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INTRODUCTION AND POTENTIAL ESTABLISHMENT OF *AEDES ALBOPICTUS* IN CALIFORNIA IN 2001

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ABSTRACT. *Aedes albopictus* was discovered in Los Angeles, California, in June 2001 in a maritime cargo container from China containing a shipment of a commercial plant product known as "Lucky Bamboo" (*Dracaena* spp.). To keep the plants alive during the ocean transit, they were shipped in 5–8 cm of water, providing an excellent habitat for *Ae. albopictus.* Mosquito infestations were subsequently detected at 15 nursery distributors of *Dracaena* in 2 northern and 4 southern California counties. The distribution of the *Ae. albopictus* infestations was limited to the vicinity of those nursery distributors with documented infestations. Infestations persisted for more than 5 months near some of the nurseries, and eggs were found in ovitraps until mid-November 2001 up to 1,000 m from the original infestation sites. Overwintering *Ae. albopictus* populations were discovered in April, July, and August 2002 at original infestation sites in Chino, San Bernardino County, and Monterey Park and Rowland Heights, Los Angeles County, respectively. Specimens were found at some sites of overwintering populations until October 2002.

KEY WORDS *Aedes albopictus,* infestation, mosquitoes, *Dracaena,* invasion biology

INTRODUCTION

Aedes (*Stegomyia*) *albopictus* (Skuse) is an aggressive daytime-biting mosquito and a known vector of dengue virus in Japan (Sabin 1952), Southeast Asia (Russell et al. 1969), the Seychelles (Metselaar et al. 1980), and southern China (Qui et al. 1981), perhaps second in importance only to *Ae. aegypti* (Knudsen 1995). Although it is a secondary vector to *Ae. aegypti* L. in urban areas (Chan et al. 1967), its importance in an endemic rural cycle in Asia is recognized (Gubler 1987). *Aedes albopictus* is a competent experimental vector of chikungunya, eastern equine encephalitis, Mayaro, Ross River, western equine encephalomyelitis, Venezuelan equine encephalitis, Sindbis, and West Nile viruses (Shroyer 1986; Mitchell 1991, 1995a, 1995b; Dohm et al. 1995; Turell et al. 2001). West Nile virus has been isolated from *Ae. albopictus* specimens collected in Pennsylvania in 2000 (Holick et al. 2002), and in at least 5 other states in 2001 and 2002.

The first established population of *Ae. albopictus* in the USA was documented in Harris County, TX, in August of 1985 (Sprenger and Wuithiranyagool 1986), and since then, this species has spread to at least 911 counties in 26 states (Moore and Mitchell 1997, Moore 1999). Isolated occurrences were discovered and eradicated in California in 1971 (Eads 1972) and 1987 (Moore et al. 1988), and in New Mexico and Washington (Moore 1999). Disease transmission has not been associated with *Ae. albopictus* in the USA. However, evidence suggests that *Ae. albopictus* may be implicated in the ecology of West Nile virus based on isolation of the virus from this species in nature (Holick et al. 2002) and its demonstrated vector competence for the virus (Turell et al. 2001).

Aedes albopictus was discovered in southern California in 2001, presumably introduced via the importation of "Lucky Bamboo" (*Dracaena* spp.). These plants were shipped in 5–8 cm of water from Guangdong Province in southern China and Taiwan. The introduction and potential establishment

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of *Ae. albopictus* was of considerable public health concern for the following reasons: 1) the notable vector competence of *Ae. albopictus* for several arboviruses, 2) the hyperendemicity in Southeast Asia for all 4 dengue virus serotypes (Gubler 1987), 3) the concurrent dengue epidemic in southern China in 2001 and 2002, 4) the ability of dengue virus to infect the oviducts of *Ae. albopictus,* subsequently infecting a small proportion of the eggs (Rosen 1977, 1987), and 5) the propensity of *Ae. albopictus* to bite people and breed in containers, making control difficult. In this article, we describe the temporal and spatial extent of the *Ae. albopictus* infestations in California, and surveillance and control activities throughout the state subsequent to detection in 2001 and 2002. The ecological considerations for the potential establishment of *Ae. albopictus* in California are discussed.

