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MOSQUITO CONTROL THEN, NOW, AND IN THE FUTURE[1]

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ABSTRACT. This is a memorial lecture honoring the late Professor Stanley B. Freeborn of the University of California. In the spirit of his life-long academic and research interests in mosquitoes and mosquito-borne diseases, I am presenting here the evolution of vector control technology, especially that pertaining to mosquitoes and mosquito-borne diseases during the 20th century. Vector control technology in the first half of this century was relatively simple, utilizing source reduction, larvivorous fish, petroleum hydrocarbon oils, and some simple synthetic and botanical materials. During the 2nd half of this century, however, various classes of synthetic organic chemicals, improved petroleum oil formulations, insect growth regulators, synthetic pyrethroids, and microbial control agents were developed and employed in mosquito control and control of other disease-vectoring insects. Among these groups of control agents, petroleum oil formulations have endured to be used through the whole century. It is likely that petroleum oil formulations, insect growth regulators, and microbial control agents will provide the main thrust against vectors at least during the first quarter of the 21st century. It is also possible that effective tools through the development of vaccines and molecular entomology techniques might become available for the control of vectors and vector-borne diseases during this period of the 21st century.

INTRODUCTION

It is indeed my distinct pleasure to deliver this memorial lecture, honoring the late Professor Stanley B. Freeborn, one of the distinguished entomologists and culicidologists who contributed immensely to our knowledge of mosquitoes and their control. He not only was a recognized scholar but also proved to be an effective and dedicated teacher, instructing undergraduate and graduate students with great enthusiasm. Toward the end of his career, Dr. Freeborn served with distinction as Provost and then Chancellor at the University of California at Davis.

During my career, I had very little overlap with Freeborn. Upon my arrival as a graduate student at the University of California, Berkeley in 1952, he had already moved to the Davis campus (known as the Farm or Cal Aggies in those days), and from there he entered the administrative services. Therefore, whatever biographical information I present here was gathered from the literature or gained from those who had professional and personal contacts with him (e.g., Thomas H. G. Aitken, Bruce F. Eldridge, William C. Reeves, and Robert K. Washino). I will attempt to give a brief biographical sketch of his career, accomplishments, and contributions. Because time does not permit me to present a complete recognition of all significant contributions he made in the area of scientific research, teaching and service, I will not attempt to touch upon his personal life or most of his professional accomplishments but instead will focus attention on his contributions to our knowledge of mosquitoes and their control and his role as teacher and researcher.

STANLEY B. FREEBORN (THE HONOREE)

Stanley Barron Freeborn was born in Hudson, Massachusetts on December 11, 1891 and died on July 17, 1960 at Davis, California. He received the B.Sc. degree from Massachusetts Agricultural College in 1914 and the Ph.D. in 1924 from Amherst College. The subject of his thesis was the classical work, "Mosquitoes of California." All of his career, with the exception of 2 wartime leaves, was spent at the University of California (UC). He started as an instructor in entomology at the University of California, Berkeley in 1914, became an assistant to Professor William B. Herms in 1916, and attained the rank of Professor and Entomologist in 1932. Aitken (1939) named *Anopheles maculipennis freeborni* collected at Davis, California in his honor. This important malaria vector is now known as *An. freeborni* Aitken on the west coast. From 1924 to 1935, he served as Chairman of the Division of Entomology at Davis and then became Assistant to the Dean of the College of Agriculture at Berkeley, and 2 years later he became Assistant Dean and Assistant Director of the Agricultural Experiment Station. In 1952, he was appointed as the first Provost of the UC Davis Campus, and in 1958 he became Chancellor there. To honor this eminent scientist, teacher, and administrator, the University of California bestowed the honorary degree of L.L.D. upon him and named the Student Center

[1] The AMCA Memorial Lecture was presented at the American and California Mosquito and Vector Control Associations Joint Meeting (AMCA 60th, CMVCA 62nd) held April 9–14, 1994, San Diego, California, USA.

Fig. 1. Professor S. B. Freeborn

on the Davis Campus Freeborn Hall. Starting his professional career in California, Freeborn studied the control of mosquitoes and their relationship to malaria under the direction of Professor William B. Herms. In a short period of time he became an authority on mosquitoes and malariology, and on account of this expertise, he served in both World Wars with the U.S. Public Health Service, developing vector control programs and studying vector-borne diseases at home and abroad.

It has been reported that Dr. Freeborn was an eloquent teacher. He taught introductory entomology, insect morphology, and arthropod vectors of diseases. Professor Bill Reeves conveyed to me that teaching insect morphology was his forte (and many of you know how dry and boring this course can be); he made instruction in insect morphology most enjoyable and stimulating. Some of his former students have related to me that Freeborn was a charming and eloquent teacher and speaker. He was very much interested in athletics and served as president of the Pacific Coast Athletic Conference. Despite the heavy administrative responsibilities, Freeborn enthusiastically instructed one or more courses in entomology.

