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Vector Control Technologies: Selected Tropical Diseases

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INTRODUCTION

The discovery at the turn of the century that some tropical diseases were transmitted by mosquitoes was a major breakthrough in understanding these diseases. The control of mosquito vectors was the earliest and often the only method of intervention against many tropical diseases. Early public health workers, such as Gorgas in Cuba and Panama, and Watson in Malaya, were able to use vector control methods such as drainage and filling, or larviciding standing water with oil and the dye "Paris green, " with spectacular success in controlling the carriers of malaria and yellow fever. These methods continued to be used until the advent of the DDT era in the mid-1940s.

This chapter reviews the current status of control technologies for the insect and other arthropod vectors of diseases such as malaria, filariasis, leishmaniasis, and arboviral infections (e. g., yellow fever). It also reviews the status of control technologies for certain mollusks (e.g., snails) that are essential in the life cycles of trematode parasites that cause diseases such as schistosomiasis. The terms vector biology and control have traditionally applied only to insects and other arthropods that carry diseases. Currently, however, these terms also apply to snail intermediate hosts.

Control of vector-borne diseases is possible only through detailed and accurate understanding of the factors involved in transmission. Such understanding is gained through meticulous and tedious observation and experimentation wherever the disease exists. Understanding the role of the vector necessarily overlaps with field studies of the human host's interaction with the environment. Cultural practices, such as storing barrels of drinking water without lids (which provide perfect breeding sites for mosquitoes), or poor sanitary habits need to be studied to best design social intervention techniques.

Prospects for the future, including the relatively new concept of integrated pest management (1PM), are summarized in this chapter. Vector bionomics, the study of vectors and their interactions with the environment, provides the scientific rationale for interventions against vectors and is described briefly below.

VECTOR BIONOMICS

Progress in vector research tends to come in small increments that relate to better understanding of vector bionomics (the study of vectors' habits and their interactions with the environment). Such research is often narrowly focused research, from which extrapolations can only infrequently be made to other vector control situations. Studies of mating habits, host preferences, oviposition (egg laying) behavior, larval habitats, flight densities, and natural infection rates with pathogenic organisms provide insights that add to our ability to understand transmission dynamics and to target interventions against susceptible vector species.

Information about the resting habits of mosquito vectors of malaria has provided the rationale for, and accounted for the success of, the indoor residual spraying of insecticides in many tropical areas. Because some mosquitoes rest on a surface before and after the blood meal, often near the person they have bitten, spraying all

available resting surfaces (the walls, ceilings, undersides of furniture, etc.) with a long-lasting insecticide (e.g., DDT) has been the method of attacking the vector species.

In many cases, this approach to malaria control has led to great reductions of malaria prevalence. (In some areas of antimalarial spraying, sandflies, vectors of leishmaniasis, have also been controlled.) Unfortunately, in many cases, lack of information about the behavior of specific populations of mosquitoes has led to failure. Some species, or subpopulations within species, exhibit a behavior pattern of entering a house to feed, but resting outside, or actually avoiding sprayed surfaces. For example, the malaria vector *Anopheles nuneztovari* in parts of Colombia and Venezuela enters houses, obtains a blood meal, and then leaves immediately to rest outside, without acquiring a lethal dose of DDT (107). *A. minimus flavirostris,* an important vector of *Wuchereria bancrofti* (filariasis) in Luzon and Palawan, the Philippines, enters houses to feed on humans only during the middle of night, when the microfilarial stage of the parasite is at its highest concentration in the blood. This particular mosquito also leaves the house to rest outside, and is unaffected by indoor spraying of DDT.

