach now faces many difficulties, although a certain measure of success has been achieved in a number of countries.

Approaches

We would now like to briefly review how we are planning to face the new challenges. The following are the main lines of activities.

Research and development

Continued emphasis is being placed on research and development. Promotion of studies on the bionomics, genetics and population dynamics as related to vector control with a goal oriented approach is made not only through the regular programme of VBC but also through the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases through its Scientific Working Groups. Investigations on several aspects of ecology, species complexes, and on the refractory behaviour of certain vectors have been emphasized. Some examples of this include the intraspecific variation in *Anopheles gambiae* s.s. and *An. arabiensis* with particular reference to their resting and movement habits, demonstration and study of the species *An. dirus* A and B, *An. culicifacies* A and B. Resting behaviour studies of *An. acontius* in Indonesia have contributed to the development of methods of rational use of insecticides and selective applications. The attraction of riverine tsetse flies to biconical and monoconal traps, have resulted in the development of cheap and effective methods of the control of these species by use of insecticide impregnated traps and further research continues to make these traps still more effective.

In the field of chemical control, WHO has operated a programme for the evaluation and testing of new insecticides for about 20 years. To date

about 2000 compounds have been evaluated for their effectiveness against disease vectors and safety to the operators and inhabitants of sprayed houses. Inasmuch as chemicals are likely to remain the cornerstone of vector control for many years to come this scheme continues in operation although, in recent years, the number of new compounds entering the scheme are fewer and fewer. It is now being modified to increase collaborative field trials with Governments.

Great emphasis has been recently placed on the development of suitable biological control agents. Bacillus thuringiensis serotype H-14 has been shown to be a very promising agent and is already commercially available. Here again the emphasis has been on an integrated approach so that this agent can be used in conjunction with other methods of vector control. The possibility of local production or formulation of the agent is being considered. This agent has already proved effective against black-fly larvae resistant to temephos and chlorphoxim the only two compounds which can be safely used in the river systems being treated by the Onchocerciasis Control Programme in West Africa. Preparations for large-scale trials against the vectors of malaria and filariasis are now under way and WHO will hold consultations soon on the local production of this agent.

Work on several other agents is in progress and WHO continues to collaborate with investigators in this field.

Amongst the larvivorous fish, several species are in current use, e.g. Gambusia and Poecilia. The emphasis now is to use this approach through community participation in the rearing and dissemination of the fish and this is the immediate short-term goal of research in this direction.

On the question of genetic control, a number of operational constraints have been identified and it is not foreseen that this method will receive active WHO support for the time being.

Environmental management source modification, drainage, proper irrigation and a multi-sectorial approach involving water development agencies for the control of disease vectors is again receiving prominent attention and this, together with the promotion of community efforts to bring about these measures, will receive growing importance in the years to come.

Training and dissemination of information

One of the major impediments in bringing about changes in vector control programmes is the lack of trained manpower. This arises out of the limited career opportunity and absence of a professional cadre within the ministries of health for medical entomologists in many developing countries. WHO has now assisted several universities in Asia and Africa and has plans to assist a university in South America in establishing courses in medical entomology leading to an M.Sc. degree in medical entomology and vector control. A few of these centres are now in operation, e.g. in Bangkok, Thailand; Bogor, Indonesia; Jos, Nigeria; Bouake, Ivory Coast and Nairobi, Kenya. Negotiations are underway for other such centres.

WHO has also actively participated in organizing training courses for middle level workers. This work has been often carried out in collaboration with bilateral agencies, such as DANIDA. About 10 such courses have been organized globally in which approximately 200 participants have been given training in practical aspects of vector control. In addition, WHO continues to support training fellowships and research grants through its regular programme or the special programme for research and training in tropical diseases.

In addition, dissemination of information through its various publications, seminars, workshops, scientific working groups and expert committees are continuously done and followed up.

Future prospects

In the immediate future, it is foreseen that a single approach through the use of pesticides will change to an integrated approach in vector control. This will be the subject of the next Expert Committee on Vector Control which will be held in December 1982 in Geneva. The trend of the global vector control programmes for disease control seems to be in the direction of community involvement through simple, economic measures, taking into consideration the whole socioeconomic factors to make a sustained and continuous effort in this direction. With the exception of a few programmes, such as the Onchocerciasis Control Programme where capital intensive measures, such as the aerial applications of larvicides seems the most cost-effective measure, comprehensive vector control using an integrated approach by selecting the most suitable combination of measures may be the solution for coming years, especially for many developing countries. This will mean a thorough study of the ecology of the vectors in the area and a good understanding of the control measures, chemical, biological and environmental and combination thereof and the ability to involve the community to attain a sustained and continuous effort towards reducing the vector density to a level that at which they do not pose a serious threat to public health. Towards this end, efforts have already been made at the vector biology and control research unit at Jakarta, but these need further expansion and study. It is thus being proposed now to expand the area of operations of the VBCRU-2 sub-unit in Semarang to include some of the outer islands and embark on research to identify specific problems and measures of control on the basis of the earlier discussion emphasizing:

(a) Integrated, multi-sectorial approach;

(b) Community action and participation.

Control of the vectors of DHF *Aedes aegypti*, bancroftian filariasis *Culex quinquefasciatus*, and Chagas' disease triatomines are other

examples where such approaches have an important role to play in many parts of the world.

The proceedings of this seminar will greatly help in the identification of some of the approaches.

CURRENT VECTOR CONTROL METHODS AND RESEARCH NEEDS IN MALARIA IN SOUTH EAST ASIA

by

Dr I.A.H. Ismail*

1. INTRODUCTION

As a result of the efforts been made by the anti-malaria campaigns in countries of the South East Asia Region the number of malaria cases decreased considerably reaching its lowest level of 228,408 cases in 1965. Since then, and until 1976, there has been a consistently increasing malaria incidence trend with the highest number of 7.3 million cases reported in 1976. In 1977, for the first time since 1965, malaria incidence showed a decline bringing the cases down to 5.6 million. As a result of augmented operations the down trend in malaria incidence has continued until the end of the decade with approximately 3 million cases reported in 1980.

The trend in the malaria incidence in the South East Asia Region is mostly affected by the situation in India, due to its large population. The two malaria outbreaks in Sri Lanka, one in 1968-1970 with an API of 50-60 and the other in 1974-1976 with an API of 30-40, also affected the malaria trend in the Region. Records of the malaria situation in countries of the Region, during the last few years, show an increase in Bangladesh, Burma, Indonesia and Thailand, a stabilization in Nepal and Sri Lanka and a decline in India and the Maldives.