Freeborn engaged himself in both fundamental and applied research on mosquitoes. One of his important contributions was a publication on the efficacy and mode of action of petroleum oil larvicides in 1918 (Freeborn and Atsatt 1918). This research provided new insights into the mode of action of petroleum hydrocarbon larvicides. Since the pioneering work of L. O. Howard (1892), an eminent American entomologist of the past century and head of the Bureau of Entomology of the U.S. Department of Agriculture who utilized kerosene for mosquito larval control, many theories and notions concerning the use and mode of action of petroleum oil larvicides were proposed. Freeborn and Atsatt (1918), in simple laboratory experiments, demonstrated that suffocation by oils was not the main mechanism for the killing action of oils, but it was primarily the toxic action of volatile materials in the composition that killed the larvae. From this classical work it is quite evident that Freeborn and colleagues were involved in applied research developing effective mosquito control tactics.

Having made a lasting mark in the area of mosquito control technology, Freeborn then turned his attention to some basic aspects of mosquito taxonomy, ecology, and faunistics. His landmark publication, "The Mosquitoes of California," was published in 1926 (Freeborn 1926) by the University of California. This publication was the most critical and complete treatment of mosquitoes of California at that time. Thirty-two species or subspecies were included (Table 1). It is interesting that the total number of mosquito species reported by Howard (1902) for the United States was only 26 as compared with 32 species in California (Freeborn 1926). In Freeborn's work, descriptions of all species, synonymies, keys to genera and species, and information on distributional patterns were provided. About 41 exquisite morphological figures were included. This highly informative publication was then followed by the publication of another timely paper titled, "Identification Guide to the Mosquitoes of Pacific Coast States" (Freeborn and Brookman 1943). Forty-four species of mosquitoes were included in this publication (Table 1). Well-illustrated keys to genera and species with clear figures as well as brief biological and ecological information on the various species were included.

Stanley Freeborn played an eminent role in the development of mosquito control programs in California and around the world. He frequently participated in the meetings of the California

Table 1. Mosquito species included in the publications of L. O. Howard (1902), Freeborn (1926), and Freeborn and Brookman (1943).

Genus	No. of species of mosquitoes recorded		
	Howard (1902) USA	Freeborn (1926) California	Freeborn and Brookman (1943) Pacific coast states
Aedes	1	15	23
Anopheles	4	3	4
Conchyliastes	2	—	—
Culex	11	9	9
Culiseta	—	—	5
Mansonia	—	—	1
Megarhinus	3	—	—
Orthopodomia	—	—	1
Psorophora	1	—	1
Stegomyia	2	—	—
Theobaldia	—	4	—
Toxorhynchites	1	—	—
Uranotaenia	1	1	—
Total	26	32	44

Mosquito Control Association and served as its president in 1935. According to Nowell's (1983) index to the first 50 annual conferences of the California Mosquito and Vector Control Association (1930–82), there are 23 entries for Freeborn during this period. Titles of his presentations represented diverse areas of research, administration, program development, and operational programs for mosquitoes and mosquito-borne diseases. Some of the topics covered included mosquito control in California and abroad, outbreaks of malaria in California, identification of mosquitoes, mosquito migrations, and other problems pertaining to mosquitoes and mosquito control programs.

From his biographical sketch and scientific accomplishments, it is clear that Stanley Freeborn had keen interest in mosquitoes and that his research activity covered both basic and applied fields. The major thrust of his research activities was directed toward vector control and vector-borne diseases. In the spirit of his interest in vector control programs, I now briefly present the progression and evolution of vector control technologies from the past into the present and also project the trends into the near future. Because of Freeborn's involvement and association with California, I will touch primarily upon vector control methodologies in California, which will not be too different from programs elsewhere. It should be remembered that a considerable amount of vector control research was also carried out by other universities, the Centers for Disease Control, U.S. Department of Agriculture laboratories, and others.

VECTOR CONTROL DURING THE EARLY 20TH CENTURY

Vector control research and mosquito control activities in particular began about a century ago. In the first quarter of the 20th century, mosquito control activities were based primarily on source reduction, the use of petroleum oils (kerosene), and the promotion of guppies and other fish (Howard 1892, 1902). These tactics (Table 2), with some modification, continued for 3 or 4 decades. Freeborn and Atsatt (1918) provided evidence for mode of action of larviciding oil mixtures. Freeborn also was involved in 1922 in the promotion of biological control agents and was overseeing the first importation and stocking of *Gambusia* in the Chico area of California (Herms 1949). He was the first person involved in the importation, stocking, and evaluation of larvivorous fish in mosquito control in California.