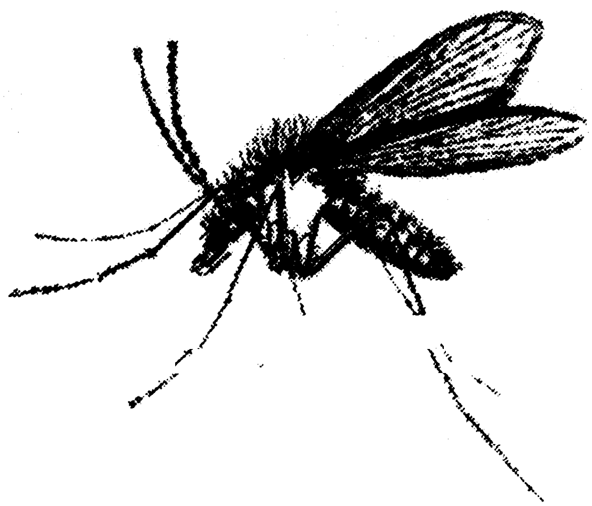

Photo credit: H. W. Brown and F. A. Neva, Basic Clinical Parasitology East Norwalk, CT: Appleton-Century Crofts, 1983). Reprinted by permission.

Sandfly, *Phlebotomus,* vector of leishmaniasis.

Control of the primary vector of a tropical disease does not always result in successful control of the disease. The disease may continue to be prevalent and a second previously unsuspected vector may be discovered. In one case, the elimination of stagnant groundwater as a breeding site for malarial vectors was followed by the discovery of another vector breeding in tiny pools of water trapped in the fronds of palm trees.

Work in the field of vector bionomics is progressing at a productive, though undramatic, pace. This area is grossly understaffed and underfunded, and there are critically few new scientists entering the field (253). Some progress of a fundamental nature has occurred in the laboratory. For example, recent work has provided information about the importance of mosquito saliva, which functions as an anticoagulant, in the mosquito's proboscis (hollow tongue). The mosquito's saliva promotes the formation of a blood gradient in tissues as it probes, helping the insect to find a blood-filled capillary. Malarial sporozoites in the mosquito damage the mosquito's salivary glands, reducing the production of saliva; the reduced production of saliva, in turn, causes an increase in probing time, and thus promotes greater transfer of sporozoites to humans being bitten (329).

Research in both the field and laboratory aspects of vector bionomics is time- and labor-intensive, but is a necessary activity for the eventual control of vectors. As noted in a study of pest control by the National Research Council (253):

> The control of arthropod vectors of disease or other pests of public health should be attempted only with recognition, and insofar as possible, an intimate knowledge, of the significance of the ecology and behavior of the target species and the epidemiology of the disease and with appreciation for environmental values that may be depreciated.

CONTROL OF ARTHROPOD VECTORS

Insecticides

Insecticides, classified as either chemical or biological, remain the primary vector control intervention. Two strategies are involved in the use of insecticides: 1) reducing the population size of the target vector (e.g., by treatment of a breeding site to kill immature forms); and 2) reducing the longevity of adult forms of the vector, so that they die before transmitting the disease (e.g., by residual house-spraying to intercept only those adult forms that feed on humans). Regardless of the strategy, all insecticides act as a selective mechanism against disease vectors, resulting in the development of resistant insect populations that have lost their susceptibility to the particular agent in use.

Chemical Insecticides

Chemical insecticides began to dominate the field of vector control around the end of World War II, with the widespread use of DDT. It was at that time that the World Health Organization's (WHO) worldwide "malaria eradication campaign" began, and through that experience that the world began to learn about the amazing capacity of insect populations to evolve that are resistant to pesticides (see box 6-A). The development of resistance called for using even more lethal chemicals.

Most insecticide development today is directed at pests of agricultural importance rather than at medically important vectors of diseases. Although many new chemical insecticides are produced and tested annually, these new chemicals are not necessarily appropriate for specific disease vectors. Also, because of research and development costs, new chemicals are expensive. The development of insects that are resistant to new chemical insecticides is a virtual certainty. The only question is simply how quickly the emergence of resistance will cause the insecticide to be abandoned.

