A DUPLEX CONE TRAP FOR THE COLLECTION OF ADULT *AEDES ALBOPICTUS*[1]

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ABSTRACT. A duplex cone trap was developed for the collection of *Aedes albopictus* adults. This device employs carbon dioxide and a visual attractant to draw mosquitoes into an air current created by a 6-volt battery-powered fan. In comparison with 8 other adult mosquito traps, the duplex cone was most effective in capturing *Ae. albopictus* females. A greater diversity of mosquito species was caught in the duplex cone trap compared with the other traps tested. In an experiment comparing the duplex cone trap with human biting collections, this trap proved to be an efficient and sensitive means of monitoring *Ae. albopictus* population changes.

INTRODUCTION

Aedes albopictus (Skuse) is an Asian mosquito species that recently became established in the United States after its apparent introduction in used tires (Reiter and Sprenger 1987, Craven et al. 1988). Since its initial discovery in Harris County, TX (Sprenger and Wuithiranyagool 1986), this species has spread to 160 counties in 17 states. *Aedes albopictus* is a known vector of dengue viruses in Asia and is considered to be a potential vector of indigenous U.S. arboviruses such as LaCrosse encephalitis virus (Moore et al. 1988, Shroyer 1986). Also, a previously undescribed bunyamwera group virus was recently recovered from field collected *Ae. albopictus* in Potosi, MO (Francy et al. 1990).

The use of traps to collect adult *Ae. albopictus* has been generally unproductive because this diurnal species is not attracted to light traps (Thurman and Thurman 1955). Use of portable suction devices, such as the backpack aspirator for collecting resting mosquitoes (Meyer et al. 1983), is laborious and time-consuming. Human biting collections are also time-consuming and may be inconsistent or biased due to differences in human attractiveness. Ovitraps, though useful in detecting the presence of *Ae. albopictus*, are of limited value because these collections may be influenced by the number of available containers and because a single female may oviposit a few eggs in several containers. In terms of pathogen isolation, except for detecting vertical transmission of arboviruses, mosquito eggs are not as useful as the adult stage for the recovery of infectious agents.

To monitor natural populations of *Ae. albopictus* mosquitoes, it would be beneficial to use a standardized collection method. A device such as a stationary suction trap would provide a means of collecting relatively large numbers of specimens that is less labor intensive than other methods. This species does respond to carbon dioxide olfactory stimulation and to visual stimuli created by dark reflective surfaces. These behavioral features, along with the tendency of this species to be active near the ground, led to the development of the duplex cone trap.

Our report on the duplex cone trap consists of 2 studies. The first investigation compared the effectiveness of the duplex cone trap with other mechanical methods commonly used to capture adult mosquitoes. Our second study compared the duplex cone trap with human-bait collections.

MATERIALS AND METHODS

Trap description: The components of the duplex cone trap are shown in Fig. 1. This trap consists of an inner cone (A) that is 41 cm high and has a base 48 cm in diameter. Thirty 2.5-cm holes were cut around the base, and the entire central cone was painted glossy black. An outer cone (B), 34 cm high with a 50 cm diam base, partially surrounds the inner cone. The outer cone is elevated 20 cm from the ground by 4 equally spaced steel legs. The outer cone surface is unpainted, so that the silver metal finish contrasts with the black inner cone. Both cones were fabricated from 26-gauge galvanized steel, and all metal connections were made with pop-rivets. Attached to an opening at the top of the outer cone is a 10 cm (O.D.) connecting collar (C) constructed from polyvinylchloride (PVC) pipe. Inserted into the collar is a chimney 46.5 cm long and 8.3 cm diam fabricated also from PVC pipe. Within the chimney is a 6.0-volt electric fan (D) of the type used in the standard CDC miniature light trap (Hausherr's Machine

[1] Use of trade names or commercial sources is for identification only and does not constitute endorsement by the Public Health Service or by the U.S. Department of Health and Human Services.

