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PRINCIPLES OF INTEGRATED PEST MANAGEMENT (IPM) IN RELATION TO MOSQUITO CONTROL[1]

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ABSTRACT. The concept of "integrated pest management" (IPM) is discussed and related to mosquito control. The basic characteristics and components of IPM are presented and a conceptual framework for mosquito IPM as part of resource management is proposed.

Integrated Pest Management (IPM) is an evolutionary stage in the sophistication and conceptualization of man's strategies of controlling pests. This is reflected in the evolution of terms from "pest control" to "integrated control" to "pest management" to "integrated pest management" with each in turn implying a broader perspective and a greater degree of ecological concern. In recent years the major attention has been on insect IPM in agriculture with the emphasis on crop protection in the context of the total crop production system. But this is being broadened to include other pests (pathogens and weeds) and to emphasize pest population manipulation in the context of the total environment with due consideration of man's role. IPM has many components developed in earlier times, but it is still new. IPM as now conceived is based on ecological principles and integrates multidisciplinary methodologies in developing ecosystem management strategies that are practical, effective, economical and protective of both public health and the environment. Early entomologists in mosquito control, and in crop protection, used ecologically based cultural methods—sometimes successfully, sometimes with questionable results and effects on other components in the ecosystem. With the development of chemical methods there were sometimes temporary spectacular successes but usually these methods were not used properly to *supplement* cultural methods, but rather they were often used to *replace* cultural methods. IPM has now been broadened to include all classes of pests and with the implication of the integration of both methods and disciplines or skills. IPM as it develops is becoming a part of total resource management.

IPM is a concept of great significance today to agricultural production, forestry resource management and to mosquito control, which is our interest in AMCA. IPM is currently being successfully applied in some major crop systems: apples, tobacco, cotton, soybeans and others. Any new emphasis or approach is accompanied with controversy and misunderstandings and this is true of IPM. There have been claims that IPM is nothing new and is nothing but a gimmick, that it is antipesticide, that it is more or less biological control. These claims are

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not true and seem to arise from misunderstandings. Therefore it is essential that we discuss the principles of IPM and its general relationship to mosquito control in order to be on a common ground. This discussion is my attempt to synthesize as succinctly as possible the commonly accepted principles of IPM based on the extensive recent literature. Being a synthesis it is not practical to cite all the literature but my presentation draws heavily on the publications listed as well as the references cited in those publications. They are suggested for further reading.

WHAT DO WE MEAN BY INTEGRATED PEST MANAGEMENT (IPM)?

Pest is an anthropocentric concept meaning simply an organism which is detrimental to man. Man selects the criteria for designating a "pest." Man also may create and intensify pest problems through his actions and behavior. Thus the pest status of an organism is closely related to man's density and mode of life. (Man is used in the broad sense of human beings.)

Truly mosquitoes are prime examples of pests. Man designates them as pests because they "bite," are often extremely annoying and sometimes transmit diseases. Excessive populations of mosquitoes affect adversely the economic growth of an area.

Man's behavior often accentuates the status of mosquitoes as pests. Examples are: human dwellings adjacent to scenic but prolific mosquito-breeding marshes, raising crops and livestock on irrigated lands with improper drainage causing new mosquito-breeding sites, pollution of the countryside with solid wastes (especially artificial containers such as drink cans and tires) which trap rainwater and harbor mosquito larvae, building in flood plains conducive to periodic broods of floodwater mosquitoes, impounding waters for flood control and/or recreation, pollution and/or blockage of natural drainage systems. Animal waste lagoons and diked dredged spoil are new man-made sources of mosquitoes of great significance in the southeastern United States. The list seems endless!

Likewise in agriculture, crop pests are those organisms (insects, disease, pathogens, weeds, etc.) which man designates as pests because they consume some of the crop and cause (or are thought to cause) economic loss which is a detriment to the producer. The actions of man have accentuated this problem. Examples are: The concentration of major crops into discrete areas, selection of plant varieties for high yield but not necessarily tolerance to pests, the desire for unblemished produce, luxuriant foliage growth due to high levels of fertilization, destruction of natural enemies which tend to suppress pest populations. The so-called "Green Revolution" is encountering unanticipated pest problems which threaten the future of the endeavor.

Whether we are speaking of agricultural production or mosquito control, it is clear that the status of a particular pest is a changing one. This is primarily due to man's changing behavior which is characterized by: increasing population, increasing rates of consumption of nonrenewable resources and increasing alteration of the environment.

