executive committee of
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PAN AMERICAN
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WORLD
HEALTH
ORGANIZATION

99th Meeting
Washington, D.C.
June 1987

Provisional Agenda Item 4.4

CE99/15 (Eng.)
5 May 1987
ORIGINAL: ENGLISH

AEDES ALBOPICTUS IN THE AMERICAS

This document is being presented to the 99th Meeting of the Executive Committee in response to Resolution XXV of the XXII Pan American Sanitary Conference, which "urged the Director of the PASB to prepare a Plan of Action to combat *Aedes albopictus* in the Region of the Americas."

The document describes briefly the biology of *Aedes albopictus* and the major diseases which it can transmit, i.e., dengue and yellow fever. Emphasis is placed on the fact that this hardy exotic vector may maintain the cycle of dengue viruses and could bridge the jungle and urban cycles of yellow fever. It may also increase the incidence of California encephalitis in North America and of other arboviral diseases of public health importance to man. Established infestations of *Aedes albopictus* have been found in the United States of America and Brazil.

The Plan of Action presented in this document has as its ultimate goal the elimination of *Aedes albopictus* from the Americas. The strategic approach calls for a focus primarily on preparation of national plans of action with PAHO activities at the regional level designed to support the national plans. In the preparation of national plans, current *Aedes aegypti* programs should be reviewed and new activities blended with these programs. Where these programs are deficient, they must be strengthened.

The Plan emphasizes the urgent need to determine the distribution of the vector in the Americas. It also stresses the importance of research studies aimed primarily to orient the introduction of appropriate adjustments in the existing *Aedes aegypti* programs and to develop improved vector control methodology.

The Plan also addresses the question of prevention of importation and exportation of the vector, which will require countries to implement appropriate legislation, to review existing international health regulations, and to make appropriate changes.

The scientific and technical background of the Plan are summarized in the appendix "Ecology, Biology and Control of *Aedes albopictus*," which is provided for information.

The Executive Committee is asked to review and to consider approval of the Plan of Action.

CONTENTS

AEDES ALBOPICTUS IN THE AMERICAS

Plan of Action

1. INTRODUCTION

The recent finding of Aedes albopictus in the United States of America and in Brazil has raised considerable concern in view of the serious public health implications resulting from the introduction of an exotic and efficient arbovirus vector in the Americas. The main concern relates to the potential threat of aggravation of the problem of dengue and yellow fever in endemic areas of the Americas and of California encephalitis in North America, as well as the possible extension of these and other arboviral diseases to new areas.

Given the presence of established infestations of Aedes albopictus in two countries of the Americas and the serious public health implications of the introduction of this efficient arbovirus vector, the problem was examined during the XXII Pan American Sanitary Conference (1986). The Conference approved Resolution CSP22.R25, 1) requesting that Member Countries note the seriousness of the problem and support activities initiated by PAHO towards its solution; 2) recommending that Member Countries initiate or continue the necessary actions for effective surveillance of Aedes albopictus and measures to prevent its further dissemination or to eradicate it, if possible; and 3) urging the Director of the Pan American Sanitary Bureau to prepare a plan of action to combat Aedes albopictus in the Region of the Americas for presentation to the Executive Committee in June 1987, to support the activities of Member Countries for early detection, surveillance and control of this vector; and to promote research necessary to improve control measures.

The Director is pleased to present the requested Plan of Action to the Executive Committee for its review and approval.

2. DISTRIBUTION, BIOLOGY AND ECOLOGY OF AEDES ALBOPICTUS*

Aedes albopictus has a wide distribution in Asia and the Pacific, ranging from temperate regions to the tropics. Although several isolated introductions were found in the continental United States as early as 1946, it was not until August 1985 that it was established in the state of Texas, and subsequently in eleven additional states. It has been found in four Brazilian states since June 1986.

There is evidence that the introduction of Aedes albopictus to the United States was in tires transported in large cargo containers from Japan, and it is suspected that importation to Brazil was in bamboo stumps from Southeast Asia. Further introduction of Aedes albopictus to other countries in the Americas seems to be imminent and may have already occurred.

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*A thorough literature review of all aspects of the distribution, biology, ecology, public health importance and control of Aedes albopictus is in press as a PAHO technical document.

Aedes albopictus is primarily a forest species that has become adapted to the urban environment. It breeds in tree holes, bamboo stumps and leaf axils in the forest and in flower vases, bowls, bottles, tanks, drums, tires and other artificial containers in cities and towns. Whereas Aedes aegypti is largely (but not entirely) restricted to breeding in artificial containers in and around human dwellings in urban environments, Aedes albopictus utilizes similar sites but is also adapted to rural environments and a wider range of breeding habitats. Unlike Aedes aegypti it is a cold-adapted species throughout its range in northern Asia; females undergo ovarian diapause and survive in hibernation. The Houston strain has been shown to undergo similar diapause. It prefers to feed on man, but will readily feed on other mammals and sometimes on birds.

3. PUBLIC HEALTH IMPORTANCE

Dengue and yellow fever are the two most important diseases of the Americas that could potentially be transmitted by Aedes albopictus. Aedes aegypti has hitherto been the only vector implicated in the urban transmission of these two diseases in the Americas. Undoubtedly, the sharp increase of dengue activity observed in the past 20-25 years is greatly due to the increase and dissemination of Aedes aegypti populations. Unfortunately, despite the existence of political mandates adopted by the American countries to eradicate Aedes aegypti, a constellation of financial, political, administrative, socioeconomic and technical problems has decreased the effectiveness of vector control programs in the Region. The rapid growth and urbanization of human populations in tropical areas and increased travel and commerce between countries have also contributed to the proliferation of this mosquito.

3.1 Dengue

Dengue fever activity in the Americas has increased considerably in the past two decades. The most notable episodes in the Americas in recent years have been the pandemic of dengue-1 in the Caribbean, northern South America, Central America, Mexico and Texas during 1977-1980, with approximately 702,000 cases; the epidemic in Cuba in 1981 with 340,000 cases of dengue-2, which included 24,000 with dengue hemorrhagic fever (DHF) and 158 deaths; and the current epidemic of dengue-1 in Brazil, with an estimated 500,000 cases thus far.

Although sporadic cases of dengue hemorrhagic fever (DHF) had been reported in the past in a few countries of the Americas, the first major outbreak of dengue hemorrhagic fever/dengue shock syndrome in the Western Hemisphere occurred in Cuba, in 1981. During this widespread outbreak 344,203 cases were reported. There were 116,143 persons hospitalized, approximately 10,000 shock cases and 158 deaths.

The Cuban outbreak of DHF could represent the beginning of a situation that occurred in Asia, where, following an initial DHF epidemic in the Philippines in 1953, the disease gradually spread to other countries.

Experimental and natural transmission data show that Aedes albopictus is a very efficient vector of epidemic dengue and has a higher susceptibility to oral infection with these viruses than Aedes aegypti, the principal epidemic vector in Asia. Moreover, Aedes albopictus has been shown to transmit all four dengue serotypes transovarially and transstadially. It is thus highly likely that Aedes albopictus could play an important role in the maintenance cycle of dengue viruses.

3.2 Yellow Fever

Yellow fever continues to be a major threat in endemic zones of South America and in adjacent areas where the virus is able to reappear after long intervals of quiescence. It is essentially a disease of workers engaged in forest activities.

Most cases of yellow fever in the Americas are reported by five countries: Bolivia, Brazil, Colombia, Ecuador and Peru which report 100 to 200 cases of yellow fever annually. The true incidence is probably tenfold higher.

The occurrence of yellow fever in close proximity to urban settings infested with Aedes aegypti and the consequent risk of jungle yellow fever urbanization are of special concern. It is believed that one reason for the non-urbanization of the virus has been the absence of a vector that can effectively utilize both the urban-suburban environment and rural or jungle areas. As Aedes albopictus can breed in urban, rural and forestal areas, it could bridge the jungle and urban cycles of yellow fever. In the laboratory, Aedes albopictus has been infected orally with yellow fever and has been shown to transmit this virus to monkeys.

3.3 Other Viruses

Experimental studies demonstrate that Aedes albopictus can be infected orally and transmit efficiently several other arboviruses. Among these are the flaviviruses Japanese encephalitis and West Nile, the alphaviruses Western equine encephalomyelitis and Ross River, and the bunyaviruses La Crosse and San Angelo. La Crosse virus causes California encephalitis, which is an important public health problem of man in North America. Should Aedes albopictus become involved in the natural transmission of La Crosse virus, the agent would spread to suburban and urban settings and lead to an increase of the incidence of California encephalitis.

4. PLAN OF ACTION FOR AEDES ALBOPICTUS IN THE AMERICAS

The problem of Aedes albopictus is not very different from that of Aedes aegypti, as these two mosquitoes have many similarities in terms of disease transmission. Consequently, many of the recommendations already approved by PAHO's Governing Bodies dealing with Aedes aegypti are applicable to Aedes albopictus.

4.1 Goal

The ultimate goal of the plan of action is to eliminate Aedes albopictus from the Americas.

4.2 Objectives

a) To determine the distribution of Aedes albopictus in the Americas.

b) To carry out Aedes albopictus surveillance and control activities, and to integrate these activities with existing Aedes aegypti surveillance and control programs.

c) To contain Aedes albopictus infestations and to reduce the Aedes albopictus population to levels such that arboviral disease outbreaks from this vector cannot occur and such that ultimate elimination of the mosquito may be feasible.

d) To prevent the importation and establishment of Aedes albopictus in non-infested areas of the Americas.

4.3 Strategies

The basic strategies of this plan of action are twofold: to promote the preparation and implementation of national plans of action and to carry out regional activities in support of national efforts.

4.3.1 Preparation of National Plans

Member Countries will be encouraged to develop national plans of action. Each plan should begin with a description of the current program for Aedes aegypti. Most of this information is obtainable from annual reports of the Aedes aegypti campaign or from the annual PAHO questionnaire of inventory of resources of Aedes aegypti programs.

4.3.1.1 Guidelines for Preparation of National Plans

A. Description of the Present Aedes aegypti Program in the Country

1) Brief history of infestation, campaigns, eradication, reinfestation.

2) Present infestation: distribution, indexes, types of breeding sources.

3) Organizational structure of the program.

4) Personnel: number, positions, education.

5) Equipment, supplies, insecticides.

6) Coverage, cycles, verifications.

7) Surveillance system: localities, frequency, personnel, methodology.

8) Training.

9) Research.

B. Present Program of Aedes albopictus (if it exists)

- Same categories as for Aedes aegypti programs.

C. Proposed Program for Aedes albopictus

In order to prepare the national plan, the following strategies and activities should be considered, always remembering that they should be integrated as much as possible with activities from an existing Aedes aegypti control program.

4.3.1.2 Activities to be Included in National Plan

A. Surveys and Surveillance

Since information on Aedes albopictus is currently very limited in Central and South America, the most important initial step will be to gain information on the presence, distribution, breeding habitats and insecticide susceptibility of this species in the various countries. This can best be achieved through initial surveys and establishment or expansion of the current continuous Aedes aegypti surveillance system. This information will be critical for planning and organizing control/eradication programs for Aedes albopictus.

Initial Surveys

Initial surveys should be done immediately in localities with highest risk of introduction and in habitats with greatest probability of proliferation of this mosquito. Key sites in each country are sea ports, airports, bus terminals, train stations and cargo shipment companies.

Tire dumps and cemeteries in these areas receive highest priority. Areas with known infestation should also be surveyed to determine distribution and habitat preference. Traditional larval surveys will be done, but field workers should also carry gear for adult collections. Infestation of plants and ornamental flowers should be especially investigated.

Surveillance

A surveillance network should be established in the same countries and in the same localities as the initial surveys, using, in addition to periodic larval and adult surveys, oviposition traps which should be checked weekly.

The system of surveys and surveillance should utilize the current Aedes aegypti program structure, personnel and methodologies as much as possible. Where these are deficient, they must be strengthened.

Incoming ships and aircraft, from countries known to be infested with Aedes albopictus should be inspected and disinsected. Special attention should be given to cargos of tires, flowers and other potential sources of larvae or eggs.

It will be important to have mosquito collections, both larvae and adult, identified as quickly as possible. This may require some decentralization of the identification procedure, and will require additional equipment such as microscopes and personnel trained in identification of container-breeding mosquitoes.

Upon discovery of an infestation of Aedes albopictus an attempt should first be made to obtain live eggs for colonization in a laboratory in a reference center, for definitive identification, biological typification and susceptibility testing before the focus is eliminated. Colonization should not be attempted in a country with a very low infestation.

Reporting Procedure

Reports of new infestations will be coordinated through PAHO and communicated immediately to all member countries. Routine surveillance reports will be made periodically to PAHO on current forms which will be revised to permit entry of information for both aegypti and albopictus. Field forms will also be modified for inclusion of both species, so that information may be collected in a consistent and standardized manner.

B. Prevention and Control

The strategies and methods of prevention and control of Aedes albopictus are very similar to those of Aedes aegypti, which have been defined in the PAHO Manual for Aedes aegypti Campaigns (1957), the PAHO Guide for Reporting of Aedes aegypti Programs (1965); and which have recently been revised in the PAHO Plan of Action for the control of Aedes aegypti (in press). Countries that already have effective Aedes aegypti control programs will be able to employ the same strategies against Aedes albopictus, with the difference that albopictus may require inspections and treatments farther from the domestic/peridomestic habitat of Aedes aegypti.