In spite of the gloomy prospects for the complete success of chemical pesticides, such pesticides still form the backbone of vector control programs and are responsible for controlling disease in many

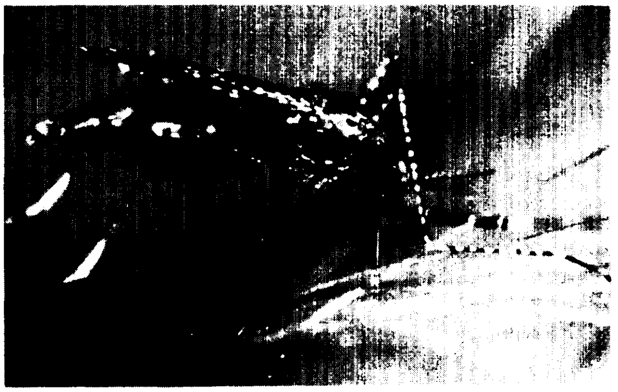

Photo credit: Robert Edeman, National Institutes of Health

An anopheline mosquito, vector of malaria, after a blood meal.

areas. Even DDT, which has been banned for agricultural use in the United States and many other countries, is still a useful chemical.

DDT **was** not banned for public health use (which is far more circumscribed than agricultural use), however, and it continues to be used in many countries worldwide for residual house-spraying against vectors, especially those of malaria. The only constraint on its use is resistance in local vector species.

The emergence of DDT-resistant strains of mosquitoes and the need to decrease the use of DDT have spurred the development of new insecticides. The principal compounds that have been substituted for DDT are malathion, fenitrothion, and propoxur. Another insecticide, pirimiphos methyl, has been field tested as a substitute for malathion in several sites where local mosquitoes have developed malathion tolerance (e.g., in Turkey and in Pakistan).

All of the newer chemical insecticides have greater immediate toxicity to humans and animals than DDT has. The irony of the replacement of DDT by other, more quickly degrading chemicals is that in order to be effective within a limited time span, the new chemicals must also be highly toxic. Thus, although the long-term environmental effects of DDT's persistence have presumably been reduced, the short-term hazards to users (i.e., workers in-

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It turned a subtle and vital science dedicated to understanding and managing a complicated natural system-mosquitoes, malarial parasites and people-into a spraygun war.

The goal of malaria eradication has now been laid aside, and current efforts to control the disease have not even held the advances made during the program. There is today an urgent need for the development of new, rational control strategies for malaria.

volved in the manufacture and application process, and people and wildlife inhabiting the areas being sprayed) have probably increased. The new insecticides are also many times more expensive than DDT, a problem that has greatly limited their use in the endemic countries unable to afford them.

Biological Insecticides

Various agents called biological control measures (see below) are in many cases more accurately described as biological insecticides. The biological insecticides include pathogenic bacteria, fungi and their products, and growth hormones. In most cases, the function and application of biological insecticides are completely analogous to those of synthetically manufactured insecticides. Often, the two types of insecticides differ only in that the former are produced by a micro-organism and the latter are produced by chemical synthesis. Most biological insecticides are directed against larval forms of arthropods, which means they are suitable only where conventional larviciding would also be feasible (e.g., where the breeding sites are easily found and treated).

Despite the appeal of using naturally occurring agents, it is not safe to assume that biological insecticides will be nonpathogenic to humans, nor that because these agents occur naturally, the target organism is less likely to develop early resistance.

Pathogenic Bacteria .—The cultivation and application to vectors of infectious or toxic agents such as viruses, bacteria, fungi, and helminths is an area of active research. So far, however, there is only one practical application in use, Bacillus *thuringiensis israeliensis* (BTI), of which the most common strain is called B.t. H-14.

BTI was first isolated in Israel in 1976, and extensive research has revealed that the bacterium produces a toxic crystalline compound (delta-toxin) fatal to virtually all insects when they ingest it. Now commercially produced, this toxin is used on farms and gardens, as well as in public health projects, in the United States and around the world. B.t. H-14 is now applied in the control of the *Simulium* (blackfly) vectors of onchocerciasis in West Africa. A number of field trials using B.t. H-14 against mosquito species are in progress.

BTI differs in its mode of action from other insecticides. It is not readily susceptible to enzymatic degradation or other biological processing within the insect. Although there is no reason to believe that BTI will differ from other insecticides in placing selective pressure on heavily exposed vector species, resulting in the eventual emergence of resistant strains, development of resistance is not expected to emerge quickly.