Management is the act, art or manner of handling, controlling, administrating or directing affairs; the judicious use of means to accomplish an end. Thus the term conveys the concept of a continuous, on-going process. In contrast, the term *control* conveys more the notion of finality within a limited time scale. It implies some type of solution and disposal of a problem. Thus a mosquito control program in the eyes of the public should "solve" the problem, i.e., get rid of the mosquitoes, whereas in reality such programs are on-going efforts to suppress and maintain the mosquito population at a level acceptable to the public. So the term "management" is much more realistic and appropriate than "control." When we inaccurately promise control and mosquitoes reappear, the public tends to regard the program as a failure when usually it is not. The failure is in communication of objectives and capabilities. Likewise in agriculture, a producer tends to expect elimination of a pest on his crop when control is the stated goal rather than management.

Inherent in the concept of *management* is the setting of some level of performance or achievement. When pests are involved it is acceptance of some level of pest abundance and more importantly some level of loss or harm that is acceptable and realistic. The concept of economic threshold is pivotal. As illustrated in Fig. 1, mosquitoes or any other pests exist in varying numbers in nature. The populations undergo fluctuations above and below some mean level. The "economic injury level" is the pest population density that produces incremental losses equal to the cost of preventing the losses. The *costs* are usually the direct monetary ones. Ideally, costs should include also the indirect ones, such as environmental impacts of control measures but those are extremely difficult to estimate and are often ignored. The *losses,* relative to mosquitoes (Fig. 2), include the threat of disease transmission and the impacts of the direct effects of mosquito attacks ("annoyance level"). Losses are difficult to measure but can often be estimated from experience. The "economic threshold" is the pest density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level. This recognizes that we cannot wait until the losses are equal to the cost of control measures because there is a time delay in the measures having an impact on the pest population density. The objective of IPM, of course, is to reduce the mean population density level so that it is below the economic threshold most of the time (from A to B in Fig. 1).

In spite of the distinctions between management and control, the term "control" will continue to be used and has a legitimate place in describing specific techniques and methods of suppressing pest population, e.g. natural control,

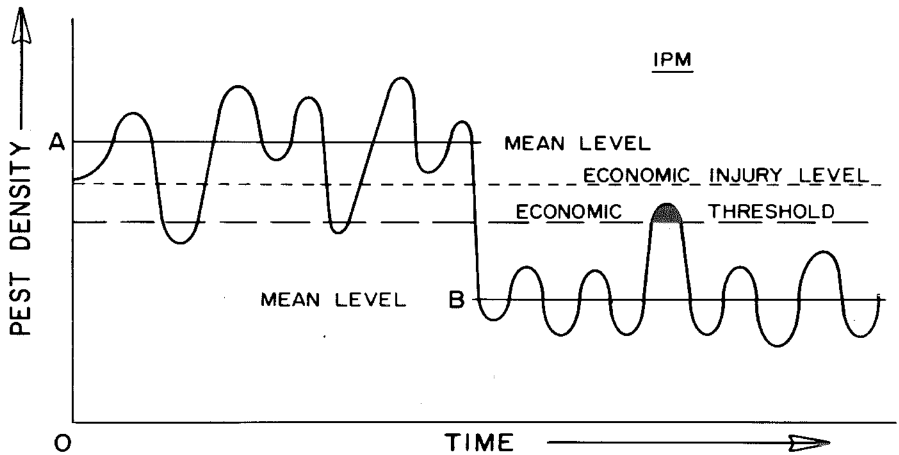

Fig. 1 Diagram of natural fluctuations of the density of a pest population, over a period of time, above and below a mean population level A. The objective of IPM is to lower the mean population level to B. The relationships of economic injury level and economic threshold are shown (see text for definitions).