Control activities in receptive areas that are not yet infested must be oriented toward reduction of their receptiveness, whereas in newly infested areas measures should concentrate on elimination of infested foci; and in areas where infestations are already established, work should concentrate on the prevention of dissemination and exportation, suppression of populations, and where possible, elimination of the infestation. The formulation of the most efficient control measures will depend on the results of surveys of breeding habitat and insecticide susceptibility, on biological studies and on fields trials of the treatment methods.

Prevention

The prevention of establishment of infestation of each country will depend on the surveillance system, the disinsection of incoming ships and aircraft, and on source reduction programs.

a) Surveillance for the early detection of importation of the mosquito is presented above.

b) Disinsection of incoming ships and aircraft and of certain cargos, especially large shipping containers with tires, flowers or other plants or receptacles which may contain eggs or larvae. Techniques using different fumigants or heat must be evaluated for their cost, effectiveness and safety.

c) Source reduction to eliminate all potential breeding sites of both Aedes aegypti and Aedes albopictus must be done continuously in and around all ports of entry, to reduce the possibility of establishment of these mosquitoes even if they are imported.

Elimination of New Infestations

Control in areas with new infestation must be treated as an emergency. New resources must be put into the existing control program and every effort must be made to eradicate the infested foci.

The following steps should be taken:

1. Surveillance should be intensified to monitor known foci, and to detect the spread into new areas or new habitats. Data should be obtained on the relative utilization of both artificial and natural containers in the domestic and peridomestic environment and at greater distances from human habitation.

2. Intensive continuous control efforts:

a) Adulticides should be applied to infested areas to suppress adult populations until larviciding and source reduction campaigns are completed. The United States of America population of Aedes albopictus has been shown to be at least partially resistant to malathion. Therefore susceptibility tests of mosquitos against insecticides must be carried out.

b) Larvicides having long residual effectiveness or slow release formulations should be applied to all water-holding containers. Special attention should be given to tires, drums, buckets and other large containers. Tree holes, bromeliads, rock holes, and other natural containers must also be included.

c) Source reduction campaigns should be used in problem foci areas where there are large accumulations of containers.

d) The public must be informed and its support enlisted.

Control or Eradication of Established Infestations

In each American country where Aedes albopictus is already well established (e.g. United States of America and Brazil), the decision must be made whether to attempt to eradicate this species or merely to contain it, prevent its further spread, and maintain the populations at low levels at which arboviral disease outbreaks cannot occur.

Programs in these countries will be similar to existing Aedes aegypti programs and the two may be integrated, but taking into consideration any differences in distribution, biology, ecology, insecticide susceptibility of the two species.

Improved solid waste programs are vital if source reduction campaigns are to succeed. Accumulations of quantities of water holding containers are generally the result of inadequate garbage collection systems.

Creation and enforcement of legislation to support control operations where appropriate under local conditions, is a valuable tool.

Even well-established infestations can be contained in one sector of the country and not allowed to spread. Detailed knowledge of the geographic distribution of the mosquito in the country is required, in order to establish surveillance and disinsection posts outside the infested area.

Each infested country has a moral and ethical responsibility to avoid exportation of pest insects and vectors to other countries, and should write and implement legislation which requires disinsection of cargo for exports. Evaluations are required of the most suitable methods.

Emergency Control During Disease Outbreaks

In the event of an Aedes-borne disease outbreak, rapid emergency control measures must be implemented. Aerial ultra low volume (ULV) application of adulticides, applied at the correct time of day, with appropriate dosage rates, speed of application, appropriate climatic conditions, etc., must be used for sufficient reduction of the target Aedes adult populations. Ground ULV spraying or thermal fogging, although less rapid and sometimes less effective than aerial ULV may be used where it is not possible to utilize aerial ULV.

Such measures must be coordinated with all levels of government, non-governmental agencies, and the media to insure correct information dissemination and cooperation from officials and the public.

Adulticiding efforts should be directed to areas having the greatest amount of new virus activity and for this reason it is essential to obtain and tranfer epidemiologic information to the mosquito control program on a frequent and timely basis.

Areas such as tire dumps, ports of entry and densely populated high rise urban areas will benefit from methodical fogging operations, where speed of applications, dosage rates, wind conditions, etc, must all be considered.

Public education is an important aspect of disease prevention. An informed public is able to provide some protection for itself in its own environment by using household insecticides to kill adult mosquitoes and by eliminating or covering of water holding container.

Source reduction, along with public education efforts, should be concentrated in areas having large number of containers and populations of mosquitoes with or without cases of dengue or other virus illnesses.

The effectiveness of control methods must be monitored or evaluated to ensure that they are accomplishing the desired objectives. Failure to evaluate control methods can result in wasteful and ineffective programs.

C. Training

Survey personnel from each country will be taught in national courses by a team comprised of at least one PAHO entomologist, one national entomologist (previously trained in an international course) and, optionally, a short-term consultant. After classroom and laboratory exercises, the participants will be transported to certain areas of the country considered to be at greatest risk for the introduction of Aedes albopictus to do the actual initial surveys. Thus, the field training for the course will also be the initial survey to detect infestation of the country.

D. Research

It will not be possible to eliminate Aedes albopictus or even control it effectively unless we have more knowledge of its distribution, modes of dispersal, breeding habitats, insecticide susceptibility and control methods. This information can only be obtained from systematic studies, which need not compromise the control efforts.

The priorities are for research on the following:

1) The ability of Aedes albopictus to spread to new areas.
2) Vectorial capacity.
3) The role of Aedes albopictus in dengue outbreaks in the Americas.
4) Aedes albopictus control.

4.3.2 Regional Activities

The following activities will be carried out from the regional level in support of national activities.

4.3.2.1 Collection and Dissemination of Information

As Aedes albopictus is an exotic mosquito in the Americas, limited information is available in member countries concerning this vector. Therefore, PAHO has initiated the distribution of technical information to national health authorities and a literature review has been prepared on taxonomic features, keys of identification, biology of the mosquito, vector competence, insecticide susceptibility and control. Obviously, such information derives from observations made with Aedes albopictus populations from Asia.

Member Countries should report regularly to PAHO results of Aedes surveillance activities. Countries with established infestations should report on the extension of infestation, breeding habitats of the mosquito, insecticide susceptibility and the control activities being implemented. PAHO will consolidate, analyse and periodically publish and distribute the current status of the Aedes aegypti and Aedes albopictus situation in the Americas.

4.3.2.2 Assistance to Countries in Undertaking Initial Surveys

Initial surveys, organized to detect rapidly the presence of Aedes albopictus, can most quickly be implemented by organizing international entomological teams consisting of PAHO, other international and national entomologists. These teams will visit key cities in Mexico, Central and South America and the Caribbean, conduct short (one day) training workshops on survey procedures and mosquito identification, and actually conduct field surveys in these areas. Priorities for surveys should be given to those countries with most importations of used tires and other known natural or artificial breeding containers from infested areas such as the United States of America, Brazil and Asia.

4.3.2.3 Training

Training on all aspects of the biology and control of *Aedes albopictus* will be carried out at both the international and the national level. Courses will include the taxonomic aspects, biology, ecology, survey and surveillance methods, vector competence, control strategies and insecticide susceptibility for both *Aedes albopictus* and *Aedes aegypti*, showing the known differences and similarities between the two. PAHO has already held a workshop on *Aedes albopictus* in CAREC in Trinidad in October 1986, primarily for vector control workers from the Caribbean Region. At least one other international workshop, for non-English speaking Latin America, is planned for 1987.

4.3.2.4 Resource Availability from PAHO

The human resources which PAHO has available to promote and coordinate activities related to vector control in general are located at both the Headquarters and at the country level. The coordination of vector control activities at the central and field level is under the Program of Communicable Diseases (HPT). HPT implements activities such as collection and dissemination of information, provides technical consultation, prepares training courses, organizes scientific and technical meetings, assists in procurement of related supplies and equipment and assists in identifying sources of financial support. In addition HPT, principally through the field staff of seven entomologists assigned to country or regional projects, provides direct technical assistance to countries, supervises and orients national vector control programs, organizes and serves as instructors in training workshops on vector control and assists in research projects on vector ecology, biology and control.

Resources are also made available through specific consultantships provided by experts particularly from universities and specialized agencies in the Member Countries.

4.3.2.5 Preparation of Manuals

PAHO will develop protocols for surveys and surveillance to be distributed and promoted in all of the countries of the Region. In addition, a field manual for the identification, surveillance and control of *Aedes aegypti* and *Aedes albopictus* should be prepared. Preliminary keys, which have already been distributed, will be modified to include the Central and South American and Caribbean species, and will be translated into Spanish.

4.3.2.6 Assistance to Countries in the Development of National Plans of Action

Each country will be encouraged to prepare its plan of action for the control of *Aedes albopictus*. The present regional plan of action presents guidelines, but adjustments will be necessary according to local situations. PAHO will provide advice and technical information for the formulation of national plans of action and will promote regional workshops to review the plans from each country.

4.3.2.7 Review of International Health Regulations

The new transportation technologies, such as the use of containerized cargo, have facilitated the dissemination of insects. For this reason, it will be advisable to review the existing international health regulations and to make appropriate changes.

5. CHRONOGRAM OF ACTIVITIES

ACTIVITY	1987 TRIMESTER			1988 TRIMESTER				1989 TRIMESTER			
	2	3	4	1	2	3	4	1	2	3	4
National											
1. Preparation of national plans of action	X	X	X								
2. To conduct initial surveys	X	X	X								
3. To implement surveillance											
4. Training	X	X	X			X		X			
5. Research			X	X	X	X	X	X	X	X	X
Regional											
1. Preparation and approval of regional plan of action	X	X									
2. Workshops to review national plans of action		X	X	X	X						
3. Preparation of protocols for surveys		X	X								
4. Preparation of field manuals for surveillance and control		X	X	X	X						
5. Collection and dissemination of information	X	X	X	X	X		X	X	X	X	X
6. Training	X	X	X								
7. Resource mobilization	X	X	X	X	X	X	X	X	X	X	X
8. Research			X	X	X		X	X	X	X	X
9. Review of international health regulations			X	X							

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IN REPLY REFER TO

APPENDIX:

"ECOLOGY, BIOLOGY AND CONTROL OF AEDES ALBOPICTUS (SKUSE)"

ECOLOGY, BIOLOGY AND CONTROL OF *AEDES ALBOPICTUS* (SKUSE)

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ECOLOGY, BIOLOGY AND CONTROL OF *AEDES ALBOPICTUS* (Skuse)

INTRODUCTION

In August 1985 *Aedes albopictus* mosquitoes were found breeding in tire dumps in Harris County, in and around Houston, Texas. The Houston *Ae. albopictus* population represented the first established infestation reported in the Western hemisphere (CDC, 1986a; Monath, 1986; Sprenger and Wuithiranyagool, 1986). Up to date, reports from eleven other states in the U.S.A. have shown the presence of *Ae. albopictus* as it moves northward, the most northern point being a little beyond 40^{o} degrees latitude (CDC, 1986c).

Furthermore, since June 1986, *Ae. albopictus* has been found in Brazil in the States of Espirito Santo, Minais Gerais, Rio de Janeiro and two areas of Sao Paulo in a total of 89 municipalities (SUCAM, October 1986; Forattini, 1986). The State of Rio de Janeiro has experienced a widespread dengue epidemic this year. Due to the extent of Brazil's *Ae. albopictus* infestation, it is believed that the first introduction in the area must have occurred some years ago (Anonymous PAHO, 1986a; CDC, 1986b). An exotic and efficient vector species of dengue and possibly yellow fever and other arboviroses has been introduced into the American

Continent. There is great concern among the countries of the Americas over the dire threat posed by *Ae. albopictus* (Anonymous PAHO, 1986b).

The purpose of this document is to put together information to date on the ecology, biology and control of *Aedes albopictus*.