2. VECTOR CONTROL MEASURES (Table 1)

2.1 Anti-adult

2.1.1 Insecticide residual house spraying

Insecticide residual house spraying continues to be the main anti-vector measure used for malaria control in countries of South East Asia. DDT, malathion and HCH are the insecticides used for this purpose.

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The first is still the insecticide most widely used.

In Burma, inspite of DDT resistance in An. culicifacies, An. annularis and possibly An. balabacensis in central, western and southern parts of the country respectively DDT continues to be the only insecticide used for malaria control.

In India, the three insecticides; DDT, HCH and malathion are being used. Resistance of An. culicifacies and An. stephensi, the two main malaria vectors, to one or more of these insecticides in different parts of the country, has reflected on their use and efficacy.

In Indonesia, An. aconitus has shown an increasing level of DDT resistance in central Java and the western part of east Java. Nevertheless, DDT continues to be used with varying degrees of success.

In the Terai of the central and western regions of Nepal where An. annularis the incriminated vector and An. culicifacies the suspected vector developed resistance to DDT and dieldrin, malathion, spraying is used on selective basis.

In Sri Lanka where malathion was introduced as an alternative insecticide after the appearance of DDT resistance in An. culicifacies there are no signs, so far, of the development of resistance in this species to the OP compounds or to dieldrin/HCH.

In Thailand, DDT continues to be the insecticide used on a countrywide basis. However, its effect on malaria transmission varies from one area to another, due to a number of factors including exophily and exophagy of the vectors, decrease in vector susceptibility to the insecticide in certain areas, and operational problems.

From the results of mosquito surveys and studies carried out in recent years it has been noted that some mosquito populations are showing an increasing shift to outdoor biting and resting. An. minimus, known as an endophilic and endophagic species in early days, is becoming more exophilic and exophagic in Thailand. It is not unlikely that the same

situation exists with other mosquito populations and vectors in different countries and areas in South East Asia. Following revision of control strategy and introduction of epidemiological stratifications with the aim of tailoring operations more closely to fit epidemiological requirements, there will no longer be blanket coverage by insecticides and this will result in a corresponding decrease in the amount of insecticide used. In the implementation of operations in stratified programmes full use will be made of available control measures in an integrated manner.

2.1.2 Space spraying

Space spraying mainly thermal fogging with malathion, fenitrothion or pyrethrum is applied as a supplementary vector control measure in a few countries and under certain situations for the control of :

a. An. culicifacies in pilgrimage and gem mining areas in Sri Lanka.
b. An. stephensi and An. culicifacies in the urban areas of India.
c. An. aconitus in areas of high transmission in central Java, Indonesia.

2.2 Anti-larval measures

2.2.1 Chemical larviciding

Larviciding with abate EC is used on a very limited scale for the control of An. culicifacies in Sri Lanka and An. sundaicus in Burma.

2.2.2 Larvivorous fish

Gambusia affinis and Poecilia reticulata are used on a relatively large scale for the control of malaria vectors in the urban areas of India.

Trials on the efficacy and use of indigenous larvivorous fish for the control of certain malaria vectors are being carried out in most countries of the region including Burma, Thailand, Sri Lanka, Indonesia and India.

2.2.3 Bacillus thuringiensis

Studies on the use and efficacy of indigenous and imported strains of Bacillus thuringiensis for the control of malaria vectors are being carried out in Thailand, Sri Lanka, Indonesia and India. So far, no large

scale trial has been undertaken in these countries. However, at present, the WHO Tropical Disease Research programme is promoting such trials in India and Indonesia.

2.2.4 Monolayer compounds

Of possible purely physical methods of control, a formulation of monomolecular organic surface film has undergone limited field trials against An. culicifacies in river beds in Sri Lanka but with inconclusive results. Another formulation of monolayer is presently under trial against An. minimus in Thailand.

3. RESEARCH

The following are the topics of research, in broad lines, needed for the control of malaria vectors.

3.1 Environmental

Due to the rapidly changing ecological picture over large areas of many countries of the region, following the implementation of major agricultural development and associated irrigation projects, and numerous hydro-electric schemes, the species succession is at present unknown in most cases. Since these areas often involve the settlement of thousands of families in a short period it is important to be able to predict the eventual species composition and malaria receptivity in such areas. Such information would facilitate the design of integrated vector control programmes especially those approaches involving environmental management, where appropriate. Where necessary methods such as intermittent irrigation, zooprophylaxis, or other agricultural practices may be introduced in an attempt to minimize the ecological imbalance.

3.2 Taxonomy of species complexes

The situation is still not clear as regards several major vector groups, such as An. leucosphyrus (including An. balabacensis/An.dirus), An. minimus, An. maculatus and An. culicifacies. The distribution of the members of these species complexes and even in many cases the identity, relation to malaria epidemiology and appropriate control measures still remains to be worked out.

2.3 Sampling methods

Sampling adult anopheline populations for purposes of operational monitoring and especially for epidemiological assessment has always posed difficulties in respect of coverage obtained and statistical significance, In addition, there is also the question of exposing mosquito collectors to drug resistant P. falciparum infection in several countries of the region.

In respect to the above it has therefore become imperative to develop sound sampling methods for epidemiological and operational monitoring with minimum exposure of human bait.

3.4 Biological control

Inspite of the popularity of the concept of biological control over many years there still remains a very large area for investigation of the efficacy of various agents for operational purposes. This includes not only fish but also insect predators, pathogens and parasites. Local surveys to determine possible indigenous agents are badly needed.

The ultimate objective of most of the above research is the improvement of vector control design and the provision of an armory of methods which can be applied in suitable locally adapted combinations for the purposes of integrated vector control.