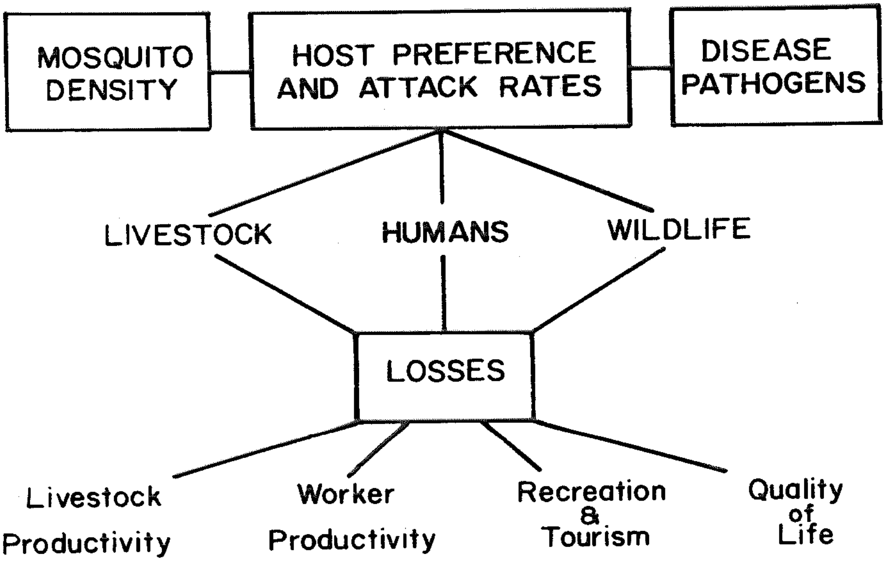

Fig. 2 Diagram of the categories of losses due to mosquitoes attacking humans, livestock and wildlife. The degree of attack at a particular mosquito density is related to the host preference of a particular mosquito species and the rate of attack under a given set of environmental conditions. The significance of the degree of attack beyond simple annoyance is determined by the presence of a disease pathogen and the vectoring capability of the particular mosquito. Losses from annoyance and disease transmission (if occurring) are expressed as reductions in livestock and worker productivities, incomes from recreation and tourism, and the quality of life for people in an area (including economic development and aesthetic enjoyment).

biological control, and chemical control. (I use the term natural control to mean all the biotic and abiotic factors in the environment that tend to reduce pest populations without the direct action of man. I use the term biological control to mean the intervention of man to manipulate natural control factors, e.g. the release of parasites, pathogens, predators.)

Integrated means to form into a whole, to unite, to incorporate into a larger unit. It conveys the idea of a judicious *meshing* of parts into a whole. It is not merely the use of several parts; often the whole is greater than the sum of the parts. Improperly done the parts may interfere with each other. Like a basketball team, the meshing of the skills of the individual players into a team effort results in more than just the sum of the efforts of those persons. Involved are complementary skills, complex interactions and compromises for maximizing the results of the total team effort.

Similarly, in dealing with pest problems, integrated refers to the judicious meshing of skills (disciplines) *and* control methods. In managing mosquito populations this would include not just entomology skills but also engineering, sanitation, ecology, wildlife and fisheries, economics, etc. As examples, the problem of rice field mosquitoes requires efforts of entomologists, agronomists and irrigation engineers; the problem of mosquitoes attacking livestock requires entomologists, livestock scientists (production and breeding), agronomists (pasture production) and engineers (irrigation, waste disposal). In agriculture, efficient crop production often necessitates a pest management program which integrates skills of the entomologist, plant breeder, plant pathologist, agronomist, economist, etc. All possible pest control methods should be considered including the broad categories of natural, biological, physical and cultural, chemical and legal.

The concept of *integrated control* (Fig. 3) is a fairly specific one which historically has meant the use of a combination of chemical and biological agents in as compatible a manner as possible. Sometimes cultural and/or physical control methods have been included. Integrated control programs are a major step in the evolution from pest control to integrated pest management. There are cases of ambiguity today in the use of the term, and sometimes integrated pest control will be used in a manner essentially synonymous with the more widely recognized term Integrated Pest Management.

Integrated Pest Management (IPM) is the sum and more of the constituent terms and meanings discussed above. Various definitions have evolved in the past few years. Sometimes the term pest management is used loosely to mean the same as integrated pest management. Although various definitions differ slightly in emphasis the spirit is the same

