Intensive Early Season Adulticide Applications Decrease Arbovirus Transmission Throughout the Coachella Valley, Riverside County, California

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ABSTRACT

In the Coachella Valley of California the seasonal onset of St. Louis encephalitis virus (SLEV), western equine encephalomyelitis virus (WEEV), and West Nile virus (WNV) has been detected consistently at the shoreline of the Salton Sea near the community of North Shore. The timing and intensity of initial amplification in the *Culex tarsalis* Coquillett/wild bird cycle at this focus seemed closely linked to the subsequent dispersal of virus to the rest of the Coachella Valley and perhaps southern California. In 2004, an attempt was made to interrupt the amplification and dispersal of WNV using ground ultra-low volume (ULV) applications of Pyrenone 25-5®. Although these localized treatments were started 1 month after the initial detection in April, surveillance indicated no dispersal from this focus at this time. However, these treatments appeared to have little effect, and WNV eventually was detected throughout the valley, with seven human cases reported in the urbanized upper valley near Palm Springs. In 2005, the initial detection of WNV at North Shore at the end of May was followed rapidly by dispersal throughout the valley precluding efforts at containment. Evaluation of ground and aerial applications at North Shore during May and June 2005, respectively, indicated variable kill of sentinel mosquitoes (overall mortality: ground, 43%; air, 34%) and limited control of the target *Cx. tarsalis* population. In 2006, aerial ULV applications with the same chemical were begun immediately following the first detection of virus in mid-April, resulting in an apparent reduction of *Cx. tarsalis* abundance and delay of WNV activity in the rural lower valley and a marked decline in transmission by *Culex quinquefasciatus* Say populations in the densely populated upper northwestern valley with no human cases reported. Key Words: Adulticide—Control—*Culex tarsalis*—*Culex quinquefasciatus*—West Nile virus.

INTRODUCTION

OUR RESEARCH ADDRESSES the hypothesis that intensive early season mosquito control directed at a critical nidus of early season virus amplification may interrupt or delay amplification, limit dispersal, and thereby preclude outbreaks of disease. Increasing early season mosquito mortality previously was shown to have a marked impact on the resulting summer population using a compartmental simulation

model (Moon 1976), but the success of this approach has not been demonstrated in the field.

The on-going epidemic of West Nile virus (WNV) in Coachella Valley has provided a unique opportunity to test our hypothesis, because the seasonal onset of transmission in southern California frequently begins in late spring or early summer at a small wetland near the northeastern shore of the Salton Sea (Reisen et al. 1992). Historically, St. Louis encephalitis virus (SLEV) and western equine encephalo-

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myelitis virus (WEEV) dispersed north and westward from this focus to the remaining shoreline and then throughout the agricultural regions of the southern valley (Reisen et al. 1995a,b) as summarized conceptually in Figure 1. This dispersal appeared to be driven by the abundance gradient of *Culex tarsalis* Coquillett that declined progressing northward and upland away from the Salton Sea (Reisen and Lothrop 1999). Although *Culex quinquefasciatus* Say from this area is a potential vector of SLEV (Meyer et al. 1983), it has not been incriminated in the transmission of SLEV in the urbanized upper valley. However, with the invasion of WNV, urban *Cx. quinquefasciatus* have assumed greater importance (Reisen et al. 2004) and required intensive surveillance and control.

Since its introduction in 2003, WNV activity has been initiated at the same early season focus during 2004, 2005, and 2006 (Reisen et al. 2008). This pattern of focal early transmission and apparent dispersal provided an opportunity to disrupt focal virus amplification through intensive early season mosquito control, because the North Shore focus lies at the extreme southeast corner of the Coachella Valley, with only a narrow corridor of wetlands and agriculture connecting this area to the rest of the valley (Fig. 1). The current study documents the impact of reactive ground, and proactive ground and aerial control by the Coachella Valley Mosquito and Vector Control District (CVMVCD) on the amplification of WNV at North Shore and dispersal to the rest of the Coachella Valley.