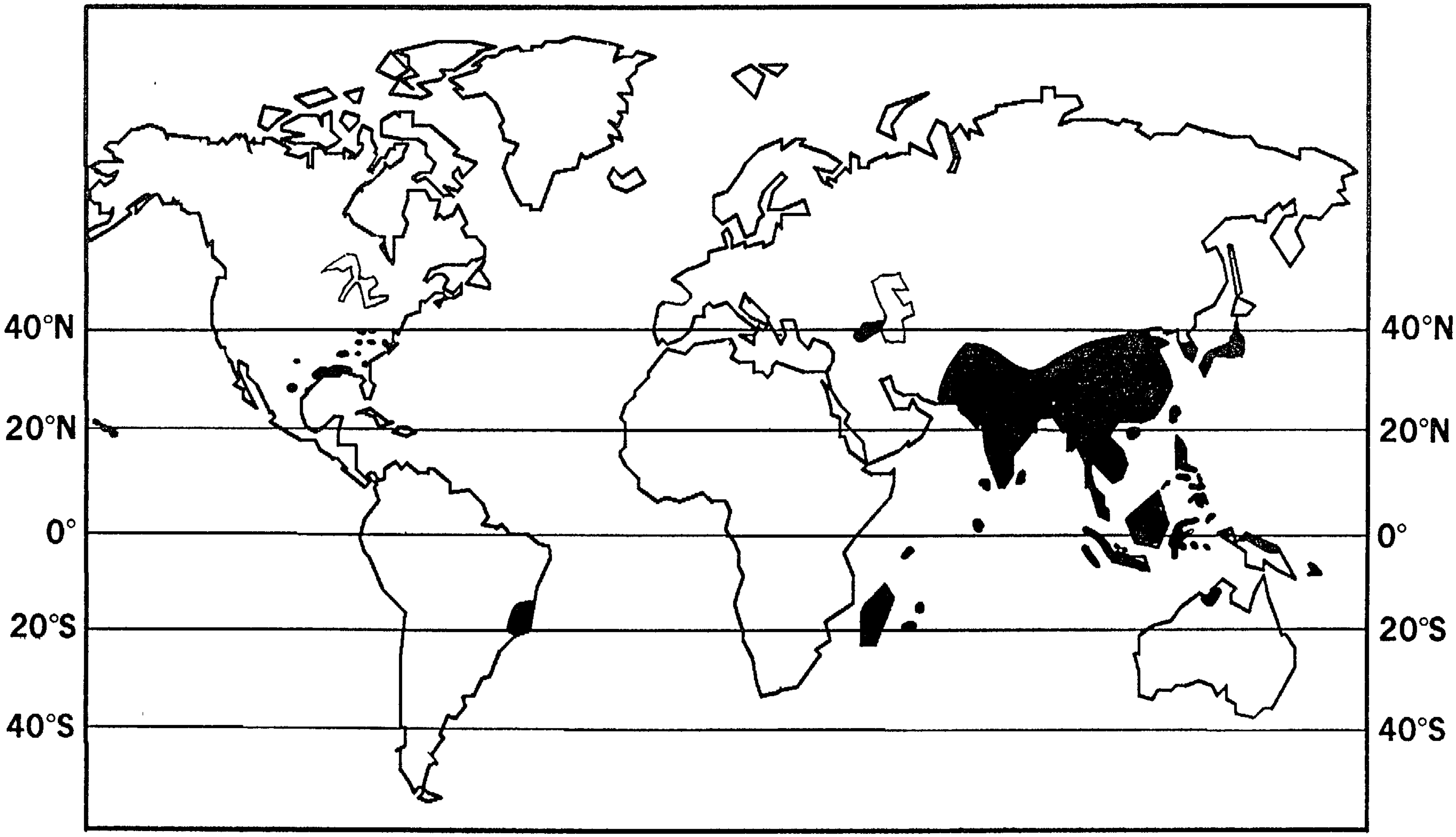
GEOGRAPHICAL DISTRIBUTION

Aedes albopictus is considered an indigenous species of Southeast Asia where it is believed that classical dengue has its origin. *Aedes aegypti* is thought to have been introduced from Africa. These two species are the most important vectors of dengue in southeast Asia (Smith, 1956; Pant, *et al.*, 1973; Chan, 1985). In Asia *Ae. albopictus* has spread northwards as far as Beijing (Peking) at 40^{o} north latitude in China (Dengue Newsletter, 1980). It is also distributed in the Korean peninsula and in Japan up to northern Honshu Japan's main island, reaching the prefecture of Sendai at 36^{o} north latitude (Hong, *et al.*, 1971; Kamimura, 1968). Beijing and now Greenville, Ohio in the United States, are the northernmost reported distribution points of *Ae. albopictus* (Moore, personal communication, 1986)

In southeast Asia the species has extended to coastal cities of Irian Jaya, in the Solomon and Santa Cruz islands, Papua New Guinea and just once has been found in Darwin Australia (Elliot, 1980). It has been reported in the Mariana, Caroline and Hawaiian Islands, Micronesian, Indochina, Asian continent and westwards in several islands of the Indian Ocean such as Madagascar, Mauritius, the Seychelles, the Chagos archipielago and Reunion islands (Surtees, 1966; Lambrecht, 1971b; Ho, et al., 1972). In one respect, Aedes albopictus is a zoographic enigma; the species has never been found in Mainland Africa (Lambrecht, 1971a; G. Craig, personal communication, 1986). Map 1 summarizes the worldwide distribution of Ae. albopictus. In addition, maps 2 and 3 illustrates the distribution in two countries in the American Region.

In relation to altitude ranges, Aedes albopictus has been found distributed up to 1800 meters in the mountains of Thailand (Scanlon and Esah, 1965). Pant, et al. (1973) reported the presence of Ae. albopictus in a Thai village located at 1700 meters. Both studies reported that in every range from sea level to the highest altitude listed the species was found. Ho Be-Chuan, et al., in 1972 reported the presence of Ae. albopictus at maximum altitudes ranging from 24 to 180 meters in West Pakistan, Sri Lanka, Taiwan and Malaya but this appears to be an underestimation of the mosquito vertical range.

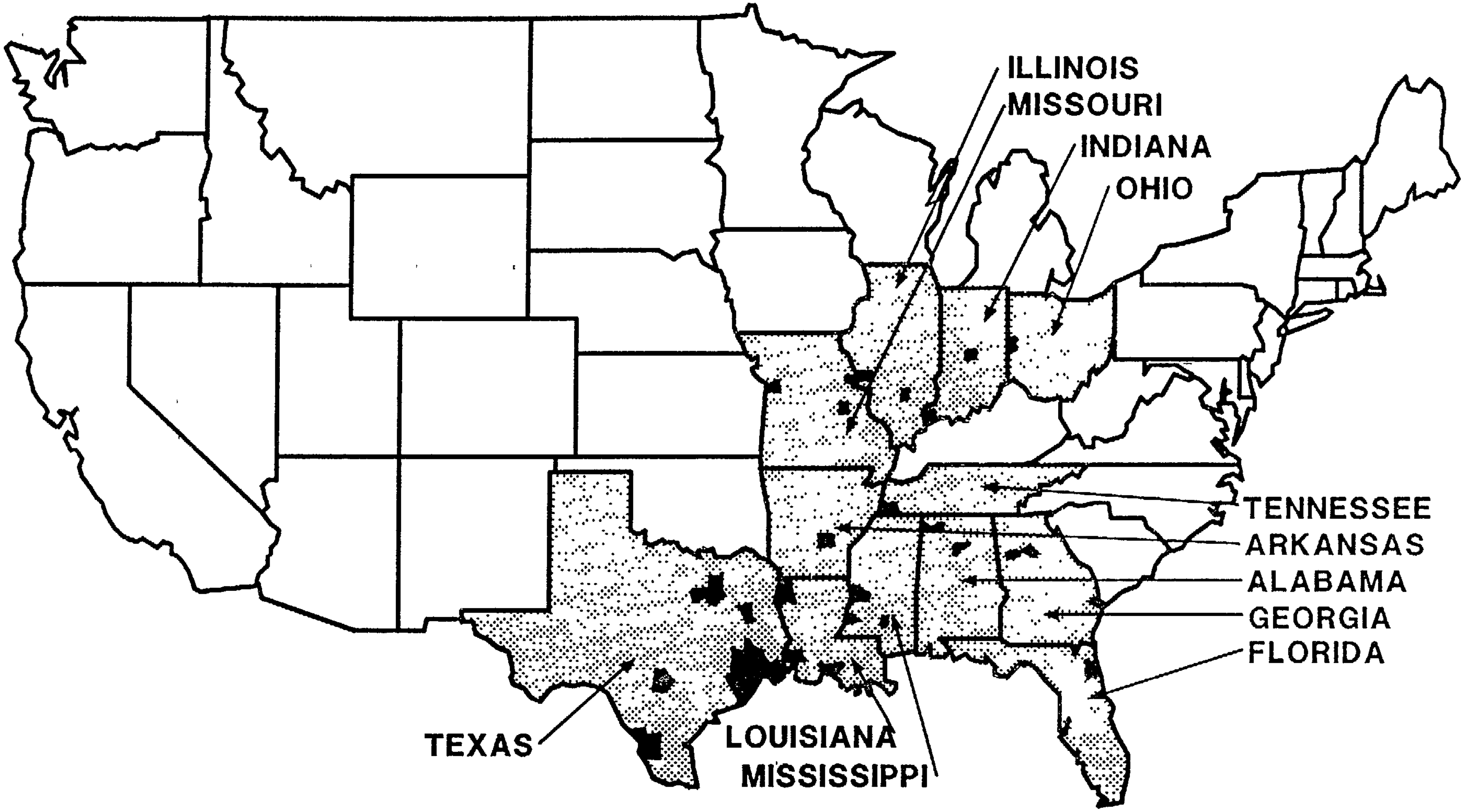
MAP 1
AEDES ALBOPICTUS DISTRIBUTION DOCUMENTED IN THE WORLD AS OF OCTOBER 1986



Sources:Hong, et.al.,1971; Kamimura, 1968.
Huang, 1972; Ho BC,et.al;1972;Elliot S,1980;
Anonymus PAHO, 1986b;CDC,1986c.

MAP 2

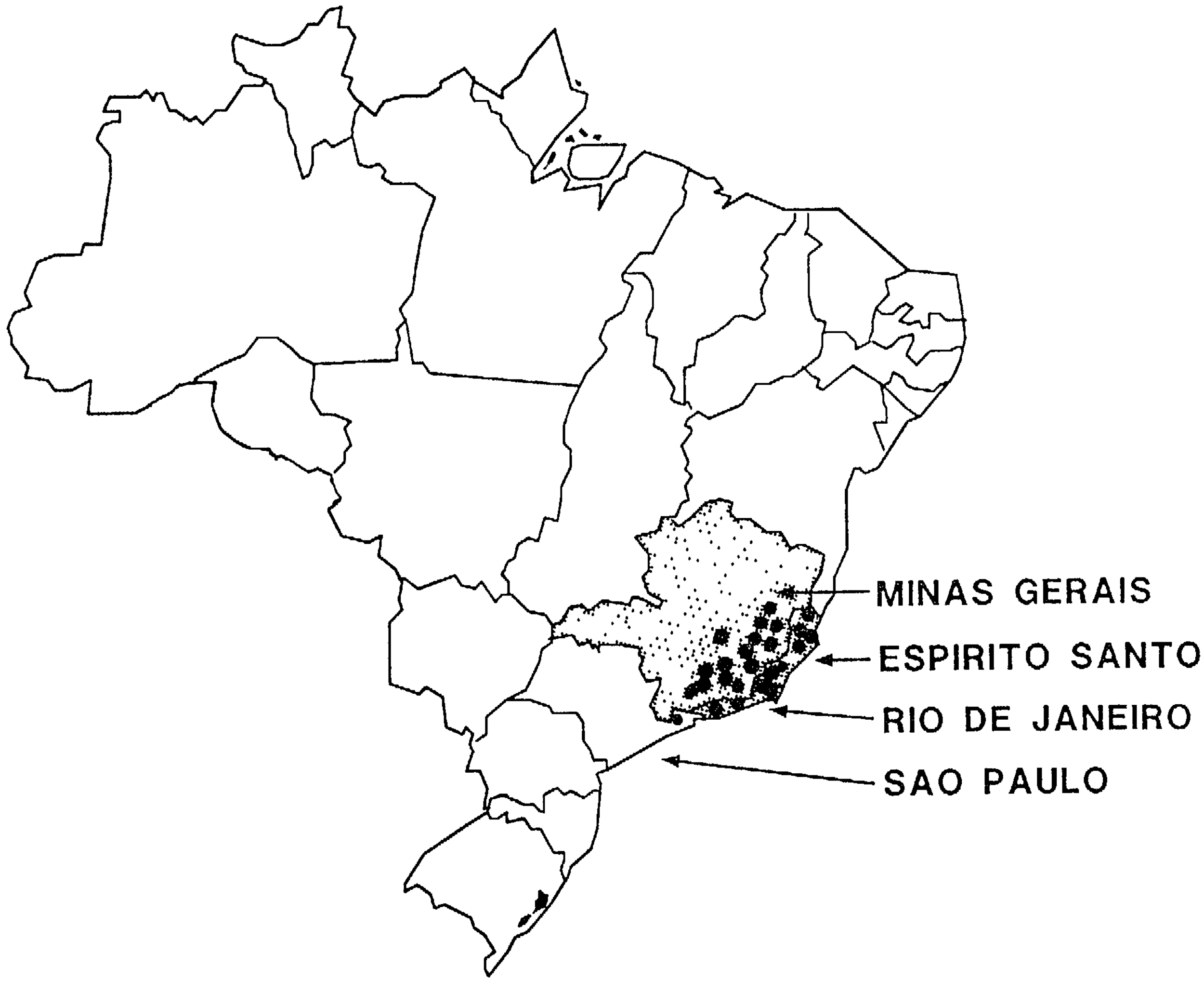
AEDES ALBOPICTUS INFESTED AREAS IN UNITED STATES OF AMERICA BY STATE. SEPTEMBER, 1986



DATA FROM: Dr. Chester Moore. Division of Vector-Borne Viral Diseases Centers for Disease Control. Fort Collins. Colorado

MAP 3

AEDES ALBOPICTUS INFESTED AREAS IN BRAZIL, BY STATE - OCTOBER, 1986



Data from: MINISTERIO DA SAUDE, Superintendencia de Campanhas de Saude Publica - SUCAM, Brazil

In comparing the distribution of *Aedes albopictus* with *Aedes aegypti*, while both species can overlap in the same urban environment (Harrison *et al.*, 1972; Azzizar, 1980; Chan, 1985), *Ae. albopictus* is more commonly found in suburban and rural areas where open spaces with vegetation are prevalent (Ho, B.C., *et al.*, 1972; Pant, *et al.*, 1973; Chan, 1985). It is generally accepted that *Ae. albopictus* was originally a sylvan species, breeding and feeding in forest fringes, which has now become very well established in the domestic environment throughout several areas of Asia (Bonnet and Worchester, 1947; La Casse and Yamaguti, 1950; Surtees, 1970; Ho, *et al.*, 1972; Miyagi, 1983).

