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AEDES ALBOPICTUS IN THE UNITED STATES: CURRENT STATUS AND PROSPECTS FOR FURTHER SPREAD

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ABSTRACT. Since its initial discovery in the continental USA in 1985, the Asian tiger mosquito, *Aedes albopictus*, has spread rapidly throughout the eastern part of the country. Infestations of *Ae. albopictus* now have been reported to the Centers for Disease Control and Prevention from 919 counties in 26 states in the continental USA. This species is believed to be established in 911 counties in 25 states. Single individuals or small numbers of *Ae. albopictus* have been intercepted and destroyed in 3 additional states (California, New Mexico, and Washington). Five states (Florida, Georgia, North Carolina, South Carolina, and Tennessee) have reported infestations in all of their counties. The current reported distribution of *Ae. albopictus* was compared to ecoregions of the U.S. Environmental Protection Agency's Level III ecoregion map. Several areas are identified as probable candidates for extension of this species based on ecological characteristics of the landscape. In other areas, populations seem likely to become locally abundant in urban or suburban oases that do not reflect the native ecology of the region. The ability of *Ae. albopictus* to transmit a variety of pathogens of human and veterinary public health importance, coupled with its ability to colonize diverse ecological settings makes continued surveillance an important issue.

KEY WORDS *Aedes albopictus*, exotic pests, invasion biology, emerging diseases

INTRODUCTION

The Asian tiger mosquito, *Aedes albopictus* (Skuse), is of considerable potential public health importance in the USA. This species probably was introduced into Hawaii late in the last century (Usinger 1944). Although specimens of *Ae. albopictus* were intercepted on several occasions at U.S. ports (Hawley 1988, Francy et al. 1990), the species did not successfully become established in the New World until the 1980s. The 1st clearly established population in the continental USA was found in Harris County, Texas, in August 1985 (Sprenger and Wuithiranyagool 1986). A previous collection of *Ae. albopictus* in Memphis, TN (Reiter and Darsie 1984), suggests the possibility of additional introductions or very rapid spread from a single focus. Additional interceptions of incoming *Ae. albopictus* were made in Seattle, WA, in 1986 (Craven et al. 1988), Alameda County, California, in 1987 (Centers for Disease Control [CDC], unpublished data), and Albuquerque, NM, in 1989 (CDC, unpublished data).

Aedes albopictus spread rapidly throughout the eastern USA (CDC 1986; Moore et al. 1988, 1990), until several states were completely infested (O'Meara et al. 1995, Womak et al. 1995). The northward and westward spread of *Ae. albopictus* was slower, presumably caused by colder temperatures in the north and drier summers in the west. Nawrocki and Hawley (1987) estimated the ultimate northern limits of *Ae. albopictus* distribution in North America, based on mean January temperatures at the northern limits of the species in Asia. However, to evaluate the potential for further dispersal, a broader range of ecological differences than temperature alone must be considered. For example, rainfall patterns shift from summer to winter toward the western USA (Bailey 1996, Figs. 7.5 and 7.8). In regions with little or no summer rain, container-inhabiting species may be limited to urban and suburban oases, where human activities result in an abundance of water-filled containers.

Political boundaries, such as states and counties, bear little relation to the natural landscape, and they are not particularly helpful in explaining species distribution. Use of ecologically based units is more helpful in understanding distribution. Ecological regions (ecoregions) map land units that are similar with respect to factors such as temperature, precipitation, elevation, and other terrain features, soil type, and potential biotic communities. Several ecoregion classifications have been developed at differing scales (Omernik 1987, Bailey et al. 1994, Bailey 1996). The U.S. Environmental Protection Agency (U.S. EPA 1996) has established 3 standard ecoregion maps, called Level I (9 classes), Level II (32 classes), and Level III (78 classes). The Level III map is based on the work of Omernik (1987), with several added classes.