FIG. 1. Pattern of West Nile virus (WNV), St. Louis encephalitis virus (SLEV), and western equine encephalomyelitis virus (WEEV) dispersal from North Shore in *Culex tarsalis* (depicted by gray arrows). Area of WNV infection in *Cx. quinquefasciatus* in urban areas depicted by white perimeter.

METHODS

Surveillance

Mosquito abundance and infection was monitored in Coachella Valley by 58 dry ice-baited CDC-style traps (CO₂T) (Newhouse et al. 1966) run biweekly, nine sentinel chicken flocks each comprised of 10 sentinel hens (Lothrop et al. 1992) sampled biweekly, and 17 gravid traps (Cummings 1992) run weekly in the upper valley during 2005 and 2006 (Fig. 2). Six additional CO₂Ts and three sentinel flocks of 10 hens each were maintained in Imperial County along the southern shore of the Salton Sea to monitor virus at wetland habitats at or near wildlife refuges. These refuges are relatively similar to the northern shore of the Salton Sea in Coachella Valley, rarely were treated for larval or adult mosquito control during the 2004–2006 period, and therefore provided a useful negative comparison area to intensively treated sites in Coachella Valley. CO₂Ts primarily moni-

tored *Cx. tarsalis*, which was the predominant vector species in rural areas, whereas gravid traps targeted *Cx. quinquefasciatus* in the urban upper valley. Sentinel chicken flocks upland from the margin of the Salton Sea were accompanied by two CO₂Ts each that have been relatively successful in collecting *Cx. quinquefasciatus* compared to gravid traps in the same areas (Reisen et al 1999). Additional CO₂Ts were run intermittently during various research projects, locally enhancing arbovirus surveillance sensitivity. Although the start dates for surveillance varied slightly among years, multiple negative samples were collected each year prior to the detection of WNV activity.

Mosquitoes were returned to the CVMVCD, where they were anesthetized with triethylamine, enumerated by species, most pooled into lots of 50 females each, and frozen at –80°C. Pools were shipped on dry ice to the Arbovirus Unit at the Center for Vectorborne

FIG. 2. Surveillance sites in the Coachella and Imperial Valleys, 2003–2006. Gravid traps were only deployed during 2005–2006.

Diseases (CVEC), where they were tested concurrently for WEEV, SLEV, and WNV using a multiplex real-time reverse transcription—polymerase chain reaction (RT-PCR) assay (Brault et al., unpublished data). Trap counts were transformed by $\ln(y + 1)$ for analyses, and abundance was expressed as backtransformed or geometric mean number of females per trap-night (Reisen and Lothrop 1999). Mosquito infection rates were estimated by a maximum likelihood method to account for variation in pool size (Biggerstaff 2003). Sentinel chickens were bled by lancet stick of the comb (Reisen et al. 1993), with blood specimens screened for antibody against WEEV or SLEV/WNV by enzyme immunoassay (EIA) and confirmed; the infecting virus was identified by plaque reduction neutralization assay (PRNT) by the Viral and Rickettsial Diseases Laboratory of the California Department of Health Services (Hom et al. 2004). Positive sentinel chickens were replaced to maintain sensitivity. Infections were expressed as the proportion of negative chickens seroconverting per 2-week interval. Protocols for the care and bleeding of sentinel chickens were approved by the Institutional Animal Care and Use Committee of the University of California, Davis.

Dead birds reported by the public to the Dead Bird Hotline (McCaughey et al. 2003)

were shipped to CVEC where oral swabs and/or kidney tissues were tested for WNV RNA using standard RT-PCR methods (Kauffman et al. 2003). Because of the low numbers of corvids present in Southeastern California (Reisen et al. 2006), relatively few birds were tested annually.

