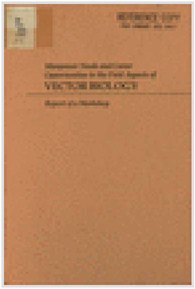

Manpower Needs and Career Opportunities in the Field Aspects of Vector Biology: Report of a Workshop (1983)

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Report of a Workshop

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PREFACE

Vector-borne diseases continue to represent a significant obstacle to social and economic development in many tropical countries. Even in the United States, viruses transmitted by mosquitoes remain considerable threats to human and animal health. Irrigation projects, land-clearing in the jungle, and refuse dumps all present opportunities for insect vectors or snails to breed or increase their contacts with human hosts. Scarce economic resources in many tropical countries have curtailed efforts to eliminate vectors through spraying or environmental measures, and cases of malaria, dengue fever, and filariasis, to mention only a few diseases, have increased notably in the past decade. Thus there has been renewed emphasis on research to discover new biologic and chemical tools for prevention and control of tropical diseases.

Strategies for control of vector-borne diseases include chemoprophylaxis, immunization, reduction of the intermediate host population or vector control, and alteration of human behavior so as to avoid contact with the pathogen or vector. Despite major advances in our knowledge of the pathology, immunology, and chemotherapy of these diseases, relatively few safe and effective drugs are available, and vaccine development is proving to be a complex, lengthy, and costly undertaking, with success not yet assured. For millions of people in developing countries, vector control is currently the only practical means of reducing their risk of acquiring such diseases as malaria, sleeping sickness, dengue, and onchocerciasis. It is likely to remain a viable primary or complementary preventive strategy for many decades.

Paradoxically, basic research in insect biology, physiology, and genetics has yielded methods with potential for controlling vectors: hormones to alter growth and reproductive behavior, biological pathogens, and genetic alterations to reduce vector populations. However, such discoveries cannot be used against important vector targets without concomitant knowledge of their ecology and bionomics gained through field studies.

For the last several decades, widespread use of DDT and other new pesticides seemed to offer hope for eradication of malaria. Indeed, the World Health Organization (WHO) and government manpower policies relating to vector control programs for *Aedes aegypti* in the Americas served to discourage commitment of a whole generation of scientists to careers in vector biology, because there was no need to hire scientists to study insects about to become extinct! A vector biologist (who is usually an entomologist) is defined as an individual engaged in the study of the biology, ecology, and control of arthropods responsible for the transmission of disease to man and his domestic animals.* Today, however, vector resistance to pesticides, parasite resistance to drugs, and failure to monitor vectors in control programs have resulted in alarming rises in malaria and dengue fever as well as other communicable diseases. Thus we find ourselves faced with a shortage of field-oriented vector biologists at a time when the need is most acute and scientific opportunities are rapidly emerging.

To address these issues, the National Research Council through its Board on Science and Technology for International Development (BOSTID) convened a workshop to assess the manpower needs and career opportunities in the field aspects of vector biology. The immediate stimulus for the workshop was a letter of 10 February 1981 from Franklin A. Neva, M.D. (chief of the Laboratory of Parasitic Diseases, National Institute of Allergy and Infectious Diseases, National Institutes of Health) to Victor Rabinowitch, then director of BOSTID. Part of the letter states:

> . . . Several of us have become increasingly concerned about the dwindling number of individuals expert in the field of biology of vectors of human disease. This has come to our attention especially with respect to entomologists knowledgeable about malaria, and malacologists in the field of schistosomiasis. But, we think this would also apply to field entomologists working in the area of arthropod-borne virus diseases, for example.
>
> Over the past decade or so, exciting research developments have focused scientific attention of the world toward immunology, cell biology and recombinant DNA technology. This is largely the trend even in the developing world, as well as in the more advanced countries. Yet, being able to deal with important health problems such as malaria and schistosomiasis requires being able to identify anopheline and snail vectors, and work out the conditions in the field under which they thrive and interact with the human population. This type of work is not considered exciting by many young biologists in the context of the times, but it is the nitty-gritty type of information and knowledge

*At the same time, medical entomologists are vector biologists with particular expertise in the epidemiology, pathology, prevention, and control of vector-borne diseases. Vector biologists with primary interest in vectors of animal diseases are normally classified as veterinary entomologists. Medical malacologists are usually considered to be invertebrate biologists with field experience in programs designed to control snail-borne disease.

that is needed to evaluate actual and potential threats of vector-transmitted diseases and to do something about their control.

Another aspect of the problem, we feel, is that effective training in field entomology requires repeated periods of working abroad in different environments to gain practical field experience. In today's scientific research scene where job opportunities and career advancement are built upon bench laboratory research, publications and professional contacts, there are few inducements and opportunities for developing a field-oriented expertise. Such an orientation need not preclude research. In fact, highly interesting critical research leads can be stimulated by the field experience, but it is a much less prolific and more uncertain, long-term affair less likely to appeal to a research granting body. Therefore, the primary objective of such career development should be trained and experienced personnel, not research publications.

If opportunities to develop such individuals can be created, how can their careers be sustained? What institutions can afford such talent that does not bring in research money? While government can absorb a few such people, most will need associations with universities, where they can teach and profitably interact with research groups to utilize their knowledge. But some mechanism of support must be devised to create a cadre of such individuals.

We feel that the NAS, or some similar group could perform a useful service in examining this issue.

This workshop was held from September 29 to October 2 in Washington, D.C., and Berkeley Springs, West Virginia (see agenda, Appendix A). Approximately 50 vector biologists and vector control experts attended the plenary session, including nationals from Brazil, Indonesia, Tanzania, and Israel and representatives from WHO. Presentations focused on the value of field research, availability of manpower for field studies of medically important insects and snails, vector field research and control activities funded by domestic and international agencies, and obstacles to career development. I would especially like to acknowledge the outstanding contributions to the plenary session made by several participants. William C. Reeves set forth broad lines of inquiry in his inspirational keynote address; Robert Gwadz, Bruce Eldridge, and Andrew Spielman each put in a tremendous effort prior to the workshop conducting mail surveys on training institutions.

Following the plenary session, workshop participants met at Berkeley Springs in three working groups that focused on (1) field experience and applications of field research to control programs, (2) training, and (3) employment opportunities. Working papers were drafted by the groups and were presented for discussion in a final plenary session. Recommendations were considered by all participants. The workshop report was prepared by BOSTID staff officer, Karen Bell,

CHAPTER 1

Need for Field Studies in Vector Biology

Vector-borne diseases constitute a major portion of the burden of illness in tropical developing countries and continue to deter human settlement and agricultural development in many areas. Although progress has been made in the development of safe and effective drugs for diseases such as malaria, schistosomiasis, and filariasis, and despite the hope of a malaria vaccine within the next decade, large-scale prevention strategies will continue to rely for some time on control or reduction of the populations of insects or snails that serve as vectors or intermediate hosts. The last several decades have seen many successes in malaria control through periodic spraying with DDT residual insecticide. However, in recent years some mosquito species have developed resistance to DDT and other insecticides, and many governments have slackened vector control efforts, resulting in an alarming resurgence of malaria cases worldwide.

The U.S. government, the World Health Organization (WHO), and other private, international, and bilateral donor agencies provide hundreds of millions of dollars in assistance to vector control programs in developing countries each year. Nearly all program expenditures are for the purchase of pesticides and spraying equipment, and for salaries for personnel. Very little of this assistance is used to train qualified vector biologists, to support field research, or to employ vector control specialists responsible for monitoring program effectiveness on a full-time basis. This situation has developed gradually over the last 20 years as a result of personnel practices in regional and global eradication campaigns directed against mosquito vectors of malaria and urban yellow fever. Ecological study of vectors was viewed as unnecessary, because application of sufficient amounts of pesticides would soon reduce their numbers to insignificant levels and eliminate these diseases.

HISTORY

The first vector biologists were the Scot, Patrick Manson, the Englishman, Ronald Ross, and the Americans, Theobald Smith and F.L. Kilbourne. Their pioneering studies at the turn of the century on the mechanisms of transmission of human filariasis and malaria and bovine babesiosis led to their independent realizations that disease reduction was best achieved by controlling the vector. Much has been learned in the 80 years since Ross first began to kill mosquitoes in Sierra Leone, and the successes have been dramatic, but the problems remain enormous. Currently WHO estimates that 1.8 billion people are at risk for acquiring malaria infection, 215 million people are affected by chronic malaria, and 150 million new cases occur annually. The toll taken by other major vector-borne diseases is equally devastating; the list includes filariasis, leishmaniasis, trypanosomiasis, the wide range of diseases caused by arboviruses, and snail-nurtured schistosomiasis.

The studies of field-oriented vector biologists from the developed countries in the 1930s and 1940s laid the groundwork for the worldwide control strategies that evolved after World War II. Persistent use of pesticides, sanitation, and general improvement of health standards eliminated vector-borne diseases from much of the temperate and subtropical world. At the same time, highly organized, centrally directed campaigns significantly reduced disease transmission in several of the larger tropical countries outside tropical Africa. Many of the leaders of *Aedes aegypti* and malaria eradication operations were physicians and engineers who functioned as entomologists. Early successes with insecticides applied on a regular basis by personnel organized under quasi-military discipline fostered the concept that basic biologic studies of vectors were not needed. In many developing countries professional entomologists were subordinate to physicians who directed control operations.

VECTOR CONTROL PROGRAMS

Arthropod- and snail-borne diseases are responsible for an enormous amount of morbidity and mortality in the tropics. In many tropical countries, vector control operations, where they exist at all, have failed to reduce disease transmission. The current resurgence of vector-borne diseases is a complicated phenomenon. Pesticide resistance in the vectors, drug resistance in the parasites, concern with environmental pollution, breakdown of control organizations, inflation in operational costs, and changes in ecological conditions have all contributed to the increasing problems. However, in spite of the development of new drugs and a greater insight into the immunology and pathology of these diseases, vector control in most cases remains the most cost-effective and often the only means of preventing them.

Mass drug-treatment programs, environmental modifications or destruction of vector breeding sites, and modifications of human habits all can be used to enhance the effectiveness of control strategies. The much-anticipated vaccines for the more important vector-borne diseases will still require significant vector control programs, particularly if vaccine protection is short-lived or animal reservoirs are involved. Of particular concern is the inadequate development of new ideas for vector control. The continued use of standard methodologies without ongoing program analysis has almost guaranteed program failure. Undetected development of insecticide resistance or changes in vector behavior ensure continued disease transmission. Ineffective programs drain public health resources, produce no improvement in human welfare, discourage participants, and are eventually abandoned. The programs are seldom reinitiated, even after the reasons for failure are determined.

There are urgent needs in virtually all tropical countries for investigations on vector biology as a basis for both present and future control operations. Research is needed to establish the biological characteristics of each of the sibling species in a vector complex and to determine the vectorial capacity, life cycle, host preferences, flight range, and preferred larval habitats of the actual or potential vectors. Control operations must be tailored to the behavioral differences of the vectors that occur from one country to another and to the varying ecological conditions within individual countries. Control operations not based on accurate biological information likely as not will end up as costly failures. The gaps in our knowledge of the biology of many important vector species reflects both the shortage of trained professionals to implement such studies and the failure of ministries of health and other authorities to recognize the need for them and ensure that such studies are carried out. Examples of such studies and their relevance to control programs follow.

Vector Identification

The identification of the primary and any secondary vectors is obviously a fundamental step in planning a vector-borne disease control campaign. In some geographic areas, the identity of the vector of some diseases and, in fact, the question of whether there *is* a vector remains unanswered. This is the case for several viral diseases, including Rift Valley fever and some of the arenaviruses. The discovery that some of the most important vector species are actually complexes of sibling species, each with a rather different biology, vectorial capacity, and susceptibility to insecticides, has had important consequences for control programs. Examples are the malaria vectors *Anopheles maculipennis*, *An. gambiae*, and *An. balabacensis*, and the onchocerciasis vector *Simulium damnosum*.