Following from the success of B.t. H-14, the search for other pathogenic bacteria has intensified. Several promising strains of *Bacillus sphaericus* have been isolated and are undergoing evaluation as larvicides.

Although biological insecticides are often assumed to have few, if any, adverse effects on humans, a recent report (305) described a corneal ulcer in a farmer following splashing of the eye with a biological agent. BTI was subsequently isolated from the ulcer. This may be an extremely rare occurrence or early warning of a potential problem.

Fungi.—Several species of fungi are being applied to vectors of disease in the hope of producing a lethal fungal infection. Those in the development and field testing stage include *Tolypocladium cylindrosporum*, *Culicinomyces clavor-*

sporus, and Coelomornyces spp. An earlier promising agent, *Metarhizium anisopliae,* has been found ineffective in the field.

Growth Hormones.—The identification and testing of insect hormones that alter growth and reproductive behavior is another area of research. The most notable example is juvenile hormone, an essential and naturally produced mediator of the growth process, which regulates insect development during pre-adult stages.

When applied in excess to insect breeding sites, juvenile hormone can prevent maturation of larvae and thus function as a biological larvicide. Safety and efficacy arguments regarding the use of this hormone as a larvicide are similar to those surrounding BTI. A drawback to the use of juvenile hormone is that resistance has now been demonstrated in some species, contrary to all earlier expectations. The high cost of juvenile hormone has limited its use in public health projects. Furthermore, juvenile hormone is useful only where Iarviciding is a feasible intervention.

Biological Control Measures

To control arthropod vectors of tropical diseases, various ingenious genetic and biological control procedures have been attempted. Many are based on the concept of introducing either sterile males or predators to a vector population, or by breeding arthropods that are resistant to infection by disease pathogens.

Introduction of Sterile Males

Large numbers of sterile hybrid males or of males sterilized by irradiation or chemicals can be released into the vector population. To the extent that sterile males outcompete normal males for females, the vector population is reduced.

The release of sterile males to control screwworm flies has been a spectacular veterinary success. Unfortunately, however, methods involving the release of sterile males are not practical for the control of mosquito vectors, nor indeed for most other medically important arthropods. Tsetse flies or other vectors with low density or reproductive potential may be controlled in this way.

Introduction of Predators and Competitors

The introduction of predators or competitors in vector populations has been tested a number of times, with variable results. These methods cannot be used in a broad-brush manner because of the many variations in the ecology and epidemiology of vector-borne disease. Only vectors breeding or existing in habitats suitable to the predator are susceptible to these methods.

The efficacy of using larvae-eating fish, such as *Gambusia* spp. and *Aplocheilus* spp., to control mosquitoes that transmit malaria is under study in a number of trials. This method works well against vectors that breed in large ponds or rice paddies, and a successful trial in northern Somalia is being extended (353).

A different tactic involves the use of cannibalistic larvae of the mosquito genus *Taeneorhynchus.* These larvae eat other larvae present in their breeding waters. The method is limited, however, to those species which share the same breeding habits as the predator.

The use of nematodes, such as *Romanomermis adicivorax* and *R. iyengari,* is under study. These worms prey on the immature forms of some insects.

Detection of Species Complexes

Scientists are investigating improved arthropod vector control using powerful new methods available for assessing genetic differences within vector species complexes. The elucidation of species complexes allows seemingly identical species to be differentiated according to their capacity as disease vectors. Once differentiated, highly specific field interventions may be initiated against the most capable vector species.

The concept of a species is theoretically simple, centering on reproductive isolation. In the case of large plants or animals, morphological and behavioral differences can be fairly easily observed and correlated to infer uniqueness as a species. In the case of many vector species, however, visually identical specimens may exhibit diametrically opposed behavioral habits (e.g., visually identical specimens of mosquitoes appear to breed in both freshwater and saltwater).

Past questions of species identity were frequently resolved through analysis of all stages of the life cycle (egg, larvae, pupae, adult) using classical taxonomic procedures, which were labor- and talent-intensive. Early attempts sorted out conflicting behavior patterns by tedious cross-breeding experiments which demonstrated reproductively incompatible populations (populations whose matings produced either no or sterile progeny).