LIFE HISTORY

In Vietnam, eggs of *Ae. albopictus* under natural conditions have been reported to reach adulthood in 7-20 days in spring and 24 days in winter (Surtees, 1966; Ho, *et al.*, 1972). Under laboratory conditions and assessing the effect of environmental parameters such as temperature and other variables, similar results have been reported by different authors.

Matsuzawa and Kitahara (1966) found that for *Ae. albopictus*, from the moment of egg laying to the adult stage and at water temperatures of 30^{o}, 25^{o}, and $20^{o}C$, developmental time of 12, 13.7 and 24.3 days, were observed respectively. Development times from egg deposition to adulthood were 12, 13.7 and 24.3 days in _Ae. albopictus_ verved at 30°, 25°C (Matsuzawa and Nitzharz, 1966). Hien (1975c) reported development times from oviposition to emergence of 11 days at 30°C, 14 days at 25°C and 23 days at 20°C. Galliard and Golvan (1957), with a lab-reared strain of _Ae. albopictus_, found that development from egg to adult took 25 days and 10 days at 18°C and 25°C, respectively. Livingstone and Krishnamoorthy (1982) determined that at room temperature (26°C - 30°C) development from egg to adult of the female _Ae. albopictus_ ranges from 11 to 12.4 days, whereas, males reach the adult stage in 10 to 11.4 days. The optimal water temperature for _Ae. albopictus_ development is said to be 25°C. At this temperature incubation period is two days (Sheng.T. and Wu, 1951; Ho, B.C. _et al._, 1972). In addition to temperature, food supply also affects the size and development of the _Ae. albopictus_ larvae. Larvae placed in contaminated water with plenty of food develop rapidly while starvation and overcrowding conditions retarded development and increased mortality under laboratory and field conditions (Mori, 1979). In general, the life cycle duration increased rapidly with decrease in food supply and decreased rapidly with increase in food supply. At 0.035mg/larva/ml., the mean life cycle duration was 6.1 days while at 0.004mg/larvae/ml., development from egg hatching to adult was 32.4 days (Chan, K.L., 1971).

Life table studies under field conditions in Singapore city showed that generation survival of *Ae. albopictus* from egg to adult appeared to be 10.7% with a total mortality of 89.3% (Chan, K.L., 1971). Gubler (1971) while studying the population dynamics of *Ae. albopictus* in nature observed that the highest mortality occurs in the egg stage. Generation survival decreased during the early months of the year but reaches a peak of 21.7% to 29.8% during the rainy season in the months of May and June. The studies were conducted in Calcutta-India.

As stated before, several variables besides temperature intervene in the life cycle of any mosquito species such as food, photoperiod, relative humidity, etc. Thus, significant information on each developmental stage will be summarized.

Eggs

Like all *Aedes* subgenus *Stegomyia* species, *Ae. albopictus* females lay their eggs singly. Each egg is attached at the water's edge in the meniscus or wet zone just above the surface. Amerasinghe and Alagoda (1984) observed that female *Ae. albopictus* follow a set pattern when they oviposit on bamboo traps. About 75% of their eggs are deposited within 16mm. of the water surface and vertically and obliquely, leaving wide spacing between singly laid eggs. Oviposition extends up to 53mm. above water level.

It is known that mosquito eggs are not fertilized until a moment before they are actually laid. Sperm stored in the spermathecae enter each fully developed egg (oocyte) as it passes the openings of the spermathecal duct on its way out. Once the eggs have been laid, development of the embryos proceeds. The actual period of embryonic development will depend mainly on temperature and relative humidity. The number of Ae. albopictus eggs surviving low humidity appears to depend upon the development stage of the embryos before they are exposed to dry conditions. Gubler (1970) found that the eggs of Ae. albopictus were highly resistant to dry conditions if the eggs were kept in humidity 4 days before they were exposed to drought. Hien (1975a) showed also in a laboratory experiment that eggs kept on wet cotton wool for four days and exposed after that to 25-26^{o} and 60-70% of relatively humidity were highly resistant to dryness. Under these conditions of exposure, the eggs with conditioned embryos produced 94.7% hatched larvae after 2 months.

The hatching percentage decreased to 24% after 4 months. Thus, the report concluded that the period of anabiosis (resting period) lasts about two months in Ae. albopictus and after that a drop in the hatching percentage of larvae follows because of the embryos perish in unfavorable conditions. After three months of desiccation egg mortality increases by 20 to 24 percent (Ho, B.C. et al., 1972; Hien, D.S., 1975a). Eggs may remain unsubmerged and almost entirely dry for comparatively long periods of time without loss of viability. Eggs survive desiccation in a wide variety of indoor and outdoor artificial containers (flower pots, earthenware jars, coconut shells, tree holes and bamboo stumps) and hatch as soon as the containers fill up with water (Feng, 1937).

One other parameter that is important for the eggs of Ae. albopictus is the amount of oxygen dissolved in the water. Low oxygen levels, usually associated with high levels of nutrients in the water, increase hatching (Hien, 1975b; Imai, and Maeda, 1976). As a batch of Ae. albopictus eggs begin to hatch the time between the emergence of the first and last larvae can range from over a few minutes to several dozen days depending mainly on water temperature. It appears that a batch of eggs sometimes undergoes a stragged, initial two-stage process: mass hatching followed by several additional small hatchings (Gubler, 1970; Hien, 1975b).

Egg diapause

In temperate regions of Japan and China, the northernmost points where albopictus occurs in Asia, the species overwinters in the egg state (Ishii, et al., 1954; Wang, K., 1962; Wang, R.L. 1966; Imai and Maeda, 1976; Mori and Wada, 1978; Mori and Wada, 1981). Survival of the northern *Aedes albopictus* depends on all or most of the eggs going into a state of hatching-supression sufficient to outlast winter. This is an inherited property known as diapause. *Ae. albopictus* is considered to show facultative diapause* which is induced by changes mainly of temperature and photoperiod, that occur at one time of the year. This allows the species to survive winter (Mori and Wada, 1981). Wang, K.C. (1962) determined that the eggs of *Aedes albopictus* hibernate for two months and a half in China during winter season, from the middle of December to the end of February. Mori and Wada (1981) stated that diapausing eggs in Nagasaki increase in number in mid September and after October all legs laid are in diapause. The period lasts until March of the next year, extending for about six months. At high temperatures and during long photoperiods *albopictus* lays non-diapausing eggs. With the occurrence of low temperatures and a short photoperiod, the eggs diapause.

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* Diapause. It is considered in this case as a period of spontaneously suspended growth or development of the insect.
Obligatory Diapause.- It is considered the case where only a single generation per year is found. Univoltine species of *Aedes* species present this phenomenon at extreme north and south latitudes.
Facultative Diapause.- It is considered the case of *Ae. albopictus* when multiple generations are possible during the year (multivoltine species). It usually occurs at midnorthern and midsouthern latitudes (aprox. 35 to 65 degrees).

Mori and Wada (1981) demonstrated that the _Ae. albopictus_ pupa and adult are the stages that are sensitive to photoperiod.

Ae. albopictus eggs from tropical areas have not demostrated overwintering capabilities, with tropical _albopictus_ survival seems to depend on erratic rather than delayed hatching. For the populations in the USA, Hawley _et al._ (1987) have demonstrated uniform sensitivity to short-day period. Populations from Houston, New Orleans, Jacksonville, Memphis, Evansville and Indianapolis all had a Critical Photoperiod of about 12.5 hours of light. Day lengths below that CP resulted in 95% (Indianapolis) to 75% (Houston) of eggs that failed to hatch. On the other hand, a strain from Cariacica City, showed no sensitivity to any photoperiod. Hamley _et al._ (1987) interpret these results to mean that all of the strains from USA had a common origin in northern Asia (probably Japan). The introduction from Brazil probably had a different origin (most likely tropical).

Egg freezing

Hawly _et al._ (1987) also found that eggs from north Asia and from the USA were more cold-tolerant than eggs from tropical sites. They subjected eggs to $-10^{o}C$ for 24 hours, a treatment that killed all _Aedes aegypti_ and tropical _Ae. albopictus_; USA strains showed 80-90% hatch. As of mid-February of 1987, eggs placed outdoors in South Bend, Indiana, in mid-October showed 100% survival. There seems little doubt that the species will overwinter in the northern USA (G.B. Craig, personal communication).

Egg Morphology

The eggs of *Ae. albopictus* are mostly cigar-shaped like those of *Ae. aegypti*, and devoid of floats. The egg morphology based on scanning electron microscopy observations is as follows: The egg generally measures 0.5mm in length and 0.15mm in width. It is blunt at the anterior end and more tapering in the posterior region. The ventral margin is more cresentic than the dorsal margin and has a conspicuous micropyllar collar more prominent than that of *aegypti*. The exochorion sculpturing has a dimorphic pattern and is more embossed on the dorsal region (C. Pumpuni C., pers. communication, 1986).

Larvae

Aedes albopictus larvae can develop under natural conditions in water with low turbidity and a wide range of PH, going from 5.2 to 7.6 with an optimal pH of between 6.8 and 7.6 (Ho, B.C. *et al.*, 1972). Water containing amino acids, ammonia of fatty acids, and in general high content of organic nitrogen resulting in high oxidation appears to be the ideal habitat for *Aedes albopictus* (Laird M., 1959). Larvae survive ranges of dissolved oxygen of 3-6 ppm and are able to withstand being submerged for 6-7 hours (Ho B.C., *et al*. 1972).

Adaptability to varied habitats enables the species to breed successfully in a wide variety of water-retaining containers. It also appears that *Ae. albopictus* larvae is even more tolerant to water with high organic content than *Ae. aegypti*, although *Ae. aegypti* now is reported from highly organic water conditions, i.e., tree holes, septic tanks, soak away pits, etc. (Knudsen, B., person. communication, 1986).

Duration and Size and duration of larval development are influenced by temperature, food supply, crowding and sex. Under laboratory conditions, Hien, (1975c) demonstrated that temperature affects the duration of larval development. At 30°C development lasts six days while at 25°C and 20°C, it took nine and 13 days respectively. The same experiment demonstrated that the fourth larval instar period is the longest, and that the effect of temperature is clearly defined for that stage. Food supply has an effect on larval development. Starvation increase the larval development period to an average of 42 days, with a mortality rate of 80%. One of the findings in this experiment was that

Ae. albopictus can successfully fast for extensive periods of time. 35% of 100 specimens emerged from larvae which had not been fed during the first three developmental stages.

Under natural and artificial conditions, high larval density appears to produce high mortality and an increase in larval developmental time. However, when compared with Ae. aegypti, Ae. albopictus was more resistant to the crowding factor (Mori and Wada, 1978; Hien, 1975c). Chang, K.L. (1971) observed under field conditions that mortality was highest in the 4th larval stage (31.1%).

Livingstone and Krishnamoorthy (1982) conducting lab experiments with Ae. albopictus larvae in India, demonstrated that the larval period of females (119-149 hours) was greater than those of males (115-141 hours).

Larvae seasonal prevalence

Larval seasonal prevalence of Ae. albopictus appeared to be closely related to rainfall. Studies in Singapore (Ho, B.C., et al., 1971), Bangladesh (Azzizar, 1980) and Japan (Toma, et al., 1982) have shown that the species is abundant during the rainy season. It is important to point out that since Ae. albopictus range extends from the tropics, to the temperate zone, larval peaks will differ.

In a representative area of the tropics such as Singapore city, *Ae. albopictus* presents 3 well defined larval population peaks; December, April-May, August-September. The population peaks of the larvae precede those of the adults by almost exactly 2 months (Ho, B.C. *et al.*, 1971). In the temperate regions, such as northern Japan, larvae of *Ae. albopictus* occur from late March through mid September, usually with a population peak observed in July or August. Larval mortality occurs in the winter (Makiya, 1973; Mori and Wada, 1978; Mori and Wada 1981).

In Kinaw Island in the Japanese subtropics, there was a high peak of larval population during June-mid July, becoming very low during November through March. Larvae were collected every month of the year (Toma, T., *et al.*, 1982).

Larva morphology

In order to identify *Ae. albopictus* larvae and differentiate them from other *Aedes* species, especially *Aedes aegypti* larvae, microscopic examination is necessary. The most significant differences between *Ae. aegypti* and *Ae. albopictus*, which sometimes share the same habitat are the following: On the mesothorax and metothorax, *Ae. albopictus* has plural hair groups, without long spines as in *Ae. aegypti*. The ventral brush of *Ae. albopictus* has 4 pairs of hairs, whereas *Ae. aegypti*'s has 5 pairs of hairs. *Ae. albopictus* comb scales have a bare apical spine and a row of small spinules basally on each side, while *Ae. aegypti*'s comb scales present several shorter stout subapical spines (Huang, 1972; CDC, 1986). See Figure 1.