DETECTION

Aedes albopictus was initially detected in June 2001 in maritime cargo containers of *Dracaena* spp. that arrived at the ports of Los Angeles and Long Beach. The containers were inspected at a U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ) station in west Los Angeles by USDA/APHIS PPQ Officers, Centers for Disease Control and Prevention (CDC) Quarantine Officers, and personnel from the Greater Los Angeles County Vector Control District (GLACVCD) (Madon et al. 2002). Historically, *Dracaena* was imported to the United States from China and other Asian countries in dry containers via airfreight. However, due to increased demand for this ornamental plant, shipments began to arrive in approximately January 2000 via cargo ships in refrigerated maritime containers. To keep the plants (20–60 cm in length) green during the ocean journey, the plants were shipped in 5–8 cm of water in small boxes (ca. 0.3 × 0.6 m) made of styrofoam, or plastic or cardboard with plastic liners, thereby providing habitat suitable for both adult and immature mosquito stages (Fig. 1).

Fig. 1. Bundles of *Dracaena* species plants packed in a styrofoam box for shipment in a refrigerated maritime container.

SURVEILLANCE AND CONTROL

Immediately after *Ae. albopictus* were discovered at the USDA-PPQ station, staff of the GLACVCD, University of California at Riverside, and the California Department of Health Services (CDHS) found the first infestation at a nursery in Rowland Heights, Los Angeles County (Madon et al. 2002). Subsequent investigations that involved numerous local mosquito and vector-control agencies and county health departments targeted known importers of *Dracaena.* Based on information provided by the USDA/APHIS and CDC, 30 importers of *Dracaena* were identified statewide. All known *Dracaena* importers and secondary distributors were inspected, and *Ae. albopictus* infestations were found at 40% (12/30) of the nurseries. Other *Dracaena* importers were identified in Florida, Nevada, Utah, Georgia, Maine, and Oregon, and this information was provided to respective state health departments. Inspections were also conducted at nurseries dealing in ornamental plant and flower production and wholesale and retail plant dealers. Inspection of these sites was not exhaustive because of the large number of nurseries and outlets. For instance, in Los Angeles and San Bernardino Counties alone, more than 1,700 and 400 establishments, respectively, were involved in commercial plant distribution.

Documented infestations were found at 15 locations in 6 California counties during the next 8 wk, specifically at 13 locations in southern California (7 in Los Angeles County, 2 in San Bernardino County, 3 in Orange County, and 1 in San Diego County), and 2 locations in northern California (1 each in Santa Clara and San Joaquin Counties) (Table 1, Fig. 2). All infestation sites were located at importer locations, except for infestation numbers 8–10, which were secondary distributors for the importer at infestation site 1. Fourteen of the infestations originated from shipments arriving from southern China, and 1 originated from a Taiwanese shipment (infestation 12). No infestations were found at the many hundreds of retail distributors of *Dracaena* that were inspected. The 2 previous infestations of *Ae. albopictus* in California (Eads 1972, Moore et al. 1988) involved imported tires at 2 sites in northern California; only a few immature specimens were detected. They therefore represented small and limited infestations compared with the situation in 2001.

Adult mosquito control was conducted with Scourge® (Resmethrin) on most arriving maritime shipments of *Dracaena.* Intensive vector-control

Table 1. Chronology of the discovery of *Aedes albopictus* in California in 2001.[1]