VECTOR CONTROL DURING THE 2ND QUARTER OF THE 20TH CENTURY

Vector control technology emphasizing source reduction and application of oils and botanical preparation (Table 2) continued into the 2nd quarter of the present century. However, a number of other strategies aimed at larval and adult control were added to the arsenal against disease vectors and pests (Table 3). A comprehensive treatment of this technology was reported by Herms and Gray (1944) in a book that provided a detailed description and analysis of vector control technology based on laws leading to the formation of mosquito abatement agencies. Source reduction and naturalistic and biological control methodologies were promoted as the primary line of defense. Oiling and the use of chemical larvicides and adulticides were considered as an adjunct to the more permanent and lasting strategies employed. Herms and Gray (1944) alluded to the problem of pest mosquitoes after interruption of disease transmission and recommended reduction or elimination of pestiferous species for the overall comfort and well-being of the public. The need for the abatement of pestiferous vectors (species serving as disease vectors, as well as those which are pestiferous) is even more important today in developed areas,

Table 2. Mosquito control and mosquito control strategies during the early part of the 20th century as reported by Howard (1902).[1]

Methods against immature and mature mosquitoes			
Early stages		Adult mosquitoes	
Chemicals	Natural enemies	Protection	Bites
Kerosene	Nematodes	Screens	Avoid scratching
Creosote oils	Sporozoans	Chlorine gas	Household ammonia
Aniline dyes	*Gastrosteus* (Stickleback)	Burn pyrethrins	Alcohol rub
Vegetable powders (pyrethrin and chrysanthemum)	*Gambusia*	Eucalyptus trees (exclude mosquitoes)	Glycerine
	Fundulus	Castor oil plants (exclude mosquitoes)	Indigo
Potassium permanganate	Western salamander		

[1] In addition to these techniques and methods, source reduction and environmental methods were recommended.

Table 3. Mosquito control technology employed during the 2nd quarter of the 20th century and beyond.[1]

Types of major mosquito control tactics
1. Source reduction, environmental management
Drainage and reclamation of freshwater and saltwater marshes
Filling, pumping, flushing
Species sanitation
2. Oils and larvicides
Petroleum oils
Cresylic acid
Pyrethrum extracts
Emulsifiers
Paris green
Phenothiazine
DDS
Other poisons
3. Fish
Gambusia affinis
Aphanius dispar
Other fish
4. Protective measures
Screens
Bed nets
Repellents
Citronella oils
Dimethyl phthalate
Ethyl hexanediol
5. Adult control
Pyrethrin sprays
Diversion to farm animals
Synthetic adulticides

[1] From Herms and Gray (1944).

where most vector-borne diseases have been eliminated or abated to an insignificant level. Among the various larvicides, reference is made to kerosene, diesel and stove oils, cresylic acid (high boiling fractions), pyrethrum extracts (aerosols) and emulsions, Paris green (copper acetoarsinite), DDT (first used in the early 1940s), phenothiazine or thiodiphenylamine (at the dosage of 2–4 g/50 gal. drum), and finally borax (sodium borate) at the high rate of 1.5 g/liter of water. Among these larvicides, DDT was the most effective material ever tested up to that time, yielding 100% kill of mosquito larvae at the concentrations of 10–15 parts per billion.

VECTOR CONTROL IN THE 3RD QUARTER OF THE 20TH CENTURY

With the advent of DDT toward the end of the 2nd quarter of this century, an unprecedented

Table 4. Relative activity and efficacy of some commonly used synthetic insecticides against mosquito larvae.

Material	Laboratory activity LC_{90} (µg/liter)	Field efficacy (lb AI/acre)
DDT	3–10	0.5–1.0
Malathion	20–50	O.S–1.0
Parathion (ethyl, methyl)	2–4	0.025–0.1
Fenthion	3–5	0.05–0.1
Chlorpyrifos	1–3	0.02–0.05
Temephos	2–5	0.05–0.10
Diflubenzuron	1–4	0.005–0.05
Pyriproxyfen	1–3	0.005–0.025
Methoprene[1]	5–20	0.05–0.25
Petroleum oils	20–50	2.0–5.0 gal

[1] Ten to 20 times more active against *Aedes* and *Psorophora* species than against *Culex* and *Anopheles* species.

flurry ensued for finding, synthesizing, and testing of novel modes of synthetic compounds during the early part of the 3rd quarter of this century. Thousands of new or modified structures were made available for testing against a variety of injurious pests. The development of 1st-generation, 2nd-generation, and 3rd-generation insecticides was realized in the 1950s and 1960s. Among the 1st-generation insecticides, organochlorine compounds, well-known and extensively used insecticides such as DDT, aldrin, dieldrin, lindane, and methoxychlor were employed in a variety of vector control programs all over the globe. The development of DDT for insect control provided a potent means of malaria eradication or control around the world, and this material is still used in some countries for this and other purposes. The use of DDT and other synthetic chemicals has reduced the risk of malaria for some one billion people who dwelled in endemic areas. Among the 2nd-generation insecticides (organophosphates) are materials such as dichlorvos, malathion, naled, methyl parathion, parathion, temephos, chlorpyrifos, fenthion, fenitrothion, and others (Table 4). The organophosphates were followed by organocarbamates, which were not used for larval control. Well known in this group were propoxur, carbaryl, bendiocarb, isolan, and others. These compounds were used primarily for adult control as aerosols or residual treatments.