TABLE 1

SUMMARY OF CURRENT CONTROL MEASURES APPLIED AGAINST MAJOR MALARIA VECTORS IN COUNTRIES OF SOUTH EAST ASIA REGION

Major Vectors	Country	Control measure				Resistant status and other remarks
		Residual house spraying	Space Spraying	Chemical larviciding	Biological Control	
An. culicifacies	Burma	DDT	-	-	-	Resistant to DDT and dieldrin
	India	DDT, HCH,mal	malathion (urban)	-	-	Resistant to DDT, HCH and malathion
	Nepal*	DDT, mal.	-	-	-	Resistant to DDT and dieldrin
	Sri Lanka	malathion	pyrethrum	abate EC	-	Resistant to DDT
An. stephensi	India	-	malathion, pyrethrum (urban)	-	Gambusia affinis Poecilia reticulata	Resistant to DDT, HCH and malathion.
An. minimus	Burma, Thailand	DDT	-	-	-	Tolerant DDT, exophily, exophagy inadequate spray coverage
	India	DDT	-	-	-	Recent information is lacking
	Nepal	DDT	-	-	-	Disappearance of vector is claimed
An. balabacensis	India, Nepal Thailand	DDT	-	-	-	Exophily, exophagy, operational difficulties (tolerant DDT in Thailand and Burma)
	Burma	DDT	-	-		
An. aconitus	(Java/Bali) Indonesia, Thailand	DDT	malathion, denitrathion	-	-	Resistance DDT, DLN

TABLE 1
Page 2

Major Vectors	Country	Control measure				Resistant status and other remarks
		Residual house spraying	Space Spraying	Chemical larviciding	Biological Control	
An. fluviatilis	India, Nepal	DDT	-	-	-	
An. annularis	Burma	DDT	-	-	-	Resistant to DDT and dieldrin
	India	DDT,HCH,mal	-	-	-	Resistant to DDT and dieldrin
	Nepal	DDT, mal.	-	-	-	Resistant to DDT and dieldrin
An. sundaicus	Burma, India, Indonesia, Thailand	DDT	-	Abate EC in Burma	-	-
An. maculatus	Thailand	DDT	-	-	-	Exophily, exophagy
An. tessellatus	Maldives	DDT	-	-	-	-
An. subpictus	Maldives	DDT	-	-	-	-

TABLE - Insecticide resistance in anopheline mosquitos in countries of South East Asia Region.

Country	Species	DDT	Dieldrin/HCH	Organophosphates
Bangladesh	An. annularis	R	-	-
	An. subpictus	-	R	-
	An. vagus	R	-	-
Burma	An. annularis*	R	-	-
	An. culicifacies*	R	-	-
	An. nigerrimus	R	R	-
	An. balabacensis*	V	-	-
India	An. culicifacies*	R	R	R
	An. stephensi*	R	R	R
	An. fluviatilis*	R	-	-
	An. philippinensis*	R	-	-
	An. subpictus*	R	R	-
	An. tesselatus*	R	R	-
	An. annularis*	R	R	-
	An. nigerrimus	R	R	-
	An. vagus	R	-	-
Indonesia	An. aconitus*	R	R	-
	An. sundaicus*	V	-	-
	An. subpictus	V	-	-
	An. farauti*	V	-	-
	An. koliensis*	V	-	-
	An. barbirostris*	R	R	-
	An. nigerrimus	R	-	-
	An. peditaeniatus	R	-	-
	An. vagus	-	R	-
Maldives		-	-	-
Nepal	An. annularis*	R	R	-
	An. fluviatilis*	V	V	-

Country	Species	DDT	Dieldrin/HCH	Organophosphates
Nepal (contd..)	An. culicifacies	R	R	-
	An. subpictus	R	R	-
	An. vagus	R	R	-
Sri Lanka	An. culicifacies*	R	-	-
	An. subpictus	-	R	-
	An. tesselatus	R	-	-
	An. nigerrimus	R	-	-
Thailand	An. minimus*	V	-	-
	An. balabacensis*	V	-	-
	An. maculatus*	V	-	-
	An. aconitus*	V	-	-
	An. culicifacies	R	-	-
	An. philippinensis	V	-	-
	An. annularis	R	-	-
	An. vagus	R	R	-

*Proven malaria vectors

R = Resistant

V = Verification required.

PROBLEM ORIENTED RESEARCH ON MALARIA VECTORS IN INDONESIA

PROGRESS AND FUTURE NEEDS

by

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1. INTRODUCTION

In many countries of tropical Asia, the major vector control problems encountered in the national malaria control programmes(MCP) are: 1) increased vector resistance to DDT; 2) the high price of promising alternative insecticides; 3) lack of field information on, and control technology against, exophilic and exophagic vector species and; 4) shortage of supervisory and field staff within the MCP which are being gradually and slowly integrated into the community health care system.

In view of the above, the WHO Vector Biology and Control Research Unit in Indonesia, in collaboration with the Ministry of Health(GOI), began detailed studies on the malaria vectors by setting up a sub-Unit in Central Java in June 1975 with financial support from the United States Agency for International Development. Studies on An. aconitus started in Central Java in 1975, followed on An. sundaicus in Bali in 1979 and An. barbirostris in South Sulawesi in 1980. An. aconitus is the most important malaria vector in rice growing areas of Java/Bali, involving a human population of 50-70 million, and An. sundaicus is the main vector in coastal areas of many islands with a population of 15-20 million at risk, An. barbirostris is a vector of both malaria and filariasis in other areas with 5 million people at risk.

2 RESIDUAL SPRAYINGS

2.1 Village-scale trials (Stage V)

During the past six years (1976-1981) four OP compounds, one carbamate, one pyrethroid and one chlorinated hydrocarbon (organochlorine) in different formulations and dosages were tested in village-scale field trials (about 1000 houses and 5000 people in an area of 10 km2) to determine their residual effectiveness against An. aconitus. Among the insecticides tested fenitrothion is the most promising alternative insecticides against DDT-resistant An. aconitus, followed by pirimiphos-methyl. With conventional total coverage at 2 g/m2, fenitrothion effectively reduced nocturnal man-vector contact rates for over 13 weeks.

Pirimiphos-methyl 25% wdp at 2 g/m2 was also effective for about 3 months but the formulation was shown to be unsuitable because of heavy, unsightly brown deposits left on surfaces and high erosion of nozzle tips. An EC formulation at 1 g/m2 was found to be effective for about 5-6 weeks in village-scale trial, and slide positive rates were reduced by over 90% in an

operational trial in East Java. The insecticides with poor fumigant effect in airborne bioassay made no or little reduction in parity and man-vector contact rates. These include malathion, chlorphoxim, decamethrin, OMS-1558 (an organochlorine) and bendiocarb.

2.2 Rational use of insecticides

Because of cost, as well as mammalian toxicity and possible resistance considerations, two village trials were carried out using reduced amounts. In the first trial, with normal total coverage at 1 g/m2, manpower requirements were the same as at 2 g/m2, but insecticide usage was reduced by one-half and the residual effectiveness only by about 15%, i.e. to 11 weeks from 13 weeks at 2 g/m2.