Pupae

Under ideal conditions, *Ae. albopictus* pupation requires two days (Surtees, 1966; Sheng, 1951; Hien, 1975c), and like other *Aedes* species, *albopictus* males emerge before females. Livingstone and Krishnamoorthy (1982) showed that the pupal development period was 31-36 hours for males, while females reached the adult stage in 49-52 hours. During the same experiment it was suggested that pupal development of the female requires a minimum darkness period of 24 hours. Hien (1975c) studied the effect of water temperature on pupal development. The results showed that at $30^{o}C$, pupal development lasted two days, at $25^{o}C$ three days and at $20^{o}C$, five days. *Albopictus* pupae survive desiccation for up to two days at $26^{o}C$ and at a relative humidity of 87%. Pupal mortality was about one percent under field conditions (Ho, B.C., *et al.*, 1972). Lack of food in the larval stages produced 50% mortality in the pupal stage, although the time of adult emergence remains the same as under ideal conditions (Hien, 1975b).

LARVAL HABITAT

Ae. albopictus is a container breeder. It breeds in both natural and artificial receptacles. *Ae. albopictus* has been found breeding in natural habitats such as tree holes, bamboo holes and stumps, coconut shells, plant axils (bromeliads), ground pool and rock pools. In artifical habitats has been found in rubber tires, tin cans, drums, earthenware containers, bottles, flower pots, cisterns and buckets. In Singapore its six major breeding habitats during the 1966-1968 period were earthware (16.5%), tin cans (15.9%), ant traps* (12.8%), rubber tires (9.9%), bowls (6.6%) and drums (5.8%). Ant traps were the most common indoor habitat and tin cans were most common outdoors. 49.8% of all breeding occurred indoors (Chan, K.L., 1985).

Ae. albopictus has been found breeding in tree holes in Mauritius, China, Nepal, Bangladesh, East Pakistan, South India, Philippines, Ryuku

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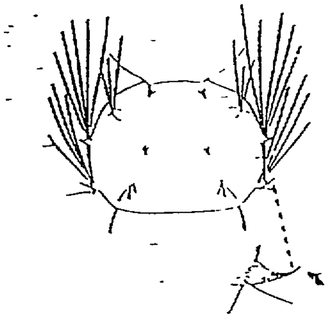
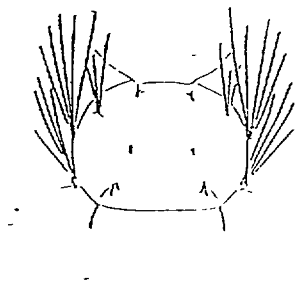
* Small ceramic jars filled with water placed under the legs of meat safes in houses without refrigerators.

Figure 1

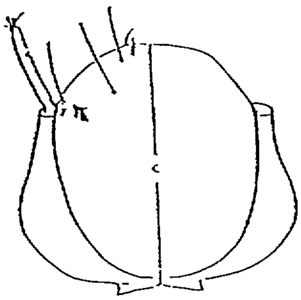
Aedes aegypti	Aedes albopictus



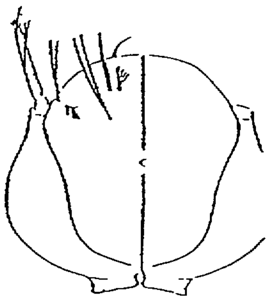
Tubercles mesothoracic and metathoracic pleural hair groups with long spines (see arrow



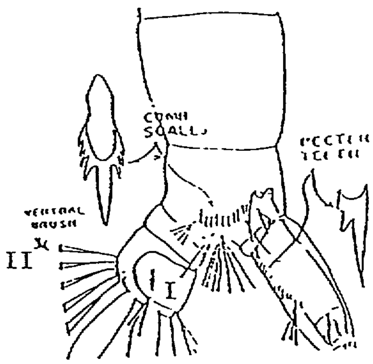
Tubercles of mesothoracic and metathoracic pleural hair groups without long spines



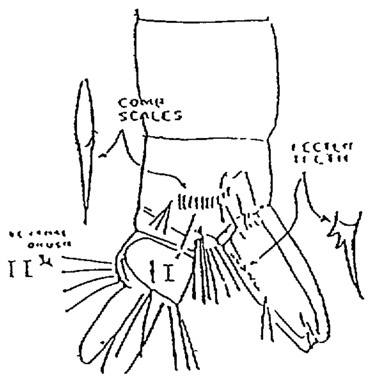
Preantennal head hair 7-C single (see arrow



Preantennal head hair 7-C double (sea arrow,



- Lateral hair 1-X about as long as saddle (arrow I)
- Ventral brush with 5 pairs of hairs (arrow II)
- Comb scales with bare apical spine and several shorter stout subapical spines
- Pecten teeth provided with 1-2 denticles at basal portion



- Lateral hair 1-x longer than arral saddle (arrow I).
- Ventral brush with 4 pairs of hairs (arrow II)
- Comb scales with bare aplical spine and a row of small spinules basally on each side
- Pecten teeth provided with 3-6 denticles at basal portion.

Source: CDC, 1986 Pictorial Key

Islands, Taiwan, Vietnam, Thailand, Malaysia, Korea, and Japan (Ho, B.C., *et al.*, 1972; Huang, Y.M., 1972; Hong, H.K., 1971; Miyagi, I., 1983).

La Casse and Yamaguti (1950) found that bamboo stumps were the most abundant breeding habitats of *Ae. albopictus* (44.8%) in Japan and Korea. *Ae. albopictus* was the most abundant *Aedes* larval specie in natural and artificial containers all through the year.

Other places have reported *albopictus* breeding in bamboo stumps, coconut shells and leaf axils, as seen from the Philippines, Thailand, Malaysia, Bangladesh, Guam (Huang, 1972; Harrison, 1972; Azzizar, 1980; Rozeboom and Bridges, 1971). *Albopictus* has also been found in rock holes and occasionally in ground pools, concrete blocks, cement drains, siphon tubes (Huang, 1972; Rozeboom and Bridges, 1972; Ho, B.C., *et al.*, 1972). Kurihara (1984) conducted a 10 year survey of the mosquitoes breeding in plant axils in some countries of tropical Asia. He determined that breeding preferences of *Ae. albopictus* for leaf axils of banana was well extended in Philippines, Malaysia, Sri Lanka and Indonesia. Taro (*Colocasia esculenta*) axils supported *albopictus* larvae in Sri Lanka, Malaysia and Indonesia. In Pandanus (tropical tree of Southeast Asia) leaf axils, *albopictus* was found just in the Philippines and Indonesia. It was not found in banana axils around Bangkok.

It has already been discussed that Aedes albopictus breeds extensively in artificial containers around Singapore and it appears very well adapted to urban environments elsewhere. La Casse and Yamaguti (1950) and Miyagi (1983) reported in Japan and Korea that it is the most common species found in artificial containers. The types of artificial containers are mainly bowls, earthenware, flower pots, glass and tin containers, and rubber tires. In urban areas of Malaysia, ant traps and earthenware jars are the preferred outdoor habitats. Earthenware containers are also the preferred habitats in Dacca City (Ho, B.C., et al., 1972; Azzizar, 1980). In Guam, tires, bowls, tins, pots, and barrels are the preferred artificial breeding habitats (Rozeboom and Bridges, 1971).

Aedes albopictus utilizes the same kind of artificial water containers that are the principal sources of Ae. aegypti. Thus, Ae. albopictus and aegypti may be often found breeding together. Reports from several studies establish that Ae. albopictus and aegypti share the same habitat (Gilotra, et al., 1967; Chan, K.L., et al., 1971; Ho, B.C., et al., 1972; Azzizar, 1980). As a result of this circumstantial association it has been hypothesized that in some parts of southeast Asia Ae. aegypti has replaced completely the indigenous albopictus from urban areas (Pant, et al., 1973). This has been supported by studies showing the better ability to compete by Aedes aegypti against albopictus (Moore and Fisher, 1969). Gilotra, et al., (1967) in studies carried out in Calcutta suggested that the two species were exhibiting the effect of competitive displacement, with Ae. aegypti being favored in urban premises and Ae. albopictus in the outdoor environment of suburban and rural areas, while in small urban gardens there was an state of equilibrium where both species existed together in equal numbers. Ho, B.C., et al., 1972, explained the relative dominance of Ae. aegypti over albopictus in urban areas of Singapore was due to factors such as urbanization, higher fecundity and shorter duration of the life cycle of Ae. aegypti Likewise, Ae. albopictus has been reported to displace Ae. guamensis from some areas of Guam and the Mariana Islands. Ae. guamensis is indigenous to Guam but Ae. albopictus is known to have been introduced in 1944. One study hypothesized that (in part due to competition) population density of Ae. guamensis decreased by as much as 95% in artificial containers and by 30% in natural habitats while that of Ae. albopictus increased (Rozeboom and Bridges, 1972).

Association of Ae. albopictus with Aedes malayensis was found in Singapore, Malaya, Thailand and Taiwan (Huang, 1972). Albopictus co-occurs with Aedes flavopictus, pseudoalbopictus, japoniensis and togoi in Thailand, Malaya, Burma, Japan and Korea (La Casse and Yamaguti, 1950; Hong, H., et al., 1975; Harrison, et al., 1972; Huang, 1972). La Casse (1950) also reported in Japan and Korea on the breeding of Ae. albopictus with Tripteroides bambusa and Uranotaenia bimaculata in tree holes.

Laird (1959) during an 18-month observation period, in several areas of Singapore city described some of the characteristics of the larval microhabitat of *Ae. albopictus* where *albopictus* larvae had an optimum development. In relation to water characteristics of flora and fauna, the larval habitat was classified as and mesosaprobic. mesaprobic waters supported a rich and diverse flora and fauna consisting of several species of diatoms, desmids, microcrustaceans, phytoflagellates (Euglenidae), ciliates and many different rotifers, cyclopids, ostracods and decapods. All of the above provided ideal conditions for *Ae. albopictus* to develop, because of the abundance of food opportunities and relatively low concentration of deleterious substances. The mesosaprobic was less suited for *albopictus* development, however, substantial densities of *albopictus* larvae were

found. The water showed free living green algae, blue-green algae (Oscillatoria), Flagelates, phytoflagellates (*Euglena*), *Paramecium*, vorticellas and some rotifers. The crustacean fauna was abundant in cyclopids and cladocerans.

Larval pathogens and predators

Several pathogens and predators of *Ae. albopictus* larvae have been described in the literature.

The Fungus Coelomomyces stegomyiae, was found on several larvae in Singapore. The second instar larvae showed the heaviest infection in the head capsule, thorax and anal papillae (Laird, 1957). The protozoan Lankesteria culicis (= Ascogregarına taiwanensis Lien + Levine, 1980)developed trophozoites in cell lining of the larval esophagus (Huang, 1972).

Laird (1957) also found a variety of pathogens such as the ciliate, Tetrahymena pyriformis, the alga, Oscillatoria brevis, the bacterium, Sphaerotilus dichotomus and the ciliate, Epistylis lacustris.

Marten (1984) has observed a copepod predator, Mesocyclops leuckarti pilosa which feeds upon first instar larvae of Ae. albopictus and is capable of eliminating them entirely. Finally, another predator that has been found successfully breeding with Ae. albopictus larvae is Toxorynchites splendens (Surtees, 1966).

ADULT BIOLOGY

Longevity

Physical factors of the environment stimulate responses which greatly modify the behaviour and biology of the adult mosquito. Among those, temperature and relative humidity play a vital role in adult survival. Gao, et al., (1984) reported that during an 8-year observation period conducted on caged Ae. albopictus, (at temperature conditions of $25 \pm 1^{o}C$ and a relative humidity of $80 \pm 5\%$), the maximum longevity of the female adults was 30-40 days. It was determined in the same study that the upper thermal death point was located at $40^{o}C$ (Lt_{50}=0.9h) and the lower death point was $-5^{o}C$ (LT_{50}=0.85 hour).

Hylton (1969) showed that longevity of the adult Ae. albopictus female reached about 84 days at a temperature of $22.2^{o}C$ and relative humidity of 80%. Ae. albopictus was tolerant of low temperatures (15.5) and high and low humidities, whereas, high temperature ($32.2^{o}C$) decreased survival independent of the range of relative humidity. It appears that the ability of Ae. albopictus to survive a range of temperatures and humidity may have favored its distribution in different climatic conditions ranging from temperate to tropical ecosystems. It has been suggested that the mechanism by which albopictus conserves body fluids at low humidities preventing tissue desiccation is through spiracular control or other moisture regulating mechanisms (Hylton, 1967).

Longevity in the laboratory is also affected by feeding. Gubler and Bhattacharya (1971) maintained mosquitoes at $26^{o}C$ temperature and 50-60% relative humidity and demonstrated that albopictus females when blood nourished lived an average of 38 days and 112 days. A maximum of 117 days has been found by Hien (1976b).

By contrast, when mosquitoes where barely fed with water, at temperatures of 25-26°C and 60-70% relative humidity, mortality began after three days. The majority of starving albopictus lived not longer than 5-7 days (Hien, 1976b). Under natural conditions a female would normally find a suitable host before the lapse of this time interval.

In nature, the longevity of *Aedes albopictus* is shorter than the one shown under laboratory conditions. In Singapore the oldest females collected in houses and human baits had undergone three gonotrophic cycles suggesting a period no greater than 11 days, while in Calcutta dissection of wild females showed only once or twice ovipositions indicating even a shorter life time than in Singapore (Ho, B. C., *et al.*, 1972; Gubler and Bhattacharya, 1971). Daily survival proportion of adult females in the field has been calculated to be 0.77-0.81 (Chai, K.L., 1971).