This paper updates the current reported county-level distribution of *Ae. albopictus*. In addition, the

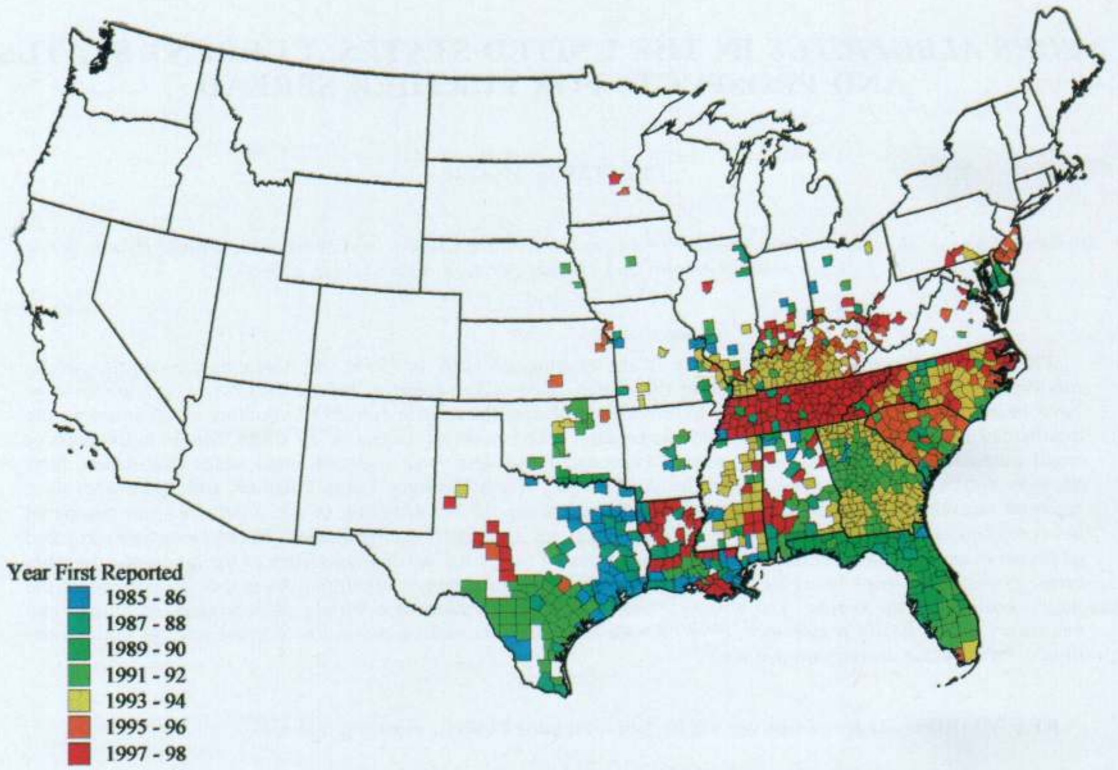

Fig. 1. U.S. counties that have reported *Aedes albopictus* infestations, by year of discovery. Two-year classes were used to simplify the map.

current distribution of this species is mapped in relation to the ecological regions of the USA. I suggest that ecological regions will be more useful than political boundaries in explaining or predicting the eventual extensions in the range of this species.

METHODS

Current distribution: The Centers for Disease Control and Prevention maintain a national database on the distribution of *Ae. albopictus*. The surveillance program for *Ae. albopictus* is a passive system. Reports are received from state and local health departments, vector control agencies, university researchers, and other sources. Reports of new infestation are entered into the database, which is linked to a geographic information system for map generation and spatial analysis of data. The surveillance program emphasizes detecting the spread of this species, monitoring its activity in areas known to be endemic for La Crosse (LAC) encephalitis and eastern equine encephalomyelitis (EEE) viruses, and monitoring its involvement in transmission of these and other domestic arboviruses. The quality and volume of surveillance data vary with the capabilities and resources available to state and local agencies.