The second trial with reduced amount of insecticide was made by spraying at 2 g/m2 only one horizontal swath between 10 and 85 cm from the ground. This "selective spraying" reduced insecticide use by about two-third and manpower by over one-half. The results indicate that the vector populations were effectively suppressed for over 2 months; 3 weeks less than total coverage at 2 g/m2 and about the same as total coverage at 1 g/m2. The rationale of this selective spraying was based on observations on the resting behaviour of An. aconitus which showed that about 78% rest below 85 cm from the ground. Based on this trials, the GOI began an operational-scale malaria control trial of this selective methods in a malaria endemic area in Java in 1981, along with total coverage of 2 g/m2 and total coverage of 1 g/m2. The preliminary results indicate that this selective methods appears to be very promising.

2.3 Community participation

To further reduce operational costs, a village-scale trial was carried out in a group of villages covering 1067 houses where fenitrothion was applied at 2 g/m2 to only cattle shelters (Kandang). This "kandang selective treatment" was based on the feeding preference of An. aconitus in Central Java, where a majority (50-99%) feed on cattle. In this trial all cattle shelters, both open and closed, were treated as in total coverage and repeated seven times/year at an intervals of 6 to 8 weeks. This method has proved to be more economic than the selective spraying; with a reduction of insecticide use by about 90% and labour requirements by over 50%. A pilot trial of this method is presently undergoing further testing for use through community participation with minimum technical assistance from local health authorities. In this trial, pirimiphos-methyl EC is applied, as in total coverage, to 130 cattle shelter in 12 hamlets and 1100 houses at intervals of 6-8 weeks by 16 spraymen appointed by hamlet heads and trained by local malaria staff.

3. SPACE TREATMENT

3.1 ULV

Weekly ground ULV treatment were made five times with 95% fenitrothion, using Fontan R12 in a group of villages covering about 1000 houses and 80 hectares of housing area surrounded by terraced ricefields. Each round of treatment was made at the rate of 40 ml/house. Entomological results showed control of nocturnal man-biting An. aconitus and resting mosquitoes in cattle shelters for a period 2-10 days after each spray round. However, considering the amount of insecticide used, short residual effects, equipment cost and intensive supervision required, it was concluded that this type of ULV application would only be useful for epidemic situations of limited area.

3.2 Thermal fogging

In 1977, thermal fog treatments with fenitrothion were made for the first time in Central Java by the Provincial for malaria control team. In 1979 10 weekly thermal fog treatments with 2% fenitrothion were applied in 4 sub-districts of the most malarious areas against the first peak of An. aconitus and 6 rounds for the second peak. However, fogging had little residual effect on vector populations as densities returned to normal levels within a few weeks after the last treatment. In most cases, parous rates were much depressed at day 3 after treatment, but returned to normal levels by day 6. The national fogging operations lasted 5 years, and in 1981-82 4% malathion was also compared.

4. LARVAL CONTROL

Throughout the coastal areas of many islands of Indonesia, there are numerous brackish water impoundments and artificially created fish ponds where An. sundaicus and An. subpictus breed concurrently. In some of the coastal areas, weekly oiling with diesel oil together with DDT residual sprayings is recommended but the programme has been unsatisfactory.

4.1 Bacillus thuringiensis H-14

In all the lagoons treated at target dosages of 2.5 l/ha, there were no pupae and III/IV instar larvae collected during a period of five days. In the lagoons with no floating algae, target dosage of 1.0 l/ha gave an equally good control as the dosage of 2.5 l/ha.

In freshwater swampy ponds in Sulawesi, B.t. H-14 at 2.0 l/ha also showed a drastic reduction of An. barbirostris larvae. Here, the reduction was also more pronounced against anophelines than culicine larvae (mainly Cx. gelidus) and the recovery rate was much slower in anopheline larvae than culicines as in the lagoons.

4.2 Insect Growth Regulator

When a slow release formulation of diflubenzuron was applied weekly to 3 lagoons with floating algae at 50 g a.i./ha, An. sundaicus and other associated mosquito species were effectively reduced for 5 days or longer as measured by adult emergence. Non-target organisms were not affected in any of the trials, as was also the case with B.t. H-14.

4.3 Conventional Larvicide/Oil

There was no complete reduction in larval and pupal densities of An. sundaicus when lagoons were treated with one-gram plastic chips, each containing 5.2% of temephos (ECOPRO 1707 EPW) or with a monolayer oil known as Monoxci-FCM.

5. RESEARCH NEEDS

5.1 Ecological studies of selected larval habitats to identify factors which could be useful in developing integrated control:

1. ricefield ecosystems for An. aconitus
2. lagoon ecosystems for An. sundaicus and An. subpictus
3. freshwater swampy ponds for An. barbirostris.

5.2 Development of mass isolation of sporozoites to determine potential vectors of local malaria in different ecological zones (using gradient technique for recovery of malaria sporozoites from anophelines; Exp. Parasitol., 42: 1-15, 1977). There are over 11 proven and 4-5 suspected vectors known to occur in the archipelagos of Indonesia. However, many of the national anti-anopheline programmes have been carried out without knowing exactly what are the potential vectors responsible for local malaria transmission.

5.3 Longitudinal studies on the ecology and bionomics of malaria vectors, with special reference to the primary vectors on the outer Islands.

Since the national strategy of malaria control is being focused on the Outer Islands in areas of economic importance, there is a need for more field information on the behaviour of the principle local vectors and their seasonal prevalence so that technically-oriented control measures can be applied for effective control. The information needed concerns 1) An. balabacensis in East Kalimantan; 2) An. subpictus in Timor, Flores; 3) An. barbirostris on Sulawesi; 4) An. punctulatus group on Irian Jaya and Maluku; 5) An. nigerrimus in the swampy and forest areas in Sumatera and Sulawesi. These are also the major technical problems encountered in the national programmes against the aconitus-borne malaria in Java and Bali.

5.4 Zooprophylaxis of malaria transmission by An. aconitus in Java and South Sumatera. Deviation of anopheline by animals for malaria control has been the subject of much discussion in the literature for many years before the event of DDT. In view of high zoophilism of An.aconitus, which is highly resistant to DDT, field studies are needed to: 1) determine what influence the presence and numbers of cattle exert on malaria transmission; 2) quantify

those aspects of its behaviour in relation to cattle which maybe exploited as a malaria control measures and 3) determine the effect of stabling of cattle in the vicinity of villages on man-vector contact or on malaria transmission. Government and private donor agencies have been concerned with malaria in connection of malnutrition among poor villagers in the porest communities.

5.5 Further studies on rational use of insecticides for control of DDT-resistant An. aconitus in Java. In anti-malaria programmes in Java and Bali a more rational use of insecticides appears to be vital because the houses are large, having about 300 m2 of surfaces (walls and roofs) to be sprayed for total coverage, while the cost of insecticides continue to increase. More efforts should be made on management and operational aspects of malaria vector control,with special consideration to community participation.