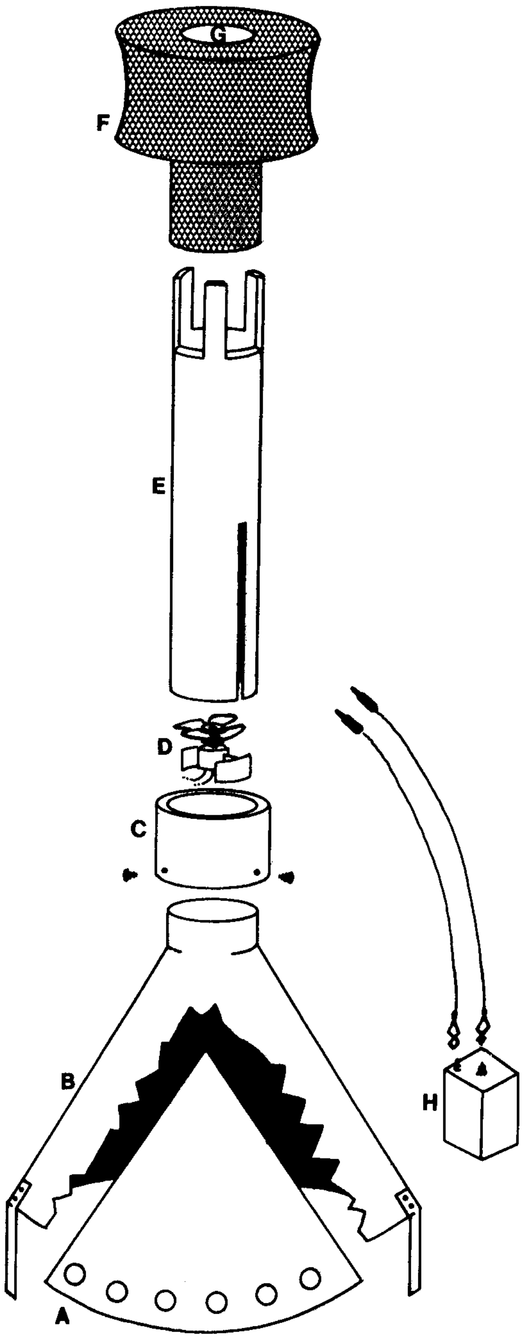

Fig. 1. Diagram of the duplex cone trap: (A) inner cone; (B) outer cone; (C) connecting collar; (D) motor; (E) chimney; (F) collecting bag; (G) reinforced cloth patch; and (H) 6-volt battery.

Works, Old Freehold Road, Tom's River, NJ). The motor is attached to the same bracket assembly used in the light trap, and this bracket is held in place by vertical slots, 14 cm long, cut into the base of the chimney (E). The fan motor, powered by a 6.0-volt lantern battery (H), drives a 7.6 cm fan with 4 blades (Thorgren Inc., Valparaiso, IN) counterclockwise to create an updraft air flow of 4.2 m/sec, as measured at the base of the chimney. The top of the shaft has slotted openings (2.5 × 15.2 cm) that are enclosed with a collecting bag (F) which is reinforced at the top with heavy cloth (G). The cost of materials for trap construction is approximately US $20.00 and it takes about 4 h to fabricate a complete unit.

To operate the duplex cone trap, first place about 1 kg of dry ice on the ground and cover this carbon dioxide bait with the inner cone. Then place the outer cone directly over the inner cone. Attach a collecting bag to the chimney and start the motor; the upward air current created by the fan circulates carbon dioxide around the vicinity of the trap. As the carbon dioxide-attracted mosquitoes approach the trap, they are lured to the base of the inner cone by the shiny black surface. While hovering near the inner cone, mosquitoes are caught in the upward air current flowing between the walls of the two cones and are propelled into the collecting bag.

Description of study sites: Two study sites were used for evaluation of the duplex cone trap. Comparison tests with other mechanical traps were conducted at the Grant Street study site located in eastern Orleans Parish, LA. This site was a 3.5-ha woodlot containing dense vegetation, mainly Chinese tallowtrees (*Sapium sebiferum*) and black willow (*Salix nigra*) trees. About 150 discarded tires, arranged in small piles, were scattered throughout the woodlot, and *Ae. albopictus* mosquitoes were present over the entire area. Within 65 m of the woodlot periphery, 9 trap stations were established at 30-m intervals. A station consisted of a shaded area, 1.5 m diam, that was cleared of any vegetation that might obstruct the trap's visual attractiveness.