Date	Infestation number	Location	Agencies involved[2]	Findings/actions[3]
June 7–15	First discovery in maritime container	Los Angeles Harbor	USDA/APHIS, CDC, GLACVCD, UCR	Adults collected, identified
June 16–20	Second discovery in maritime container	Long Beach, Los Angeles County	GLACVCD, UCR, USDA/APHIS	Immatures collected, containers adulticided
June 22, 23	1	Rowland Heights, Los Angeles County	GLACVCD, DHS	Adults feeding, immatures collected
June 27	2	Monterey Park, Los Angeles County	San Gabriel Valley MVCD, DHS	Adults feeding
June 29, July 2	3	San Martin, Santa Clara County	Santa Clara County VCD, DHS	Larvae and adults collected
July 3	4	Alhambra, Los Angeles County	San Gabriel Valley MVCD	Adults collected
July 6	5	Chino, San Bernardino County	West Valley MVCD	Larvae and adults collected
July 6	6	Chinatown, Los Angeles County	GLACVCD	Larvae and pupae collected
July 9	7	Chino, San Bernardino County	West Valley MVCD	Adults collected
July 12	8, 9, 10	Brea, Costa Mesa, Westminster; Orange County	Orange County VCD	Adults collected
July 17	11	Vista, San Diego County	San Diego VSP	Larvae collected, plant water drained, August 7, adults collected
July 19	12	South San Francisco, San Mateo County	San Mateo County MAD, DHS	Pupa collected at USDA inspection site
July 20		Lodi, San Joaquin County	San Joaquin County MVCD, DHS	Larvae, pupae, and adults collected
July 23	13	City of Industry, Los Angeles County	San Gabriel Valley MVCD	Larvae collected, plant water drained
August 13	14, 15	El Monte, Los Angeles County	San Gabriel Valley MVCD	Adults collected, plant water drained

[1] No *Aedes albopictus* infestations were detected by agencies conducting surveillance in the following counties: Alameda, Contra Costa, Fresno, Lake, Riverside, Sacramento, San Francisco, Santa Cruz, Solano, and Yolo.

[2] APHIS, Animal & Plant Health Inspection Service; CDC, Centers for Disease Control and Prevention; GLACVCD, Greater Los Angeles County Vector Control District; DHS, California Department of Health Services; MVCD, Mosquito and Vector Control District; UCR, University of California, Riverside; USDA, United States Department of Agriculture; VCD, Vector Control District; VSP, Vector Services Program; MAD, Mosquito Abatement District.

[3] Extensive larviciding and/or adulticiding was performed at all sites.