MALARIA IN THE AMERICAS: A COMMENTARY

The Situation

Malaria continues to be one of the major health problems in the Americas. From 1976 to 1980, the number of cases increased by 56.6% from 379,364 cases in 1976 to 544,216 in 1980. In the Americas at the end of 1980, 49.5% of the population living in the original malarious areas were in areas where malaria has been eradicated, 25.1% in areas where malaria transmission has been interrupted (consolidation phase) and 25.4% in areas where transmission still exists (58.7 million people). Migration to and from these latter areas increases the number of individuals at risk.

The Programs

DDT continues to be the insecticide of choice but in agricultural areas of Central America it, as well as malathion, fenitrothion, and propoxur do not work effectively (See Table 1). Areas with known DDT resistance include Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua and Panama where the principal vector is *Anopheles albimanus*. There may be other areas with resistance but few countries in South America do susceptibility testing.

Space spraying around dwellings with diagnosed cases is common in parts of Venezuela. A small program of space spraying of temporary houses of migrant labour was started in Guyana but has since stopped. A space spraying program in the city of Guayamerin, Bolivia is planned to begin at the end of this year's floods.

Antilarval operations are increasing but probably have not had the emphasis they deserve. Haiti was active in environmental management in 1977-1978 but stopped in 1979. However, in 1980 they once more began larviciding, use of larvivorous fish and maintenance of drainage canals. Nicaragua has a pro-

gram to eliminate or reduce breeding places by drainage, land fill, stream diversion and use of larvivorous fish. Bolivia has used petroleum on breeding places in Guayamerin and is beginning a program using larvivorous fish in Santa Cruz. Ecuador, Guatemala and El Salvador are using larvicides whereas Colombia and Guatemala have begun small biological control activities.

Because of financial restrictions, many countries have been forced to focalize their vector control activities to only areas of greatest risk.

Antimalarial drugs continue to be used extensively in all programs in presumptive as well as in radical cure treatments through the collaboration of 187,000 existing information posts and 7,100 evaluators. The drugs are distributed also as mass drug administration in order to control or prevent epidemic outbreaks, to serve as the principal control measures where vector control is not practical or is ineffective or to protect certain population groups such as migrant labour.

Blood slides are collected by malaria evaluators, voluntary collaborators or health service posts. In 1980 a total of 8,900,046 blood slides were examined with 599,216 positive for malaria parasites. The annual blood parasite incidence is 2.59 per 1,000 inhabitants.

The Cost

In 1979 the total budget for all malaria programs was US$ 112, 957,881 or a 27.4% increase over 1978. By 1980 the budget had increased to US$ 131,426,259 or an increase of 18.1% over 1979. From 1957 through 1980 the total investment in malaria programs was US$ 1,422,824,416 of which US$ 1,256,943,911 or 88.34% were provided by national governments and US$ 165,880,505 or 11.66% by international and bilateral cooperations.

The Problems

For a number of years PAHO has listed the same principal problems affecting the majority of the malaria programs. These are:

1. Physiological resistance of the vectors to insecticides (Central America and Haiti).
2. Evasive behavior of vectors to avoid contact with treated surfaces (*Anopheles nuñeztovari* in Venezuela and Colombia).
3. *Plasmodium falciparum* resistance to antimalarial drugs (Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Panama, Peru, Suriname, Venezuela).
4. Movement of populations especially associated with socio-economic development and poor housing in rural areas (Bolivia, Brazil, Colombia, Ecuador, Peru, Mexico and all Central America). Political and economic unstability also contributes to this problem.
5. Increasing cost of operations and shortages of financial resources have left many programs treating malarious areas on a priority basis, and giving emphasis only to epidemic outbreaks and other emergencies. The economic factor has contributed greatly to the reduction or breakdown of surveillance activities.
6. Problems associated with socio-political and cultural aspects and human bahavior.

Solutions

At present there are no clear cut approaches to the solution to the malaria problem. Cases of malaria will increase as will budgets and many governments will be forced to assign monies to other priorities with a better chance of success. However, the Organization has been emphasizing that research although not an ultimate answer may be a step to improve control in restricted

areas. In other words, research to answer specific local problems. There are two major obstacles to this solution; lack of money and lack of adequately trained investigators. In some countries, there is also a lack of structure to engage in research.

At present it is possible to list the following research activities in the Americas:

1. In Guatemala, a field trial using Deltamethrin (OMS-1998) against An. albimanus.
2. In Mexico, a field trial using chlorphoxim against An. albimanus.
3. In Haiti, a field trial to compare the relative efficacy of malathion and fenitrothion.
4. Malaria immunological studies in Colombia using non-human primates.
5. Development of seroepidemiology as a tool to study malaria endemicity.
6. Malaria chemotherapy, especially the mefloquine study in Brazil.
7. Evaluation of application equipment in Colombia.

Training in malaria has not reached a desirable level in the Americas. In many programs malaria expertise is being reduced by retirement or resignation and recruitment of new staff is difficult. Training is available in the following institutions:

1. School of Malariology and Environmental Sanitation, Maracay, Venezuela (Non-degree).
2. Ministry of Health of Colombia (SEM, INS and National School of Public Health). Primarily for national staff but some international participants.
3. School of Public Health of the Department of Health and Welfare of Mexico (Master's degree course).

4. National Malaria Eradication Service of Mexico. International training course for malaria field supervisors.

Assistance

PAHO maintains field malaria staff in Mexico, Guatemala, Honduras, El Salvador, Colombia, Ecuador, Bolivia, Brazil, Suriname, and Haiti. In addition each year consultants and PAHO staff participate in program evaluations and reformation of national programs and PAHO provides fellowships for training national staff. PAHO also provides some economic cooperation for equipment, antimalarial drugs, vehicles and insecticide susceptibility test materials. In addition, it provides services to purchase with national funds supplies and materials. There are regular meetings sponsored by PAHO, of the Directors of national malaria services.

Other international programs such as the Special Program for Research and Training in Tropical Diseases of WHO/UNDP/World Bank, United Nations Capital Development Fund, and United Nations Emergency Operations have recently contributed to specific malaria programs.

Bilateral assistance has been largely USA-AID support in Haiti and Bolivia (PL-480 funds), Japanese donation of fenitrothion to Haiti and training programs offered by the Governments of Colombia, Mexico, and Venezuela.

(The majority of the information appearing in this report comes from the 1979 and 1980 PAHO Status of Malaria Programs in the Americas.)