Evaluation of the duplex cone trap in relation to other human-bait collections was performed at the Michoud study site, which was also located in eastern Orleans Parish. This densely wooded 50-ha area contains large stands of sugarberry (*Celtis laevigata*) and has numerous tire piles located along the woodlot perimeter. Most tire piles contained from 100 to 500 casings, and *Ae. albopictus* mosquitoes were abundant in the area. For our comparison tests, a single sampling station was established within 4 m of a central tire pile that contained about 500 casings. Five tire piles with an additional 900 tires were located within 50 m of the sampling station.

Comparison with other mechanical traps: Eight traps were tested and compared with the duplex cone trap: CDC gravid trap (Reiter 1983), CDC miniature light trap (Sudia and Chamberlain 1962), dry ice trap (Bioquip Products, Santa Monica, CA 90406), hamster trap, horizontal tire gravid trap, Malaise trap (Breeland and Pickard 1965), Trinidad trap (Worth and Jonkers 1962) and a vertical tire gravid trap. The CDC miniature light trap, dry ice trap, Malaise trap and Trinidad traps were baited with 1.0 kg of dry ice. The hamster trap was essentially a CDC miniature light trap with 2 caged hamsters suspended on opposite sides of the inlet tube. Cages were enclosed with a fine mesh nylon screen to keep mosquitoes from feeding on the hamsters. The CDC gravid trap was used with an attractant-filled, 0.5-liter black oviposition cup placed at the base of the inlet tube. The oviposition attractant was made by adding 1.0 g of rabbit pellets to 3.8 liters of water and incubating this mixture for 3 days at 27°C. The horizontal tire gravid trap consisted of a discarded automobile tire with 6, 7-cm diam holes equally spaced around the tread. The tire was placed flat on the ground and a plastic container with 1.0 liter of oviposition attractant was placed on the ground inside the tire. A plywood board large enough to cover the tire opening was placed over the casing. Projecting from an opening in the center of the tire cover was a 2-m length of flexible plastic tubing, 10 cm diam. Negative air flow was created by a 12-volt suction motor (Model 2C646, Dayton Electric Mfg. Co., Chicago, IL 60648) placed at the end of the plastic hose. Mosquitoes were caught in a screened 0.5-liter collection carton placed inside the tubing near the point where the hose connects to the trap cover. The vertical tire gravid trap operated in a similar manner, except that 3 tires with sidewalls attached together were placed with the tread side on the ground. The suction motor hose was connected to one end of tires and the screened collection cup was placed inside the hose-trap coupling. Approximately 1.0 liter of oviposition attractant was placed inside the middle tire.

Tests were normally conducted 3 days a week and, on each sampling day, individual traps were assigned randomly to a particular station. Traps were generally operated for a 6-h collection period (0900–1500 h). Afterwards, the collecting bag was placed in a cold insulated chest, and specimens were returned to the laboratory for species identification and sex determination. Species were identified using Darsie and Ward (1981) and Darsie (1986).

Comparison with human-bait collections: The duplex cone trap was compared with a commonly employed means of measuring mosquito population density: human landing/biting rate collections. Sampling was conducted between 0900 and 1500 h each weekday between May 15 and June 29, 1989. Before the duplex cone trap was set up at the sampling station, human biting rate collections were made by 2 samplers. One collector was positioned at the station where the duplex cone trap was to be placed, and the other sampler collected mosquitoes at a station 15 m away. Both biting rate collection stations were within 4 m of the central tire pile. The same 2 human biting samplers were used throughout this study.