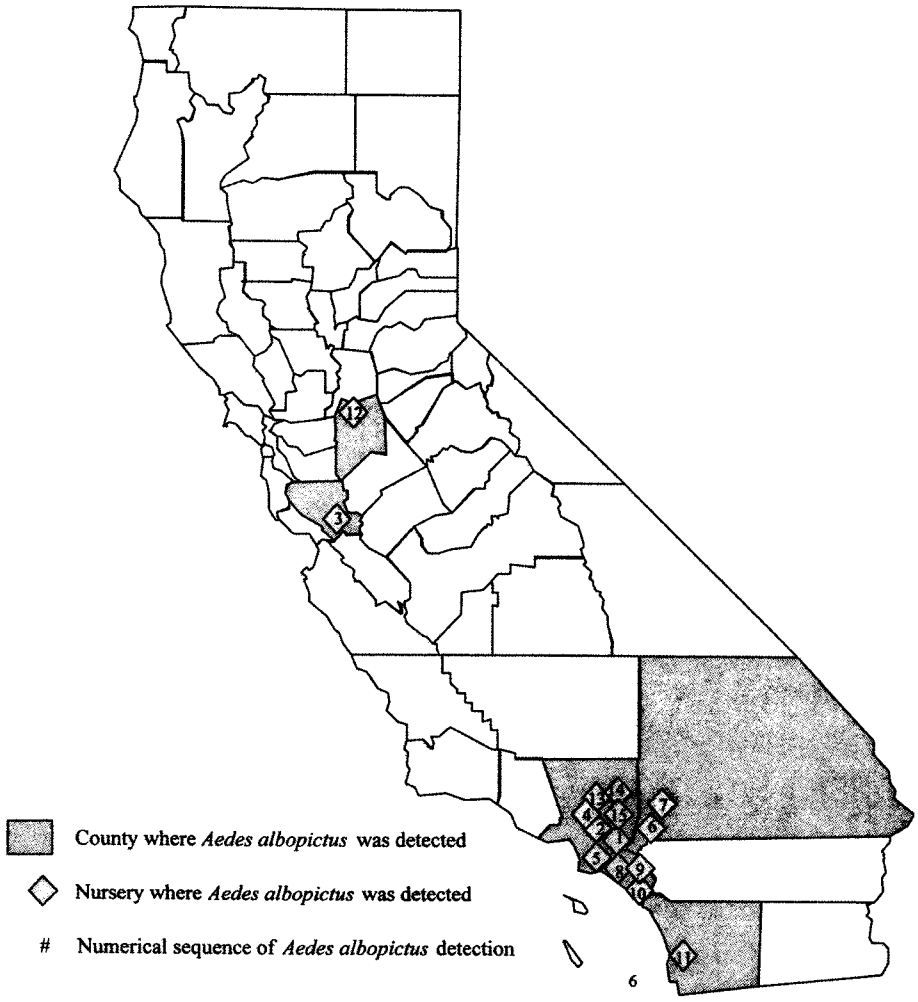

Fig. 2. Location, by county, where *Aedes albopictus* infestations were discovered in California in 2001. Counties shown in gray had 1 or more documented infestations. Overwintering populations were discovered at infestation sites 1, 2, and 7 in August, July, and April 2002, respectively.

operations were also conducted at all infestation sites, including adulticiding with Scourge, larviciding individual boxes of *Dracaena* with VectoBac® 12 AS (*Bti*), Altosid® (methoprene) pellets, Pyrenone® (pyrethrin), or Agnique® (monomolecular film), and source reduction. An example of the scope of the control operations is described by Madon et al. (2002), who reported that during a 6-month period in 2001, GLACVCD staff adulticided more than 200 maritime cargo containers at the port prior to opening and inspecting containers, and treated more than 34,000 individual boxes of *Dracaena* with a larvicide. Infested nurseries located in Vista, San Diego County, and Monterey Park, Los Angeles County (Fig. 3), retained approximately 2,000 individual boxes of *Dracaena* plants for the period June–September 2001, posing a significant problem for control activities. Furthermore, the water in the boxes was allowed to evaporate for 1 wk prior to refilling, providing an opportunity for eggs deposited on the moist substrate of the container and plant stems to hatch. In some nurseries with heavy infestations, *Ae. albopictus* was observed to complete its life cycle sporadically for several months in spite of control efforts.

Large numbers of *Ae. albopictus* continued to repopulate infestation sites in southern California in early July, even though GLACVCD had adulticided the maritime cargo containers. The process of unloading plastic boxes containing *Dracaena* in water from a maritime cargo container is shown in Fig. 3a. This container (11.2 m [length] × 2 m [width] × 2.4 m [height]) had been adulticided twice before it was transported from the USDA/APHIS PPQ station in west Los Angeles to the nursery in Monterey Park. Numerous adult *Ae. albopictus* were observed flying out of the container, and staff complained of being bitten by mosquitoes while the

A.

B.

Fig. 3. Plastic boxes containing *Dracaena* species plants in water at a Monterey Park, Los Angeles County, infestation site being A) offloaded from a refrigerated maritime shipping container and B) larvicided with Altosid® pellets (methoprene), and adulticided with Scourge® (resmethrin).

more than 150,000 plants in 500 plastic boxes (approximately 300 plants/box) were being unloaded from the container. The San Gabriel Valley Mosquito and Vector Control District (SGVMVCD) immediately applied adulticide (Scourge) and larvicide (Altosid) at the nursery, rapidly reducing biting rates from 10 mosquitoes/min to almost 0. (Fig. 3b).

Significant progress was made in halting the introduction of *Ae. albopictus* into the USA on July 2, 2001, when the CDC enacted an embargo of shipments of *Dracaena* in standing water into ports of the USA, permitting shipments arriving before July 17 to be adulticided and released to the importer. In response to the embargo, the vast majority of exporters in China and importers in California stopped transport of the product in standing water. At least 1 air shipment destined for an importer in Maine was refused entry in San Francisco under the direction of CDC staff. After the embargo was enacted, *Dracaena* continued to arrive as "dry shipments" of bundles of 10–20 plants packed in water-absorbent materials and wrapped in plastic bags (Fig. 4). Live immature *Ae. albopictus* were collected by GLACVCD staff at 1 site where only dry shipments had been received (infestation 6). Staff of the GLACVCD continued adulticiding dry shipments arriving in southern California through at least October 2002 because adult mosquitoes could potentially have entered the open cargo containers in Asia (Madon et al. 2002).