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Table 1

INSECTICIDE USAGE

INSECTICIDE	HOUSES TREATED			
	1979		1980	
	Number	%	Number	%
DDT	8,681,894	87.6	9,152,957	97.6
Fenitrothion	392,295	4.0	80,244	0.9
Propoxur	61,359	0.6	36,623	0.4
Malathion	10,089	0.1	-	-
Other	11,952	0.1	105,118	1.1
Mixtures	747,726	7.6	-	-
TOTAL	9,905,315	100 -	9,377,942	100 -

VECTOR CONTROL AT COMMUNITY LEVEL

by

Jean MOUCHET ::

1. INTRODUCTION

The promotion of health defined by the Declaration of Alma-Ata (1978) implies that everyone should be in receipt before the year 2000 of health care including: "Education concerning prevailing health problems and the methods of preventing and controlling them; promotion of food supply and proper nutrition; an adequate supply of safe water and basic sanitation; maternal and child health care, including family planning; immunization against the major infectious diseases; prevention and control of locally endemic diseases; appropriate treatment of common diseases and injuries; and provision of essential drugs"

This programme, which is in reality very broad, is inconceivable other than in terms of decentralization of health projects and participation of the basic communities. Vector control, which is an integral part of the prevention of endemic diseases, has hitherto been organized at higher, national or regional levels and based on well defined techniques that were often cumbersome and costly. The rural or urban communities that derived benefit from these measures were for the most part mere spectators, who were more or less well-informed about what was being attempted. The individual or collective hygiene projects in which they took part were most often imposed on them by coercive measures.

Things are radically changed by the transfer of vector control activities to the village level; the spectators will become the actors; they will, therefore, have to be thoroughly informed as to the aims of the actions planned and the results expected from them so that they can decide on their voluntary participation. Conversely, the health authorities will have to suggest only methods that have been found to be effective under the local epidemiological conditions, that are compatible in their execution with the local cultural context, and that do not place excessive socio-economic burdens on communities that are often hard put to it to survive from day to day. A new type of relationship should be established between communities and health "technicians", who would become advisers rather than leaders.

:: Prepared by J. Mouchet as WHO temporary adviser and presented at the meeting of Directors of WHO collaboratoring centres on the evaluation and testing of new Insecticides, Geneva, 9 -15 March 1982, VBC.PDS/DCC.82/WP 11

2. THE AIMS AND CONDITIONS OF VILLAGE SCALE VECTOR CONTROL

Vector control is essentially a preventive measure which in itself or, more often, in conjunction with drug administration should make it possible to reduce endemic diseases and to prevent or control epidemics. However, to the extent that health is not merely the absence of disease but the pursuit of individual wellbeing, vector control should also result in a reduction of pests. This effect which is directly felt by the people is one of the incentives prompting them to take part.

The starting of such operations must be preceded by:

- an entomological and epidemiological evaluation of the proposed methods in the context in which they will have to be used;
- a socio-economic feasibility study;
- planning concerned with structures, personnel and finance;
- a study of the prospects for continuity of operations.

2.1 ENTOMOLOGICAL AND EPIDEMIOLOGICAL EVALUATION OF THE PROPOSED METHODS

The control methods recommended must be simple, effective, cheap and adapted to local ecological and social conditions. Some of them, such as house spraying or individual protection, are of universal application. But the majority of the others yield very different results depending on the situation. Some examples can be recalled:

- In the Far East deforestation around villages is an effective means for the control of A. balabacensis. The practice applied in the forest areas of Central Africa would increase the number of A. gambiae breeding places.
- Larval control which is an effective means of malaria control in the arid regions of the Middle East is of very limited interest in areas of Africa where the disease is highly endemic. In these last areas it can hardly reduce the Anopheles vector populations below the critical transmission threshold.* **
- Rice field in areas like China are considered as main sources of malaria vector where a larval control has to be carried out. In hyperendemic areas of Africa although the development of rice fields increases the number of Anopheles in the nearby villages, there is a lack of evidence that results in an intensification of malaria. So larval control in rice fields is often questionable

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* Carnevale, P., Molinier, M., Mouchet, J. (1981) Rev. Epidemiol. Santé publique (In press).

** Molineau, I. & Gramichia, G. (1980) Le Projet Garki, WHO publication, 354 pp.

With the exception of treatment carried out inside the house, most of the techniques are not used alone but in combination under the name of integrated control. This type of intervention should stem from a highly pragmatic attitude involving the use of all the available methods, chemical and biological, for the control of a vector or a group of vectors. Many techniques are, in fact, recommended, ranging from the filling in of footprints so as to deprive Anopheles of breeding places to the use of eucalyptus fumigation to repel mosquitoes. However, very few authors have attempted to select the techniques applicable in a given situation, and none have tried to assess the results obtained. The measures proposed especially as regards the larval control would be extremely burdensome for the communities and inconvenient for the population fully occupied in agricultural work.

Each technique should be evaluated for both entomological and epidemiological achievements. A compound may be an excellent larvicide and still have no effect on the disease control if larval control is not the appropriate method of attack in the local context. In this respect it is surprising that we had no knowledge of any epidemiological evaluation of the larvivorous fishes which have been in use for 60 years.

When several control techniques are to be used simultaneously the whole set of the techniques should be evaluated from both entomological and epidemiological points of view under the conditions in which the operations will be carried out.

The volume of operational research prior to the launching of any operation may seem considerable. But it is essential so that only completely effective methods would be suggested to the communities. It is the basis for respect between the partners and for the establishment of mutual confidence.

2.2 SOCIO-ECONOMIC FEASIBILITY STUDY

Every ethnic group has its own culture within which the representation of disease/diseases and approaches to treatment is more or less original. Medical concepts of western origin having a different rationality have penetrated to a very varied extent, depending on the society; the mass of the people in the countryside very often still remain attached to their traditions. Their participation in vector control measures involves giving them a clear explanation of the cycle of the pathogen, of which they are often unaware, and of the aims of the actions which they are asked to undertake and the expected results.

Although a reduction in the nuisance of insect bites is not the main aim in most instances, it is nevertheless one of the effects most immediately realized by the people. It is a general demand , and to some extent it is through it that confidence and the continuity of operations will be maintained There are known instances, for example, of malaria control compaigns being rejected by the inhabitants because of the proliferation of DDT-resistant bugs. What needs to be done to avoid such incidents is clearly to determine the various aspects of all the vector problems arising at the village level so as to be able to explain them to the people, taking the local cultural context into account.

There are some techniques that may be incompatible with local customs (for example, tsetse fly control in the "sacred woods" in West Africa). What must be done then is to proceed in a different way or to find a compromise solution with local representatives.