Human landing/biting rate collections first involved a 2-min baiting period in which a collector would sit on a small stool and expose the lower legs. The collector did not permit mosquitoes to land on skin or clothing during this time. For the next 5 min, those mosquitoes that landed anywhere on the body were caught in a 50-ml screened vial attached to a portable aspirator (Meek et al. 1985). Only those mosquitoes that landed were caught. After each collection, vials containing mosquitoes were placed in a cold insulated chest and returned to the laboratory. Mosquitoes were killed by freezing, identified and counted.

Approximately 25% of each day's collection of *Ae. albopictus* females were dissected to determine the frequency of insemination, blood feeding and egg development. Insemination was determined by examination of the spermatheca for the presence of sperm, recent blood engorgement was determined by the presence of blood in the midgut, and females were considered gravid when ovaries contained maturing or fully formed oocytes. Parity was determined by tracheal examination of dried ovaries, as described by Detinova (1962).

Meteorological data were obtained from a National Weather Service reporting station located about 2 km from the Michoud study site. Daily minimum, maximum and average temperatures, along with total daily precipitation, were recorded.

RESULTS

Comparison with other mechanical traps: After 108 or more hours of trap operation, a total of 991 female *Ae. albopictus* were caught in the 9 traps at the Grant Street site (Table 1). The duplex cone was the most effective trap for collecting *Ae. albopictus* females, capturing 40.6% of the total number caught. In addition, the duplex cone trap caught 8 of the 10 mosquito species captured in this experiment. The hamster and CDC gravid traps were most effective in capturing *Ae. albopictus* males with each catching about 20% of the 438 males collected. More species were captured in the duplex cone trap than were collected in any other single trap.

The hourly trap collection of *Ae. albopictus*

Table 1. Mean number of female mosquitoes caught in traps for each 6-h trap day at the Grant Street site between June 17 and August 24, 1988.

Trap	Hours tested	*Aedes albopictus*	*Aedes atlanticus*	*Aedes sollicitans*	*Aedes taeniorhynchus*	*Aedes triseriatus*	*Aedes vexans*	*Anopheles crucians*	*Culex quinquefasciatus*	*Culex salinarius*	*Psorophora ferox*
CDC gravid	144	4.2	0.0	0.2	0.1	0.4	0.0	0.0	0.0	3.8	0.0
CDC light	108	1.1	0.0	0.0	0.3	0.1	0.0	0.0	0.2	1.9	0.0
Dry ice	144	0.9	0.2	0.2	0.1	0.6	0.0	0.0	0.0	3.5	0.0
Duplex cone	150	16.1	0.0	1.9	0.2	1.0	1.0	0.4	0.2	0.4	0.0
Hamster	150	6.0	0.0	0.2	0.0	1.1	0.2	0.0	0.0	1.8	0.0
Horizontal tire gravid	132	1.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.0	0.0
Malaise	114	2.7	0.0	0.3	0.0	0.6	0.1	0.0	0.0	0.0	0.1
Trinidad	150	4.2	0.0	0.1	0.2	1.5	0.0	0.0	0.0	3.6	0.1
Vertical tire gravid	126	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0

females and males is shown in Fig. 2. As indicated here, the duplex cone trap was responsible for 61.8% of the total hourly collection of *Ae. albopictus* mosquitoes. Least effective were the dry ice trap and both tire gravid traps; each contributed 5% or less to the total *Ae. albopictus* collection.

Comparison with human-bait collections: Comparisons between the duplex cone trap and the human-baited biting rate collections are shown in Table 2. *Aedes albopictus* was the predominant species caught in both collections. However, in addition to *Ae. albopictus* caught in both types of samples, 11 other mosquito species were collected in the duplex cone trap, and 10 additional species were caught in the human biting collections. For comparison with biting collections, only the number of *Ae. albopictus* females are reported in Table 2. However, 85 *Ae. albopictus* males were caught in the duplex cone trap, and no males of any other species were collected. When each species is ranked according to the number caught, the duplex cone trap and the human biting collections were most attractive to the same 5 species: *Ae. albopictus*, *Ae. triseriatus* (Say), *Ae. atlanticus* Dyar and Knab, *Culex salinarius* Coq. and *Coquillettidia perturbans* (Walker). *Aedes albopictus* females accounted for 27.4% of the total duplex cone trap collection and 57.3% of the total human biting collection. This difference in sample proportions was due to the large number of *Cx. salinarius* and *Cq. perturbans* mosquitoes caught in the duplex cone trap. A comparison of *Ae. albopictus* capture rates shows that the mean number of females caught per hour in the cone trap was nearly equal to the number caught per minute in the biting rate collections.