Vector Distribution

In planning a vector-borne disease control program it is essential to know not only the distribution of the disease but the distribution of the vectors, potential vectors, and reservoirs. Armed with this information, authorities can be prepared for outbreaks of disease throughout the vector's range. Surveys to obtain such information must be carried out frequently as vector distribution is dynamic and changes often, sometimes as a result of ecological changes caused by man. For example, surveys carried out within the last year in Colombia have shown that *Aedes aegypti* is found in areas and at altitudes from which it has never previously been reported, thus considerably extending the areas in that country at risk to dengue, dengue hemorrhagic fever, and urban yellow fever--as well as the areas in which vector control operations must be carried out.

Population Densities

In most cases the presence of a given vector species is a threat to public health only if the density of the species is high enough to sustain transmission of disease. Indices of population densities can be an important measure of the degree of control being obtained, however; in the case of the oriental rat flea, Xenopsylla cheopis, the index is a partial measure of the degree of risk of plague transmission. Density information can be crucial to the guidance of control programs; knowledge of when vector densities are likely to rise or fall as a result of temperature or humidity changes will help predict the greatest periods of risk for disease transmission and will guide decisions on control. Some forms of biologic and genetic control require studies of absolute densities per given geographic area, often as a part of establishing life tables for the vector.

Host-feeding Patterns

Some important vector species such as Culex tritaeniorhynchus and Anopheles aconitus are primarily zoophilic. Yet their population densities are so great that the small proportion of the population that feeds on man is more than adequate to ensure transmission of disease. Where there is an animal reservoir, the fact that the vector feeds on both the reservoir species and man ensures completion of the animal reservoir/mosquito vector/human host cycle. Even knowledge of which species are entirely zoophilic is of importance in excluding them as potential threats and therefore targets in a vector-borne disease control program. It is also essential to learn the extent to which a particular vector species obtains its blood meals from more than one variety of mammal, and the relationship of blood feeding to parasite development.

Resting Sites

Determining whether the vector species under study rests indoors or outdoors will be relevant both in assessing its vectorial capacity and in deciding on the most effective control measures. Some known mosquito vectors such as An. balabacensis and many Aedes species rarely, if ever, rest indoors and are thus not subject to control by residual insecticide applications to wall surfaces. With some species of Glossina, the outdoor resting sites are known and are so circumscribed that adequate control can be obtained by applying insecticides to trees or plants within the height limits in which Glossina are known to rest. Generally, the more specific the knowledge of the adult resting place, the more specific the control measures can be, with concomitant saving in cost and environmental contamination.

Flight Range

The distance a given vector may fly after its emergence from its larval habitat may vary from a few dozen meters, as in the case of *Phlebotomus* sand flies, to more than 300 km in flies of the *S. damnosum* complex. Vector control programs must consider flight range when determining the extent of the control barrier to be created around the area to be protected. Mark/release/recapture studies use a variety of physical markers such as dusts, paints, and radioactive tracers (e.g., P^{32} or even biological markers such as eye color mutants). The Onchocerciasis Control Programme in West Africa is devoting considerable attention to investigation of *Simulium* flight range. A sound knowledge of biology, statistics, and genetics are necessary to carry out these studies.

Larval Biology

Adequate knowledge of the preferred larval habitats of vector species or pest species of mosquitoes will determine whether that stage is subject to effective or economic control. Many important mosquito vectors, including *An. gambiae* spp., *An. arabiensis*, and *An. balabacensis*, breed for the most part in multitudes of small rain pools, making larvicidal measures quite impractical. Others, including *An. sinensis*, *An. aconitus*, and *Cx. tritaeniorhynchus*, breed over such large areas of rice fields in the Western Pacific and Southeast Asia that control by larvicides would be uneconomic. In Asia and the Americas, *Ae. aegypti* breeds primarily in man-made containers and is therefore subject to efficient control by larvicidal or environmental measures aimed at eliminating its breeding places. Information on larval biology, especially life cycles, is equally important in vectors other than mosquitoes, and such information determines where and with what frequency chemical or biological larvicides can be applied against black fly vectors of disease or *Simulium* pest species, or whether larvicidal control is not feasible at all, as is the case with tsetse or *Phlebotomus*.

VECTOR BIOLOGY FIELD RESEARCH IN SELECTED DEVELOPING COUNTRIES

Workshop participants from developing countries were asked to prepare brief papers on the current status of vector biology field research and training in their own institutions. The following sections were adapted from papers presented by nationals from Brazil, Indonesia, and Tanzania, in addition to a paper about India sent by Dr. Rajagopalan (Director, Vector Control Research Center, Pondicherry), who was unable to attend the meeting.

Brazil

Approximately 40 percent of Brazil's 120 million people living in rural areas are at risk for one or more vector-borne diseases; schistosomiasis, Chagas disease, malaria, plague, and some arboviruses remain significant threats. Successful campaigns to eliminate yellow fever and malaria from the cities were conducted in the early part of this century. A division of the national ministry of health (SUCAM) is responsible for carrying out epidemiologic studies and activities to control endemic communicable diseases, including vector studies. Very little vector field research is sponsored by SUCAM or other government agencies beyond basic studies for monitoring insecticide resistance or for taxonomic purposes.

Despite the availability of excellent research facilities and entomologic collections in several states, few Brazilian entomologists are entering the field as a scientific career. An older generation experienced in vector campaigns has not been replaced; foreign scientists must be imported to deal with the most complex vector problems. University graduates in biology prefer to concentrate in laboratory-based disciplines or enter commercially attractive fields related to agriculture. Only one institution offers a graduate-level regular course on medical entomology; it is attended by approximately 15 students from Brazil and other Latin American countries for 4 months each year. Job opportunities for professional entomologists to teach, conduct research, and direct vector control programs are almost nonexistent as a result of hiring policies in the ministries of health and higher education.

India

An estimated $200 million is being spent annually in India on malaria control programs, a large proportion of which is for import of insecticides and antimalaria drugs. In spite of this large financial commitment, little success in combating malaria has been reported. The National Malaria Eradication Programme is also in charge of control of two other vector-borne diseases, namely, Japanese encephalitis (epidemics of which occur periodically in different parts of India) and filariasis (about 300 million people are living in endemic areas and are exposed to the risk of infection).

Only since 1975 have efforts been made to recruit more entomologists for vector control programs; there are currently 72 units (in the National Malaria Eradication Programme) with entomology positions.

In 1975 the Indian Council of Medical Research, recognizing the need for continued research on vector biology and control and to develop manpower, established the Vector Control Research Centre in Pondicherry, and the Malaria Research Centre in New Delhi. These two institutions, along with the National Institute of Virology at Poona, are at present carrying out in-depth studies on the biology of many vector species. Individual scientists in many research institutions and universities have been conducting laboratory and academic research on such topics as cytogenetics, translocations, and the biochemical basis of insecticide resistance--topics that have little relevance to the immediate needs of the country for the control of vector-borne diseases. Field research has virtually gone out of fashion, mainly because of lack of facilities, incentives, motivation, and career opportunities.

Many research institutions are now attempting to create opportunities for research and to provide career structures. There are also proposals to start a master's course in medical entomology, with emphasis on field-oriented applied research. However, it will take several years before a trained cadre of vector biologists is available. In India and in other developing countries, vector control is linked with disease control organizations, where a medical degree is requisite for career advancement to positions of prestige and substantial administrative responsibility.

There is no established research component in the vector-borne disease control programs, and most of their strategies are based on old theories or on advice from international organizations. Research findings are not readily accepted and do not tend to be fed into operational programs. As a result, many relevant findings on field aspects of research on vector biology and control remain of academic or theoretical interest only.

Indonesia

Vector-borne diseases such as malaria, filariasis, schistosomiasis, plague, and dengue hemorrhagic fever are still a problem in Indonesia. An estimated 90 percent of the entire budget for communicable disease control is spent on vector control. Indonesia consists of over 13,000 islands, each with its own ecosystem that differs from one island to the other, resulting in varied fauna and flora. Vector behavior and ecology also differ from one island to another, a major reason why vector control programs have not been very effective. Integrated control measures should be initiated, but much research is needed to develop control technologies applicable in each ecosystem. Studies should include development and testing of local and appropriate technologies and consideration of human behavior and other socio-economic factors.

In 1969 the National Institute of Health Research and Development was established. Scientists--including entomologists, parasitologists, mammalogists, and acarologists--are currently involved in vector biology research at the institute's Biomedical Research Centre and Health Ecology Research Centre. Although some career opportunities exist, it is difficult to find qualified candidates with research aptitude. A cadre of scientists is being built up gradually through adequate training both in and outside the country.

The Health Ecology Research Centre currently has only 2 Ph.D.s, 2 M.Sc.s, and 8 graduate degree holders--a staff that is insufficient to meet national needs. Indonesia's many islands and 147 million people require dedicated scientists with expertise in different fields.

Minimum personnel requirements in the coming 5 years are estimated as follows:

- 3 specialists in mosquito ecology
- 2 specialists in disease transmission dynamics
- 1 taxonomist
- 2 specialists in insecticide application
- 2 specialists in noninsecticidal control methods
- 3 specialists in mammal ecology
- 2 specialists in zoonotic disease transmission
- 3 taxonomists (mammals, ectoparasites, and endoparasites)
- 1 arbovirus specialist
- 1 veterinarian

Tanzania

With an area of 945,000 km^2, Tanzania is one of the largest countries in Africa. It is also among the poorest 25 countries in the world. Many vector-borne diseases are endemic, including malaria, bancroftian filariasis, trypanosomiasis, onchocerciasis, endemic relapsing fever, schistosomiasis, and arboviruses. The enormous range in latitude, altitude, and proximity to the sea or inland lakes gives rise to varying rainfall and vegetation patterns, which in turn lead to ecological stratification. These factors inevitably influence, to varying degrees, vector habits and habitats. Recent socioeconomic changes such as urbanization, irrigation, deforestation, and creation of man-made lakes greatly influence insect vector populations, both quantitatively and qualitatively. Studies relating to these activities are essential to achieve a better understanding of field vector biology, ecology, epidemiology, and vector control.

Field research in vector biology and control in Tanzania is undertaken by several national institutions such as the National Institute for Medical Research (NIMR), the Tanzania Livestock Research Organization (TALIRO), the Tropical Pesticides Research Institute (TPRI), the University of Dar es Salaam, and the Ministry of Health (by the onchocerciasis research team stationed in Tukuyu). The National Institute for Medical Research, established in 1980, inherited the research facilities at Amani and Mwanza previously overseen by the East African Medical Research Council. Much of the good quality field research undertaken at both centers had almost come to an end in the late 1970s--the expatriate European staff left, and the overwhelming majority of the Tanzanians left behind lacked sufficient experience to conduct independent research. The new institute's principal efforts in the last 2 years have concentrated on revitalizing these centers.

Current field research includes genetic and behavioral studies of malaria and filariasis vectors, the ecology of *Simulium*, and snail population genetics. Ticks and tsetse flies, two important livestock disease vectors, are also being investigated. In general, many of the field research activities in Tanzania over the last few years have lacked high quality, mainly because there are only a few researchers and most are inexperienced. They lack expert training and guidance as well as literature, equipment, and even supplies. There is some hope, however, that the creation of the research institute in 1980 will correct these very grave deficiencies and build needed linkages to vector control programs.

There are very few vector biologists in Tanzania, and they usually cannot be recruited through advertisements. The National Institute for Medical Research has therefore begun to recruit fresh graduates with bachelor of science degrees from the University of Dar es Salaam, which is Tanzania's only university. These recruits will spend a year becoming familiar with NIMR studies before being sent to a university outside the country to pursue master's or doctoral course work. Field research for a Ph.D. degree will be undertaken in Tanzania under the supervision of the NIMR and foreign faculty with African experience. By the end of 1985 the NIMR hopes to have 6 entomologists who have completed at least the M.Sc. degree. At present only the director of NIMR has a doctorate in medical entomology.