In the 1960s and 1970s, chemists began to alter and build on the structural features of natural pyrethrins. A whole host of photostable or unstable moieties were obtained. This group of insecticides was designated as the synthetic pyrethroids. These compounds have a very high level of activity against mosquito larvae, but because of their high toxicity to fish and some other nontarget organisms, none of these compounds has been developed for larval control, at least in the United States. The synthetic pyrethroids are employed primarily for the control of adult mosquitoes or as materials of choice for impregnation of protective clothing and bed nets. Compounds used in adult control are allethrins, tetramethrin, resmethrin, cypermethrin, permethrin, deltamethrin, lambdacyhalothrin, and others.

The decades of the 1960s and 1970s also experienced increased research on genetic control of vectors. Numerous areas of genetic techniques such as translocations, cytoplasmic incompatibility, meiotic drive, and sterile hybrids were investigated (Whitten and Foster 1975), but none of these tactics became usable. Similarly, much research was conducted on chemosterilants, but none of these compounds became operational in vector control programs. It is equally important to note the voluminous research on the evaluation and development of biological agents such as protozoa, fungi, nematodes, and other parasites and pathogens. Thus far none of these agents has yielded tangible results as a tool in vector control programs.

ENVIRONMENTAL CONCERNS AND DECLINE IN USE OF INSECTICIDES

In the 1960s, environmental concerns with the widespread use of persistent chemicals and their bioaccumulation in the biosphere surfaced among scientists and the lay public. The publication of *Silent Spring* by Rachel Carson in 1962 gave impetus to increased public concerns regarding the use of pesticides. These events further accelerated the already established trend to reduce the use and further development of "hard core" pesticides and triggered an eventual decline in the use pattern of many pesticides characterized by high mammalian toxicity and posing risks to nontarget biota and the environment. Com-