Figure 3 shows the daily population fluctuations for *Ae. albopictus* adults caught in the

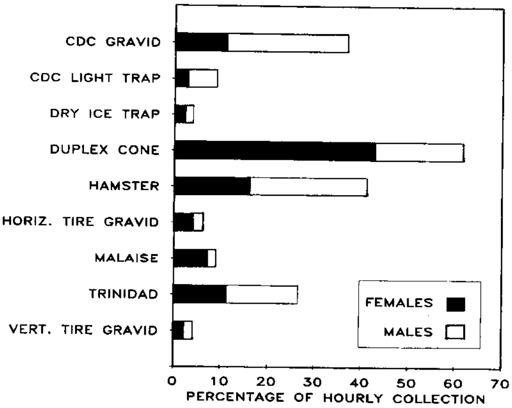

Fig. 2. Percentage of hourly collections of *Aedes albopictus* females and males caught in the traps tested.

Table 2. Comparison of duplex cone trap and human biting rate collections from the Michoud study site from May 15 through June 29, 1989.

Species	Cone trap collections[a]				Human biting rate collections			
	Total no. caught	Mean no. caught/h	SD	% of total	Total no. caught	Mean no. caught/min	SD	% of total
Ae. albopictus	1,459	45.6	23.7	27.8	1,394	45.0	18.2	57.3
Ae. atlanticus	481	15.0	21.5	9.2	163	5.3	7.0	6.7
Ae. sollicitans	12	0.4	1.1	0.2	11	0.4	1.0	0.5
Ae. taeniorhynchus	1	<0.1	0.2	<0.1	—	—	—	—
Ae. triseriatus	599	18.7	26.7	11.4	540	17.4	17.5	22.2
Ae. vexans	30	1.0	3.6	0.6	57	1.8	4.1	2.3
An. crucians	282	8.8	8.2	5.4	24	0.8	1.2	1.0
An. punctipennis	48	1.5	4.2	0.9	2	<0.1	0.3	<0.1
Cq. perturbans	793	24.8	23.4	15.1	89	2.9	4.8	3.7
Cx. quinquefasciatus	143	4.5	12.8	2.7	7	0.2	0.6	0.3
Cx. salinarius	1,327	41.5	50.2	25.3	119	3.8	5.4	4.9
Ps. ferox	72	2.3	3.8	1.4	26	0.8	1.5	1.1

[a] Female mosquitoes only.

duplex cone trap at the Michoud study site. Seven population density peaks were observed at intervals of approximately 7 days: May 17–18, May 23–24, June 2–3, June 9, June 15, June 22 and June 29. Average daily temperatures varied no more than 2.5°C from the 26.9°C overall mean temperature (22.2–31.7°C range), and the pattern of these changes did not correspond to fluctuations in trap or biting collections. Rainfall of 1.0 cm or more was measured approximately 6–9 days before each population peak. Similar cycles of activity were observed for this species in the human biting collections (Fig. 3).

Of the 1,459 *Ae. albopictus* females caught in the duplex cone trap at the Michoud site, 337 were dissected to determine insemination, blood engorgement and ovarian development. Evidence of successful mating was observed in 59.3% of the females examined; however, an indication of recent blood feeding was seen in only 4.5% of the samples. Nine of the 15 blooded specimens caught were found to be three-fourths or more engorged. We found 14.5% of the examined females to be gravid and 12.8% were parous. In comparison, 314 *Ae. albopictus* females caught in the biting collections were dissected to determine blood engorgement and ovarian status. The results showed that blooded, gravid and parous specimens were 8.1, 8.8 and 11.5% of the sample, respectively.