Field research on vectors has become very difficult to undertake without support from foreign donor agencies. Unprecedented inflation and an almost total lack of foreign exchange have forced the government to cut back on most development projects, including medical research, although there have been no reductions in allocations to agriculture and related research. The financial crisis has also affected the local availability of laboratory supplies. Some years ago, many supplies could be obtained from local dealers, but their stocks are now depleted and these items must be imported with scarce foreign exchange. The same situation applies to equipment, glassware, and literature. Gasoline, when available, is costly at the official price of US $1 per liter.

NEED FOR U.S. SCIENTISTS IN VECTOR BIOLOGY RESEARCH AND CONTROL

Collaboration with Developing Countries

Many U.S. scientists have spent long periods of time abroad working in vector research and control, beginning on a large scale in the 1930s with federally funded bilateral assistance to malaria programs and the Rockefeller Foundation's research centers in malaria and arboviruses. From 1950 to the present, the U.S. Agency for International Development (USAID) has contributed close to $1 billion in support of overseas malaria programs. In the mid-1960s this support peaked, with 70 U.S. malaria advisors stationed in 37 different countries. Today USAID has only 3 career positions for malaria advisors and provides malaria program assistance to fewer than 10 developing countries. Other U.S. agencies have scientists stationed overseas or support vector field research conducted by Americans in developing countries.

U.S. involvement in tropical vector biology problems has shifted away from providing resident technical advisors who monitor bilaterally funded control operations and toward smaller scale scientific collaboration with counterparts from developing countries. Such counterparts have often been trained in U.S. institutions but are not necessarily working directly with operational control programs. The chief result of these changes has been a drastic reduction in the number of U.S. vector biologists with field research experience related to control programs.

Donor agencies such as the World Health Organization, the World Bank, and USAID should be able to call on highly skilled and experienced experts for a wide range of advice in planning and evaluating programs they sponsor. At the same time, they must expect that these complex programs will be implemented and supervised by equally competent personnel. Neither situation exists today. These agencies repeatedly engage a handful of qualified consultants for short-term assignments to assist vector control organizations in developing countries in preparing project proposals or to evaluate progress achieved and recommend changes. Expertise in the donor countries has been diminished by retirement without replacement. Expertise in the recipient countries has seldom existed. Lack of trained vector biologists in the administration of these field programs has made communication between donor and recipient difficult and implementation of new technologies often impossible. It is important to note that the $140 million spent annually in Latin America by national governments on malaria control programs does not include full-time staff positions for qualified vector biologists to be involved in their planning, implementation, or application of research findings in the field.

Universities in the United States and other industrialized countries appear increasingly unable to respond to the challenge of greater involvement in field-oriented vector biology research and training in the tropics. Although numerous institutions already support a wide range of programs in vector biology, most of these programs are primarily laboratory oriented. Field opportunities are usually limited to studies of domestic vector species. Only a few research centers in the developed world support overseas activities in vector biology and disease control in developing countries. However, most of these centers lack personnel with experience and primary interests in overseas field research. The difficulties in recruiting, training, and supporting such individuals will be discussed at length in subsequent chapters of this report.

Domestic Needs in Vector Biology Research and Control

The usual or "traditional" demands for vector biology field research in the United States emanate from a variety of institutions and agencies with differing charges and responsibilities. The levels of research activity and the settings in which they take place may be equally variable. Participants investigating basic aspects of vector biology may include the staff of whole laboratories, small teams, or single individuals employed by academic institutions or such federal agencies as the Centers for Disease Control, the National Institutes of Health, the U.S. Department of Agriculture, and the U.S. Army. Other specialists may be found within state health departments and universities. Studies of an applied nature may also be addressed by these scientists as well as by members of mosquito abatement districts and industrial research groups.

A number of mosquito-transmitted viruses in North America pose a significant public health threat. Equine encephalitis, which is often fatal to horses and humans, may have an epizootic cycle involving rodents and birds. St. Louis encephalitis infections are widely distributed in the United States, as are its Culex vectors. Of considerable concern is the increasing prevalence in the United States of Aedes aegypti, the major vector of dengue and dengue hemorrhagic fever virus strains; dengue has caused epidemics and many deaths in recent years in the Caribbean and has recently reentered Texas.

Ticks have also become increasingly important due to the movement of population to suburban-rural environments and the increase of outdoor recreational activities in rural settings. Rodent-associated pathogens, transmitted to humans by fleas, continue to be important in both rural and urban environments. Cockroaches also may contaminate food with enteropathogenic agents and also produce allergenic substances. In addition to vectors, other arthropods may also be of public health importance. Trauma associated with insect stings and their venoms is a significant, often life-threatening health problem. Hypersensitivity to insect bites may constitute a serious problem and require expensive treatment.

Vector biology and control studies in the United States can be viewed as a balanced continuum, reaching from the field to a laboratory setting. Field study topics usually emphasize key ecological aspects of vector species and may include natural history, population dynamics, and surveillance for vector potential. Vector control studies may emphasize evaluation of technology or potentially useful insecticides and biological control agents. Complementary laboratory studies that make use of field material include collection of specimens for systematic taxonomic studies, identification of potential vector species, pathogen evaluation as part of an organized surveillance program, and initiation of laboratory colonies. The availability of such biological materials in a controlled environment provides further research opportunities in vector competence, physiology, and genetics. Also, by correlating field and laboratory observations, life-table statistics and population models can be generated by computer for planning of control operations.

The need for vector taxonomy and the availability of systematic collections cannot be overemphasized, for the success of both research and control programs relies heavily on the careful identification of species and species complexes. There is, however, a growing shortage of qualified taxonomists in all areas of biology, and the training, recruitment, and career opportunities for such specialists have been diminishing during the past decade. The problems associated with the paucity of systematists, many of whom are needed for vector control programs, have been of major concern to members of the U.S. Association of Systematic Collections and its Council on Applied Systematics (CAS). The CAS is now actively exploring methods by which training and career development of systematists, including those concerned with vector species, can be revitalized.

As noted above, the needs for vector biologists are varied and often interrelated. In addition to their research activities, these scientists may be involved as teachers or advisors to health agencies. Traditional teaching needs occur at both the university and federal levels. Certain segments of industry, state and municipal health departments, mosquito abatement districts, and snail control regions also require the advisory and supervisory services of trained vector biologists.

INTERNATIONAL ASSESSMENT OF THE PROBLEM

Workshop participants concluded that field research in vector biology is needed (1) as an integral part of control efforts to monitor the response of vectors and devise alternate control strategies, (2) to conduct surveillance of known or potential disease vectors, and (3) to develop and test new approaches for vector control. The numbers of field-oriented vector biologists are currently below the critical level required to address worldwide problems of vector-borne diseases. Participants therefore stressed the immediate task of training the next generation of field researchers, especially the core groups who will be able to provide scientific leadership and serve as role models in developed and developing countries.

In developing training strategies for medical entomologists, malacologists, and vector control specialists in the tropics, public health agencies and donor organizations need to assess realistically present and future manpower needs. Such an assessment should include a survey of the number of medical entomologists and malacologists required for the study and control of vector-borne diseases, as well as an examination of factors contributing to the disparity between the number actually employed and that required. Costs of vector control programs in local currency and foreign exchange should be calculated carefully. The programs should be considered with regard to their known effectiveness or the consequences of failure to maintain them. In each country, projections should be made for numbers of entomologists and malacologists needed for teaching and conducting research at universities, operational research laboratories under ministries of health, for the administration of operational programs at a central level, and in the supervision, implementation, and evaluation of field control programs.

CHAPTER 2

Training

For the medical entomologist or vector biologist, basic academic training in a broad range of subjects must be coupled with opportunities for applying this knowledge to vector populations in the field. Until laboratory-developed information can be regularly applied to the field setting, new control methodologies will not evolve. The interplay between laboratory and field must be emphasized, and greater opportunities for training in field research must be provided. Only then can today's problems be addressed and the individuals necessary for training the next generation of vector biologists be developed.

Field-oriented research on the biology and integrated control of disease vectors must be conducted primarily in countries where these diseases remain a major problem. In contrast, academic training of medical entomologists and vector biologists can take place both in developed and developing countries. There is a growing realization that there is a diminishing number of U.S. medical entomologists and institutions with resources, expertise, and tropical experience to adequately train new vector biologists (both U.S. and foreign). In the less developed countries, the needs are much greater and the deficiencies are even more acute.

If the United States is to help developing countries to strengthen their capacity to properly train and meaningfully employ scientists in vector control and disease research projects, it must first act to strengthen its own vector biology resources. A strong program in research and training in medical entomology would allow the United States to fill its own needs, meet its overseas commitments, and provide training to scientists from the developing world. This section analyzes training and research programs in medical entomology and vector biology currently under way.

VECTOR BIOLOGY AND MEDICAL ENTOMOLOGY TRAINING IN THE UNITED STATES

Vector biology training as a discipline in the United States finds itself divided among three distinctly different academic settings: departments of entomology at land-grant universities, schools of medicine or public health, and departments of biology. In an attempt to better characterize these programs and assess their relative weaknesses and strengths, three surveys were conducted independently by workshop participants prior to the workshop. The first (Eldridge) focused on the land-grant institutions; the second (Spielman) queried the medical schools, schools of public health, and departments of biology; and the third survey (Gwadz) examined institutions with proven records for training vector biologists, their faculties, programs, opportunities for field research, current students, and recent graduates. There was significant overlap among the three surveys, and from them emerged a clearer picture of medical entomology and vector biology training in the United States.

Land-Grant Institutions

Land-grant institutions are those so designated or created by the Land Grant College Bill (Morrill Act) of 1862. The bill awarded large tracts of land to the states to serve as the financial foundation for the creation of colleges; thus the term "land grant." The Hatch Bill of 1887 authorized the development of state agricultural experiment stations and provided a regular source of research funds for their operation.

Most of the state experiment stations conduct entomological research within departments of entomology. Despite their principal mandate to conduct research aimed at increasing food or fiber production, experiment stations have traditionally conducted research to improve human health through improved sanitation and nutrition and control of vector-borne human and animal diseases. It is important to note that the major textbooks in medical entomology in this century were written by faculty members at land-grant institutions.

Because arthropod pests and vector-borne diseases can significantly affect animal populations, research on vectors at the experiment stations has been stronger in veterinary than in medical entomology. Moreover, emphasis in medical entomology and vector biology has been on vector field biology and control. Because "service to the state" is a primary mandate of faculty members in the land-grant system, research emphasis has been on pest and vector species of local or regional importance. Few of these departments have developed overseas research programs on vectors of tropical diseases.

Of the 51 land-grant institutions identified for the mail survey, 44 responded to a questionnaire regarding their programs in vector biology and medical entomology (see Table 1 and Appendix B). Thirty-one departments said that they offered opportunities in vector biology research and training, although only 23 of these both offered specific courses in medical entomology and employed a medical entomologist with an active research program on vectors. Of these 23 departments, 13 have a recent history of training significant numbers of vector biologists, and only 7 have more than 1 faculty member involved in vector biology research and training (see Table 3).