Mosquitoes from 2 sites were trapped and tested for the presence of viral pathogens by the University of California at Davis. Seven and 14 *Ae. albopictus* submitted from Santa Clara County VCD and San Joaquin County MVCD, respectively, were tested for infections with dengue, Japanese encephalitis, Murray Valley encephalitis, and Saint Louis encephalitis viruses; all were negative.

Surveillance in and around infestation sites continued through 2001 to evaluate the success of the control operations and to monitor whether *Ae. albopictus* had spread beyond the confines of the nurseries. Mosquitoes apparently continued to oviposit at the nurseries in Montery Park and Rowland Heights, Los Angeles County, into November, more than 5 months after they were detected.

OVERWINTERING POPULATIONS AND ERADICATION

No evidence of persistent *Ae. albopictus* infestations were observed during active surveillance conducted between mid-November 2001 and March 2002 at sites in southern California that were infested in 2001. However, on April 1, 2002, West Valley MVCD (WVMVCD) discovered a population of *Ae. albopictus* at a Chino, San Bernardino County site that apparently had successfully survived the winter. Adults were collected while attempting to feed, and immature specimens were found in 1 of the containers that had been flooded in an attempt to propagate *Dracaena* held at the nursery since 2001. These same containers had been used in 2001 to propagate *Dracaena*. Presumably, eggs that were oviposited on the containers or on the plants themselves during the infestation in 2001 hatched subsequent to flooding in late March 2002. Immature stages and adults were identified in the laboratory at WVMVCD; specimens were also prepared for future genotyping. All sources of wa-

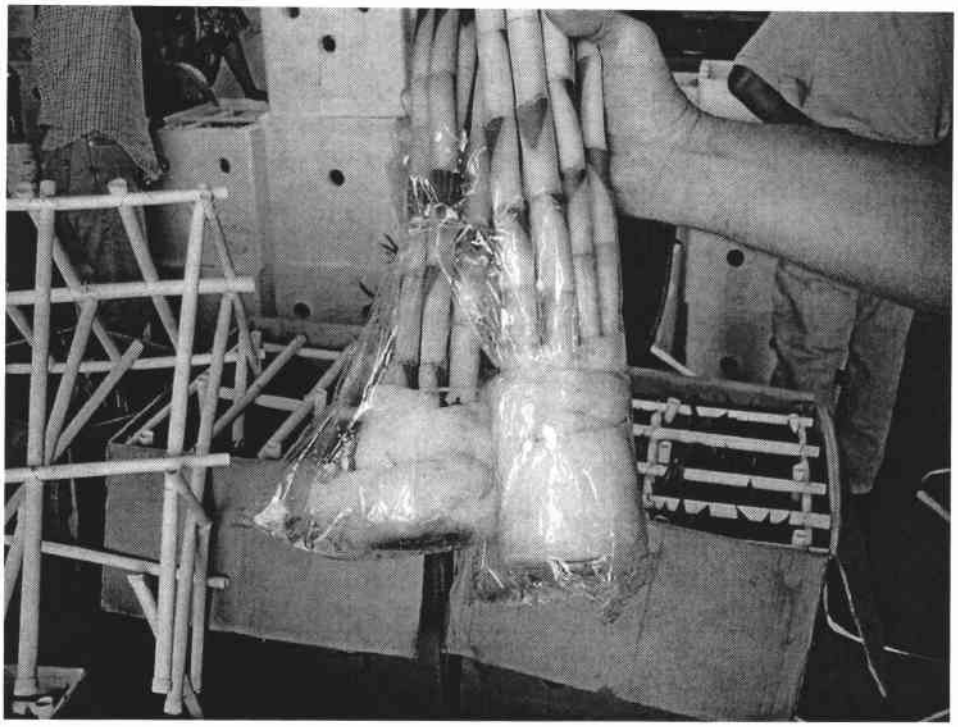

Fig. 4. "Dry" shipment method observed at infestation site number 15 in El Monte. This method has been commonly used since the July 2, 2001, Centers for Disease Control and Prevention Embargo of shipments containing standing water. *Dracaena* spp. bundles are individually packed in Crystal Earth® (polymer resin) or other water-absorbent materials and wrapped in plastic bags prior to shipment from China. Most shipments, like those shown here, do not contain standing water in the shipping box (cardboard and Styrofoam boxes shown in background); however, some do contain standing water inside the plastic bags.