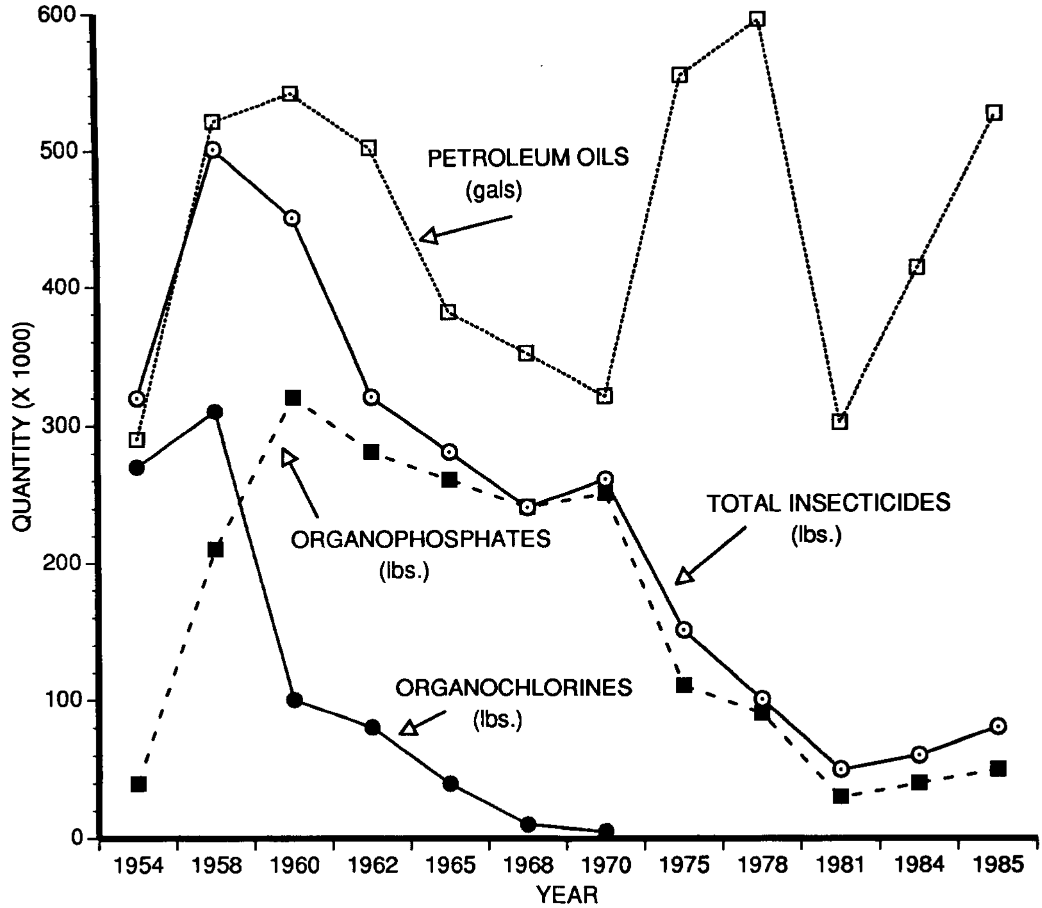

Fig. 2. Quantities of mosquito larvicides including petroleum hydrocarbon oils used in California mosquito control programs from 1954 to 1985 (from California Mosquito and Vector Control Assoc. Inc., Yearbooks, 1954–85).

pounds perceived as posing potential risks to the environment and human health came under intensive scrutiny and evaluation. As a matter of fact, the decline in the use of organochlorine insecticides in mosquito control in California (Fig. 2) had already started before the appearance of *Silent Spring*. The amounts of petroleum oils used remained relatively constant between 1954 and 1985, while the amounts of organophosphates, increasing in the 1950s, declined drastically in the 1980s. The environmental concerns further culminated in a rapid decline in the number and quantities of synthetic organic pesticides used in the United States, and in California in particular. The 3rd quarter of this century saw the emergence and decline of synthetic pest control agents on an unprecedented scale. The quantities of organophosphates used in California declined further, reaching the lowest level in 1990 (Fig. 3). Quantities of petroleum oil used remained constant (350,000–400,000 gallons/year) whereas the use of insect growth regulators (IGRs) starting in 1986 began to increase. It is likely that the quantities of IGRs in the next quarter (1st quarter of the 21st century) will increase above the present levels.

Another important change in the use of mosquito control agents occurred in the use of adulticides in 1990. When the use of propoxur was canceled in 1990 (Fig. 4), there was an increase in the usage of malathion, pyrethrins, and synthetic pyrethroids. As naled is being withdrawn from further use, the options for adult control are becoming very few. In the not too distant future we will rely on only 2 or 3 chemical control agents for adult mosquitoes.

The quantities of vector control chemicals used in California are only estimates, because not all agencies practicing vector control submit reports to the California Mosquito and Vector Control

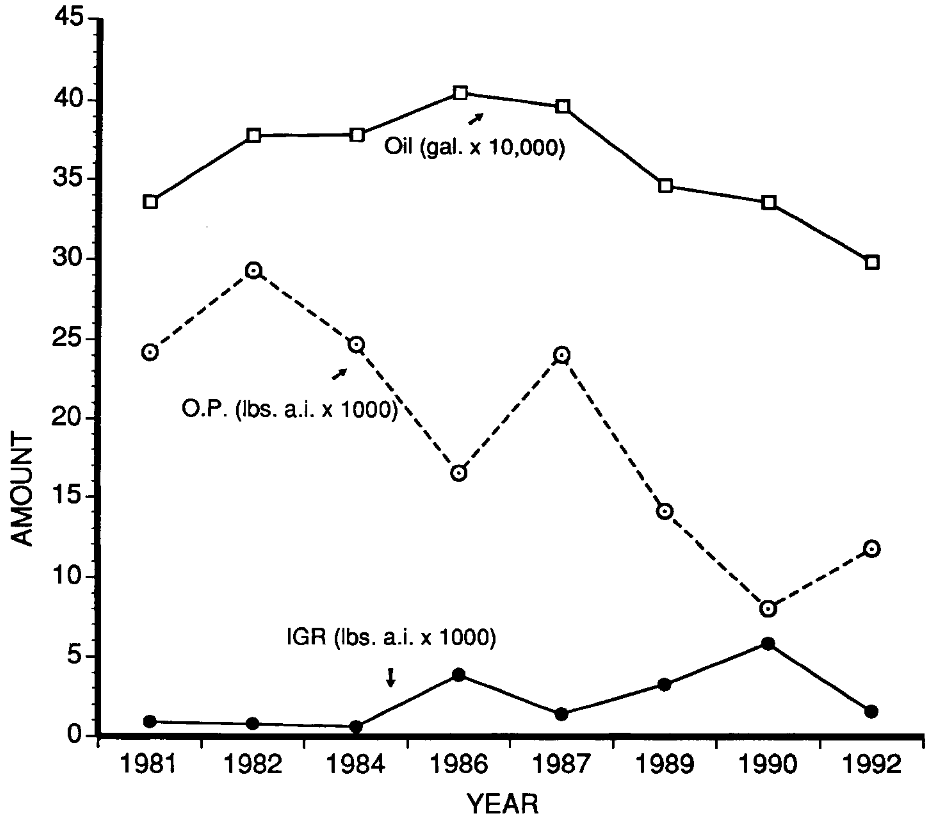

Fig. 3. Quantities of mosquito larvicides including petroleum hydrocarbon oils used in California mosquito control programs from 1981 to 1992 (from California Mosquito and Vector Control Assoc. Inc., Yearbooks, 1981–92). O.P. = organophosphates, IGR = insect growth regulators.