Formal course work leading to the master's or doctoral degree in entomology in the various land-grant universities emphasizes, by design,

TABLE 1 Programs in Vector Biology Field Research and Training, Land-Grant Institutions

State/ Territory	Institution	Indicated They Had a Program	Course in Medical or Medical/ Veterinary Entomology	Research in Vector Biology
Alabama	Auburn University	yes	yes	yes
Arkansas	University of Arkansas	yes	yes	yes
California	Univ. of Calif./Berkaley	yes	yes	yes
	Univ. of Calif./Davis	yes	yes	yes
	Univ. of Calif./Riverside	yes	yes	yes
Colorado	Colorado State University	yes	yes	no
Delaware	University of Delaware	yes	yes	yes
Florida	University of Florida	yes	yes	yes
Georgia	University of Georgia	no	yes	no
Hawaii	University of Hawaii	no	yes	no
Idaho	University of Idaho	no	no	yes
Illinois	University of Illinois	yes	yes	yes
Indiana	Purdue University	yes	yes	no
Iowa	Iowa State University	yes	yes	yes
Kansas	Kansas State University	no	no	no
Kentucky	University of Kentucky	yes	yes	no
Louisiana	Louisiana State University	yes	yes	yes
Maine	University of Maine	yes	yes	no
Maryland	University of Maryland	yes	yes	no
Massachusetts	University of Massachusetts	yes	yes	yes
Michigan	Michigan State University	yes	yes	yes
Minnesota	University of Minnesota	yes	yes	yes
Mississippi	Mississippi State Univ.	yes	yes	yes
Montana	Montana State University	no	no	no
Nebraska	University of Nebraska	no	no	no
New Hampshire	Univ. of New Hampshire	no	yes	yes
New Mexico	New Mexico State University	no	no	no
New York	Cornell University	yes	yes	yes
North Carolina	North Carolina State Univ.	yes	yes	yes
North Dakota	North Dakota State Univ.	no	yes	no
Ohio	Ohio State University	yes	yes	yes
Oklahoma	Oklahoma State University	no	yes	no
Oregon	Oregon State University	yes	yes	yes
Pennsylvania	Pennsylvania State Univ.	yes	yes	yes
Puerto Rico	University of Puerto Rico	yes	no	no
South Carolina	Univ. of South Carolina	yes	yes	yes
Tennessee	University of Tennessee	yes	yes	yes
Texas	Texas A&M University	yes	yes	yes
Utah	Utah State University	yes	yes	no
Vermont	University of Vermont	no	no	no
Virginia	Virginia Polytechnic Inst.	no	yes	no
Washington	Washington State Univ.	yes	yes	no
West Virginia	West Virginia University	no	yes	yes
Wisconsin	University of Wisconsin	yes	yes	yes

NOTE: Based on questionnaire--excludes those not responding.

traditional entomology courses. Clearly lacking in most of these programs are courses (for example, virology, parasitology, and bacteriology) that relate to the pathogenic organisms transmitted by arthropods. Epidemiology and pathology are seldom taught even where collaborative programs have been developed between entomology, biology, and veterinary medicine departments within the same university. Training is usually very strong in the control aspects of vector biology, but, with few exceptions, the medical side of "medical" entomology is deficient. In most cases, the graduates of land-grant universities are trained primarily as vector biologists and require additional training to develop expertise in the medical aspects of the science.

Schools of Public Health and Schools of Medicine

Medical entomology programs in several schools of public health or medicine were developed in recognition of the critical role played by arthropods as vectors of many of the world's most important infectious diseases. Spielman sent questionnaires to 17 health science departments regarding the current status of their programs in medical entomology. Of the 15 responses, only 7 departments within schools of public health or medical schools indicated that they have active programs leading to advanced degrees in medical entomology (Table 2). Two new programs, the University of South Carolina School of Public Health and the Uniformed Services University of the Health Sciences, have been established but do not yet have full-time students. At Tulane, a currently dormant malariology program anticipates expansion in the near future. The University of Maryland Medical School in Baltimore operated a major medical entomology research facility in Lahore, Pakistan, for more than 20 years. Recently funded once again, the University of Maryland program expects to restore the station and increase research in the epidemiology of vector-borne diseases. Coupled with the department's strong interests in rickettsiae and their vectors, Maryland shows promise for developing an important program for future training of field-oriented medical entomologists.

The traditional departments of public health and medicine at Harvard, Yale, Johns Hopkins, and the University of California at Berkeley and at Los Angeles continue to support programs in medical entomology. In addition to programs for doctoral students and post-doctoral fellows, they regularly offer courses in medical entomology and the epidemiology of vector-borne diseases to public health workers studying for master of public health (MPH) degrees in their schools. The Yale program in medical entomology and arbovirology is the largest in this group with 7 faculty members indicating interest in vector-borne diseases and their transmission and control. The Old Dominion University/Eastern Virginia Medical University has a long-standing focus on ticks and tick-borne diseases; this program has awarded a number of master's degrees and has recently initiated a Ph.D. program.

TABLE 2 Medical Entomology Training Programs

Institution	Program Status
Schools of Public Health or Medicine	
Arthropod-Borne Disease Research Unit Department of Biomedical and Environmental Health Sciences School of Public Health University of California Berkeley, CA 94720	Active
Laboratory of Medical Entomology Department of Immunology and Infectious Diseases Johns Hopkins School of Hygiene and Public Health 615 North Wolfe Street Baltimore, MD 21205	Active
Department of Tropical Public Health Harvard School of Public Health 665 Huntington Avenue Boston, MA 02115	Active
Infectious and Tropical Disease Section Division of Epidemiology School of Public Health University of California Berkeley, CA 94720	Active
Department of Tropical Medicine and Parasitology Louisiana State University Medical Center 1542 Tulane Avenue New Orleans, LA 70112	Latent
Department of Biological Sciences School of Sciences and Health Professions Old Dominion University/Eastern Virginia Medical School Norfolk, VA 23508	Active
International Center for Public Health Research School of Public Health University of South Carolina Post Office Box 699 McClellanville, SC 29458	Developing

TABLE 2 Medical Entomology Training Programs (Continued)

Institution	Program Status
Schools of Public Health or Medicine	
International Health Program University of Maryland Medical School 10 South Pine Street Baltimore, MD 21205	Active
Malariology Program Department of Tropical Medicine School of Public Health and Tropical Medicine Tulane University 1430 Tulane Avenue New Orleans, LA 70112	Now dormant; expansion anticipated
Department of Preventive Medicine/Biometrics Division of Tropical Public Health Uniformed Services University of the Health Sciences School of Medicine 4301 Jones Bridge Road Bethesda, MD 20814	Developing
Section of Medical Entomology and Yale Arbovirus Research Unit Department of Epidemiology and Public Health Yale University School of Medicine 333 Cedar Avenue New Haven, CT 06520	Active
Departments of Biology	
Acarology Laboratory Department of Biology Georgia Southern College Statesboro, GA 30458	Active
Department of Biological Sciences University of Illinois - Chicago Circle Box 4348 Chicago, IL 60680	Active
Vector Biology Laboratory Department of Biology University of Notre Dame Notre Dame, IN 46556	Active

Because of their location in schools of public health or medicine, these training programs provide their students with a unique opportunity to interact with clinicians and others involved in tropical medicine. Epidemiology of infectious diseases forms an important part of the medical entomology curriculum. Available courses tend to emphasize diseases (for example, malaria, filariasis, arbovirus infections). The major curriculum deficiency is the lack of formal course work in entomology and vector ecology, which poses a serious problem for students who have not had adequate exposure to traditional courses in entomology. In these schools the medical aspects of medical entomology often far outweigh instruction in basic entomology.

The impact of these schools in presenting concepts of medical entomology to MPH candidates cannot be underestimated. Many of these graduates go on to assume high administrative offices in national and international health organizations and can significantly influence the employment and deployment of medical entomologists in their native countries.

Departments of Biology

Within departments of biology in private universities in the United States, two programs in medical entomology stand out with respect to faculty commitment, diversity of curriculum, and development of graduate and postdoctoral students. Georgia Southern College, with an emphasis on tick biology, trains most of its students to the master's level and has supported a number of postdoctoral associates. The Vector Biology Laboratory of the University of Notre Dame maintains the largest training program in the United States for doctoral and postdoctoral degrees.

Curricula in these biology departments include the traditional entomology and acarology courses, with special opportunities for training in physiology, genetics, ecology, and population biology of vectors. The program at Notre Dame is particularly strong in parasitology and virology. Neither institution has a medical or public health school and therefore does not offer courses in epidemiology or pathology of human diseases.

Analysis of Medical Entomology Training in the United States

The Delphi or "expert judgment" method was used by Gwadz to prepare a list of the major institutions involved in training medical entomologists and vector biologists. The list was compiled by several vector biologists; some centers may have been missed, but in general the survey covered the majority of recognized programs. The survey was more specific than those of Eldridge and Spielman and focused on faculty, current students, and graduates of these programs. Twenty-seven institutions were contacted; 24 responded including 15 land-grant departments, 7 schools of public health or medicine, and 2 departments of biology. Table 3 summarizes the findings from this survey.

TABLE 3 Survey of Leading Training Centers for Medical Entomology and Vector Biology in the United States

State	Institution	Number of Faculty	Number of Students (Current)	Number of Postdocs (Current)	Number of PhDs Awarded Since 1970	Postdocs Trained Since 1970
LAND-GRANT INSTITUTIONS						
CA	U. Cal./Berkeley	3	6	1	8	5
	U. Cal./ Davis	2	7	1	12	5
	U. Cal./Riverside	3	5	0	10	6
FL	Vero Beach Lab. of U. of Florida	7	0	2	0	4
GA	U. of Georgia	1	0	0	6	1
IL	U. of Illinois*					
IA	Iowa State	1	5	0	7	0
MD	U. of Maryland*					
MA	U. Massachusetts	1	3	1	2	1
MI	Michigan State	1	2	0	4	0
NJ	Rutgers*					
NY	Cornell	1	3	0	4	1
NC	N.C. State	3	4	2	9	4
OH	Ohio State	3	7	0	3	0
OR	Oregon State	1/2	0	0	0	0
TX	Texas A&M	2	11	0	11	1
WA	Washington State	1	0	0	6	1
WI	U. of Wisconsin	1	3	0	9	0
	SUBTOTAL	30 1/2	56	7	91	29
SCHOOLS OF PUBLIC HEALTH OR MEDICINE						
CA	U. Cal./Berkeley	5	3	0	5	0
	UCLA (Los Angeles)	1	8	1	5	7
CT	Yale	7	3	4	5	4
LA	Tulane	1	1	0	5	0
MD	Johns Hopkins	1	9	1	8	1
MA	Harvard	1	3	1	4	7
VA	Old Dominion U.	4	6	0	0	1
	SUBTOTAL	20	33	7	32	20
DEPARTMENTS OF BIOLOGY						
GA	Georgia So. Coll.	3	6	3	2	10
IN	Notre Dame	7	11	9	19	29
	SUBTOTAL	10	17	12	21	39
	TOTAL	60 1/2	106	26	144	88

*Did not respond to questionnaire.

Current Faculty Status

Of the 24 reporting institutions, 11 listed a single faculty member with a primary interest in medical entomology. Among the land-grant universities, only the University of Florida, which includes the Florida Medical Entomology Laboratory at Vero Beach with 7 medical entomologists, supported more than 3 faculty members; 7 of these departments had only 1 position involved with vectors.

Among the health-related institutions, Harvard, Tulane, Johns Hopkins, and the University of California at Los Angeles showed a single permanent faculty member responsible for medical entomology. Larger programs and faculties exist at Yale (7 faculty members), University of California at Berkeley (5), and Old Dominion University (4).

Georgia Southern College lists 4 full-time faculty members, while Notre Dame's Vector Biology Laboratory has 7 faculty members conducting research on vectors. The medical entomology program at Notre Dame is enhanced by 5 faculty positions in parasitology, one of the largest parasitology training programs in the United States.

Current Enrollment

Table 3 presents a summary of current student populations in vector studies at the 24 universities. Although the survey does not differentiate master's from doctoral candidates, it identifies over 100 students with majors in medical entomology and vector biology. The distribution of postdoctoral fellows currently working in medical entomology at the various universities shows that the majority of fellows are located in departments of biology or associated with health institutions.

Table 3 lists doctorates awarded in medical entomology and vector biology from 1970 to 1984 by the 24 universities. Obviously, some of the smaller programs not queried awarded degrees during the period, but their contribution to the total trained in the United States is estimated to be quite small. Eight of these schools produced over 64 percent (91/144) of the doctorates: Notre Dame (19), University of California at Berkeley, public health and entomology combined (14), University of California at Davis (12), Texas A&M (11), University of California at Riverside (10), North Carolina State (9), University of Wisconsin (9) and Johns Hopkins (8).