DISCUSSION

In comparison with other traps, the duplex cone trap was the one most productive for collecting *Ae. albopictus* females: nearly 3 times more effective than the hamster trap and 4 times more effective than either the Trinidad or CDC gravid traps. Although *Ae. albopictus* males were often observed hovering near the base of the inner cone, they were seldom caught. It is possible that males did not orient on the inner cone in the same way that females did and thus were less apt to be caught in the air current. This selective bias may be overcome by reducing the scale of the duplex cone trap to increase the negative air pressure between both cones.

A comparison of the duplex cone trap with human biting and ovitrap collections showed that the cone trap is a potentially useful surveillance tool. The pattern of temporal variation in duplex cone trap collections oscillated with a periodicity similar to that observed in the human biting collections. Because hourly collection rates for *Ae. albopictus* in the duplex cone trap corresponded well with the per-minute rate in human biting rate collections, it is possible this trap may be a good method for estimating rates of man-vector contact. The duplex cone

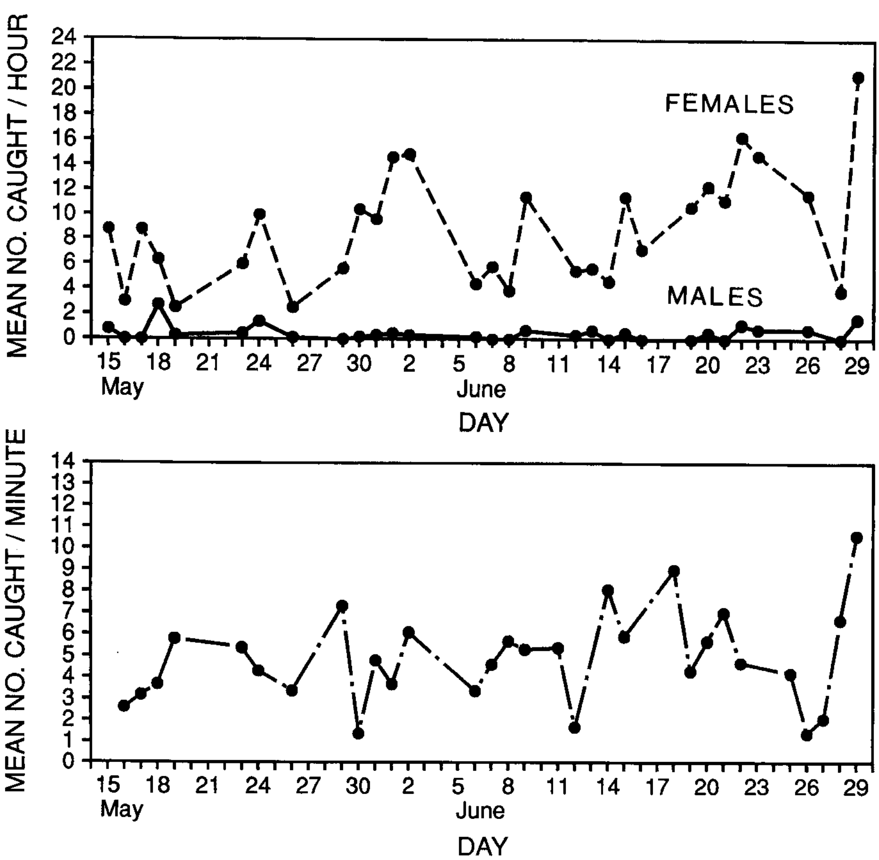

Fig. 3. *Aedes albopictus* females and males caught in the duplex cone trap (upper panel) and in human bait collections (lower panel) from May 15 through June 29, 1989, at the Michoud study site.

trap can be operated simultaneously in several locations and this trap avoids the problem of differential attractiveness that occurs when human bait is used.

Although ovitraps may be useful in detecting the presence of *Ae. albopictus* in an area, the results take time to obtain. Besides the time required for collection, it takes several days for conditioning and hatching the eggs, and for rearing larval progeny to a stage suitable for identification. Also, the presence of competing wet containers can influence ovitrap results. In contrast, duplex cone trap collections will show quickly whether *Ae. albopictus* is present and indicate a relative level of adult population density. Mosquitoes caught in the duplex cone trap can also be used for pathogen testing or for dissection to evaluate the physiological age of females. The trap as tested was not selectively attractive to gravid females; however, using an oviposition attractant in the duplex cone trap may make this device more appealing to gravid females.