Several alternative technologies are now available which, in conjunction with classical taxonomic and ecologic studies, can answer questions of vector identity. Cytogenetic studies may be performed using photomicrographs of the chromosomes in the salivary glands of insects. (Chromosomes in the salivary glands exist as multiple intertwined copies which are large enough for isolation, preparation, staining, and photomicography, allowing for mapping and comparison of banding patterns of the genes.) In addition, isoenzyme electrophoresis has been used to investigate questions of insect species and strain similarity. Certain enzymes, common to all related species, are functionally identical but differ in their chemical composition. The differences can be detected and used to identify separate species or strains. This method is being assessed on wild-caught mosquitoes in Tanzania (353). More recently, DNA hybridization techniques have been developed to demonstrate whether or not a match exists between the chromosomes of insects whose species identity is uncertain (94).

Identification of Disease Organisms Within Vectors

In addition to problems of controlling insect vectors, there are difficulties in determining whether and to what extent a vector is harboring a disease-producing organism.

Immunologic work on malarial sporozoite vaccines (see ch. 7 and case study B) has resulted in the development of two methods to detect sporozoite forms of the malaria parasite in mosquitoes. Each species of the malaria parasite ***(P]asnmfiurn*** spp.) has one predominant, unique surface antigen, and monoclinal antibodies (MAbs) against each of the different species' antigens have been produced. Using these MAbs, investigators developed a radioimmunoassay (RIA) and an enzyme-linked immunosorbent assay (ELISA) (36,435) that can sensitively and specifically identify the presence of sporozoite forms of the malaria parasite in crushed preparations of field-captured mosquitoes (69). These immunoassay replace the previous method of detecting sporozoites, which was manual dissection of the salivary glands from individual mosquitoes, followed by microscopic examination. (See ch. 8 for a full discussion of these diagnostic tests.)

The RIA and the ELISA greatly facilitate several types of field investigations and may lead to better understanding of malaria transmission dynamics and vector control. They will allow field researchers to: 1) identify new vector species; 2) determine the relative prevalence of the various malaria species, specifically those extremely uncommon or clinically or microscopically unrecognized; 3) correlate vector species with transmission of particular malaria species; and 4) quantitate each vector species' role in transmission (vectorial capacity) by its infection rate.

Similar technologies will probably be developed for the diagnosis of other vector-borne pathogens, and this will greatly facilitate field research and surveillance of diseases such as onchocerciasis and filariasis (155).

Control of Trypanosomiasis Vectors

Two insect vectors against which some progress has been made are the tsetse fly, conveyor of African sleeping sickness (African trypanosomiasis, and the reduviid (or kissing) bug, which spreads Chagas' disease (American trypanosomiasis).

Tsetse Fly Control

Field research on the life cycle and bionomics of tsetse flies *(Glossina* **spp.) has demonstrated differential susceptibility and vectorial capacity among fly populations. Various techniques of tsetse fly control have been used over the decades, including the placement of sticky patches on the backs of plantation workers, clearing of fly habitat vegetation along river banks, and ground and air spraying of DDT and other insecticides. As** yet, no tsetse fly resistance to insecticides exists, and in fact, the insecticides are highly effective, though expensive.

Field trials of tsetse fly traps are under way in various locations. A trial in Burkina Faso (formerly Upper Volta) achieved excellent success in reduction of Glossina numbers using a biconical trap (195,353). A cheaper monoconical trap has also been developed, which is insecticide-impregnated and attracts flies by odor. Insecticide-impregnated screens and car tires have also been tested (353).

Reduviid Bug Control

Currently, control of the reduviid bug vector of Chagas' disease is the only practical measure against this disease. Over the long term, improvement of rural housing is the single most important intervention against Chagas' disease. Poorly constructed, substandard housing provides both breeding and resting sites for the reduviid bugs. Periodic spraying of residences with residual insecticides is one method of control. A recent innovation has been the application of paints and plasters containing slow-release malathion, which controlled the vector for up to 1 year.