Mating behaviour

Natural mating behaviour of *Ae. albopictus* was reported in a Calcutta experiment (Gubler and Bhattacharya, 1972). It was found that male albopictus swarmed around the feet and ankles of a human observer. Female albopictus arrived later and were mated as they approached the host to feed. Mating took place in flight, and usually occurred within 1 to 3 feet of the ground. Most of the mating lasted from 5 to 15 seconds. A majority of the copulating females captured were nulliparous and most were inseminated in the vicinity of the host. The same study reported swarming behaviour of males also at the bases of trees and over cane baskets with some copulation and insemination of females. It has been reported that one copulation is sufficient for the fertilization of one batch of eggs and that females are not inseminated unless they are 30 to 36 hours old (Ho, B.C., et al., 1972).

Oviposition behaviour

Under laboratory conditions Del Rosario (1963) found that the first blood meal was taken 2 days after emergence and the gonotrophic cycle was found to last 3 to 4 days before oviposition at a temperature of 24-29^{o}C and 80-93% relative humidity. Gubler and Bhattacharya (1971) observed also that the first blood meal of Ae. albopictus females took place two days after emergence with a gonothropic cycle lasting 3-5 days after a blood meal and at temperatures of 25-26^{o}C and relative humidity of 50-60%. Hien, D.S. (1976a) demonstrated in the laboratory that although the majority of Ae. albopictus females took their first blood meal on the second or third day of emergence, a small percentage (11%) took meals in the first day of emergence. The same study showed that the gonotrophic cycle after a blood meal lasted 3 to 3.5 days at temperatures of 25-26^{o}C and relative humidity of 60-70%. Under natural conditions Mori and Wada (1977) demonstrated that with an average field temperature of 25^{o}C the period from emergence to the first blood meal of Ae. albopictus was about 2 days and the duration of one gonotropic cycle was 5 days. The results were completely in agreement with laboratory experiments.

During the blood feeding process of the Ae. albopictus females, Hien (1976a) observed that the mosquitoes were ready to take blood meals several times during a single gonotrophic cycle on the second and third day after the first meal. Gubler and Bhattacharya (1971) also observed that Ae. albopictus females took blood for a second time in a single gonotrophic cycle. According to Hien (1976a), this behaviour deserves further study since interrupted meals of mosquitoes are often the cause of mechanical transmission of infectious diseases.

The duration of the gonotrophic cycle is determined by dissection of females (Detinova, 1962). Shrinking ovarioles indicate the end of each gonotrophic cycle. Using this methodology Mori and Wada (1977) determined that albopictus females are ready to feed again within 24 hours after oviposition.

The number of eggs laid by a female *albopictus* depends on the physiological age of the mosquito, the body weight after emergence and particularly on the size of the blood meal (Hien, D.S., 1976b). On the average, *Ae. albopictus* females lay eggs after a blood meal of at least 0.7mg. For females taking from 0.8mg to 2.5mg of blood, the average number of eggs in the first gonotrophic cycle was 72/female (Hien, D.S., 1976b). The study also demonstrated that the number of produced eggs increased with the size of the blood meal taken by the female (about 85 eggs and above at 2.0mg of blood). Gubler and Bhattacharya (1971) found that the mean number of eggs in the first gonotrophic cycle was 63.4 eggs/female. Similar results were obtained in two separate studies. Udaka (1959) reported 62 eggs per female feeding on sugar and blood. Soekiman, *et al.*, (1984) observed an average of 57.5 eggs average per female after a single blood feeding.

The number of eggs laid also depends on the physiological age of the female, showing progressive decrease with increasing age (Gubler and Bhattacharya, 1971; Hien, D.S., 1976b). Generally speaking, it appears that the first gonotrophic cycle produces the highest number of eggs with a gradual decrease in the subsequent cycles. On the average, *Ae. albopictus* females were found to produce 283-344 eggs/mosquito during their life cycle in the laboratory (Gubler and Bhattacharya, 1971; Hien, D.S., 1976).

Autogeny has been observed in laboratory strains of Ae. albopictus (Bat-Miriam and Craig, 1966; Cui, K.L., 1982). Autogeny in this case is defined as egg maturation without an exogenous source of protein, i.e., the blood meal. With strains from Mauritus and Madagascar, Bat Miriam and Craig (1966), demonstrated that adults fed only with sugar and raisins produced a few eggs. The strain from Mauritus was able to present autogeny for 12 generations. Cui, K.L. (1982) observed that larvae collected in Guangzhou city and reared in the laboratory displayed autogeny, i.e. new emerging females laid eggs without a blood meal. The autogeny index reported in the Guangzhou strain varied from 1.96 to 2.96, while in the Mauritus strains it was 2.7 eggs/female.

In relation to oviposition activity and horizontal and vertical ecological stratification, Gubler (1971) determined that in a series of 18 ovitrap collections most of the eggs collected were recovered at ground level but some were deposited at a height of 15 meters, in the top of trees in Calcutta India. In Peradeniya, Sri Lanka, Armerashinge and Alagoda (1984) made similar observations. Albopictus females laid about 52% of their eggs at ground level. There was also a decrease in oviposition with increasing height above ground. At 3.5 meters 33% of the eggs were laid and at 7 meters just 16% of the total amount of eggs were obtained. The results suggest that Ae. albopictus females, although prefering horizontal range stratification for oviposition, are able to migrate and oviposit in the tree tops.

Oviposition sites are affected by habitat type, light, temperature and humidity as well as subtle influences such as characteristicas of the water (biotic and abiotic) and even oviposition surface (Bently, et al., 1976; Amerashinghe and Alagoda, 1984). Ho, B. C., et al., (1972) reported that female albopictus preferred to oviposit, under laboratory conditions, in habitats with a grey rough surface and low reflectiveness rather than in habitats with a smooth black surface and high reflectiveness. Yap (1975) observed that ovitraps coated with red and black colors were the preferred oviposition sites among other ovitraps with different colors. In their natural habitat, albopictus usually lay eggs in water reservoirs in which the process of decaying of vegetable matter takes place (Hien, D.S., 1976b). The quality of larval food appears to affect the oviposition capacity of the adult. This was observed in albopictus females reared with banana powder in the larval stage, showing that egg laying was particularly weak except at constant temperature (Ho, B.C., et al., 1972).

In nature, albopictus females seldom laid all of their mature eggs in a single oviposition. Instead, they appeared to move from place to place leaving behind each time a few eggs. The female probably lays all immature eggs during the course of several ovipositions, each of which she interrupts to fly to other containers. This is considered a species survival mechanism (Rozeboom, L., et al., 1973).

Host preference

Aedes albopictus females feed on a wide range of mammals as well as birds. However, albopictus prefers to feed on man (Ho, B.C., et al., 1972). In Thailand and the Hawaiian islands, Ae. albopictus females collected in a sylvan environment fed on man, horses, pigs, buffalo, bovine species, dogs, chickens, and boobies (Tempelis, et al., 1970; Sullivan, et al., 1971). In the Hawaiian islands, 93% of the females fed on mammals and 7% on birds. Under laboratory conditions, albopictus feeds on man, rabbits, mice, chickens, rats, and guinea pigs (Del Rosario, 1963; Ho, B.C., et al., 1972; Mori and Wada, 1981). Some authors have also reported that albopictus females in breeding cages fed on snakes and frogs (Miyagi I., 1972).

Biting behaviour

On the average, Ae. albopictus females take their first blood meal two days after emergence (Del Rosario, 1963; Hien, D.S., 1976b). Adult females are vigorous daytime biters (although they have been found sometimes biting at night) and, typically, outdoors (Feng, 1938; Sheng T., 1951; Surtees, 1966; Ho, B.C., et al., 1972; Pant, et al., 1973). The diurnal biting cycle of Ae. albopictus appears to be generally bimodal with one period in early morning and the other in the late evening (Gubler, D., 1971; Ho, B.C., _et al._, 1973; Basio and Santos-Basio, 1974). In Calcutta, Gubler (1971) observed that diurnal activity of _Ae. albopictus_ females presented a maximum peak between 6-8 hours in the morning and a minimum peak between 16-18 hours in the afternoon. In Singapore, well-defined biting activity of female _albopictus_ was shown with a morning peak just after sunrise at 7:30 and an evening peak after sunset from 17:30-18:30 hours. The prominent evening peak may be an important contributing factor to disease transmission since usually in certain tropical areas outdoor human activity increases in late afternoon (Ho, B.C., _et al._, 1973).

In the Philippines, Basio and Santos-Basio (1974) observed a minor biting peak between 9 and 10 hours in the morning and a major peak between 16 and 17 hours. The biting cycle was similar in 4 different geographic areas.

Vertical biting activity of females was observed as high as 9 meters during the peak biting time in Calcutta, although its activity is predominantly at ground level (Gubler, D.S., 1971).

Population studies of _Ae. albopictus_ conducted by Mogi and Yamamura (1981) indicate that the attraction of _Ae. albopictus_ for a human bite depends on several factors such as: sex, age, race, clothes, mosquito responsiveness after circadian rhythm, microclimatic conditions or undetermined individual factors of the host. Thus, females attack man under the guidance of CO_2, moisture, organic chemicals and visual factors including movement. It was determined in the same study that the range of attraction of a man for Ae. albopictus is a circle with a radius of about 4-5m (an area of 50-80m^2). The host seeking pattern of Ae. albopictus appears to follow two phases: an initial random flight, and a directional flight after encountering the stimuli from a host. This is supported by the fact that albopictus distribute vertically within the range where stimuli from man on the ground are effective.

Seasonal abundance of adults varies according to the geographic area. Therefore, seasonal biting activity is influenced mainly by temperature and rainfall. In the tropics, such as in Singapore city, there are 3 population peaks of adults, one in March, a second in June-July and a third in November-December. Thus, female feeding activity peaks during those three dates. These populations peaks closely follow those of rainfall (Ho, B.C., et al., 1971). Toma, et al., (1982) on the subtropical island of Okinawa, found females feeding throughout the year with peaks in feeding activity occurring from April to June and August to November. In temperate areas of Japan, adult peaks occur from late March to mid September. La Casse and Yamaguti (1950) in Honshu, Japan, observed that biting rates of albopictus had their peak during the last two weeks of August.

Flight Range

Bonnet and Worchester (1946) determined during a mark-release-recapture studies with *Ae. albopictus* that the maximum recapture distance was 134 meters. Thus, it is apparent that *albopictus* has a short flight range and rarely reaches up to 500 meters (Stojanovich and Scott, 1965).

Resting Behaviour

Aedes albopictus adults have been found resting outdoors in clearings and rubber plantations in malaria, and in China, the adults appeared in mosquito nets, kitchens, drawing rooms, pig sites or among welds in the field (Surtees, 1966; Ho, B.C., 1972).

Adult morphology

The adults of the genus *Aedes* can be differentiated from other *Culicidae* because their abdomen is pointed. *Ae. albopictus* has a scutum with a prominent median silvery stripe. The main characteristic that distinguishes *Ae. albopictus* from *aegypti* is the conspicuous lyre-shaped silver pattern in the scutum of *aegypti* compared with the distinct lontigudinal silver line of *albopictus*. The CDC pictorial key (fig. 2) and figures 3 and 4 show these differences in more detail for the adult stages of both species together with some other American species.

DISEASE RELATIONSHIP

Ae. albopictus has been shown in the field and in the laboratory to be a suitable species for infection with and transmission of pathogens of medical importance. Among these are filarial worms, avian malarias and several arboviruses. Shroyer (1986) reviews the relationship of this species to arboviruses.

1. Filarial worms

Wild species of *Ae. albopictus* mosquitoes in Sangla-buri, Thailand, have shown the presence of *Dirofilaria* spp. (Harinasuta C., *et al.*, 1970). *Ae. albopictus* is considered an important vector of dog filariasis (heartworm disease) which is caused by Dirofilaria species in Japan (Mori and Wada, 1977). In addition, laboratory experiments have demonstrated that *Ae. albopictus* can be infected with *Dirofilaria immitis* (Galliard and Ngu, 1938; Stojanovich and Scott, 1965).

However, *Ae. albopictus* is *not* a vector of human filariasis due to *Brugia* or *Wuchereria* (Sasz, 1976). The larval worms fail to develop in the thoraxic muscles. Rosen et. al. (1976) justified their release of Ae. albopictus on s small paxific atoll as an attempt to replace a vector of filariasis (*Ae. polynesiensis*) with a non-vector (*Ae. albopictus*). Unfortunately, *Ae. albopictus* failed to persist on the atoll.