Postdoctoral training from 1970 to 1982 shows a distribution similar to the current postdoctoral population. Over two-thirds of the 88 fellows were trained in biology or health-related departments, and one-third of the 88 were trained at Notre Dame.

Training of Foreign Scientists

The role of U.S. universities in training foreign scientists for careers in medical entomology and vector biology has never been fully analyzed. Twenty-seven foreign students have received doctorates between 1970 and 1982, and 15 are currently enrolled at the 24 institutions surveyed. In addition, 18 postdoctorals were trained and 6 are currently in training, all in departments of biology or health.

Opportunities for Overseas Field Research in Vector Biology at U.S. Institutions

At the land-grant institutions, field research, where done, is usually directed toward management of pest populations. Programs at the University of California at Davis, University of California at Riverside, North Carolina State, and Texas A&M are primarily oriented toward field programs in population dynamics and control of insect pests of man and animals. The Vero Beach Medical Entomology Laboratory recently merged with the University of Florida entomology department and today offers excellent opportunities for field research on problems in Florida associated with insects that bite. The programs at University of California at Berkeley (in cooperation with its School of Public Health), University of Massachusetts, University of of Wisconsin, Rutgers, and Iowa State are heavily involved in field studies of arboviruses and their vectors. Few of the land-grant departments operate overseas research programs in medical entomology. Michigan State (Sudan) and Cornell (Central America) are exceptions.

Schools of public health and programs within medical school departments have a long tradition of work on field aspects of medical entomology both in the United States and overseas. Most of these departments are in private universities and have flexibility in developing collaborative arrangements with overseas research facilities. The program at Berkeley, a state institution, is an exception in that its field orientation is primarily toward problems associated with arbovirus vectors in California.

Johns Hopkins has conducted long-term field studies in India, Bangladesh, on various South Pacific islands, and is currently working in West Africa. Harvard entomologists are involved in the Bahamas, Brazil, and Egypt, while maintaining studies of the vectors and epidemiology of tick-borne babesiosis and Lyme disease in the eastern United States. The arbovirology program at Yale is one of the strongest with research connections in the United States and overseas.

Among the departments of biology, only the Notre Dame program sustains field activities at home and abroad. The Notre Dame Vector Biology Laboratory directly manages the local county mosquito abatement program and has access to a large field research facility in upper Michigan. Notre Dame staffed and operated a USAID-sponsored mosquito field research facility in Mombasa, Kenya, in the past, and continues to collaborate with a number of field-oriented U.S. and foreign research units.

From the surveys of Eldridge, Spielman, and Gwadz, it is evident that medical entomology and vector biology training programs in the United States are diverse in nature and in several cases vigorous and productive in their research and development of scientists. Although no single program is able to offer a "complete" curriculum that includes all aspects of entomology, parasitology, epidemiology, and public health, many of the programs offer a range of courses in both the laboratory and field aspects of medical entomology.

The land-grant universities are particularly strong in classical entomology and vector control technologies. The schools of medicine and public health emphasize diseases, epidemiology, and patterns of transmission. The two strong programs in biology departments offer particularly well-rounded instruction in vector biology, parasitology, and population studies. Opportunities for field studies are included in some, but not all, programs.

Conclusions about Training in the United States

Medical entomologists and vector biologists have traditionally entered the field by various paths. Many of the earliest workers were physicians drawn to medical entomology by the realization that disease control could, in many cases, be best achieved by controlling the vector. Even today a number of medically qualified individuals have, or are seeking, master's and doctoral degrees in medical entomology.

Undergraduate preparation for graduate work in vector biology and medical entomology can take many forms. Because of the variety of specializations within the broader designation of medical entomology, no rigid undergraduate program is suggested, nor is one generally advisable. At the undergraduate level, such a program should be available in most departments of biology. At the graduate level, no one department offers all the courses listed.

Ideally, preparation for a career in medical entomology should include a strong undergraduate background in general biology (see Table 4). Graduate work should emphasize entomology and vector biology, usually in one of the land-grant departments or departments of biology. Postdoctoral training should be used as a means of broadening experiences and also of specialization. Departments of entomology can provide the best opportunities for those interested in vector control. Graduates of entomology departments might find that time spent in schools of public health or medicine could broaden their appreciation of epidemiology and vector-borne diseases.

Workshop participants concluded that a variety of programs are involved in training scientists for careers in vector biology. They agreed that the strongest vector biology training programs are characterized by:

- Clear institutional commitment to the long-term support of vector biology training and research

- Diverse training opportunities, i.e., two or more faculty members with expertise in different areas of vector biology (e.g., control, ecology, genetics) and/or with different groups of disease vectors (e.g., mosquitoes and ticks)

- Ongoing field research opportunities preferably within nearby enzootic disease foci
- Extramural support for research and/or training activities
- Cooperation and collaboration with other vector biologists or allied scientists in other departments or at sister institutions
- Opportunities to interact with operational vector control programs
- Collaboration with institutions in tropical locations that could provide student and faculty exchanges between the United States and developing countries for research, training, and strengthening of developing country institutions.

VECTOR BIOLOGY TRAINING IN DEVELOPING COUNTRIES

For many years, vector biologists from developing countries were trained exclusively by academic institutions in the developed world. A major problem facing the students was the lack of field activities relevant to vector populations and ecology of their own countries. With the objective of making these countries more self-reliant and in order to train the students of developing countries, the World Health Organization (Vector Biology and Control and Tropical Disease Research) supports centers for training at the master's level. In addition, WHO staff anticipate the need for supporting a small number of graduates who wish to obtain doctoral degrees in the United States or other developed countries. It is hoped that these individuals could complete their course work in residence abroad, with the understanding that they return home to undertake their field research under the supervision of specialists or academic advisors from developed or developing countries.

The eight regional training centers receiving WHO support are located as follows:

Africa
University of Nairobi, Kenya
University of Jos, Nigeria
University of Abidjan, Ivory Coast

Southeast Asia
Mahidol University, Thailand
University of Bogor, Indonesia

Central and South America
University of Minas Gerais (Belo Horizonte), Brazil (to be established late in 1983 or 1984)
University of Panama, Panama (currently assisted by PAHO)

To be established in 1984
University of Madras (Pondicherry), India

TABLE 4 Academic Courses for Vector Biology Training

Bachelor's		Master's/Doctoral
Year 1	General zoology	Biology of vector insects and acarines (including taxonomy, morphology, physiology, ecology, population genetics, behavior, and pathology)
	General botany	
	Inorganic chemistry	
	General physics	
Year 2	Invertebrate zoology	Integrated pest management
	Vertebrate zoology	Pesticide toxicology
	Organic chemistry	Infectious disease epidemiology
	Algebra or calculus	Pathology
	Spanish or French	Immunology
		Infectious bacteria & rickettsia
Year 3	Microbiology	Animal virology
	Genetics	Helminthology
	General entomology	Protozoology
	Biochemistry	Vertebrate biology & classification
	Biostatistics	Advanced biostatistics
	Spanish or French	Exploratory data analysis
		Computer usage
Year 4	Community ecology	
	Animal behavior	Other Possibilities
	Evolution	
	Parasitology	Scientific writing
	Limnology or hydrology	Public health administration
	Freshwater ecology	Research techniques
	Meteorology	Systems ecology
		Phycology
	Other Possibilities	Mycology
		Plant ecology
	Malacology	Biogeography
	Vertebrate physiology	Plant taxonomy
	Molecular biology	
	Developmental biology	
	Public health	
	Systematics	

VECTOR BIOLOGY TRAINING IN DEVELOPED COUNTRIES OUTSIDE THE UNITED STATES

Outside the United States, several major centers are involved in research and training in vector biology and medical entomology. In Great Britain the London and Liverpool schools of tropical medicine have a long and illustrious tradition of research and training with particular emphasis on training scientists from less developed countries. Although field research is limited or nonexistent in Great Britain, overseas laboratories in former colonies have proved to be exceedingly productive. Because of contracting colonial interests and increased fiscal pressures, the future of British training in tropical medicine is currently in jeopardy.*

ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), the highly regarded overseas research program of the French government, operates a major medical entomology research and training center outside Paris and posts entomologists throughout the French-speaking tropics.

Smaller programs exist in a number of European countries, but none are comparable to those in Great Britain or France.

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*More information about this situation is contained in Transactions of the Royal Society of Tropical Medicine and Hygiene, Vol. 75, Supplement 1981, pp. 1-60 (Manson House, 26 Portland Place, London W1N4EY).

CHAPTER 3

Career Opportunities in Vector Biology

DEMAND FOR VECTOR BIOLOGISTS

Just as integrated control programs are being developed for agricultural pests, programs to control vector-borne diseases must develop strategies that incorporate management of vector populations, vaccines, drugs for treatment and prophylaxis, and management of environmental resources. In the future, professionals will be needed who can integrate and apply findings from molecular biology, microbiology, medicine, engineering, and vector biology.

At the plenary session of the workshop, representatives from U.S. federal, state, and local agencies, professional associations, universities, developing country institutions, and the World Health Organization described the current situation regarding employment opportunities and career positions for vector biologists. Reliable estimates of professionals engaged primarily in field research are difficult to obtain, either because the category is broadly defined or because there are multiple agency interests. In general, however, all workshop presentations identified a need for more personnel to conduct field research on human disease vectors of international importance. Table 5 summarizes the data contained in these presentations.

World Health Organization

Entomologists and malacologists are employed by the World Health Organization (WHO) at a number of levels. In country offices, 24 entomologists are employed in programs of investigation and control of such diseases as malaria, filariasis, trypanosomiasis, and arboviruses. Programs are initiated at the request of governments or as a result of dialogue between the government and WHO. WHO also has teams that carry out investigations on the epidemiology of malaria or other vector-borne diseases in similar areas in more than one country.

Of 6 regional offices of WHO, 5 have 1 or more regional vector biology and control advisors. At WHO headquarters, most entomologists and malacologists are employed in the Division of Vector Biology and Control (VBC); currently there are 7 Ph.D. entomologists,

TABLE 5 Career Positions in Vector Biology and Control, 1982

Level of Institution or Agency	Number of Full-time Positions[a]
International	
Agency for International Development[b]	3
Bilateral Overseas Programs[c]	74
Food and Agriculture Organization of the United Nations	1
International Atomic Energy Agency	10
Pan American Health Organization	14
World Health Organization	54
National	
Department of Agriculture	
Gainesville, Beltsville, Lake Charles, Denver (plus veterinary entomology labs)	29
Department of Defense	
Army	82
Navy	26
Air Force	14
Department of Health and Human Services	
Centers for Disease Control, Atlanta	3
Centers for Disease Control, Ft. Collins	10
National Institutes of Health (NIAID)	4
State and Territorial	
Departments of entomology, land-grant universities	30
Health sciences and private universities	20
State vector biology and control agencies[d]	104
Local	
Vector biology and control agencies	739
Private sector	Unknown

[a]In this table, "position" means a permanent job requiring graduate training in medical entomology.

[b]Four additional positions on a contractual basis.

[c]Estimates or positions by country are as follows: Australia (2), Belgium (3), Canada (1), Denmark (1), France (25), Germany (8), Israel (1), Japan (6), Netherlands (2), United Kingdom (20), USSR (5).

[d]Includes data from 33 states and territories, but total may be low due to underreporting.

1 malacologist, 1 insecticide chemist, 2 medical toxicologists, 3 environmental engineers, and 4 technical officers. The VBC Division provides services to the regions and to the disease control divisions including the Malaria Action Programme, the Parasitic Diseases Programme, the Communicable Diseases Division, and the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases.