Photo credit: Dr. Robert Edelman, National institutes of Health

Reduviid bugs, the vectors of Chagas' disease, live in the thatched roofs of houses such as this one.

CONTROL OF SNAIL INTERMEDIATE HOSTS

Although mosquitoes, biting flies, and other blood-feeding insects are the usual emphasis of vector control programs, one of the most important tropical diseases, schistosomiasis, involves snails in the transmission cycle. The snail is actually an intermediate host rather than a true vector, as the parasite is released by the snail into a body of water and enters through the skin of a human host when the person comes in contact with it through bathing or wading.

Controlling snail populations, like controlling insect vectors of diseases like malaria, is one way of controlling the spread of schistosomiasis. Snail control methods are analogous to those used in insect control, namely alteration of snail habitats and mollusciciding (direct poisoning of snails).

Artificial lakes and irrigation projects can lead to the spread of schistosomiasis, through the expansion of habitats for the snail intermediate host (390). Various environmental or engineering measures have been used successfully for snail control, such as irrigation canals lined with cement in Japan, and reclamation of swamps in the Philippines. Mollusciciding was one of the interventions used to reduce the incidence of schistosomiasis on the island of St. Lucia (see ch. 5). Each approach is potentially effective, but requires careful management and is expensive.

Molluscicides

Attempts have been made to control snail hosts since the early 1900s, when the role of snails in the schistosomiasis transmission cycle was elucidated. A number of chemical compounds have been used over the decades. Independent of the agent used, an important concept in snail control has been the use of "focal mollusciciding" which concentrates effort on the often localized areas of actual transmission (58,284). Since only those areas of known transmission are molluscicided, focal mollusciciding saves chemicals and personnel. However, good diagnostics and surveillance mechanisms are needed for focal mollusciciding to be effective. For molluscicides, as for insecticides, both biological and chemical agents have been used.

Chemical Molluscicides

Two molluscicides are commercially available: copper sulfate, available since 1920, and niclosamide, available since 1959. Scientists have recently investigated slow-release compounds, which would reduce the logistical demands of frequent, periodic applications to snail habitats (176). Organotin compounds, very cheap and shown to be highly effective in laboratory and field trials, are undergoing research and development (176).

The development of chemical means of controlling snails has been hindered by a lack of information about the biochemistry and metabolism of the snail intermediate hosts and about the mode of action of molluscicides. B-2 (a dichlorobromophenol) is a molluscicide used extensively in Japan (353), It has been shown to affect several important glycolytic metabolic steps in *Oncomelania* and *Biomphalaria,* two important genera of schistosomiasis vectors.

Plant-Derived Molluscicides

Plant-derived molluscicides have been investigated as possible alternatives to chemicals for a number of years, because plant-derived compounds could be less costly and would probably be less toxic to forms of life other than snails. The assumption is that plant-derived compounds will pose less of an environmental hazard than chemicals, and it is possible they could be developed through village level, self-help schemes (399).

Screening for potential molluscicides has concentrated on plants with known medicinal properties. Many of these have been identified as containing active molluscicidal compounds. The most thoroughly studied is *Phytolacca dodecandra,* whose berry extract (ended) has been used in Ethiopia. Other promising species are *Ambrosia maritima* and other species of that genus, and *Anacardium occidentals.*

The search for effective plant-derived molluscicides has been impeded by the lack of knowledge about snail metabolism and physiology. Currently, the Special Program for Research and Training in Tropical Diseases (TDR) is promoting the development of screening methodology and developing goals for the use of plants (353).

Biological Control Measures

The most promising biological agents for controlling the snails involved in the transmission of schistosomiasis appear to be competitor snails, such as *Marisa cornuarietis,* which has been used in Puerto Rico. In the course of browsing over vegetation, *M. cornuarietis* eats all stages of the snail *Biomphalaria* spp. Other competitor snails under study are *Pomacea, Thiara,* and *Helisoma* spp. (176,353).