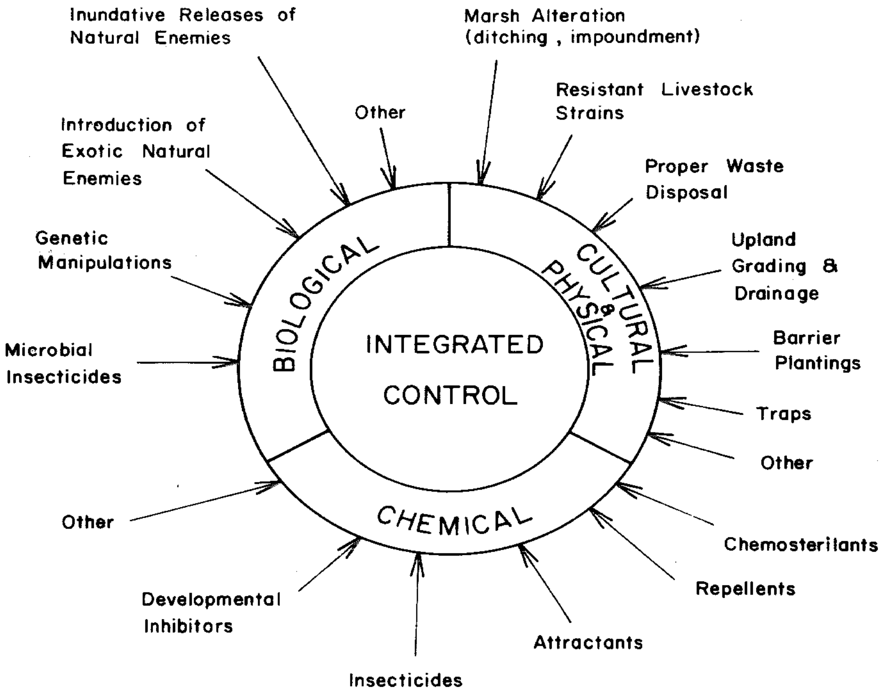

Fig. 3 Diagram of the components (cultural and physical, chemical, biological) and their potential constituent methods to be considered in an "integrated control" approach to mosquito control.

for all. IPM means a systems approach that encompasses not only the immediate objective of preventing pest losses but also consideration of long-term objectives with regard to economics, society and the environment (Glass 1976). It is the selection, integration and implementation of pest control action on the basis of predicted economic, ecological and sociological consequences (Rabb 1972). It is the reduction of pest problems by actions selected after the life systems of the pests are understood and the ecologic as well as economic consequences of these actions have been predicted, as accurately as possible, to be in the best interest of mankind (Rabb 1970). These definitions all say essentially the same thing.

A clearer understanding of the meaning of IPM may come from a list of the characteristics or features (grouped as 7 points):

1. IPM is not a method of control *per se* but rather it is a holistic approach. It is a mixture of applied philosophy and applied sciences. IPM provides for decision-making and implementation of actions based on both scientific and value judgments. Whether or not to take action requires economic data *and* a determination that the action is in the long term best interest of the public (Fig. 4). It is an attempt to take a satellite view of pest populations and their suppression and to develop a set of guidelines as to methods to be used to attain the optimum end results. It recognizes that populations of pests and man are dynamics. It recognizes that both local and general effects of pests and pest suppression actions must be considered as part of total resource management.

2. IPM has the objective of lowering the *mean level of abundance* of the pest so that the frequency of fluctuations, spatially and temporally, above the economic threshold is reduced or eliminated. In other words, the objective is to manipulate the pest population so as to reduce the losses. It recognizes that pests cannot be eliminated but often must be reduced to tolerable levels. IPM is concerned with the populations of a pest in a sizeable area, not in a very localized site such as

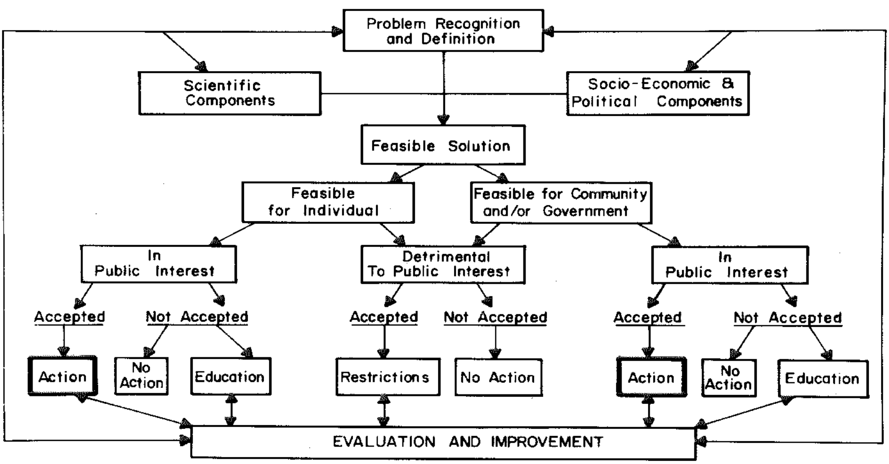

Fig. 4 Diagram of the interrelationships of the scientific and non-scientific (socio-economic and political) components in reaching a recognition, definition and decision on an appropriate response to deal with a pest problem and to evaluate and improve the decision over a period of time.

one field or one yard. The area is as large as possible and practical. It may be a few farms or towns, part of a county, an entire county, a region or a habitat (e.g. a valley, a peninsula, a coastal zone). Since the area in which the pest population is being managed has to have boundaries somewhere, there will be pest immigration and therefore the degree of pest suppression will be less near the margins than in the center. It is important that the public realize this.