ter at the nursery that contained immature mosquitoes were destroyed, and adulticides were applied within the nursery compound. During attempts to rear immature stages in the laboratory, high mortality was observed in pupae. Additionally, reduced fecundity and poor survival of emerging adults was documented. These phenomena are consistent with the effects that are often observed when mosquitoes are exposed to sublethal doses of methoprene (Sithiprasasna et al. 1996). The effects could be due to the residual activity of Altosid pellets that were applied to containers of *Dracaena* during control efforts earlier in 2001 at the nursery. Subsequent surveillance at this site indicated that *Ae. albopictus* that survived the winter were controlled.

A second population that survived through the winter was discovered near a previously infested site in Monterey Park, Los Angeles County, on July 12, 2002, by SGVMVCD. Viable *Ae. albopictus* eggs were found in ovitraps placed approximately 5 m from the outside wall of the nursery. Subsequently, adults were found immediately outside the perimeter of the nursery (1 landing mosquito/min). No immature stages were found in or outside the nursery; however, 5 discarded truck tires were found outside the nursery. One of these yielded 7 *Ae. albopictus* larvae after being flooded. No additional larvae were found after the tires were flooded several more times. Subsequent surveillance in the immediate vicinity of the nursery yielded *Aedes* spp. eggs (presumably *Ae. albopictus*) that were collapsed and did not hatch. The area inside and immediately outside the nursery was adulticided with deltamethrin. The nursery moved some weeks later, but the SGVMVCD continued to monitor the vicinity of this site. On August 29, 2002, a single *Ae. albopictus* larva was found along with *Culex quinquefasciatus* larvae in an unattended swimming pool approximately 500 m from the originally infested site. The pool was treated with Golden Bear® GB-1111 larvicidal oil, and ovitraps at this site and in the vicinity have not yielded any eggs to date. On October 15, 2002, a single *Ae. albopictus* female was found dead in an oviposition cup. She had deposited 3 eggs that failed to hatch. Surveillance will continue at and around the vacated property.

On August 27, 2002, a third population of *Ae. albopictus* was detected in a previously infested nursery in Rowland Heights, Los Angeles County, by the GLACVCD. Eggs were initially discovered in ovitraps placed inside the nursery, and the fol-

lowing week, numerous host-seeking adults and immature stages in containers of *Dracaena* were detected. It is hypothesized that this infestation may be attributed to a new introduction because *Ae. albopictus* were detected only after the nursery resumed importing *Dracaena* in maritime containers from southern China. Control operations consisted of 2 applications of Scourge to control adults, followed by a meticulous application of Atosid® pellets to the water of containers of *Dracaena.* It appears that control efforts have been successful at controlling *Ae. albopictus* and preventing it from being established in the immediate environment around the nursery in Rowland Heights.

CONTROL AND PREVENTION RECOMMENDATIONS

In response to the detection of *Ae. albopictus* at numerous sites in California in 2001 and the significant threat to public health, CDHS recommended the following activities to contain and ideally eradicate infestations: 1) apply adulticides to plant-holding areas, and sustained release methoprene to water in plant-holding containers where *Ae. albopictus* breeding is detected; 2) continue to monitor adult populations after insecticide treatments to ensure that the population of *Ae. albopictus* is eradicated at the nursery; 3) monitor *Ae. albopictus* populations above and below ground around the periphery of infested sites and in the vicinity of the site, utilizing oviposition traps or other appropriate surveillance methods to determine if populations have been established outside the borders of the nursery; 4) continue spot monitoring of infestation sites as future shipments are received; and 5) train nursery staff on methods to reduce infestation risk (e.g., maintain water levels to prevent repeated drying and reflooding of *Ae. albopictus* eggs should they be present; properly dispose of water).