Association Survey. Therefore, the actual quantities of materials used are greater for each category than reported in the Yearbooks.

VECTOR CONTROL IN THE 4TH QUARTER OF THE 20TH CENTURY

With the environmental movement in full swing in the 1960s and 1970s, scientists turned their attention to the development of selective biorational pesticides and integrated pest management tactics during the 3rd quarter of this century, which became operational in the 4th quarter. As a result of these efforts, the IGRs methoprene, fenoxycarb, and diflubenzuron were developed and registered during this period for different uses. Additional compounds manifesting developmental regulating properties also were developed and have been used in other countries. Some of these compounds such as pyriproxyfen are being developed now for mosquito control in the United States. Another important development in the field of vector control was the isolation and development of spore-forming and toxin-producing bacteria for vector control. The entomopathogenic bacterium *Bacillus thuringiensis* subsp. *israelensis* (*B.t.i.*) was registered in 1980 for mosquito and blackfly control, and another bacterial agent, *B. sphaericus*, was registered in 1992. This latter microbial control agent has been used in operational control programs abroad but has not yet been made available in the United States. Soon after registration of *B.t.i.*, various preparations of this microbial control agent found their way into vector control programs. From 1982 onward, the quantities of this agent employed in vector control increased, reaching a peak in 1990–91 (Fig. 5). Although not all vector control agencies reported, the data are indicative of the trend purporting the use of *B.t.i.*

The foregoing is a brief historical treatment of the development and use of vector control strategies during the 20th century. As we approach the end of this century, few viable options for

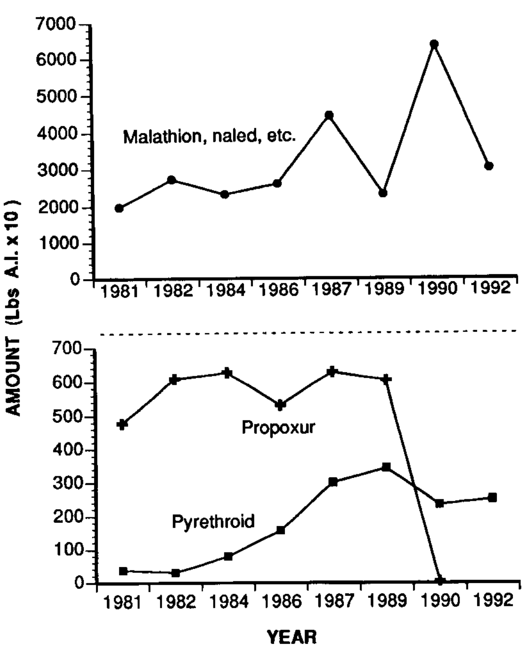

Fig. 4. Quantities of chemical compounds used as adulticides in California mosquito control programs from 1981 to 1992 (from California Mosquito and Vector Control Assoc. Inc., Yearbooks, 1981–92).

mosquito and vector control are at our disposal. We are still relying heavily on petroleum oil formulations, which have been greatly improved over those used in the first half of this century. Only a few of the old synthetic compounds, such as resmethrin, malathion, and a few others, are still available for mosquito control. Among the new generation of insect control agents, methoprene and diflubenzuron are used in localized situations. The microbial agents are extensively used now. These agents and other biorational pesticides will continue to be used to the end of this century and into the 21st century. Source reduction and elimination of mosquito breeding sites in wetland marshes and wildlife habitats will no longer be an acceptable option in many areas. Environmental management tactics have to be acceptable and compatible with the diversity and abundance of animal and plant taxa in aquatic habitats.

VECTOR CONTROL IN THE EARLY 21ST CENTURY

Having more or less spanned a whole century, I would now like to look into the crystal ball and project future trends in the development of vector control technology. Present indications are that petroleum oil formulations of one kind or another, the biorational pesticides methoprene, diflubenzuron, and others (from synthetic endeavor or plant origins), as well as microbial control agents will continue to be utilized at least during the first quarter of the 21st century. New and effective environmentally friendly agents will be developed, but the pace of such development will be unnecessarily slow unless the world experiences epidemics and pandemics of vector-borne diseases. Even in the absence of vector-borne disease outbreaks, we still need to develop new control agents at a more rapid pace than we are doing currently. Most hematophagous and pestiferous arthropods, aside from vectoring disease agents, also impair the health and well-being of millions of people. The intensity of this constant annoyance is so great that the populace at large will unequivocally demand control of noxious insects in both developed and developing countries regardless of their involvement in the transmission of pathogenic organisms.