The duplex cone trap could also serve as a valuable tool in ecological studies on survivorship and dispersal in which marked *Ae. albopictus* adults are recaptured. Multiple traps could be arranged to collect mosquitoes dispersing from a release point. This would avoid many of the problems associated with making collections with portable hand-operated aspiration devices.

In conclusion, the duplex cone trap is an effective means of collecting *Ae. albopictus* mosquitoes. It is efficient, easy to construct and simple to operate. This device has many applications for operational surveillance by vector control agencies and for research studies on natural populations of *Ae. albopictus.*

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REFERENCES CITED

Breeland, S. G. and E. Pickard. 1965. The Malaise trap—an efficient and unbiased mosquito collecting device. Mosq. News 25:19–21.

Craven, R. B., D. A. Eliason, D. B. Francy, P. Reiter, E. G. Campos, W. L. Jakob, G. C. Smith, C. J. Bozzi, C. G. Moore, G. O. Maupin and T. P. Monath. 1988. Importation of *Aedes albopictus* and other exotic mosquito species into the United States in used tires from Asia. J. Am. Mosq. Control Assoc. 4:138–142.

Darsie, R. F., Jr. 1986. The identification of *Aedes albopictus* in the Nearctic region. J. Am. Mosq. Control Assoc. 2:336–340.

Darsie, R. F., Jr. and R. A. Ward. 1981. Identification and geographical distribution of mosquitoes of North America, north of Mexico. Mosq. Syst. Suppl. 1.

Detinova, T. S. 1962. Age-grading methods in Diptera of medical importance. W. H. O. Monogr. Ser. 47.

Francy, D. B., N. Karabatsos, D. M. Wesson, C. G. Moore, J. S. Lazuick, M. L. Niebylski, T. S. Tsai and G. B. Craig, Jr. 1990. A new arbovirus from *Aedes albopictus*, an Asian mosquito established in the United States. Science 25:1738–1740.

Meek, C. L., M. V. Meisch and T. W. Walker. 1985. Portable, battery-powered aspirators for collecting adult mosquitoes. J. Am. Mosq. Control Assoc. 1:102–105.

Meyer, R. P., W. K. Reisen, B. R. Hill and V. M. Martinez. 1983. The "AFS Sweeper," a battery-powered backpack mechanical aspirator for collecting adult mosquitoes. Mosq. News 43:346–350.

Moore, C. G., D. B. Francy, D. A. Eliason and T. P. Monath. 1988. *Aedes albopictus* in the United States: rapid spread of a potential disease vector. J. Am. Mosq. Control Assoc. 4:356–361.

Reiter, P. 1983. A portable, battery-powered trap for collecting gravid *Culex* mosquitoes. Mosq. News 43:496–498.

Reiter, P. and D. Sprenger. 1987. The used tire trade: a mechanism for the world-wide dispersal of container breeding mosquitoes. J. Am. Mosq. Control Assoc. 3:494–501.

Shroyer, D. A. 1986. *Aedes albopictus* and arboviruses: a concise review of the literature. J. Am. Mosq. Control Assoc. 2:424–428.

Sprenger, D. and T. Wuithiranyagool. 1986. The discovery and distribution of *Aedes albopictus* in Harris County, Texas. J. Am. Mosq. Control Assoc. 2:217–219.

Sudia, W. D. and R. W. Chamberlain. 1962. Battery-operated light trap, an improved model. Mosq. News 22:126–129.

Thurman, D. C., Jr. and E. B. Thurman. 1955. Report of the initial operation of a light trap in northern Thailand. Mosq. News 15:218–224.

Worth, C. B. and A. H. Jonkers. 1962. Two traps for mosquitoes attracted to small vertebrates. Mosq. News 22:18–21.