Limits to dispersal: Several commonly available ecoregion maps were evaluated for complexity (number of classes) and for gross concordance with the currently reported distribution of *Ae. albopictus*. The U.S. EPA Level III ecological regions (ecoregions) map, in vector format, was obtained from the U.S. EPA World Wide Web site (U.S. EPA 1996) (the Appendix lists ecoregion names and numerical codes). The ecoregion map was imported into TNTmips GIS software (MicroImages, Inc., Lincoln, NE), and converted to a raster image file (1,000-m × 1,000-m pixels). A map of the counties positive for *Ae. albopictus* was converted to raster format (1,000-m × 1,000-m pixels), and the portion of each ecoregion occupied by positive counties was determined.

RESULTS AND DISCUSSION

Current distribution

The pattern of dispersal of *Ae. albopictus* over time (Fig. 1) shows a general eastward and northward pattern, with earlier discovery of infestations in the Southeast and the Gulf Coast states, and more recent discoveries farther north. The apparent absence in some areas, such as parts of Alabama, Mississippi, and Arkansas, probably indicates a lack of vector surveillance programs rather than the

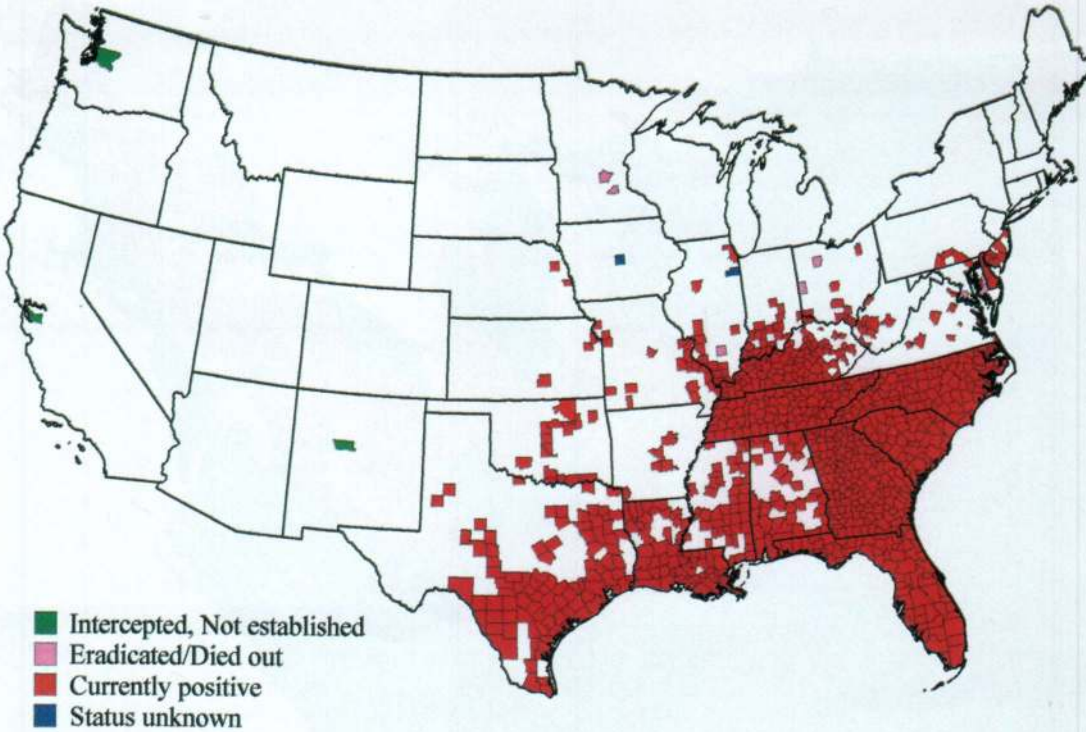

Fig. 2. *Aedes albopictus* distribution map showing 1) interceptions (not established), 2) populations that were eradicated or died out, 3) currently positive counties, and 4) reported positive counties whose current status is unknown or in doubt because of conflicting reports or other data.

absence of *Ae. albopictus*. The continued northward expansion of this species extends its distribution into additional enzootic foci for LAC encephalomyelitis virus. Of particular interest is the 1997 discovery of *Ae. albopictus* in Peoria, IL, because this area has long been a major focus of LAC encephalomyelitis virus activity.

