IMPORTATION OF *AEDES ALBOPICTUS* AND OTHER EXOTIC MOSQUITO SPECIES INTO THE UNITED STATES IN USED TIRES FROM ASIA

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ABSTRACT. Between May 18 and December 4, 1986, 79 seagoing containers and their contents of 22,051 used tires were inspected for adult mosquitoes as well as eggs and larvae. Of the total inspected, 5,507 tires (25%) contained significant amounts of water. No adults or eggs were found. Fifteen tires contained mosquito larvae that were identified as *Ae. albopictus*, *Ae. togoi*, *Culex pipiens* complex, *Tripteroides bambusa* and *Uranotaenia bimaculata*. The infestation rate for all species was 6.8 infested tires per 10,000 tires (wet and dry) inspected. *Aedes albopictus* larvae were most frequently collected, occurring at a rate of 20 infested wet tires per 10,000 inspected.

INTRODUCTION

In August 1985, the Harris County Mosquito Control District in Houston, Texas, discovered that *Aedes albopictus* (Skuse), an exotic mosquito species that is a vector for dengue and dengue hemorrhagic fever, had infested Harris County (Monath 1986, Shroyer 1986, Sprenger and Wuithiranyagool 1986). Larvae and breeding adults were found in a wide variety of domestic and peridomestic containers, but particularly in used tires. The association of *Ae. albopictus* with used tires was of interest because of two previous introductions of this species into the United States via retrograde shipments of used military tires from Asia after World War II and the Vietnam War. On neither of these occasions did this species become established (Eads 1972, Pratt et al. 1946).

In 1983, a single female *Ae. albopictus* was captured in a light trap in Memphis, Tennessee. No more were captured; and, while the origin of this single mosquito was uncertain, it was speculated to be related to containerized cargo from Asia (Reiter and Darsie 1983). In retrospect, it is possible that *Ae. albopictus* had already become established in Harris County, Texas by 1983 and that the Memphis collection represented a chance introduction from the Texas focus.

It is now accepted that used tire casings imported for retreading and resale from northern Asia into the United States were the probable source of the infestation in the United States (Hawley et al. 1987). The present study was undertaken to confirm this hypothesis, to define quantitatively the risk of importations, and to provide a baseline of information necessary to interdict further introductions.

MATERIALS AND METHODS

Ascertainment of used tire importation. The magnitude of used tire shipments from Asia was determined from U.S. Department of Commerce statistics available for the period from 1970 through 1985. Data for 1986 were obtained on a monthly basis. By federal law, the content and quantity of all cargo imported into the United States must be declared to United States Customs before it can clear ports of entry. These declarations were used to determine imminent arrivals of used tire shipments from Asia. Containers of used tires were inspected between May 18 and December 4, 1986.

Inspection methods. Sealed freight containers were placed on "inspection hold" by U.S. Customs, trucked to bonded warehouses, and unloaded by a front-end loader. Before unloading, the originating port, U.S. destination, and container number were recorded from the shipment manifest. Once unloaded onto the warehouse floor, the interior of each tire was inspected using a flashlight. Water was removed by dipper or a suction device, placed into a white pan, and examined for larvae. Larvae were stored first in vials containing the original water in which they were found and later transferred to similar vials containing 70% ethanol as a preservative or were held in a solution containing ground rabbit food for rearing to the adult stage.

Dry tires were inspected for watermarks. When watermarks were noted, the interior of the tire was brushed to collect mosquito eggs. The debris obtained was collected using a flat piece of aluminum fitted against the inner contour of the tire and then emptied into plastic bags. On return to the laboratory, the contents of the bags were first examined for the presence of eggs and subsequently were flooded with

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water containing ground rabbit chow. The debris was kept at 26°C for 10 days to hatch any eggs that may have been present. Battery-powered aspirators and capture nets were used in bright light to capture any resting or flying adults when the container was first opened and subsequently unloaded.

Identification methods. Larval and adult mosquitoes were identified to species at the Division of Vector-Borne Viral Diseases (DVBVD), Centers for Disease Control (CDC), Fort Collins, Colorado. Selected specimens were sent for confirmation to Dr. Bruce Harrison and Mr. E. L. Peyton, Walter Reed Biosystemics Unit, Museum Support Center, Smithsonian Institution, Washington, DC.

Disinfestation methods. When live mosquito larvae were discovered in tires, the entire content of the container was fumigated with methyl bromide. Alternatively, each tire was steam-cleaned with a 5% detergent solution at a nozzle temperature of 88°C to kill any larvae or eggs present before the shipment was released.

RESULTS

Large numbers of used tires were imported into the United States in 1985 and 1986 (Table 1). Although used tires are imported from many countries around the world, the nine *Ae. albopictus*-infested countries listed in Table 1 accounted for over 27% of total used tire imports in both years. Two countries, Japan and Korea, exported >96% of the used tires from *Ae. albopictus*-infested countries in both 1985 and 1986, with Japan shipping the majority of tires in each year.