PICTORIAL KEY TO MOST AEDES ADULTS
INHABITING NATURAL AND ARTIFICIAL CONTAINERS IN THE U.S. (INCLUDING PUERTO RICO)

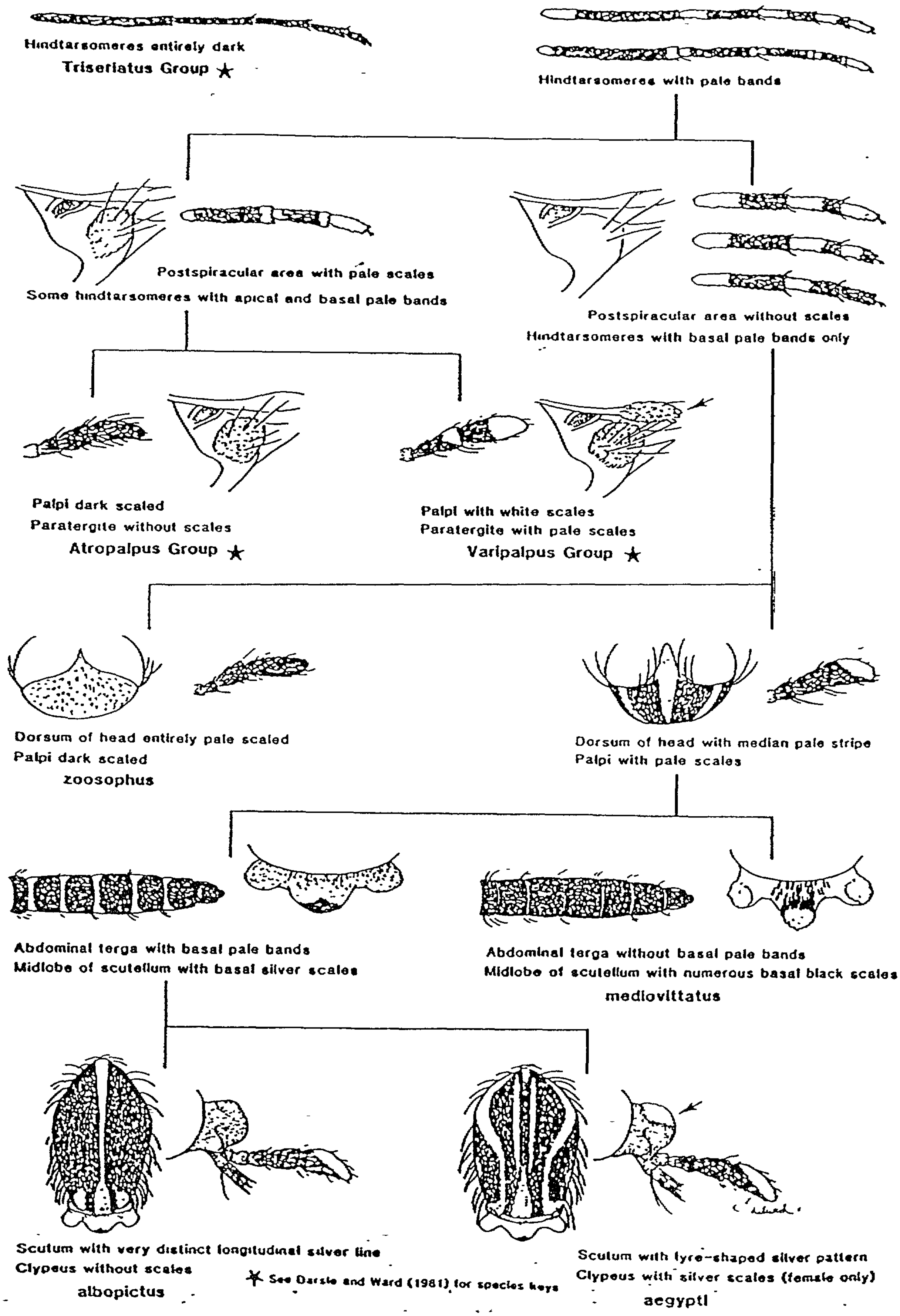


FIGURE 3 Aedes albopictus specimen at right, shows the distinnct longitudinal silver line on the scutum. At left one Aedes aegypti shows its conspicuous lyre-shaped silver pattern.

(Mosquito pictures under processing)

(Mosquito pictures under processing)

FIGURE 4. Aedes albopictus male and female specimens showing their longitudinal silver line on the scutum.

2. Avian Malarias

Experimentally, avian malarias have been transmitted by *Ae. albopictus*. Laird (1941) infected lots of *Ae. albopictus* with *Plasmodium lophurae* by letting them feed on a heavily infected duck. After that, transmission experiments were carried out on normal ducks produced measurable levels of parasitemia in the mosquito from day 12 on. Russell and Menon (1942), working with *Plasmodium gallinaceum*, demonstrated that *Ae. albopictus* females feeding on infected fowls developed sporozoites in the salivary glands and gut after 15 days. Transmission of *Plasmodium gallinaceum* to normal fowls, according to the authors, was very easily accomplished.

Medically speaking, *Ae. albopictus* stands out for its potential to transmit many arthropod-borne viral diseases (arbovirus) to humans. A description of some of the most important arboviral diseases and their potential relationship to *Ae. albopictus* is summarized below:

3. Dengue

Dengue viruses consist of an antigenic subgroup of four closely related but antigenically distinct virus designated dengue 1, 2, 3 and 4, which belong to the genus *Flavivirus*, family Flaviviridae (Westaway, *et al.*, 1985).

All serotypes produce dengue fever which is an acute, often incapacitating, but self-limited febrile illness characterized by headache, myalgia, arthralgia and rash. Epidemics of the disease annually affect hundreds of thousands of people in tropical areas of the world. Dengue hemorrhagic fever, dengue shock syndrome is considered a severe childhood disease though it can affect adults as well. It is caused by the same flavivirus as dengue fever with a case-fatality rate of 5% to 10% and appears to have immunopathologic basic (Monath, 1986). Dengue hemorrhagic fever is a major cause of morbidity and mortality among children in many countries of southeast Asia and recently in the Americas (Guzman, et al., 1984, Monath, 1986).

Ability to transmit dengue by Ae. albopictus was first shown in studies involving human volunteers as far as 1930 (Simmons and Reynolds, 1931). More recently, Ae. albopictus has been shown to transmit all four dengue virus horizontally and vertically (transovarially). Rosen, et al., (1983) demonstrated that Ae. albopictus was able to transmit transovarially all four dengue serotypes. Quantitative experiments reported also by Rosen (1985) determined than Ae. albopictus was much more susceptible to oral infection with all four dengue serotypes that Ae. aegypti. Evidence of naturally-infected Ae. albopictus was demonstrated by Rudnick and Chan (1965).

Moreover studies have found Ae. albopictus associated with epidemics of dengue fever over the years (Chan, Y.C., et al., 1971). Ae. albopictus which has been incriminated as a vector of dengue in Asia, when it often overlaps in distribution with Ae. aegypti. Both species are known to be vectors of dengue viruses. Thus, it is often difficult to determine their relative contribution to disease transmission. However, during massive epidemic of dengue in the Scychelles Islands and in Guandong China in which Ae. aegypti was absent, the principal role of Ae. albopictus has been determined (Metselaar, et al., 1980; Qiu, et al., 1981). Thus, experimental and natural association of the four dengue virus with Ae. albopictus has been documented in several occasions.

4. Japanese Encephalitis

Japanese Encephalitis virus is another member of the genus Flavivirus, family Flaviviridae, which belong to the West Nile antigenic complex. Monath (1985) in a complete account of the disease describes it as being the most important of the arbovirus encephalitides in terms of morbidity and mortality. Epidemics of Japanese encephalitis recur in temperate areas of Asia and in northern part of tropical southeast Asia. Illness may be manifested by a febrile headache syndrome, aseptic meningitis or encephalitis. When neurological disorders appear they are usually accompanied by fever, chills, anorexia, nausea and vomiting, dizziness and drowziness. Case fatality rates during epidemics range from 20 to 50%, but the high rates reflect recognition of only the most severe cases.

In the laboratory, Ae. albopictus has been found to be susceptible to experimental infection to Japanese Encephalitis virus. Rosen and Lien, 1978 have demonstrated that Ae. albopictus was able to transmit the virus transovarially. Female Ae. albopictus mosquitoes infected with Japanese encephalitis virus either by intrathoraxic inoculation or by ingestion of a virus sucrose-erythrocyte mixture transmitted the virus to a small percentage of their F_1 progeny. At least five F_1 females Ae. albopictus adults transmitted Japanese Encephalitis virus to chicks by feeding on them.

Huang (1982) reported that seven strains of encephalitis virus were isolated from field collected Ae. albopictus larvae obtained from Fukien, China.

5. Yellow Fever

Yellow fever virus is an arthropod-borne virus belonging to the flavivirus group. The viral disease is endemic in tropical regions of America and Africa. The disease may range from a very mild clinical form to a malignant one. Depending on the severity, the signs and symptoms of the disease usually are fever, headache, nausea, epistaxis, albuminuria, body pain and in severe cases, oliguria, black vomitus, melaena and even uterine haemorrhage (WHO, 1985).

Dinger, et al. (1929) reported that *Ae. albopictus* females were infected orally with yellow fever virus and able to transmit the agent to monkeys in laboratory controlled experiments.

Monath (1986) has suggested that, considering *Ae. albopictus* ecological adaptability, the species could bridge the gap between the transmission cycles of jungle and urban yellow fever potentially favoring the spread in villages and towns, particularly in endemic areas of South America. *Ae. albopictus* could fill an ecological niche analogous to *Ae. simpsoni*, a major bridging and epidemic vector of yellow fever in East Africa.

6. Chikungunya

Chikungunya virus belongs to the family Togaviridae, genus *Alphavirus* which causes a dengue-like disease in man. The disease has an abrupt onset, with high fever, myalgia and sudden intense pains in one or more joints (Shope, 1985). The disease is known in several countries of

Africa and Asia. Outbreaks of Chikungunya fever have been recognized in Angola, Congo, Zimbabwe, Senegal, Nigeria, Thailand, India, Malaysia, Cambodia and Philippines (International Catalog of Arboviruses, 1985), during which tens of thousands persons were infected.

Ae. albopictus adults are highly susceptible to infection with chikungunya virus in laboratory experiments and also capable of transmitting the virus by bite (Mangiafico, 1971; Yamanishi, *et al.*, 1983). High infection and transmission rates for *Ae. albopictus* (100% and 69%, respectively) readily testify to the importance of this mosquito as a potential vector of Chikungunya (Mangiafico, 1971). The virus has not been recovered from wild specimens of *Ae. albopictus*.

7. California Serogroup viruses

La Crosse and San Angelo virus are classified in the genus *Bunyavirus* of the family Bunyaviridae which belong to the California Serogroup viruses. Isolation of La Crosse viruses has been reported only from U.S.A. La Crosse virus causes a form of encephalitis affecting children in the north central U.S.A., including Minnesota, Wisconsin, Illinois, Indiana, Ohio and New York. San Angelo virus is known from Texas, Arizona, New Mexico and Colorado and apparently known just as a zoonoses. La Crosse virus infection may be manifested as a high febrile illness or by generalized convulsions with high fever. Vomiting focal seizures, paralyses, abnormal reflexes and mental manifestations are common (Shope, 1985), with neurological sequellae prevailing for years after acute illness.

Transovarial transmission of La Crosse and San Angelo viruses has been demonstrated in Ae. albopictus species (Tesh, 1980). In the case of San Angelo virus, the species has been very efficiently infected orally and parenterally and transovarial transmission has been monitored for up to 38 consecutive generations (Tesh and Shroyer, 1980; Shroyer, 1986).

In addition, Ae. albopictus from Houston, Texas has been found capable of oral transmission of La Crosse virus to suckling mice at a rate of 40-50% on days 14 and 21 following an infective blood meal (De Foliart, et al., 1986).

8. Other arboviral diseases

Under laboratory experimental conditions several other arboviruses have shown their ability to infect Ae. albopictus. Furthermore, Ae. albopictus females were able to transmit them by bite after infection. Among these are: Orungo virus (Tomori and Aitken, 1978), Western equine encephalomyelitis (Simmons, et al., 1936), Ross River (Kay, et al., 1982) and West Nile (Akhter, et al., 1982).

Vertical transovarial transmission in *Ae. albopictus* has also been demonstrated with the flaviviruses Banzi, Bussuguara, Ilheus, Kokobera, Kunjin, Keystone, and Uganda -S (Tesh, *et al.*, 1979; Tesh, 1980). Also, transovarial transmission has been observed in *Ae. albopictus* eggs with St. Louis encephalitis (Rosen, *et al.*, 1978; Hardy, *et al.*, 1980).

Some arboviruses have been able to replicate in *Ae. albopictus* specimens following inthratoraxic inoculation. However, there is no information on whether *Ae. albopictus* can be orally infected with these arboviruses and subsequently transmit them by bite. The list of these viruses includes the Phleboviruses Arumowot, Bujaru, Chilibre, Icoaraci, Itaporanga, Karimabad (Tesh, 1975) and the rhabdoviruses Chandipura, Gray Lodge, Joinjakaka, Piry, Sigma and Vesicular stomatitis (Rosen, 1980).

AEDES ALBOPICTUS IN THE AMERICAS AND THE PROBLEM OF CONTROL

Mode of dissemination and origin

Since the discovery of *Ae. albopictus* in twelve states of the USA and eighty nine municipalities in Brazil (Moore, pers. comm., Sept. 1986; SUCAM, October 1986) questions of how the mosquito was introduced in the first place and by what means it can spread to new areas have arisen.

There is compelling evidence that used tires in containers imported from Asia and containing larvae and ova of Ae. albopictus are responsible for its introduction in the USA (Monath, 1986). After the Houston experience, where tires were found to be the main breeding source of Ae. albopictus (Sprenger and Wuithiranyagool, 1986), surveys carried out in other states have focused on tire yards. all positive countries thus far have reported albopictus breeding in tires, in addition to artificial and natural water-filled containers. During 1986, many areas in Louisiana showed that Ae. albopictus had spread from tire piles into tree holes; in the vicinity of Baton Rouge, they spread through forested areas at a rate of about 100 yards per week (L. Meek, personal communication. In Indianapolis, they spread quickly from tireyards to domestic container 1/2 mile away (M.J. Siasko, personal communication).