Human cases were detected passively by medical providers in Coachella Valley, and were reported to Riverside County Health Department and to the Viral and Rickettsial Diseases Laboratory of the California Department of Public Health.

Control

Although our report focuses on adulticide applications, the CVMVCD for the past decade also has attempted to suppress mosquito populations in the North Shore area with a larviciding program using VectoBac® (Valent BioSciences, 870 Technology Way, Libertyville, IL) and the growth regulator Altocid® (Wellmark International, Schaumburg, IL). The arrival of WNV necessitated enhanced suppression leading to the adulticide applications reported in the current paper. Ground applications were done by a truck-mounted Pro-Mist® ultra-low volume (ULV) fogger (Clarke Mosquito Control Products, Inc., Roselle, IL) using undiluted

TABLE 1. *Cx. tarsalis* INFECTION RATE AT RURAL NORTH SHORE, *Cx. quinquefasciatus* INFECTION RATE IN THE URBANIZED UPPER VALLEY, AND OVERALL INFECTION RATES FOR COACHELLA VALLEY, ESTIMATED BY THE MAXIMUM LIKELIHOOD METHOD (BIGGERSTAFF, 2003)

		<i>Cx. tarsalis</i>		<i>Cx. quinquefasciatus</i>	
		North Shore	Total	Upper Valley	Total
2004	Pools Tested	244	1153	147	230
	WNV positive	37	92	2	4
	IR	5.35	2.01	0.59	0.76
	LL	3.83	1.62	0.11	0.25
	UL	7.70	2.45	1.92	1.81
2005	Pools Tested	499	2198	475	662
	WNV positive	11	39	53	54
	IR	0.50	0.42	4.19	2.92
	LL	0.27	0.31	3.18	2.22
	UL	0.88	0.57	5.44	3.78
2006	Pools Tested	293	1823	689	930
	WNV positive	4	36	2	2
	IR	0.37	0.47	0.31	0.07
	LL	0.12	0.34	0.13	0.01
	UL	0.88	0.64	0.64	0.24

IR, MLE infection rate per 1,000; UL and LL, upper and lower 95% confidence limits of the IR estimate.

TABLE 2. MEAN SENTINEL MORTALITY DURING GROUND APPLICATIONS OF PYRENONE 25-5 DURING MAY 2005 AT THE COMMUNITY OF NORTH SHORE, COACHELLA VALLEY

Cluster	<i>n</i>	24-May	26-May	28-May	Mean
NW	9	65	55	18	46a
Mid	6	26	47	0	24b
SE	12	59	41	34	49a
Mean	27	59a	47a	21b	43

Means followed by the same letter were not significantly different ($p > 0.05$) using a Fisher's LSD test, n = number of cages in each cluster.

Pyrenone 25-5[®] (Bayer Environmental Science, Montvale, NJ) at the rate of 0.0025 lb/acre of active ingredient. Routes were designed to follow all available roads to give maximum coverage. Aerial applications were done by a single-engine, fixed wing aircraft (Air Tractor 301, Air Tractor Inc., Olney, TX) equipped with two Micronair[®] AU5000 atomizers (Micron Sprayers Ltd., Bromyard Industrial Estate, Bromyard, Herefordshire, UK). Pyrenone 25-5

was diluted at a ratio of 1:2 with BVA Spray 13[®] oil (BVA Inc., Wixom, MI) to minimize evaporation and aid in droplet descent (Lothrop et al. 2007b).