Established populations of *Ae. albopictus* now have been reported to the CDC from 919 counties in 26 states in the continental USA (Fig. 2). Single individuals or small numbers of *Ae. albopictus* have been intercepted and destroyed in 3 additional states (California, New Mexico, and Washington, shown in green), as noted above. The species is believed to be established in 911 counties in 25 states (shown in red). Limited focal infestations in at least 8 counties (pink in Fig. 2), mostly in northern states, apparently have been eliminated through persistent control efforts by state and local agencies, perhaps aided by severe winter temperatures. For example, periodic reinfestation in Minnesota has been reported, but source reduction and other measures have prevented establishment. Nonetheless, other areas in northern states such as Illinois, Indiana, and Ohio continue to be infested. The northernmost established infestation in the USA is in Chicago, IL. The current status of several counties earlier reported as positive in Maryland, Illinois, and Iowa is in question because of conflicting reports (shown in blue). Areas for which no data exist in the CDC database appear in white in Fig. 2.

Aedes albopictus has been found as far south as Cameron County, Texas, extending across the border into Mexico (CDC 1989, Ibañez-Bernal and Martinez-Campos 1994). In the East, the species is found from New Jersey south to Monroe County, Florida. In 1998, the known range extended westward to Terry County, Texas, and Douglas County, Nebraska. In the Northeast, the species has been found in several Pennsylvania and New Jersey counties. During 1998, North Carolina became the 5th state to document *Ae. albopictus* in all counties (the others are Florida, Georgia, South Carolina, and Tennessee).

Limits to dispersal of *Ae. albopictus*

Aedes albopictus is quite capable of surviving in the total absence of human artifacts. In these settings, the underlying environmental characteristics will play a dominant role in determining where the species will or will not become established. Environmental subdivisions, such as the ecoregions used here, will be of more use in these natural settings in predicting the eventual spread of *Ae. albopictus* than will political subdivisions such as state and county boundaries. The establishment of *Ae. albopictus* in natural settings may be of consid-