Brazil's infestation appears to be linked to the international sea port of Vitoria in the State of Espirito Santo (Anonymus PAHO, 1986b). As a matter of speculation, there is information that importation of ornamental plants from Southeast Asia takes place through the port. Leaf axils of the plants potentially can hold ova of Ae. albopictus and could have passed easily undetected (Lŏpez Antuñano, personnal comm., 1986). In addition, importation of used tires from USA takes place regularly, thus, it is possible that a secondary dispersion of Ae. albopictus may have been responsible for its introduction in Brazil (U.S. Depart. Comm.

and Jap. Tariff Assoc., 1985). It appears that USA's and Brazil's infestation are a classical example in which increased travel and commerce between countries have contributed to the proliferation of a non-native species. However, the data of Hanley et. al. (1987) on diapause and photoperiod sensitivity indicate that the Brasil and USA infestastions have a different origin.

Recent studies in two of the North American strains of Ae. albopictus one from New Orleans and the other from Houston, have shown overwintering ability in both populations. Both strains exhibit photoperiod sensitivity and cold-hardiness characteristics similar to strains originating in temperate Asia (Nagasaki, Tokio, Korea and Beijing) (Hanley et. al. 1987). The cold-adapted strains of Ae. albopictus can affect the extent of the northern expansion of the species in the USA, increasing greatly its potential public health threat.

Studies carried out to determine differentiation among mosquitoes collected at several sites in the same city and among populations from different cities, showed relatively high levels of genetic variation in the Houston and New Orleans populations. The results suggested large and independent introductions of Aedes to both cities and support the idea that the Houston and New Orleans populations (Black et. al. 1987) were the first sites of introduction in the United States. Populations in two other cities (Memphis and Jacksonville) may have been established by a few migrants from either Houston or New Orleans, Rai (1986) reviews studies on the genetic of Ae. albpictus.

In general, it is believed that populations that are highly variable, i.e. genetically plastic, are more able to avoid control measures and to develop resistance. Some partial resistance to organophosphates, specifically malathion, has arisen in the New Orleans population (Anderson M., N.O. mosquito control district, personal comm., 1986).

There is a considerable amount of current research to determine the geographical origin of the strain or strains of Ae. albopictus in the American continent. The information obtained will help to better predict the probable spread of the species and the chances of success of control efforts. Also, by identifying the origin of the populations, introductions can be curtailed. Maps two and three show the geographical distribution of the infestations in the USA and Brazil. Clearly, introduction of Ae. albopictus to other countries of the Americas appears to be imminent or has already occurred due to factors such as rapid expansion of commerce and traffic by land, air and sea. In addition, the lack of adequate entomological surveillance and vector control activities in the majority of the countries of the American continent contribute to the spread

Control

The control or eradication of *Aedes albopictus* is more difficult than that of *Ae. aegypti* because *Ae. albopictus* is found further from human habitation and in a greater diversity of habitats. Population suppression may be economic only close to human communities. Very few studies or evaluations have been made of the control of *Ae. albopictus*. This species has rarely, if ever, been the primary target of a control program. Most often it has been secondary to *Ae. aegypti*. The most extensive control program of *Ae. aegypti* and *Ae. albopictus* has been carried out since 1968 in Singapore. This is an integrated program, including environmental management, health education, legal measures, and community participation. Chemical control is reserved only for outbreaks of dengue hemorrhagic fever (WHO, 1986).

Chemical control

It would appear that house-to-house control, directed specifically at *Ae. aegypti*, is less effective for *Ae. albopictus* which requires coverage of larger areas including the forest. On an island in the Gulf of Thailand, temephos applications and malathion fogging gave effective suppression of the *Ae. aegypti* population, but did not reduce significantly the *Ae. albopictus* population (Gould, *et al.*, 1970).

In 1955, Dowling reported control of Ae. albopictus with 15% dieldrin applied at 0.802 per acre (88 ml per ha) with a SwingFog (R) portable thermal fog generator. With one treatment of an entire 11.5 square kilometer island near Singapore, good control was achieved for 10 days, but the population built up rapidly in numbers during the third week. With two treatments separated by an interval of one week, more prolonged control was achieved, still with 92% reduction up to 8 weeks.

In Singapore, chemical control is used only during oubreaks of dengue haemorrhagic fever. During an epidemic in 1973, special attention was given to 400 construction sites where vector breeding and harborages were profuse. All of the construction sites were fogged with biomesmethrin, mixed with equal parts of piperonyl butoxide synergist, to kill adult mosquitos, and the containers were treated with 1% temephos sand granules or 1% malathion emulsion to kill the immature stages. However, DHF cases continued, and it was then found that the dominant species at these sites was Ae. albopictus. When large-scale fogging of premises in high endemic areas was implemented, a significant drop in the DHF incidence occurred (WHO, 1986).

In Louisiana, ULV applications of the synthetic pyrethroid bioresmethrin gave 60% reduction of an adult Ae. albopictus population lasting for about 3 days (Anderson, N. O. Mosq. Control District, personal communication, 1986).

Brown (1986) reports that Ae. albopictus is resistant to the organochlorines DDT, dieldrin and HCH in India, Malaysia, Southeast Asia, the Philippines and Japan and resistant to the organophosphate malathion in Singapore and Vietnam, fenthion in Malaysia and fenitrothion in Madagascar. Preliminary data from Louisiana show partial resistance to malathion (Anderson, ibid.).

Biological control

There have been almost no field trials with predators, parasites or pathogens of Ae. albopictus. Reports have been limited mostly to findings of field infections and species associations.

The predatory mosquito larva Toxorhynchites splendens was found to be frequently associated with Ae. albopictus in Singapore, and Chan (1968) concluded that "... T. splendens can probably be most effectively utilized for the control of Aedes albopictus in rural areas...". On the other hand, Newkirk (1947) believed that T. splendens would occupy a minor role in the elimination of mosquitos: "Its long life and few offspring, when compared to Aedes albopictus... and its low survival rate tend to nullify the importance of (T.) splendens in biological control". An attempt to reduce the breeding of Ae. albopictus by introducing small numbers of T. inornatus in Hawaii in the 1920's failed when this predator died out (Gerberg, 1985).

The technology currently being developed for the mass rearing and field trials of *T. brevipalpis* and *T. rutilus rutilus* for the control of *Ae. aegypti* in the Americas (Gerberg, 1985) may be utilized with even better results against *Ae. albopictus*, considering that there is greater overlap of the breeding habitats of these predators with *Ae. albopictus* in natural containers away from houses than with the more domestic breeding sources of *Ae. aegypti*.

In laboratory tests with the parasitic mermithid nematode *Romanomermis culicivorax*, *Ae. albopictus* was rated a "3" on a susceptibility scale of 1 to 5, indicating that the host showed moderate physiological resistance (Finney-Crawley, 1985).

Roberts *et al.* (1983) report two observations of laboratory infection of *Ae. albopictus* with viruses: densonucleosis virus which only retarded growth at low temperatures, 16°C, and *Nodamura* virus, a small RNA virus which infects vertebrates and which caused death in *Ae. albopictus* when innoculated into the thorax of the adult, but little mortality when ingested by adults or when larvae were immersed.

The laboratory susceptibility of *Ae. albopictus* to the bacterium *Bacillus thuringiensis* var. *israelensis* was found to be lower than *Ae. aegypti* from Enugu, Nigeria and Djakartu, Indonesia, but higher than *Ae.*

aegypti from Bora Bora (de Barjac and Coz, 1979). In Thailand, pathogenic gram-positive spore-forming bacilli (Bacillus sp.) were found infecting Ae. albopictus) (Hembree, 1979).

Three species of gregarine protozoans of the genus Ascocystis were found infecting Ae. albopictus in Taiwan (Lien and Levine, 1980). Beier and Craig, Jr. (1985) state "Although many workers have suggested the potential of gregarines as control agents, these parasites appear to be relatively harmless to their natural mosquito hosts".

Various species of the pathogenic fungus Coelomomyces were found parasitizing Ae. albopictus larvae from bamboo stumps and tree holes in Taiwan from 1953 until 1976 (Laird et al., 1980). Two species of this fungus, predominantly C. stegomyiae, were collected parasitizing Ae. albopictus in Singapore and introduced into three atolls of the Tokelan Islands of New Zeland in 1958. Two years later the fungi had reduced significantly the population of Ae. polynesiensis and by 1963 there was a four-fold increase of parasitized larvae (Laird, 1967).

Environmental Control

Environmental management involves the elimination or reduction of vector breeding sources. Commonly known as source reduction, it appears to be the most effective single method of Aedes vector control so far. the basic principles for source reduction consist basically in the elimination of breeding sources in order to disrupt the mosquito immature life cycle. These measures can be implemented by carrying out simple measures such as burying or destroying unwanted water bearing receptables. Measures include particular attention to reducing surface water standing in and around sea ports, bus terminals, train stations, airports, and in small containers such as discarded tires which are favored breeding sites of the Aedes species. Other measures used are upending large containers such as jars, drums and water tanks kept in the open and covering water-holding containers with tight-fitting lids. In the domestic environment people can be encouraged to change water at weekly intervals in containers like water jars, flower vases and ornamental containers, whose inside may be scrubbed to dislodge Aedes eggs and thoroughly rinsed before refilling with water.

In Singapore, where Ae. albopictus populations were found to have three peaks during the year, fluctuating with rainfall, the best control measures were aimed at removing the population peaks by destroying the major sources of breeding during the period just preceding these peaks (WHO, 1986).

The most effective form of environmental control is to modify completely and permanently the area where mosquito production occurs. Slums, which were the areas responsible for most Aedes breeding in Singapore, have been virtually eliminated by a government national housing program. By 1984, more than 75% of the total population were housed in government-built apartment buildings. This did not solve the problem of large houses with compounds, however, where Ae. aegypti indices were low, but where Ae. albopictus house infestation was almost 100%. These premises would usually have suitable Ae. albopictus breeding habitats such as tin cans, tree holes and leaf axils of plants (WHO, 1986).

Health education

Public health education is aimed particularly at the neighborhoods of lower socioeconomic level where Aedes indices are highest. In order to motivate the people to eliminate and prevent mosquito breeding in their own premises, health education programs implement distribution of pamphlets, seminars, workshops, talks and slogans over radio, television and in schools, posters, feature articles in newspapers and magazines, exhibitions and film strips, and the personal message of the vector control officer working door-to-door. In Singapore, it was concluded that "There is no doubt that continous routine health education measures contributed immensely to the prevention and control of *Aedes* breeding in premises." (WHO, 1986).

Legal measures

The legal component of *Aedes* control has two aspects: laws which permit the health inspector to enter each premises and examine all potential breeding sources, and legislation which makes it illegal to have breeding places on the premises. In Singapore, the Destruction of Disease Bearing Insects Act permits the control officer to serve orders and summonses on offenders found breeding or harboring mosquitos. For a private house owner, an order is served when breeding has been confirmed. If breeding is still found after the 14-day grace period, a summons is served and the offender must pay a fine. The maximum fine for first-time offense is US$ 500 or three month's jail or both. Generally building contractors and developers would be fined more heavily than individual private house owners. From 1973 to 1981, 54,297 orders and 7,047 summons were served, and the revenue collected from fines (about US$ 100,000 per year) was channeled back for the control and prevention of mosquito breeding in premises (WHO, 1986).

Integrated control

No single control method is ever sufficient to reduce mosquito levels to low levels for a long period of time. It is necessary to combine the various methods from our vector control arsenal in the most effective, economic and safest possible way. In Singapore, a system of routine vector surveillance, continous year-round source reduction, health education and fogging of premises in areas with greater than 5% of houses infested, was implemented in 1974. This system was effective in achieving year-round control of the vectors Ae. aegypti and Ae. albopictus, and was also successful in preventing two epidemics which swept through other parts of the region (WHO, 1986).

CONCLUSIONS

The information about Ae. albopictus presented in this document portrays a very complex species. From the public health standpoint, the tremendous potential of Ae. albopictus to serve as arbovirus host and vector is clear. Although some of the discussion is speculative at this point, Ae. albopictus has been shown through experimental and biological data to be one of the most important species from the standpoint of the transmission of pathogens. It is clear from the data shown that the vector competence of the species for pathogens of medical importance is very high. It is conceivable that under appropriate environmental circumstances, Ae. albopictus might become a maintenance and an epidemic vector for several arthropod-borne viruses in the American continent. We know that Ae. albopictus is an excellent vector of dengue viruses and preliminary results with the Ae. albopictus Houston strain have shown high susceptibility to experimental oral infection with the four dengue serotypes (Moore, C., pers. comm., 1986). If Ae. albopictus spreads into Central America and the Caribbean it can change the scenario of dengue disease in the area. Ae. albopictus breeds in urban, rural and forested areas in water retained by artificial containers and natural vegetation. It is exophilic and prefers to breed outside human dwellings. It feeds on both man and domestic animals with relative utilization governed by host availability. There is recent evidence of an enzootic cycle of Dengue virus analogous to those of jungle yellow fever in which Dengue viruses are maintained in sylvan cycles. This adds to its potential danger as a maintenance vector.

It is imperative to know if Ae. albopictus is susceptible to infections with other important America arboviruses and whether or not it will transmit these diseases by bite in the natural environment. The potential spread of Ae. albopictus require the urgent attention of the scientific community of all the Americas.

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