Other International Agencies

A substantial number of entomologists are employed by the Food and Agriculture Organization of the United Nations, although most of them are obviously concerned with plant protection or stored food product protection. Some are involved with tsetse fly and tick investigations.

The International Atomic Energy Agency, concerned with application of the sterile insect technique to the control of insects of medical, veterinary, and public health importance, employs several entomologists. Due to a shortage of medical entomologists in the donor country (such as Denmark and Sweden), some bilateral agencies hire foreign entomologists.

Developing Countries

Field research being conducted by vector biologists in selected developing countries was described in Chapter 1. Workshop participants agreed that the shortages of highly trained vector biologists described in that chapter were typical of most developing countries. Many vector control programs do not have full-time staff positions for a highly qualified entomologist or malacologist. Universities and government research institutes rarely, as yet, have vector biologists who have been trained in or exposed to the new disciplines of molecular biology or cytogenetics. Creation of additional new positions is not likely to happen without explicit policy directives from national governments, who usually control hiring in federal universities and communicable disease control agencies.

Employment Opportunities in the United States

Agency for International Development

At present there are only 3 permanent staff positions for vector biologists at USAID within the category of malaria advisors. There are four contract positions for personnel overseas. However, the agency occasionally funds vector biology field research projects on malaria either directly or through other domestic agencies. The Office of the Science Advisor recently announced a new program of funding for research on innovative biological vector control methods.

Armed Forces

The U.S. military maintains a large cadre of medical entomologists deployed to satisfy worldwide commitments for vector-borne disease control. At present, 122 medical entomologists serve as commissioned officers in the Army (82), the Navy (26), and the Air Force (14) (Table 6). They are assigned to various jobs in the continental United States or abroad within their respective services.

Graduate training in entomology with strong emphasis on medical entomology is an employment prerequisite in these organizations with a master's degree being a minimum requirement. Entomologists with a bachelor's degree occasionally may be accepted to satisfy operational needs of vector control.

Career opportunities for medical entomologists in the armed forces have been steadily on the rise since 1970, with the exception of the Air Force where the emphasis has shifted to operational and environmental pest control programs. Few additional positions are anticipated in the future to meet expanded programs. Others will become available as personnel leave or retire from the active service.

TABLE 6 Commissioned Entomologists in the U.S. Armed Forces

Service	Number	Educational Entry Level	
		M.Sc.	Ph.D.
Air Force	14	7	7
Army	82	48	34
Navy	26	12	14
TOTALS	122	67	55

Department of Agriculture

Insects Affecting Man and Animals Research Laboratories, Gainesville, Florida This laboratory employs 25 full-time professional scientists in addition to 3 or 4 postdoctoral entomologists conducting studies on control methods for insects of medical and veterinary importance. Research on methods and compounds for personal protection from biting arthropods are also conducted. The laboratory receives financial support from the Department of Defense for studies applicable to military needs. Significant turnover from retirement of senior scientists since 1970 has created and promises to continue to create job opportunities for medical entomologists.

Arthropod-borne Animal Diseases Research, Denver, Colorado Research activities have been expanded in recent years due to the recognition of the importance of *Culicoides* as pests of livestock and as vectors of blue tongue virus. Four professional entomologists are conducting studies on this group of biting flies.

Department of Health and Human Services

Centers for Disease Control (CDC) Vector-borne disease currently represents a small proportion of the total operation of CDC. Field activities include the development and/or evaluation of control technology equipment and material. Consultation work is concerned with the epidemiology and control of vector-borne disease. The CDC currently employ 11 medical entomologists who conduct basic and applied research on the epidemiology of arboviruses and plague. The Division for Parasitic Diseases has 6 medical entomologists who conduct research on vector-borne parasitic diseases with emphasis on malaria and who also provide supportive consultation, field, and laboratory services. A postdoctoral fellowship program has recently been established that would include entomologists.

National Institute of Allergy and Infectious Disease (NIAID) NIAID is a major source of funding for research and research training in vectors of human disease. In FY 1982, the NIAID extramural training component consisted of 2 institutional training programs ($192,553) and 1 individual training award ($17,736).

The NIAID intramural medical entomology program, with 1 tenured scientist, is a major component of the malaria research effort of the Laboratory of Parasitic Diseases. The unit is primarily concerned with the physiology, behavior, and genetics of anopheline vectors. Recent collaboration with New York University has resulted in the application of monoclonal antibodies to surface components of plasmodial sporozoites to determine the sporozoite infection rates of mosquitoes. The Epidemiology Branch at the Rocky Mountain facilities has 3 acarologists to maintain its interest in tick-borne diseases and is active in field investigation on the epidemiology of Lyme disease.

The intramural medical entomology program provides the opportunity for research training of 1 medical entomologist per year. Since 1974, 5 postdoctoral medical entomologists have received research training in the intramural program for periods of 3-4 years. It also provides technical support in medical entomology to 2 NIAID staff members assigned to the Ain Shams Center for Research and Training on Vectors of Human Disease in Cairo. Constraints in the intramural budget and limited laboratory space will prevent expansion in the immediate future. The medical entomology program will, however, move to larger facilities on the NIH campus in 1983.

The extramural training program is expected to suffer further constraints as part of an overall reduction in NIAID/NIH support for research training imposed both by a primary commitment to support for investigator-initiated grants and by federal policy regarding the proper NIH role in training. NIAID currently does not support contracts in vector pathogens with its regular funds and is unlikely to do so in the foreseeable future due to current commitments that exceed contract funds.

State Agencies in Vector Control

State health agencies are a major employer of vector biologists. Donald Womeldorf, a workshop participant, queried state departments of health regarding their employment of vector biologists. He reported that 19 of 33 states responding to his 1982 poll had positions for a total of 104 vector biologists. Seven states anticipated an increase in the number of positions over the next 5 years.

Duties of vector biologists include (1) providing support to local agencies (training, technical consultation and assistance, overall program guidance); (2) conducting vector surveillance and control (coordination of surveillance, liaison with laboratory and epidemiologic services, evaluation and interpretation of data, control recommendations); and (3) serving as liaison with regulatory agencies in planning for vector control.

Local Agencies

For FY 1980, 739 local mosquito abatement districts spent more than $84 million for vector control, primarily directed against pest mosquitoes. The problems and programs are quite varied. Traditionally the most efficient or successful programs have evolved in states with a strong university faculty in medical entomology (such as New Jersey, Illinois, and Indiana). In California and Florida, state health department medical entomologists have been instrumental in the development of excellent mosquito control programs.

Effective administration of these programs requires a high level of proficiency in vector biology field operations and evaluation. Many of the programs are not staffed by trained vector biologists but should be. There is a serious shortage of university or health department vector biologists to provide the necessary expertise for development and guidance of mosquito control in most areas of the United States. In summary, expanding local mosquito and vector control programs can be improved immeasurably by additional assistance and use of vector biologists from university and federal and state health agencies.

Private Sector

There are basically three types of organizations in the private sector that offer employment opportunities:

1. Chemical and pharmaceutical companies
2. Consulting organizations
3. Pest control companies (or other service organizations).

Pharmaceutical companies that produce drugs for zoonoses may require medical entomologists and malacologists for research and testing of their products. Consulting organizations, such as Insect Control & Research, Inc., have medical entomologists on their staff. Pest control operations also employ medical entomologists.

No serious attempt was made to obtain information from private firms regarding the number of vector biologists employed. Only 4 of the 110 U.S. respondents listed in the 1982 World Directory of Vector Research and Control Specialists* compiled by Gerberg (a workshop participant) are employed by commercial or industrial companies.

COLLABORATION BETWEEN VECTOR BIOLOGISTS IN THE UNITED STATES AND DEVELOPING COUNTRIES

A number of mechanisms have evolved over the years that provide field research and training opportunities for individuals interested in the biology of vectors.

From 1962-1980, the International Center for Medical Research and Training (ICMRT) program, National Institutes of Health, supported major overseas activities of 5 universities: University of Maryland Medical School in Lahore, Pakistan, and Salvador, Brazil; Johns Hopkins School of Hygiene and Public Health in Calcutta, India, and Dacca, Bangladesh; University of California in Kuala Lumpur, Malaysia, and briefly in Oaxaca, Mexico; Tulane University in Cali, Colombia; and Louisiana State University in San Jose, Costa Rica. The Maryland and California programs were particularly active in entomology. Although no longer NIH-funded as international centers, these units serve as models for overseas research and training. This program ended in 1980. Unfortunately, there was no published evaluation by the NIH to assess the effectiveness of the program, and there was no provision to absorb the trained staff at the termination of the projects. However, a number of foreign as well as U.S. students received unique training opportunities.

The NIH-sponsored International Collaboration in Infectious Disease Research (ICIDR) program replaced the ICMRT program in 1980. Michigan State University in the Sudan and the Harvard School of Public Health in Brazil operate programs that include entomological components and provide training opportunities to U.S. and foreign scientists both in the United States and in the host countries. It is not yet clear whether these ICIDRs can function as successfully as did the ICMRTs for the training of scientists in field entomology.

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*Available from Eugene Gerberg, Insect Control and Research, Inc., 1130 Dillon Heights Avenue, Baltimore, Maryland 21228, USA, by sending $2.00 to cover mailing costs.

From 1970-1975, the Vector Biology Laboratory of the University of Notre Dame, with funds from USAID, operated a mosquito biology research station in Mombasa, Kenya, as part of the International Center for Insect Physiology and Ecology (ICIPE). The unit provided field experience to a number of pre- and postdoctoral trainees.

The Gorgas Memorial Laboratory in Panama remains one of the more important sites for overseas field research. Independently funded by the U.S. Congress and private sources, it has provided a base for field-oriented studies for decades and full-time employment to a number of entomologists.

The U.S. Army laboratories in Thailand, Brazil, Panama, Malaysia, and Kenya, and the U.S. Navy laboratories in Egypt, Indonesia, and the Philippines have the largest field-oriented entomology research programs outside the United States and still provide some of the best opportunities for overseas research.

The Laboratory of Parasitic Diseases, National Institute for Allergic and Infectious Diseases, NIH, with funds from USAID, is involved in a program to study the "Epidemiology and Control of Arthropod-borne Diseases in Egypt and Israel." This tripartite collaborative program, which supports major entomological studies in Israel and Egypt staffed by local personnel, also provides for the posting for a minimum of 2 years, of 2 NIH-selected entomologists (1 with an M.D. degree in addition to a degree in entomology). These 2 entomologists are stationed at Ain Shams University in Cairo. Their charge is to develop field-based studies on the vectors and epidemiology of malaria and Rift Valley fever, working as a fully integrated part of the Ain Shams research program.

The CDC has maintained small research and training centers in Central America and the Caribbean. However, its primary orientation is toward the arbovirus vectors in the United States.

FACTORS AFFECTING DEMAND FOR VECTOR BIOLOGISTS

Policies of the U.S. Government

United States federal agencies involved in vector control activities in developing countries include the Agency for International Development, the Department of Agriculture, the Department of Health and Human Services, and the Department of Defense (DOD). Their programs are usually aimed at satisfying needs and requirements mandated by Congress. For example, the Department of Defense must be prepared to prevent and treat tropical ailments of U.S. military troops, and the Department of Health and Human services is primarily responsible for the health needs of the U.S. population. The U.S. Department of Agriculture has very limited operations in foreign countries in the medical entomological and malacological fields. The few existing programs have a primary orientation toward veterinary problems of a zoonotic nature.

Workshop participants agreed that the Agency for International Development has the most flexibility of any federal agency in promoting scientific collaboration between U.S. and developing country investigators and in providing field research experience. Both the 1980 and 1983 USAID Health Policy Papers state that the agency will consider supporting research and training in connection with malaria and schistosomiasis control programs. In many cases, USAID assistance to control programs abroad involves short-term visits of technical advisors with considerable field operational experience.