3. IPM recognizes that man is manipulating the environment and we attempt to influence those choices of manipulations so that ecological processes can operate to regulate pest populations. IPM seeks to preserve and to enhance the natural factors regulating pest populations.

4. IPM attempts to predict pest population trends and to anticipate the effects of control methods, other practices, and weather on those trends. Consequently, it is essential to acquire knowledge of the pest's life systems (including factors affecting the growth of pest populations, i.e. pest population dynamics). Pest population monitoring and weather monitoring are the practical essentials for both short term and long term predictions.

5. IPM requires a conceptualization of all recognizable components affecting the pest population level and the effects of suppression tactics. This is inherently complex with many factors involved and many interactions among the factors. Systems analysis is required. This is simply an orderly approach to complex events by means of breaking the system down into manageable parts and subsystems, i.e. making predictive models. This may initially be descriptive through the use of flow charts and diagrams. It will evolve more and more to mathematical models as the need is justified and the data are available. The use of computers allows handling more data and examining more correlations than we could possibly accomplish otherwise.

6. IPM requires the continued development of *methods* of pest control so that the choices of alternatives (options) are many and the best fit to a circumstance can be made. This includes the use of pesticides and the need for the development of new ones as well as other methods. Conceivably a situation may arise when a single method may meet all the criteria and be an acceptable management tactic and, likewise, eradication in special circumstances may be the best tactic. These are not automatically and forever rejected in IPM. But clearly in most all cases the pest problem is too complex for these "simple" tactics and a multimethod ecological approach is required.

7. IPM is based on ecology—the ecology of pests and man (both of which are poorly understood). IPM is a part of area resource management—how to wisely use the finite earth's resources in such a way that man and nature can coexist successfully for the longest time possible. Ultimately it boils down to man's self-interest to maximize the quality of his life and the longevity of his species.

HOW MAY WE CONCEIVE MOSQUITO IPM?

Mosquito control has historically included many of the concepts discussed above as components of IPM. Included have been: The concept of area-wide mosquito population management, crude economic thresholds (light trap counts and landing rates), source reduction to lower the mean population level, encouragement of natural control factors (especially fish), public education, and legal restraints. The advent of DDT and subsequent synthetic organic insecticides tended to dilute the holistic approach to mosquito control, but it still exists. We can do better in explaining mosquito control and showing that it is IPM in many ways. At the same time we must analyze mosquito control practices in light of the modern concept of IPM and upgrade mosquito abatement programs. Programs must become more and more sophisticated and become increasingly active in the total resource management of an area. To accomplish this, the operational phase needs greatly improved abilities to predict mosquito populations and to predict the impact of control options on that population and on the environment (resources). This requires much more in-depth analysis of the components of a "mosquito problem" including mosquito population dynamics, human behavior, control options, and resource values.

Fig. 5 illustrates my concept of the interrelationships among analysis of a mosquito problem, mosquito IPM and resource management. Management of the total resources of an area must be based on the ecology of that area and on ecological principles. Mosquitoes are only one small (although important) component of the ecosystem and must be viewed in that perspective. Efforts to alter the mosquito density may have significant non-target impacts and consequently an IPM program must be an integral part of the total resource management system, i.e. the mosquito IPM program must be as compatible as possible with other management systems and *vice versa*. For examples, the practices of land utilization, waste disposal and mosquito IPM interrelate and, in the absence of an overall resource management scheme, may inadvertently be incompatible.

An operational mosquito IPM program must consist of calculated responses to the mosquito density. This requires monitoring the weather, habitat changes and the mosquito population and attempting to predict the trends in the mosquito density in order to know whether or not to initiate appropriate action in an IPM program. Before we implement an action we need some method to predict the likely effects of that action; i.e., will the mosquito density be reduced? We have crude mosquito monitoring procedures (light traps, landing counts, complaint rate), but they lack uniformity and standardization