Ability of the CVMVCD to effectively disperse spray droplets into the target treatment area by ground and aerial ULV applications was assessed by bioassay during 2005 using replicated sentinel cages (Townzen and Natvig 1973) containing 15–25 mosquitoes positioned

FIG. 3. Sentinel mosquito cage distribution for the evaluation of ground and aerial ultra-low volume (ULV) applications in 2005.

at 1–3 m in height (Lothrop et al. 2007a) and by impingement of droplets on 25 mm × 75 mm Teflon[®]-coated glass slides rotated by a Bio-Quip[®] (Rancho Dominguez, CA) Aerosol Droplet Sampler (“slide spinner”). Droplets were counted in size ranges of $\leq 40 \mu$, 41–70 μ , 71–100 μ , and $> 100 \mu$. For the ground ULV assessment in May 2005, sentinels and slide spinners were clustered at three sites within the treated area (Fig. 3) to sample droplet penetration through representative landscapes. The NW cluster was set in low desert scrub, the middle cluster was set along a *Tamarix* stand within a dry wash, and the SE cluster was deployed along four transects through a small residential community at Mecca Avenue. Slide spinners were distributed among the sentinel clusters. The aerial trial was done in the same

region in June 2005, but the sentinel transects and two slide spinners were deployed only within the small community, and downwind and toward the shoreline vegetation.

RESULTS

Culex tarsalis abundance at 14 CO2Ts operated biweekly at North Shore varied markedly among the 4 years of monitoring (Fig. 4A). Overall vernal geometric means during 2003, 2004, and 2005 (38.8, 34.7, and 41.1 females per trap night, respectively) without intensive adult control were significantly greater than during 2006 (27.8 females per trap night, respectively) when intensive adulticide operations were conducted ($F = 2.92$, $df = 3, 204$, $p =$

FIG. 4. Geometric mean number of *Cx. tarsalis* collected per CO2T night at North Shore area, Coachella Valley (A) and marshes at the southern shore of the Salton Sea, Imperial County (B). Arrows show the periods of intensive ground (2004) and aerial plus ground (2006) adulticide applications. Geometric monthly means during April–June are shown in the insets.

0.04). These means were markedly lower than observed historically at North Shore (Reisen et al. 2002), when the Salton Sea peaked at -266.75 feet below sea level, peripheral marshes were more extensive, and before intensive springtime larval control using Vecto-Bac and Altocid pellets was initiated. Differences among years were attributed to the impact of adulticiding during April (Fig. 4), because the month by year interaction effect was significant ($F = 4.48$, $df = 6, 204$, $p < 0.001$) when tested by a three-way analysis of variance (ANOVA) with year, month and sites as main effects. In addition, *Cx. tarsalis* abundance at six CO2Ts in Imperial County did not show a significant reduction in abundance during 2006 ($F = 1.97$, $df = 3, 73$, $p > 0.05$) and even though there was a significant month by year interaction ($F = 5.52$, $df = 6, 73$, $p < 0.001$), May 2006 had the highest vernal mean (Fig. 4B).

2003

WNV invaded Imperial County in July and then Coachella Valley in August (Table 1). No human cases were reported, and low-level enzootic transmission seemed confined to rural areas in the lower valley at the Salton Sea. WNV was not detected in 275 pools of *Cx. quinquefasciatus* or sentinel chickens at upper valley sites.

2004

Despite extensive efforts to contain WNV following the early spring detection on 14 April, virus dispersal during 2004 followed the historical pattern shown in Fig. 1. Although mostly confined to the lower valley in *Cx. tarsalis* (Table 1), there was low level infection detected in *Cx. quinquefasciatus*, seroconversions at sentinel chicken flocks, and seven hu-

FIG. 5. Distribution of positive mosquito pools, sentinel chicken flocks, dead birds, and human cases, Coachella Valley, 2004.

man cases in the upper valley by the end of September (Fig. 5). Ground ULV applications at North Shore began on 17 May (Fig. 6), one month after initial detection of WNV on 14 April. Although all WNV activity appeared to remain contained near the North Shore focus during the month between detection and intervention, ground applications over the next 56 nights failed to interrupt WNV transmission at this site or elsewhere throughout most of the Coachella Valley. Gravid traps were not run routinely in the upper valley at this time; however, positive pools of *Cx. quinquefasciatus* collected at CO₂Ts were detected in the upper valley in association with the seven human cases (incidence of approximately 2.18 cases per 100,000).