The Asian ports of origin of the inspected tires and the United States ports of inspection are listed in Table 2. All of the tires inspected were from Japan, and 77% of the inspections were at the port of Seattle, Washington. The destinations of the inspected used tires within the United States included 23 cities in 15 states, representing every geographic region of the country except New England and the mid-Atlantic states (Table 3).

The majority of inspections (89%) were carried out from October through early December 1986. A total of 22,051 tires were inspected (Table 4). Twenty-five percent of the tires contained water, and an additional 10% had watermarks, indicating that they had held water at some time. Fifteen tires contained mosquito larvae, for an infestation rate of 6.8 tires per 10,000 tires inspected. No eggs hatched from the flooded debris from 2,213 tires with watermarks. Rates of recovery of *Ae. albopictus* larvae were 5/10,000 for all tires inspected and 20/10,000 for tires with water. No adults were recovered from any of the 79 containers.

Larvae of four genera (five species) and an unidentifiable pupa were found in the tires (Table 5). *Aedes albopictus* was the mosquito most frequently recovered. In addition, *Ae. togoi* (Theobald), *Tripteroides bambusa* (Yamada), *Uranotaenia bimaculata* Leicester, and a member of the *Culex pipiens* complex were found.

DISCUSSION

The results of this study support the hypothesis of Hawley et al. (1987) and demonstrate

Table 1. Numbers of used tires imported into the United States from *Aedes albopictus*-infested countries, 1985–86.[a]

Country	1985 No.	1985 (%)	1986 No.	1986 (%)
Japan	894,083	94.0	549,198	92.6
S. Korea	25,840	2.7	40,484	6.8
India	16,943	1.8	1,440	0.2
Surinam	9,400	1.0	40	<0.1
Taiwan	1,741	0.2	—	—[b]
Indonesia	1,208	0.1	0	0.0
Hong Kong	1,115	0.1	591	<0.1
Sri Lanka	792	<0.1	696	0.1
Singapore	54	<0.1	99	<0.1
TOTAL	951,176		592,548	

[a] Source: U.S. Department of Commerce. Tariff Schedules of the United States Annotated.

[b] Data for Taiwan from 1986 are currently being revised by the U.S. Department of Commerce.

Table 2. City of origin of inspected containers of used tires and United States ports of inspection, May–December 1986.

Asian origin	No. of containers	U.S. inspection ports	No. of containers
Tokyo, Japan	46	Seattle, WA	61
Kobe, Japan	14	San Francisco, CA	9
Nagoya, Japan	10	Long Beach, CA	5
Yokohama, Japan	4	Chesapeake, VA	2
Osaka, Japan	3	Longview, WA	2
Hakata, Japan	2		
TOTAL	79		79

that used tires, especially those that contain water, are at least one mode for introducing *Ae. albopictus* and other exotic Asian mosquitoes into the United States mainland. In two previous introductions of *Ae. albopictus*, which did not result in established infestations, this mosquito species arrived in retrograde shipments of military used tires by commercial firms that acquired the tires overseas (Eads 1972, Pratt et al. 1946). The 1984 report of a single captured female *Ae. albopictus* in Memphis was not shown to be directly related to tires but was speculated to be a result of modern, seagoing containerized freight (Reiter and Darsie 1984).

Table 3. United States destinations of inspected tire casings from Japan.

City	State
Jacksonville	Florida[a]
Tampa	Florida
Chicago	Illinois[a]
Fairmont City	Illinois
Jackson	Illinois
Indianapolis	Indiana[a]
Des Moines	Iowa
Detroit	Michigan
Minneapolis	Minnesota
St. Louis	Missouri[a]
Billings	Montana
Omaha	Nebraska
Cincinnati	Ohio[a]
Cleveland	Ohio
Columbus	Ohio
Oklahoma City	Oklahoma
Tulsa	Oklahoma
Portland	Oregon
Memphis	Tennessee[a]
Nashville	Tennessee
Houston	Texas[a]
Longview	Washington
Seattle	Washington

[a] States known to be infested by *Aedes albopictus* as of September 1986.

Table 4. Tire casing inspection results, May 18–December 4, 1986.

Ports visited: 5
Containers inspected: 79
Tires inspected: 22,051
Tires dry without watermarks: 14,046 (65%)
Tires with water: 5,507 (25%)
Tires with watermarks: 2,213 (10%)
Tires infested with mosquito larvae: 15
Rates of infestation: 6.8 per 10,000 tires (total)
27.2 per 10,000 tires with water

Several other possibilities for the introduction of *Ae. albopictus* exist. Retrograde shipments of used military tires are not subject to duty upon reentering the U.S. mainland and are not reported in the U.S. Customs data we rely upon to identify containers of used tires. Other possible sources include returning household goods of U.S. military and nonmilitary personnel stationed in infested areas and shipments of plants and flowers. Hawaii is infested with *Ae. albopictus*, but records of interstate commerce between those islands and the U.S. mainland are not available.