The inhabitants of villages are greatly involved in cultivating their plot of land and in solving the material problems of everyday life in an environment that is often impoverished. The part which they are asked to play in vector control must not be too onerous and must be compatible with carrying out the work on which their survival depends; in agricultural development projects it must not hold back economic expansion. Any participatio beyond the capacity of the people would rapidly be given up.

Lastly, the occupation of the land*, and the location of villages** relative to contamination sites are problems that must be taken into consideration, but whose importance often becomes apparent only after very extensive geographical research. We know, for example, that onchocerciacis is not of the utmost severity when population density is in excess of 50 inhabitants/km^2; consequently, the optimum level of population of the valleys is a true prophylactic measure which is partly dependent on rural communities.

Very serious consideration must be given to socio-economic constraints when drawing up operational plans for vector control. They must be allowed for in health education if its message is to "get across". This health education should be an integral part of school curricula, which involves retraining school teachers; it could be implemented by the involvement of schoolchildren in community health operations. Collaboration between medical research workers and those dealing with the social and economic sciences and even agronomy is essential at this level.

2.3 PROBLEMS CONCERNED WITH STRUCTURES, PERSONNEL AND FINANCE

The structural set up for village scale vector control varies in accordance with the political organization of States.

The primary health worker should have at least two roles in vector control:

- the organization of health education;
- the giving of advice to the members of the community who will carry out the control operations, unless he does so himself.

To carry out this task successfully he will have to have received epidemiological and entomological training, or rather to have been steeped in the epidemiological and entomological problems which he will have to solve locally.

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* Hervouet & Prost in Maitrise de l'espace agraire et développement en Afrique tropical, Colloque Ouagadougou, 1978, Mem. ORSTOM, No. 89, 1979, pp. 179-190

** Subra, R., Mouchet, J. & Brengues, J. (1975) Environment africain, 1, pp. 78-88.

The members of the community involved in carrying out operations should receive sufficient training to enable them successfully, to accomplish the tasks with which they are entrusted.

Some activities taken over from national campaigns, such as insecticidal treatment inside dwellings, may require a specialized worker, who would be full-time or part-time depending on the size of the village. It is rather unlikely that the primary health worker, who has many tasks, could himself provide this service, or that an unpaid member of the community could devote sufficient time to it.

Given the limited skills of the primary health worker, work at the village level must have a solid backing from specialists whose responsibilities are to work out the operational plans, to supervise their execution, and possibly to suggest new solutions. This backing should be less of a control body than a dynamic promoter of new techniques adapted to the local conditions.

By their very constitution these backing groups involve fully qualified entomologists with a good knowledge of epidemiology and also epidemiologists who will have to receive preliminary training. Far from representing a saving of scientific personnel, the transfer of vector control to the community level will necessitate increased expertise in the spheres concerned if it really wishes to comply with its assigned aims.

No discussion of the overall financial aspects of the transfer of vector control to the village level is contemplated here; in any case, these aspects vary appreciably from situation to situation. Although the financial implications are expected to be reduced, they will nevertheless remain quite considerable: purchases of drugs, pesticides, spraying equipment, material for use in control (traps, for example), and health education materials; the maintenance of sprayers of various equipment, and possibly of vehicles; the salaries of permanent or temporary personnel to the extent that all the needs cannot be met by voluntary labour.

A programme will not be viable unless its financial implications are compatible with the resources of the country or the community.

2.4 THE CONTINUITY OF OPERATIONS

The lack of any certainty of continuity is a criticism often levelled at major national campaigns, especially those receiving outside resources. The same question may legitimately be raised for decentralized operations at the peripheral level. For how long will the villagers retain their enthusiasm and agree to work unpaid on these activities, one of the features of which must be their perpetuity.

It is obvious that the motivation derives from perception of the beneficial effects on health and well-being. But this must be maintained by active and lively health education. While acceptable temporarily during an epidemic, requests that are too constraining will not be carried out for very long. It is for this reason that it seems reasonable to restrict the participation of communities to measures of undoubted efficacy.

It is equally essential for there to be competent personnel in the village and regular financing.

Lastly, the measures envisaged must be technically feasible in the long term. Much stress has been laid on the use of indigenous plants that have insecticidal, molluscicidal or repellent properties. Before their use is recommended, it has to be verified that they are plentiful enough for the source of supply not to be rapidly exhausted.

3. PROPOSED ACTION

A number of techniques or combinations of measures for which responsibility can be transferred to the village or which can be considered for decentralized vector control projects have emerged from an examination of questionnaires sent by WHO to public health officials and from the consultation of WHO specialists. Entomological and epidemiological evaluation under operational conditions is already possible for some of them, but there is a need for additional preliminary information and research on the intrinsic effectiveness of others.

All of these measures may be grouped under four headings:

(1) support for existing national campaigns;

(2) transfer to the peripheral level of techniques already employed in national or regional campaigns;

(3) measures specific to village communities;

(4) measures to integrate vector control with agricultural activities.

3.1 SUPPORT FOR EXISTING NATIONAL CAMPAIGNS

- Preparation of the people through health education for the intervention of disinsectization teams;
- support for geographical surveying, especially the pinpointing of isolated dwellings and bush farming huts;
- participation in malaria case detection;
- it is envisaged in the onchocerciasis control project in Guinea, Guinea-Bissau, Mali, Senegal and Sierra Leone that entomological evaluation should be under the responsibility of teams operating at the village level, but that have received good technical training and are well directed.

3.2 TRANSFER OF TRIED AND TESTED TECHNIQUES TO THE VILLAGE

- Transfer of house spraying and larval control measures carried out by national teams. Evaluation is concerned merely with the

proper carrying-out of the work and the cost. The choice of the insecticide according tothe vector susceptibility has to be adviced by the specialists at the central level.

- The Independant Commission whose task it was to define the long-term evolution of Onchocerciasis control in the Volta Basin has proposed the trial transfer of black fly larvicidal treatment, currently carried out by helicopter, to a village team operating on the ground. This team would be headed by national specialists of high standard so that the results could be evaluated.

3.3 MEASURES SPECIFIC TO THE VILLAGE

3.3.1 Measures for operational assessment

- Although mosquito nets are a simple and effective individual means of protection, they are often badly used and poorly looked after, which makes them ineffective. Information on the manufacture, maintenance and installation of mosquito nets is a task of health education. Their impregnation with an insecticide, preferably a fast acting one, would make them more effective, even when poorly looked after. Research along these lines is currently in progress; such is the variety of the textiles employed, both natural and synthetic fibres, that the impregnation technique must be examined for each.

- Water filters, even of a very improvised nature, would enable dracunculiasis to be avoided where drinking-water is not available. This is essentially a health education problem.