Detection of Species Complexes

As is true in the case of many insects, susceptibility to infection in the case of snails varies between species and strains. Isoenzyme electrophoresis has been developed for the detection of species complexes in various snail populations (173,174) and used experimentally to identify snail populations with differing susceptibility to schistosome infection (227). Knowledge of susceptibility will increase our understanding of the epidemiology of schistosomiasis transmission.

INTEGRATED PEST MANAGEMENT (1PM)

A new emphasis is being placed on an integrated approach to vector control based on 1PM strategies. 1PM strategies emphasize the need for combining basic field studies of vector bionomics—the study of the interaction of vectors with their environment—with biological and chemical control agents. In contrast to single-tactic programs based on chemical insecticides, 1PM stresses multifaceted environmental measures reduce disease transmission. In the Panama Canal Zone, an

IPM-type program eliminated malaria; then DDT was added to the control program, and screening and drainage practices were neglected. The single-tactic approach failed when the mosquitoes became resistant to DDT, and malaria returned.

Theoretically, 1PM requires an intimate knowledge of all factors relating to vector biology and disease transmission. Critical factors are selected and monitored for change, and tailored intervention techniques are applied as needed to control the vector. Successful 1PM models are based on the analysis of factors such as weather/climate, vector density, pathogen infection rate, and other indicators that are of predictive importance for disease transmission. In practice, 1PM has sometimes meant nothing more than using several insecticides in combination, instead of just one.

Paradoxically, in many vector control projects, intuitive intervention may lead to counterproductive results (329). For example, insecticide spraying may reduce the population of larvae in a breeding site, but have the unexpected result of producing more robust adults, better able to transmit disease, because of reduced competition for food.

RESEARCH NEEDS

Insecticides and Molluscicides

The search for cheap, safe, and effective insecticides and molluscicides, whether of chemical or biological derivation, characterizes research in all vector-borne diseases. The lack of an obvious profit element greatly inhibits commercial development of any insecticide having only public health applications. However, agricultural pests remain a subject of intense research, and there will quite likely be benefits for public health problems.

Two methods are used in developing new insecticides. In the first case, knowledge about toxic substances is used to test known and newly synthesized compounds against a range of target species. In the second case, knowledge is developed about the physiology and biochemistry of target species in order to identify critical enzyme pathways or other life functions against which insecticides could be made. Further research is needed in either instance.

Vector Bionomic Studies

There is a continuing need for better understanding of the biology of all disease vectors: identification of new vectors, vectorial capacity, physiology, genetics, insecticide susceptibility, behavioral characteristics such as biting, resting, and breeding habits, and any other factors that contribute to the maintenance and transmission of disease.

Improved means of detecting disease-causing agents within vectors is an important area in need of research and development. There is a vital need for increased numbers of trained personnel at all levels of research (253).

SUMMARY

Attempts to control arthropod vectors and intermediate hosts such as snails are relatively recent, proceeding from the discovery of their role in human disease transmission around the turn of this century. For several decades, physical methods were the only means available for controlling vectors of tropical diseases. Study of the behavior and natural history of vector species was encouraged by the requirements of physical control methods. After World War II, the old methods were largely abandoned in favor of synthetic chemical insecticides, whose promise was to eradicate vector species, particularly the mosquito vectors of malaria.

The field of vector control is slowly emerging from total reliance on chemical control methods toward 1PM (integrated pest management). 1PM, at least theoretically, includes chemical, biological, and physical control methods, once again requiring more intimate knowledge of the lives of vectors, now including knowledge of their genetic and biochemical characteristics. 1PM is as yet a new field, but one in which there is a great potential to influence the occurrence of disease in developing countries.

It is unlikely that any new medical intervention, whether a chemotherapeutic drug or a vaccine, will be sufficient by itself to reduce significantly the prevalence of vector-borne tropical diseases. To control vector-borne tropical diseases, several methods adapted to local conditions are probably necessary.

Public health authorities are beginning to emphasize basic vector control engineering measures, such as drainage, filling, and control of water bodies. However, these physical measures alone are not sufficient for disease control, and unless new methods are developed, there will be few if any practical alternatives to insecticides.