Although an embargo was placed on shipments of *Dracaena* in standing water, the moist stalks of the plants may serve as substrate for oviposition during plant processing in Asia. For instance, oviposition may occur after the plants are harvested, bundled, and placed in standing water to encourage sprouting. As described earlier, *Ae. albopictus* larvae were detected in a dry shipment that was subsequently flooded in a Chinatown nursery in Los Angeles. This provides preliminary evidence that dry shipments may serve as a vehicle to introduce *Ae. albopictus.* To reduce the risk of *Ae. albopictus* being introduced via dry shipments, CDHS collaborated with CDC to develop recommendations for processing and shipping *Dracaena* for exporters in Asia. Recommendations included processing *Dracaena* shipments in mosquito-free facilities, from the time plant stalks are first placed in water until the time they are placed in maritime cargo containers. The facilities should have screens and doors that close automatically. Mosquito adulticides should be applied regularly as space sprays in the facility to kill any mosquitoes that may enter. It was also recommended that a residual mosquito-control agent be applied to each box of *Dracaena* just before it is packed into the maritime cargo container and sealed. This would prevent any eggs that are present in the maritime container or on the *Dracaena* from developing. The California Department of Health Services encouraged vector-control districts and local health departments to share these recommendations with wholesale importers of *Dracaena* within their respective jurisdictions and with exporters in Asia.

SUMMARY: POTENTIAL FOR ESTABLISHMENT

The discovery of 2 distinct overwintering populations of *Ae. albopictus* in southern California indicates that Ae. *albopictus* from southern China could become established locally. Currently, western Texas represents the western most establishment of *Ae. albopictus* in the continental USA. Most populations along the western edge of its distribution in the USA occur in local habitats where human-induced alterations to the microclimate create conditions that are suitable to survival (Moore 1999). Although Washburn and Hartmann (1992) demonstrated that overall ecological conditions in California might not be conducive to the establishment of populations from temperate climates, it is important to consider the wide variety of habitats and ecological niches where *Ae. albopictus* currently exists. This was clearly demonstrated in 2001–2002 in California, where tropical *Ae. albopictus* populations introduced principally from southern China became established and survived the winter in the dry Mediterranean climate of southern California in spite of intensive surveillance and control. Guangzhou, China (23°N) has a mean annual rainfall of about 1,500 mm; most of it occurs during the summer monsoon in April–September. Temperatures usually vary from 8 to 17°C. In contrast, the mean annual rainfall in Monterey Park, CA (34°N) is only 452 mm, with most rainfall occurring during the winter (November–April) and with monthly temperatures that range from 13 to 24°C. Coincidentally, the 2001–2002 rainy season in southern California was the driest on record, with only about 100 mm of rain recorded. There is field and laboratory evidence suggesting that new introductions of *Ae. albopictus* experience a reduced infection by its gut parasite *Ascogregarina taiwanensis,* thus conferring introduced populations a significant competitive advantage over competing species (Aliabadi and Juliano 2002). Such an advantage in survivorship, although transient, may facilitate range expansion and establishment of *Ae. albopictus.*

It appears that the following actions largely controlled *Ae. albopictus* infestations in California and

minimized reintroduction: 1) comprehensive surveillance in and around infested sites, 2) intensive mosquito-control operations, 3) an embargo by CDC in July 2001 that prohibited shipments of *Dracaena* in standing water, and 4) *Dracaena* importer/exporter cooperation. Continued vigilance is necessary to detect cryptic populations of this potentially significant public health vector that may still exist in California and to prevent new ones from emerging. It is estimated that there are more than 2,000 nonindigenous arthropod species currently established in the USA (Office of Technology Assessment 1993). The significant potential for exotic species to become established is illustrated by evidence suggesting that 5–10% of introduced species become established and 2–3% actually expand their ranges (di Castri 1989). Efforts to prevent *Ae. albopictus* populations from becoming established may be difficult but will become more crucial in coming years as resources to monitor these mosquitoes may compete with resources to address West Nile virus in California.

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