We recognize that sampling biases are present in this study. Although used tires from infested areas enter most major United States ports on all coasts, all of our identified cargoes for inspection originated in Japan and all were inspected on the west coast. Another bias in our study that may have produced an artificially low infestation rate is the timing of our inspections. Of 79 containers inspected, 70 (89%) were inspected between October and early December. Thus, the majority of containers inspected would have left Japan during a period of decreasing photoperiod and daily temperature; both of these factors would reduce breeding activity, induce egg diapause, and thus reduce the number of tires containing larvae. The rate of tire infestation with larvae may well be higher during warmer months with longer photoperiods.

The failure to recover eggs from any tire brushings is probably due, in part, to the difficulties inherent in the collection method and to the possibility that eggs collected in the late fall months were in diapause and, therefore, were not likely to hatch without prechilling.

Extrapolating from the rate for *Ae. albopictus* infestation of 20 infested tires per 10,000 wet tires and assuming no seasonal variation in infestation rates, we would estimate that 1,390 tires with *Ae. albopictus* entered the United

Table 5. Mosquito larval species collected from Japanese tire casings.

Species	No. of positive tires	Rate of infestation: Per 10,000 total tires	Rate of infestation: Per 10,000 wet tires
Aedes albopictus	11	5.0	20.0
Aedes togoi	2	0.9	3.6
Culex pipiens complex	3	1.4	5.6
Tripteroides bambusa	1	0.5	2.0
Uranotaenia bimaculata	1	0.5	2.0
Pupa unknown species (disintegrated)	1	0.5	2.0

States in 1985 and 999 in 1986. For reasons noted above, these estimates are probably low. During the period of this study, 15 states were listed as destinations for the inspected tires. In 1985, 30 states were specified to U.S. Customs as consignment destinations. These 30 states included 11 of the 12 now known to be infested. Of the other 19, we judge that 14 are moderately (California, Michigan, New Jersey, New York, Oregon, Pennsylvania, Washington) or highly (Iowa, Maryland, Missouri, North Carolina, Oklahoma, South Carolina, Virginia) receptive to *Ae. albopictus* infestation.

Of the other species found in tires, *Ae togoi* is an exotic species to North America that has become established in Washington state and British Columbia (Belton 1980). *Culex pipiens* complex are worldwide in distribution. The species *Tripteroides bambusa* and *Uranotaenia bimaculata* are unknown in the Americas (Knight and Stone 1977). These and other exotic container-breeding mosquitoes could potentially enter in used tires from Asia and become established in North America. Three examples of the diseases they could introduce, are: 1) *Ae. polynesiensis* (dengue and Ross River fever), 2) *Armigeres* spp. (Sepik fever), and 3) *Cx. tritaeniorhynchus* (Japanese encephalitis, Sindbis fever, and West Nile fever) (Karabatsos 1985, Shroyer 1986).

Continuing introductions of *Ae. albopictus* in tires imported from Asia have implications for genetic diversification of existing populations as well as for transovarial transmission of viral diseases endemic in Asia (Shroyer 1986). Work by Hawley et al. (1987) shows that populations of *Ae. albopictus* already in the United States exhibit photoperiodic sensitivity and cold-hardiness consistent with a temperate Asian origin. To date, no *Ae. albopictus* infestations have been detected in south Florida, south Texas, or Mexico, suggesting that these populations of temperate zone-derived *Ae. albopictus* do not adapt well to subtropical climates. If true, introductions of more tropically adapted strains might have important consequences for these now uninfested areas.

Another potential adverse effect of genetic diversification is insecticide resistance. Strains of *Ae. albopictus* studied to date have been classified as "moderately" resistant to malathion (World Health Organization 1968). More resistant strains could be introduced, making control efforts even more difficult.

The ability of *Ae. albopictus* to transovarially transmit viruses endemic in Asia, such as dengue, means that these viruses could be introduced to the United States mainland by infected ova or larvae. Likewise, JE virus can be transmitted transovarially by *Cx. tritaeniorhynchus*, as can dengue and Ross River viruses by *Ae. polynesiensis*, species which could also be introduced by used tires (Pratt et al. 1946). Clearly, the public health interests of the United States require a program of interdicting shipments of mosquito-infested tires.

Since the discovery of *Ae. albopictus* and other exotic larvae in water-containing used tires from Japan, several procedures have been implemented or are under study to prevent further importations by this mode. Working with various trade associations in the tire industry, we were able to advise major Asian exporters of used tires that their product should arrive in the United States clean and free of water. Containers with tires found to be infested with larvae were quarantined and refused entry into the United States until they were either fumigated or steam-cleaned, a process that destroys eggs as well as larvae.

While we now have reasonable grounds for optimism regarding a great reduction or a virtual elimination of further introductions of *Ae. albopictus* and other exotic species in used tires from Asia, there are three major problems: 1) the large numbers of improperly stored, commercially valuable used tires, and illegally dumped, valueless used tires, both of which can serve as breeding containers within the United States; 2) intra- and interstate movement of infested tires, and 3) exportation of infested tires from the United States to other countries. The last two problems arose because no regulations govern the movement of used tires, no data on their movement are readily available, and no provisions or statutory authority exist for inspection of cargoes exported from the United States. Dealing with the improper storage and illegal dumping of used tires will require the enactment of statutes to enforce proper storage, providing proper economic disposal facilities, and enforcing their use.

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