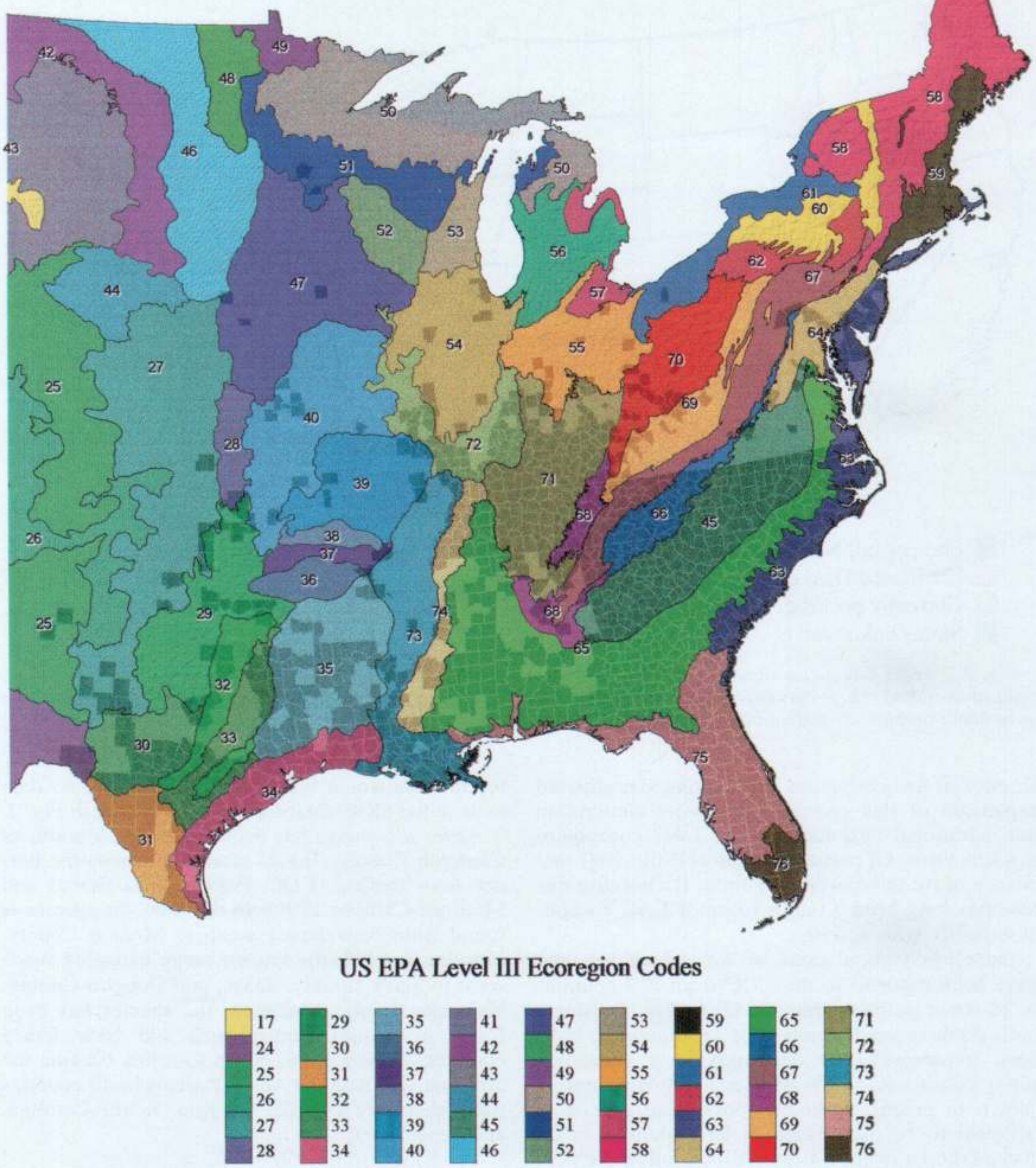

Fig. 3. Map of U.S. Environmental Protection Agency Level III ecoregions showing all counties that have reported *Aedes albopictus*. Positive counties appear as darker, hatched outlines beneath the ecoregions. Only those ecoregions that appear in the map are shown in the legend. See the Appendix for ecoregion names associated with the numeric codes.

erable public health importance because the species is most likely to become involved in enzootic arbovirus transmission cycles in these settings.

Fig. 3 shows the distribution of positive counties by ecoregion. The effect of varying surveillance efforts is immediately apparent in several areas. Several states show currently negative areas within ecoregions where *Ae. albopictus* is common in the adjoining states (e.g., along the North Carolina–Virginia border in regions 45—Piedmont, 65—Southeastern Coastal Plains, and 63—Mid-Atlantic Coastal Plains). *Aedes albopictus* can reasonably be assumed to be present in many of these adjoining areas but has not yet been detected. By using the