Research on microbial control agents might possibly develop new strains possessing high potency and broad-spectrum activity or improve and broaden the activity of existing products. Also, the role of genetic engineering in cloning toxin-producing genes in other organisms such as Cyanobacteria could yield a system that could be used in mosquito control programs (Berry et al. 1991, Bulla et al. 1991). However, many ecological studies on the survival, distribution, and persistence of transgenic organisms are needed before these transformed organisms can be introduced into the environment. In recent years, concerns have been expressed regarding the possibility of development of resistance to the toxins expressed in plants or bacteria that are present constantly in the environment (Stone et al. 1991). From all indications, repeated applications of microbial toxins produced by the parent organisms might be the most practical and acceptable mode of vector control operations.

Research on vaccines and molecular entomology has been given high priority in recent years. Progress has been made in the area of vaccine development, at least for targeting single malaria pathogens, and an effective vaccine might be in the realm of possibility during the early part of the 21st century. However, it should be recognized that vaccines, at least at the outset, may be aimed at only a single disease or pathogen or a given strain. Although current advances in vaccine research seem promising, we will still need many traditional tools to fight and control vector-borne diseases and human pests not targeted by the development of successful vaccines. Notwithstanding these problems, it is quite desirable to promote vaccine development and use as a part of an overall vector control technology.

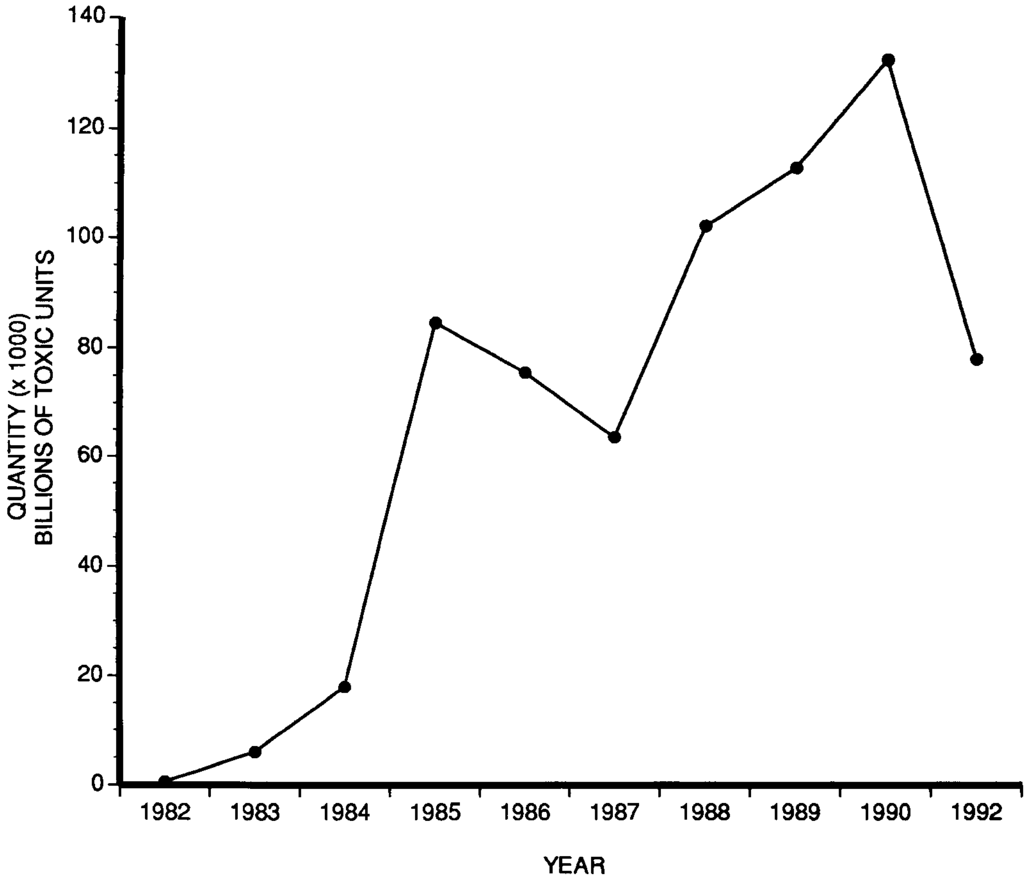

Fig. 5. Quantities of *Bacillus thuringiensis* subsp. *israelensis* used in vector control (mosquito control) programs in California from 1982 to 1992 (from California Mosquito and Vector Control Assoc. Inc., Yearbooks, 1982–92).