- This improvement of dwellings, eliminating visiting places of reduviid bugs is regarded as a good method for the control of Chagas' disease. An epidemiological evaluation would he highly desirable.

- Traps impregnated with insecticides have proved to be very efficient tools for controlling reverine tsetse flies in the savannah zones of West Africa* and the Congo.** The method could be transferred to the village level. There is a need for research on traps that should be as cheap as possible, effective against other tsetse species which develop in other ecological situations, especially in the forest areas.

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* Laveissière (C.) & Couret (D.), 1981 - Lutte contre les glossines reveraines à l'aide de pièges biconiques imprégnés d'insecticide, en zone de savanne humide. V. Note de synthèse. Cah. ORSTOM, sér. Ent. méd. Parasitol., (1), 49-54.

** Lancien (J.), Eouzan (J.-P.), Frezil (J.-L.) & Mouchet (J.), 1981 - Elimination des glossines par piégeage dans deux foyers de Trypanosomiase en République Populaire du Congo. Cah. ORSTOM, sér. Ent. méd. Parasitol., 19 (4), 239-47.

- Deforestation and the clearing of undergrowth for the control of various exophilic Anopheles: An. balabacensis and possibly An. nunez-tovari; epidemiological evaluation.

- Larval control treatment or treatment of the vegetation around villages for control of the same exophilic Anopheles species; epidemiological evaluation.

- Elimination of highly productive breeding places of Culex quinquefasciatus such as suburban drains or some stream estuaries (Mayotte, for example). Given that severe filariasis syndromes arise from the cumulative effect of repeated infections, any reduction in the number of bites postpones or even avoids the appearance of clinical complications. This is true both of lymphatic filariasis and of onchocerciasis.

- Control of Aedes aegypti by the elimination of household breeding places or their neutralization (the cleaning of containers), as well as by their treatment with insecticides (Temephos) made available to the villagers. Entomological evaluation is relatively easy, but epidemiological evaluation is complicated because we just do not know the threshold number of bites for the development of dengue epidemics. It most probably varies, depending on the immune status of the population. Larval or imaginal indices that are epidemiologically significant in different situations should be determined.

- Epidemiological evaluation of the use of larvivorous or herbivorous fishes must be speeded up. There has been a special WHO workshop devoted to fishes as biological control agents.

- Evaluation of variously integrated measures for the control of larvae of malaria vectors proposed separately or in conjunction with the treatment of dwellings and chemotherapy. This is a difficult but necessary task involving the determination in several selected sites of:

  (a) the reduction in the biting rate resulting from the carrying out of a range of measures carefully chosen for their acceptability to the people;

  (b) the outcome of such a vector reduction in the malariometric indices. It is more difficult to assess in terms of morbidity and mortality (in fact the real incidence of the disease) the results achieved by vector control in highly endemic areas where people develop a strong immunity.

3.3.2 Measures for consideration

- The collection of all available information on natural products especially plants ⁘ , known as insecticidal, molluscicidal or

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⁘ Jacobson & Crossby, 197 - Naturally occuring insecticide, Dekkerel, 580 pages.

repellent action. The carrying out of limited trials of their activity, and of their toxicity for man, mammals and non-target organisms. Estimation of the availability of the product or of the local production potential. The availability of repellents that are cheap and easy to apply, and capable of reducing the number of black fly bites, would be very interesting in regions where there is severe onchocerciasis.

- It has been suggested (Darwish, personal communication) that house spraying of insecticides should be replaced by covering the walls with materials (paper or fabric) impregnated with insecticides. These materials, which would be patterned or carry educative messages, could be placed in the houses by the occupants. Problems relating to the manufacture of articles having a good residual effect, that could possibly be re-impregnated, and that would be within the means of the countries concerned have still to be examined.

- VBC has reviewed the available information on biological control agents and has lent its support to research on the most promising of them. This action should be continued.

- The use of Cyclops sp. for Aedes control is being evaluated in Tahiti and seems promising ***

- Several field trials of the effectiveness of mucilaginous seeds should enable the future of this method to be decided.

- Information on the scope for the production of Bacillus thuringiensis in villages.

- Information on the performance of the traps for Culex, Aedes and sand flies.

- Information on very simple methods for the destruction of bed bugs.

- Information on rat-proof containers, which would probably be more useful for the storing of foodstuffs than for public health.

3.4 INTEGRATION OF VECTOR CONTROL WITH AGRICULTURAL ACTIVITIES

Agricultural development schemes, which are very often based on irrigation, modify local epidemiological conditions as regards malaria, schistosomiasis, filariasis, etc.

National specialists on vector control must draw the attention of representatives of village communities to the risks that the introduction of new cultivation methods may entail. Together they must examine the best ways of limiting or even eliminating these risks by simple methods. For example, the periodic drying out of rice fields or rotation of the spillways of small dams may be effective measures.

However, the problem will have to be examined in relation to each particular case, especially as regards dams, which should be the subject of very precise epidemiological studies. There is a need to decide which are the regions in which vector control operations must be carried out and where, conversely, such operations would not yield significant results.

The introduction of certain crops may favourably change the environment. Eucalyptus plantations dry out marshy land by lowering the table water. The growing of the lotus in stretches of water eliminates the plants that support the larvae of Mansonia, the vector of Brugia malayi.

Lastly, renewed interest in zooprophylaxis is to be noted, although the proposals remain unclear. On the other hand, it seems practically certain that several species of zoophilic Anopheles in South-East Asia have become anthropophilic as a result of depletion of the numbers of cattle, and that this has led to a considerable increase of malaria in some previously little affected regions. Whether or not increase in cattle breeding would reverse the situation could be considered.

4. CONCLUSIONS

It is far from the intention that the few suggestions set out here should be restrictive. This report is more in the way of an appeal to the creativity and, at the same time, the common sense of researchers, inviting them to define the measures that can give expression as regards vector control to the resolutions adopted by various conferences for the promotion of health for all by the year 2000.

What should be proposed at the village scale is not a menu for all occasions but only specific actions "à la carte", to borrow an expression of R. le Berre.

The definition of each of these actions requires the concerted efforts of a multidisciplinary team to select methods of proven efficacy, that are both acceptable and accepted at the socio-economic level, and the continuity of which can reasonably be envisaged. The same group of specialists will have to provide constant technical and scientific support to those responsible in the villages, and also an assessment of the operations.

It will probably be only during the next decade that the scope, but also the limits and constraints of village scale vector control will become clearly apparent. Experience will enable existing strategies to be improved and new ones to be defined.