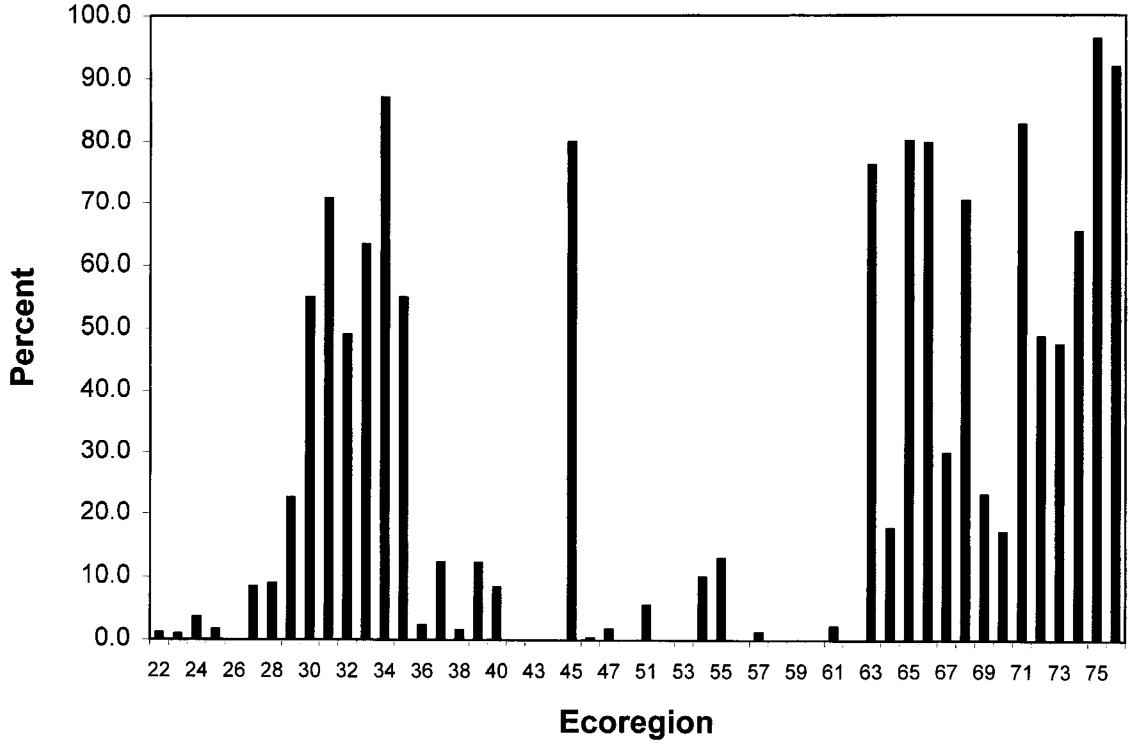

Fig. 4. Percent of U.S. Environmental Protection Agency ecoregions (regions 1–21, 77–78 are omitted) that were positive for *Aedes albopictus* through December 1998. Percentages were determined by converting county polygons to 1-km pixels, and the positive and negative areas were calculated for each ecoregion polygon.

data from Fig. 3, local health departments, university researchers, and other individuals and groups can better identify the most likely areas to add new records for their state or region.

The proportion of each ecoregion that is positive for *Ae. albopictus* is shown in Fig. 4. The apparent clustering of positive ecoregions (30–35 and 63–76) is due to the numbering sequence of the regions, and has no particular significance. *Aedes albopictus* is found essentially throughout ecoregions 75 (Southern Coastal Plain) and 76 (Southern Florida Coastal Plain) at the scale of this study. Ecoregions 34 (Western Gulf Coastal Plains), 45 (Piedmont), 63 (Middle Atlantic Coastal Plain), 65 (Southeastern Plains), 66 (Blue Ridge Mountains), and 71 (Interior Plateau) all had *Ae. albopictus* reported from 75% or more of their area. *Aedes albopictus* likely will become widespread in these regions. For other regions to the north and west, the distribution by ecoregion is not as clear.

The relation between the distribution of *Ae. albopictus* and environmental factors is complicated by the fact that this mosquito is able to colonize the human habitat. Human-induced alterations to urban and suburban environments (such as nonindigenous trees and shrubs, artificial watering schemes, and artificial container habitats) may drastically alter the locale from the underlying ecoregion characteristics. Although urbanization may partially offset the limitations imposed by the ecoregion, at some point human modifications likely will be insufficient to override underlying environmental factors such as extreme dryness or low temperature. For example, in some regions, particularly the more westerly ones, infestations seem to be clustered in and around major urban areas (e.g., St. Louis, Kansas City), where parks, residential gardens, and other human-constructed artifacts alter the natural ecology of the region. Given the characteristics of those western ecoregions, this distribution pattern seems likely to continue, and *Ae. albopictus* will at most become locally abundant, rather than widespread.