Very recently, attention has been turned toward research on molecular entomology. It is known that a certain proportion of a given vector population is refractory to infections by parasites and pathogens. The genetic basis for these phenotypes and other characters has been the subject of numerous speculations and fundamental research. Collins et al. (1986) were successful in selecting *Anopheles gambiae* Giles refractory to infection by the simian malaria *Plasmodium cynomolgi.* They further showed that this refractory feature, which is genetically controlled, was also operative against other malaria parasites including those of human malaria. In the refractory *Anopheles,* the living ookinetes are fully encapsulated after passage through the midgut wall. This discovery resulted in a flurry of research initiatives on genetic mapping of some *Anopheles* mosquitoes, and the future potential of genetic engineering as a tool against mosquito vectors was expressed by several researchers (Crampton et al. 1990, Miller and Mitchell 1991, James 1992, Aldhous 1993). With genomic knowledge of mosquitoes and the genetic technology to alter mosquitoes and other vectors, it is conceivable that at least some vector-borne diseases might be controlled through genetic manipulations of the vectors. However, these approaches will require detailed field ecological studies to evaluate the success of this technology. Likewise, these approaches will be species specific and will likely not become available for practical use during the next decade or so.

With these limitations of biotechnological approaches, it is still imperative that research on developing a diverse cadre of traditional approaches of vector control is not slighted. Even if we are successful in controlling a disease through alterations of pathogen–vector interactions, we will still have to control hematophagous and pest species by traditional techniques and methods, at least over the next quarter of a century or longer.

Among the more practical and less sophisti-

Table 5. Examples of single strategy and combination of strategies in an integrated control technology of mosquito larvae.

Single strategies		
Biocides	Inundative predators (e.g., fish alone)	Combination biocides + fish
Selective	Time lag (weeks)	Most effective
Provide short-term control	Poor control initially	Short-term control
	Provide long-term control	Long-term control
Weekly or biweekly treatments	No reproduction/cold	Reduced rates of biocides
Not cost effective/large areas	No reproduction/short daylight	Cost effective
Low potential for recycling	Not cost effective/large areas	Fewer treatments

cated methods for the control of vectors and pest species, I see a good potential in the development and application of integrated vector control strategies. Utilization of biological control agents such as predators (invertebrate and vertebrate) in conjunction with safe biorational pesticides will go a long way toward controlling vectors and pests (Table 5). This area of technology is an emerging one, and in a few years we should see its application in some vector control programs.

Another area of research that could lead to the development of practical solutions is the development and use of behavior-modifying chemicals (semiochemicals). Chemical stimuli of host origin facilitating feeding responses in vectors could be formulated and used in monitoring or used directly in vector control programs. An equally promising area for research on semiochemicals is, for example, the identification of mosquito oviposition attractants and repellents. We have been able to identify several natural products (3-methylindole, some phenols, and others) that regulate mosquito oviposition behavior (Millar et al. 1992). For the first time, these simple chemicals were tested in the field (Beehler et al. 1994). Oviposition repellents of some *Culex* mosquitoes have been identified and evaluated (Hwang et al. 1980, 1982; Kramer et al. 1980). Some of these repellents (nonamoic acid and others) were tested under semi-field conditions (Schultz et al. 1982). The use of semiochemicals and host attractants could enhance our options to control vector and pest mosquitoes. These types of chemical agents may be employed in monitoring adult populations or used in population management.

It should be emphasized that techniques and methodologies used in vector control programs should be simple and safe. Sophisticated methodologies will not be applicable in all situations where financial and technical requisites are lacking. A good example of a simple and readily available technology is the development and registration of a new petroleum oil larvicide known as Rodspray Mosquito Larvicide (RML), which was cleared by the Environmental Protection Agency in mid-1994. This larvicide is a blend of petroleum hydrocarbons and essential food-flavoring oils. We first tested this formulation in 1992, and field experiments were carried out in 1993. Because of the simplicity and safety of the products in the formulation, the registration process was duly accelerated. There is a ray of light in the long tunnel of the registration process because regulatory agencies may be looking favorably upon the registration of simpler and safer pest control agents. Availability of this new larvicide will provide vector control programs with additional tools.

There is indeed a great need for a variety of techniques and methodologies for mosquito control. This need is predicated on the nature of diverse groups of mosquitoes breeding and developing in many types of habitats. No single tactic will be sufficient to provide a solution in all situations. Integration of simple traditional control methods will go a long way toward controlling mosquitoes in a variety of habitats and situations.

In the absence of an adequate arsenal of practical and usable tactics for vector control, it is imperative that we attack perplexing problems from an ecological perspective and integrate the few available tools into a practical and cost-effective vector control technology. In our studies on a stagnant water mosquito (*Culex tarsalis* (Coq.)), we found that natural regulating factors (such as oviposition cues, predators, etc.) play an important role in the natural decline of mosquito larvae (Mulla 1990). Combining these natural or biological control agents with safe biopesticides will go a long way toward achieving satisfactory control of at least some species of mosquitoes in some habitats. Extending and implementing this integrated vector control technology to other areas or species will require implementation of comprehensive applied ecological research at the field level.

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