Workshop participants recognized, however, that activities funded in recent years may not have allowed either long-term continuing involvement from U.S. scientists or long-term training opportunities for vector biologists from developing countries. According to a 1982 General Accounting Office (GAO) report (Malaria Control in Developing Countries: Where Does It Stand? What is the United States Role?), the ability of USAID to provide technical assistance to developing countries in malaria control has declined, while recipient governments have often failed to train or support control specialists. Nevertheless, funding for spraying programs has continued because of perceived humanitarian need, despite doubts about effectiveness against the vector species. A new USAID malaria policy document is being prepared as a result of the GAO report and will address research and manpower needs.

Policies of Developing Country Governments

Many communicable disease control agencies in developing countries regard vector control or eradication as an operational, logistic, and financial problem. Applied research is usually directed toward finding the most economical approaches for spraying pesticides. Technical advice is sought from WHO experts stationed in the country or region. Career positions for professional vector biologists within ministries of health are rare, since preference is usually given to physicians who are considered qualified to direct research and hold senior administrative positions.

International and bilateral assistance organizations are in a relatively good position to influence national government practices with regard to vector biology field research. They often provide foreign currency to purchase pesticides and spraying equipment. However, even when training or research is built into assistance packages, neither donor nor recipient agencies devote enough sustained attention to the formation of a cadre of field researchers, their supervision, and subsequent career development.

Research Grant Support for Field Studies

Funding for vector biology field research is difficult to obtain, especially from competitive grants awarded by the National Institute of Allergy and Infectious Diseases or the National Science Foundation. Relatively few proposals are received for field research as compared to laboratory proposals. For example, only 1 or 2 percent of all proposals received by the Division of Environmental Biology in the National Science Foundation are concerned with basic vector biology field studies. In general, field research proposals do not fare well in competition with proposals for basic research unless the funding organization gives special emphasis to field studies on vectors. WHO reports that proposals for vector field research received by its Tropical Disease Research and Training Programme are often poorly prepared and lack sufficient detail about methods and implementation. In addition, the number of such proposals is relatively small and, in fact, declining.

For some time, NIAID has supported vector biology research through its tropical medicine and parasitology study section. In fiscal years 1979-1982, approximately 60-70 projects that relate in some way to vectors have been funded annually (see Table 7). This number represents only about 4.5 percent of the total number of NIAID extramural projects in all categories. Many of these projects do not include research on vectors but really consist of basic studies on insect physiology or behavior. Only slightly more than half the projects were based at the 27 training institutions mentioned in Table 3 and in Chapter 4. Although a clear trend is not readily discernible from 4 years of information (that does not include data on project proposals received), it seems apparent that research activity in U.S. institutions concerned with vector biology training is declining. This situation is likely to be exacerbated in the future with projected reductions in NIH training funds.

In addition, field studies pose formidable obstacles to the junior investigator. They require vehicles, fuel, and often a large number of field staff. Assistance for implementing such studies must frequently be sought from disease control programs and a variety of other sources. International collaborative arrangements may take 1-2 years to complete. And research grants increasingly exclude education, travel, and applied research as objectives.

SUPPLY OF VECTOR BIOLOGISTS

Estimates of the number of professional vector biologists who are available to work in applied research and control activities are very difficult to produce. Gerberg reported preliminary results that he obtained in preparing the first edition of the *World Directory of Vector Research and Control Specialists*. Entries were based on individual responses to a questionnaire published in several journals and circulated widely in 1981 and 1982. The number of individuals listed probably represents less than half of the total number of medical entomologists who are active in field studies. Of 563 names listed, 217 (located in 74 countries) have doctoral degrees. The United States has 82 of these, Latin America has 22, Asia and the Pacific have 46, while the 67 listed for Africa are primarily expatriates.

TABLE 7 NIAID Grants for Research Related to Vector Biology in Fiscal Years 1979-1982

FY	Total Number of Funded Projects in 4 Categories[a]	Total Annual Budgets for 4 Categories[a]	Number of Funded Projects Located in Leading Vector Biology Training Institutions[b]	Total NIAID Budget for Extramural Projects	Total Number of NIAID Extramural Projects
1979	67	$4,930,748	42	$116,636,000	1,441
1980	74	5,342,879	44	137,191,000	1,571
1981	65	5,311,703	34	154,701,000	1,630
1982	59	5,253,133	32	157,200,000	1,537

[a] Includes data from NIAID computer files under categories of (1) mosquitoes, (2) ticks, (3) mites, and (4) biological regulation of vectors.

[b] See Table 3 and Chapter 4 on medical malacology training, which name 27 vector biology training centers.

CONCLUSIONS

Vector-borne diseases remain an immense burden in developing countries, causing much morbidity and mortality, which impede development. When considered as priorities by ministries of health, their control consumes much of the already low public health budgets in these countries. Despite this situation, the number of qualified professional vector biologists is woefully inadequate. In addition, knowledge of vectors and the ability to control them can be greatly improved by application of new methods and materials. Their effective and economical use against vector species, however, requires the training of an adequate professional cadre in entomology and malacology as part of health care programs.

What type of career position would be ideal for facilitating collaborative field research between U.S. scientists and counterparts in developing countries? Although employment by one of the international or federal agencies has the potential to provide meaningful and productive opportunities for field research, most of these positions are linked to specific programs, and opportunities for innovative research are often limited. The ideal situation requires three components: (1) an overseas study site or collaborating institution, (2) a firm U.S. support base, and (3) funding to cover salary and research costs in both places.

The overseas site should be associated with an ongoing research program, research institute, or university. International laboratories (for example, ICIPE in Kenya, and Gorgas Memorial Laboratory in Panama) all have multifaceted ongoing programs with laboratory facilities, staff, vehicles, drivers, and connections to the local government. In many developing countries there is no need to establish, staff, and stock independent expatriate research facilities. Universities, national disease control programs, and national research institutes usually have basic research facilities and can contribute some of the infrastructure necessary to work efficiently in field situations. Close cooperation and interaction with responsible health officials and university faculties at the overseas site is essential.

The United States base is equally important. The young investigator should have a stable appointment or affiliation, preferably at an academic institution. The appointment should be regular faculty and tenure track. This, of course, requires a major commitment on the part of the cooperating institution, but that commitment is not unreasonable. The U.S. institution should have a viable, ongoing program in vector biology with sufficient faculty who can interact and who have an interest in cooperating in an overseas research effort.

Frequently in programs such as the ICMRT and ICIDR, provisions are made to provide advanced training to foreign students and professionals at both the developing country institution and at facilities in the United States. Such training serves to enlarge the scientific base of the host country, although frequently the educational and health infrastructures are not sufficiently developed to guarantee the maximum utilization of acquired skills. Continued professional and scientific contacts between former students and teachers help to maintain research activities even when institutional support is lacking.

In the long run, vector-borne disease control problems will have to be attacked by citizens of countries with the greatest burden of disease. The most urgent need, therefore, is to strengthen and ensure the training of such personnel in the universities of these countries or in regional programs. The role of vector biologists in the developed countries (including the United States) in assisting with this training and in the conduct of basic research is of the utmost importance. There is also a need to maintain, and indeed strengthen, the training of vector biologists in the developed countries as a resource for the vector biology and control training programs in developing countries.

CHAPTER 4

Applied Malacology

In recent years the conventional definition of a vector biologist has been expanded to include those concerned with the biology and control of molluscs of medical and socioeconomic importance. The discipline includes the study of all molluscs that (1) act as passive agents for the dispersal of microbial pathogens and viruses, (2) serve either actively or passively to introduce toxins into man, or (3) assume the role of intermediate or parasitic hosts for helminths that cause parasitic infection and disease in man and domestic animals. It has been in the role of studying and controlling host molluscs, particularly the intermediate-snail hosts of *Schistosoma*, that the medical or applied malacologist has most frequently been identified as a vector biologist. Historically, as well as today, the development of the discipline and the opportunities and demand for its practitioners have been intimately associated with the worldwide interest in schistosomiasis and, to a lesser extent, fascioliasis. It should be noted, however, that *all* trematode parasites infecting man and his domestic animals must spend a portion of their life cycle in a suitable molluscan host.

Applied malacology formally originated as an offshoot of parasitology and tropical medicine; its practitioners, until fairly recently, were with rare exception trained as medical parasitologists or physicians. By being hidden under the mantle of parasitology and lacking a visible identity of its own, applied malacology has been deterred to some extent both in attracting students and in the establishment of a formal training regimen. On the other hand, comprehensive training in both parasitology and applied malacology is an asset that deserves to be encouraged.

TRAINING

Although data are difficult to obtain, one may correctly surmise that opportunities for formal training in applied malacology are limited. For example, in a recent survey (1980) to determine the extent to which malacology is taught in the United States, questionnaires were sent to 134 selected members of the American Malacological Union (AMU)*; of

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*Questionnaire prepared and distributed by Dr. Harold W. Harry. The AMU is the only national organization in the United States solely devoted to malacology. In 1980 it had approximately 650 members.

69 respondents, 32 indicated that some type of malacology course was taught at their institution. However, at only 2 institutions (the Department of Tropical Medicine, School of Public Health, Tulane University, and the Department of Tropical Public Health, Harvard School of Public Health) were the courses identified as dealing directly with medical malacology. To be sure, there are other centers where individuals are trained in applied malacology (for example, the University of Michigan, Ann Arbor, and the University of California, San Francisco). Choices, however, are limited.

Information regarding training at overseas institutions is also limited. Centers of training have generally been established in countries where schistosomiasis is endemic or in industrialized countries with former colonial ties. In South America, 2 centers immediately come to mind: the Oswaldo Cruz Foundation, Rio de Janeiro, Brazil, and the group working on schistosomiasis at the Federal University of Belo Horizonte, Brazil. In the Republic of South Africa, there are active units at Poschefstroom University and the Bilharzia Field Unit at Nelspruit. In Egypt, a group of malacologists is conducting research at Ain Shams University. In Europe, centers include the unit at the British Museum of Natural History, London, England; Winches Farm, London School of Hygiene and Tropical Medicine, London, England; and the Danish Bilharziasis Laboratory and the WHO-collaborating Centre for Applied Malacology at Charlottenlund, Denmark. In Asia, malacology is taught at the Centre for Applied Malacology, Department of Biology, Mahidol University, Bangkok, Thailand.

The World Health Organization coordinates the training of medical malacologists working in schistosomiasis control either through close collaboration with international centers or during on-site training courses in endemic countries. WHO currently collaborates with Mahidol University, Bangkok, Thailand; the National Schistosomiasis Control Program in the Philippines; and the Danish Bilharziasis Laboratory supported by the Danish International Development Agency (DANIDA) which trains African students. In addition, WHO provides support to other national and regional training courses. Some of these are medical entomology courses leading to a master's degree, with a component in medical malacology.

If one accepts the premise that, in part, the number of textbooks concerned with a subject reflects the teaching activity and/or interest in the discipline, then it should be noted that during the past 20 years only 4 books have been published for the teaching of medical malacology. The first appeared in 1960, in Portuguese; the others, in English, in 1962, 1965, and 1974 (none has a second edition).

Opportunities for field training in areas where snail-borne diseases are endemic are still too few, and close liaison with developed countries may be lacking. When such training is available, it is most often tied to specific grants or projects of senior investigators and, consequently, may be limited in time, may lack perspective and continuity, and may be subject to the vagaries of granting institutions. On the other hand, in many of the developing countries where endemic trematode diseases exist, field studies are viewed with disdain as "second-class" science. Consequently, professors and their students are most likely to engage in problems that can be solved at the laboratory bench rather than in the field where the real problems of disease prevail.

MANPOWER SITUATION

Who, what, and where are the applied malacologists? If these individuals are defined in the broadest context of the discipline, then the majority will be found in universities, as invertebrate zoologists, physiologists, geneticists, and so forth; however, it is unlikely that even 1 in 20 has had more than a casual acquaintance with field situations, and even fewer have had actual experience in programs designed to control snail-borne diseases. All too frequently, field experience for the academic is in the form of short-term consultantships or grants, which are more apt to produce dilettantes than professionals. Those few individuals functioning as medical malacologists and/or associated with actual control operations have usually been members of the armed forces, employees of international, governmental, or philanthropic agencies, or belong to the national staff of schistosomiasis control programs.