In the far western states (California, Oregon, Washington), annual rainfall exhibits a Mediterranean pattern with the majority of precipitation falling in the cooler winter months. Adaptation to this seasonal pattern would require substantial changes in the biology and behavior of *Ae. albopictus* to successfully compete with existing species such as *Aedes sierrensis* (Ludlow).Although such changes have been shown to be possible in the laboratory (Washburn and Hartmann 1992), they seem unlikely in nature.

Finally, factors other than the ecological characteristics of an area will greatly influence the distribution of *Ae. albopictus,* given the role that humans play in transporting this mosquito (Craven et al. 1988, Reiter 1998). For example, Moore and Mitchell (1997) suggested that transportation by humans might have accounted for some of the observed clustering of positive counties along the interstate highway system in the years immediately following introduction. Similarly, patterns in transportation and commerce may help to explain some current distribution patterns, such as the relative scarcity of *Ae. albopictus* infestations in the Northeast.

Aedes albopictus is a vector of dengue viruses in Asia and could become involved should dengue be reintroduced into the USA. This species is a competent vector of several other viruses of public health importance in the USA, at least under experimental conditions. Since the discovery of *Ae. albopictus* in the USA, 5 arboviruses (EEE, Cache Valley, Keystone, Tensaw, and Potosi) have been isolated from this mosquito (Moore and Mitchell 1997). The ability of *Ae. albopictus* to colonize and become abundant over a wide portion of the USA, including areas where those viruses are enzootic, is of concern. Continued monitoring of the distribution of this species is important, as is monitoring its potential involvement in the transmission of arboviruses to humans and domestic animals.

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APPENDIX

U.S. Environmental Protection Agency Level III ecoregion codes and descriptors. Seventy-eight ecoregions are included in the Level III classification. Only those regions shown in Fig. 3 are identified in this Appendix. For a complete listing, consult the U.S. Environmental Protection Agency's World Wide Web site (U.S. EPA 1996).

Code	Region name	Code	Region name
17	Middle Rockies	50	Northern Lakes and Forests
24	Southern Deserts	51	Northern Central Hardwood Forests
25	Western High Plains	52	Driftless Area
26	Southwestern Tablelands	53	Southeastern Wisconsin Till Plains
27	Central Great Plains	54	Central Corn Belt Plains
28	Flints Hills	55	Eastern Corn Belt Plains
29	Central Oklahoma/Texas Plains	56	S. Michigan/N. Indiana Drift Plains
30	Edwards Plateau	57	Huron/Erie Lake Plains
31	Southern Texas Plains	58	Northeastern Highlands
32	Texas Blackland Prairies	59	Northeastern Coastal Zone
33	East Central Texas Plains	60	Northern Appalachian Plateau and Uplands
34	Western Gulf Coastal Plains	61	Erie/Ontario Lake Hills and Plain
35	South Central Plains	62	North Central Appalachians
36	Ouachita Mountains	63	Middle Atlantic Coastal Plain
37	Arkansas Valley	64	Northern Piedmont
38	Boston Mountains	65	Southeastern Plains
39	Ozark Highlands	66	Blue Ridge Mountains
40	Central Irregular Plains	67	Central Appalachian Ridges and Valleys
41	Northern Montana Glaciated Plains	68	Southwestern Appalachians
42	Northwestern Glaciated Plains	69	Central Appalachians
43	Northwestern Great Plains	70	Western Allegheny Plateau
44	Nebraska Sand Hills	71	Interior Plateau
45	Piedmont	72	Interior River Lowland
46	Northern Glaciated Plains	73	Mississippi Alluvial Plain
47	Western Corn Belt Plains	74	Mississippi Valley Loess Plains
48	Lake Agassiz Plain	75	Southern Coastal Plain
49	Northern Minnesota Wetlands	76	Southern Florida Coastal Plain