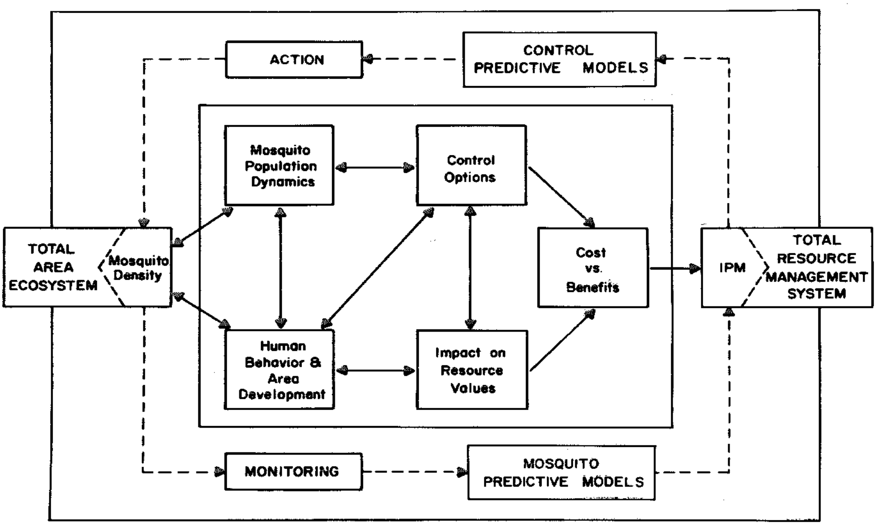

Fig. 5 Diagram of the interrelationships among area resource management (outer solid line box), operational mosquito control and IPM (middle broken line) and the components in the analysis of the appropriate IPM program for mosquitoes in a given area (inner solid line box).

and are inadequate for modern mosquito IPM. We generally lack adequate data on weather and habitat changes. Predictive models both for trends in mosquito densities and the impact of control methods are not available, and we rely on intuition and experience (sometimes with considerable success). Mosquito IPM needs to be more firmly grounded on more sophisticated mosquito, weather and habitat monitoring and on predictive mathematical models of mosquito population dynamics and the effects of implementing various actions.

A mosquito IPM program will consist of elements tailored to the mosquito problem in a particular area. Thus, an in-depth analysis of the mosquito problem, as shown by the inner box of Fig. 5, must be performed. Such an analysis is extremely difficult, for it includes knowledge of the population dynamics of the particular mosquito species and the interrelationship with development and human activities in the area. Depending upon these interrelationships there will be a variety of control options which must be evaluated as to their effectiveness, acceptabilities and impact on the environment and resource values. This will then allow a judgment of the cost of reducing the mosquito density versus the benefits to be derived. Costs and benefits should be interpreted in the broadest sense to include not only monetary ones but also environmental and aesthetic ones over a long period of time. The estimation of overall long term costs versus benefits is the important output from in-depth analysis of the mosquito problem in an area. This output is essential to defining the strategies and tactics to be used in a mosquito IPM program.

Obviously, all that is considered above cannot be accomplished immediately. However, it is important to conceptualize our goals and have some kind of guide to where we are going in mosquito control. We are on the right road but need to accelerate our pace to accomplish wider adoption and greater sophistication of mosquito IPM.

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Paper No. 2

APPLICATION OF THE CONCEPT OF INTEGRATED PEST MANAGEMENT (IPM) TO MOSQUITO CONTROL PROGRAMS

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ABSTRACT. Integrated Pest Management (IPM), as it relates to mosquito control, is simply the proper and systematic execution of all the facets comprising an organized mosquito abatement program. Therefore, the various organized mosquito abatement programs in the United States which are being properly executed are primary examples of how the philosophy of IPM may be applied to solving mosquito-related problems. The TVA (Tennessee Valley Authority) mosquito management program stands as another example of the beneficial results which can be realized when a specific mosquito problem is approached in a systematic manner.

Scientists are now joining forces to develop management strategies for mosquito problems that have yet to be solved. An example of this is the Cooperative Research, USDA, Regional Project, S-122, designed specifically to begin developing strategies for the systematic management of mosquito populations emanating from riceland areas in the southern United States. Most recently, this concept and approach was expanded through the auspices of a research grant proposal to EPA to include nearly all rice producing areas in the United States. If funded, the latter research program will involve the coordinated scientific and educational input from a consortium of 6 universities in Texas, Louisiana, Mississippi, Arkansas and California.

As part of this panel, I was asked to explain how the concept of Integrated Pest Management (IPM) can be applied to mosquito control programs and to give examples of the application of this concept which are already in force. Dr. Axtell has already presented an excellent general overview of the concept; and, by the nature of his presentation, one can see that IPM means different things to