Countries in which snail-transmitted diseases are a major problem need at least 1 (probably more) scientist with comprehensive training (M.Sc. level at a minimum) and experience in applied (medical/veterinary) malacology. These scientists should be assigned, if possible, to units dealing with the diverse problems of vector biology and control. All staff in such units should have had some formal training (of at least 2 months' duration) in applied malacology with the aim of promoting multidisciplinary potential. If such units are needed but do not already exist, they should be created within government institutions, ministries of health, etc. Apart from the availability of adequate working facilities to include practical field activities, career structure development must not be neglected.

CONCLUSION

In many developing countries, demands for fresh water are increasing as a consequence of the expansion of irrigation schemes to provide agricultural products and by the need to develop hydroelectric power requisite for economic and social progress. Fulfillment of these demands will create new snail habitats with a concurrent increase and spread of snail-borne diseases. Vector biologists with special training in applied malacology are, unfortunately, virtually nonexistent, both in the developed countries where such schemes and impoundment plans are often formalized and funded and in the developing countries where their skills are best applied. The development of this type of manpower resource is of both national and international concern and warrants serious consideration.

CHAPTER 5

Conclusions and Recommendations

The workshop steering committee reaffirms and supports the findings and recommendations of a 1976 National Research Council study report on pest control and public health (Pest Control and Public Health, Volume V of a study titled Pest Control: An Assessment of Present and Alternative Technologies). The first recommendation of the study team is highly germane to the present workshop report and is therefore reproduced below:

> 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.
>
> The Study team therefore recommends that increased educational opportunities be made available in all aspects of integrated control of arthropods of public health significance.

NEED FOR FIELD STUDIES IN VECTOR BIOLOGY

There is an urgent need in almost all tropical countries to develop new or improved strategies for control of major arthropod vectors of human disease. In many countries the effectiveness of current vector control programs is unknown. Field studies on the behavior, genetics, and bionomics of confirmed or suspected arthropod vectors are required in every region or country where vector-borne diseases constitute a public health problem, so as to ensure that control strategies are based on accurate biological information. Such studies must be conducted frequently because human population movements, development schemes, and agricultural use of pesticides are constantly changing the population structure or vectorial capacity of insect and snail vectors.

- It is recommended that at least 5 percent of all U.S. bilateral assistance provided to developing countries for vector control programs be used to support collaborative vector biology field research by U.S. and developing country scientists. Encouragement should be given to projects in which research is proposed and conducted jointly by control program officials and academic scientists. Much of the assistance currently provided by USAID to developing country governments is intended to support short-term needs for spraying equipment and pesticides. Vector biology field research is often regarded as low priority within control programs and, as a consequence, may not receive firm budgetary commitments. Workshop participants agreed that 5 percent of vector control assistance is a reasonable proportion to be designated for field studies, considering (1) that the findings will be relevant to control activities, and (2) that many federal agencies set aside 1 percent of their budgets for evaluation.

The number of highly qualified vector biologists with field experience is presently below the critical level required to provide basic knowledge needed for the control of endemic vector-borne diseases in the tropics. Ironically, though, it must be recognized that qualified vector biologists from developing countries often do not find jobs in their own countries. Long-term investments in appropriate training, supervision, and career positions are needed to remedy this situation. Workshop participants expressed concern that international organizations and donor agencies have been placing major emphasis on short-term training courses for vector control professionals and technicians while neglecting long-term academic and field training. Yet such long-term training commitments cannot be made responsibly without a careful assessment of future manpower needs and creation of career opportunities for trainees.

- It is especially recommended that donor agencies support or conduct a vector biology manpower needs assessment in each developing country or region in which they currently support training programs or courses in vector biology. These assessments should consider the number of professional vector biologists needed for teaching, basic research, applied research, and management of vector control programs.

TRAINING

Academic training programs in the United States for professional vector biologists are rarely identified as such. Rather, medical entomologists and malacologists engage in teaching and research within departments of biology, entomology, epidemiology, and tropical medicine. These in turn are located within schools of public health, medicine, or agriculture and in faculties of arts and sciences. The number of master's and doctoral students and postdoctoral fellows trained in vector biology at U.S. universities is usually proportional to the number of faculty members with research interests in arthropod vectors.

Three workshop participants carried out independent mail surveys of academic research and training centers in medical entomology and malacology. Their findings were correlated and analyzed together. The workshop steering committee noted that only 12 departments currently have 2 or more faculty members with interests in medical entomology, while only 2 departments (as of July 1983) train medical malacologists. Financial support for these training programs comes primarily from research grants, NIH postdoctoral fellowships, NIH training grants, the Environmental Protection Agency, U.S. Department of Agriculture, Department of Defense, and the World Health Organization. Workshop participants estimated that if current trends continue, only 10 new doctoral candidates can be expected to enter U.S. vector biology programs annually.

Both postdoctoral training and university-based training in medical entomology have declined (see Table 3). Since 16 percent of the approximately 100 master's and doctoral candidates presently enrolled in U.S. academic programs in medical entomology are foreign nationals, workshop participants concluded that U.S. university departments in vector biology are an important resource for long-term training of students from developing countries. However, this international training role should be strengthened, adapted to meet developing country needs, and enlarged if U.S. centers are to maintain long-term collaborative relationships with vector biologists in developing countries. The following recommendation was endorsed as a possible solution to these problems.

- The U.S. Department of Health and Human Services, Department of Defense, and Agency for International Development should coordinate and contribute funding to establish a competitive Faculty Development Award Program in Vector Biology with the aim of strengthening faculty resources in selected U.S. academic training centers (or combinations of centers). At least 15 5-year awards should be made over a 3-year period to individual junior faculty members based at several institutions in the United States. Recipients should be selected on the basis of their potential ability to train U.S. and foreign vector biologists for work in developing countries. This program might be designed similarly to Title XII activities involving USAID and U.S. agricultural universities (see USAID Policy Directive on Title XII, PD-4, October 5, 1982). One of these activities establishes a Joint Career Corps in which university faculty agree to spend about one-third of their time overseas with USAID programs tours of 2-4 years.

Formal academic training is not sufficient to produce a vector biologist capable of organizing and conducting field studies. Supervised field experience for several years is critical in the formation and orientation of such a professional. This is especially true today, when money for overseas travel is scarce and laboratory research on insect physiology, genetics, molecular biology, and microbiology produces results and publications rapidly. Even in developing countries, quality field experience may be difficult to obtain due to lack of emphasis on field research and the absence of appropriate role models. Highly trained vector biologists returning to their own countries from the United States are often given administrative duties or inappropriate teaching assignments that preclude involvement in research. In addition, they may be isolated from the multidisciplinary skills needed for field studies.

Collaborative programs provide excellent opportunities for young scientists from developed and developing countries to gain appropriate field experience in vector biology. Examples of such programs are the National Institutes of Health's International Centers for Medical Research and Training and its International Centers for Infectious Disease Research grants, the USAID-funded tripartite project in Egypt on arboviruses, and the laboratories maintained by the Centers for Disease Control in Central America and the Caribbean. New programs that may provide field experience training opportunities are the USAID's Office of the Science Advisor's research support for vector biology and the National Research Council's research project on mosquito vectors.

- The U.S. Department of Health and Human Services, Department of Defense, and Agency for International Development should cooperatively develop a competitive grants program to support research and training in vector biology. Funds should be available for predoctoral, postdoctoral, and faculty research projects. Recipients could be from both developed and developing countries. A significant part of the activity of each grant should be carried out in a developing country. Preference in larger program grants might be given to units created from the combined resources of 2 or more departments of institutions and to those activities (1) involving strong collaboration between vector biologists from developed and developing countries, (2) dealing with field biology of tropical disease vectors, and (3) with a strong training component. Donor agencies are urged to be flexible and to consider long-term field research fellowships for junior investigators.

CAREER OPPORTUNITIES

The number of academic positions for vector biologists in U.S. universities is not expected to expand significantly over the next decade. Almost all of the state health departments responding to a questionnaire indicated they needed more professional vector biologists, while about one-fifth anticipated an increase in the number of positions. Comparison of numbers of federal agency positions for vector biologists was difficult because different levels of training were required for each position. Very few private companies or consulting firms in the United States employ professional medical entomologists, largely because of the low demand for services and the traditional expectation that vector control is a responsibility of public health authorities. Career opportunities in vector biology appear most stable in the armed forces, but have declined dramatically in USAID and the

U.S. Public Health Service. Of all U.S. government agencies, the Public Health Service deals with the widest variety of activities involving vectors.

- It is recommended that the Surgeon General of the U.S. Public Health Service commission an independent, external review of all agency programs related to vector-borne disease, with special consideration given to the adequacy of professional staffing. Such a review is currently being conducted at USAID with respect to the agency's support for malaria control.

Career opportunities for vector biologists are seriously lacking in most developing countries where manpower needs are the greatest. The causes of this situation include hiring policies of national governments, scarce financial resources, lack of highly qualified candidates, and lack of training programs. Vector biologists in universities have little contact with professionals in vector control programs.

- It is recommended that public health authorities in countries with a high burden of illness from vector-borne diseases create appropriate career positions for professional vector biologists. Such positions should include long-term training opportunities, if necessary, and affiliation with a research institute or university. In addition, a designated portion of their time should be spent in field research.

MALACOLOGY

Separate recommendations were not formulated for malacology training and career development, because the term vector biology is intended broadly to include the study of snail hosts of human diseases. It is hoped that applied malacology training and research will be included in any programs intended to support career development in vector biology.

APPENDIX A

Agenda

September 29--Plenary Session

9:30 am	Welcoming Remarks John Hurley Director of BOSTID
9:45 am	Introduction George Craig Workshop Chairman
10:00 am	Overview of Problem William Reeves
10:30 am	Opening Addresses: Contributions of Vector Biology Field Studies to Disease Control Norman Gratz, Louis Miller, Wilbur Downs
11:30 am	Discussion
12:00 pm	Lunch break

STATUS OF MANPOWER RESOURCES FOR VECTOR BIOLOGY FIELD STUDIES

1:00 pm	Brazil--Leonidas Deane Survey in United States--Robert Gwadz Malacology--Edward Michelson Directory--Eugene Gerberg WHO (International)--Rene LeBerre U.S. Public Health Service--George Hutton
3:00 pm	Discussion

STATUS OF FIELD RESEARCH AND CONTROL ACTIVITIES

3:30 pm International Organizations--Norman Gratz

4:00 pm United States Agency for International Development--James Erickson

4:20 pm Land-Grant Universities--Bruce Eldridge

4:40 pm Other U.S. Universities--Andrew Spielman

September 30--Plenary Session

STATUS OF FIELD RESEARCH AND CONTROL ACTIVITIES (Continued)

9:00 am U.S. Department of Agriculture--Ralph Bram
State Health Departments--Donald Womeldorf
Military--Moufied Moussa
Centers for Disease Control--Robert Kaiser
National Institute of Allergy and Infectious Diseases--Karl Western
Tanzania--Wen Kilama
Malacology--Jack Burch

10:45 am Discussion

11:20 am Obstacles to Career Development--George Davis

11:35 am Discussion

12:30 pm Lunch break

1:45 pm Working group participants depart for Coolfont.

October 1--Working Group Sessions

Working groups prepare outlines of their reports, discuss and agree on recommendations, and draft report.

October 2--Final Plenary Session of Working Group Participants

9:00 am Chairmen present reports and recommendations of working groups, followed by discussion.

12:00 pm Lunch

1:30 pm Depart for Washington, D.C.

APPENDIX B

Mailing List for Survey of Entomology Training in Land-Grant Institutions

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