2005

WNV was first detected at North Shore on 29 May, 1 month later than in 2004, and then

rapidly appeared in the *Cx. quinquefasciatus* population in the urbanized upper valley (Fig. 7), preventing any attempt at containment. Extensive gravid trapping was initiated in the upper NW portion of the valley (Fig. 2), increasing the sensitivity of *Cx. quinquefasciatus* sampling, the number of pools tested to 662, and the infection rate to 4.19 per 1,000 (Table 1). Midseason enzootic activity, July–September, in the upper valley was widespread, with *Cx. quinquefasciatus* infection rates as high as 34 per 1,000 in one residential neighborhood. Reactive ground adulticide treatments were made at sites throughout the valley with elevated mosquito infection rates. Widespread distribution and high mosquito infection rates in the upper valley were associated with five reported human cases (incidence, 1.56 per 100,000), comparable to 2004.

Reactive adulticide applications at North Shore provided the opportunity to assess the operational efficacy of ground and aerial ULV

FIG. 6. Route for ground ultra-low volume (ULV) treatments at North Shore, 2004.

applications. Three alternate nights of ground ULV applications of Pyrenone 25-5 in May 2005 at North Shore provided variable sentinel mortality at three sites along the Salton Sea shoreline (Table 2). Overall, 43% of 2,786 *Cx. tarsalis* sentinels in 27 cages were dead at approximately 12 h after application. Mortality following treatments 1 and 2, when NW winds were 1 and 3 mph, respectively, was significantly greater ($F = 11.2$, $df = 2, 72$, $p < 0.001$) than during treatment 3, when the winds were 8–10 mph from the SE. During treatments 1 and 3, winds carried the fog to sentinels along the shore to the SW and into the small community at Mecca Avenue, but not into the *Tamarix* along the wash, at the central cluster of cages (Fig. 3), where significantly lower sentinel mortality was recorded ($F = 5.4$, $df = 2, 72$, $p = 0.007$), and not to the majority of shoreline vegetation, where the

natural population tends to be concentrated (Lothrop et al. 2002). The Mecca Avenue community consisted of small houses with low and relatively open desert landscaping, allowing effective particle dispersal for at least 1.5 blocks (130 m) from the truck route, although efficacy varied over time among replicate applications. There were significant differences ($F = 11.2$, $df = 4, 54$, $p < 0.001$) among abundance of *Cx. tarsalis* at traps within the different treatment zones (Fig. 9), but these differences in abundance remained consistent over time, because both the time and interaction effects were not significant ($p > 0.05$), indicating that the spray did not alter abundance. In agreement, percentage control calculated using the formula of Mulla et al. (1971) was negative, indicating no control. Failure to detect a significant suppression of abundance may have been associated with

FIG. 7. Distribution of positive mosquito pools, sentinel chicken flocks, dead birds, and human cases, Coachella Valley, 2005.

rapid replacement of adults emerging from nearby wetland habitats.

Three consecutive nights of aerial treatment at North Shore in June 2005 were assessed by five CO2Ts distributed along the shoreline and 16 cages of mosquito sentinels positioned within the Mecca Avenue community. Mortality among these sentinel cages was more variable than observed at the same sites during the May ground treatment. Overall, 34% of 1,132 mosquitoes deployed in 16 cages on 3 nights were dead 12 h after spray, with means of 12–49% over the 3 nights of treatment and 0–97% among cages on the same night. There were distinct gaps in coverage, where the particle cloud apparently missed the target area during spray 1 and produced minimal mortality during sprays 2 and 3. There was no significant ($p > 0.05$) reduction in abundance comparing *Cx. tarsalis* catch 2 nights before to 2 nights after treatment: mean abundance of *Cx. tarsalis* per CO2T night in the core area decreased from 20 to 14 females, while the controls decreased from 163 to 99 females per CO2T night. Percent control using Mulla's formula was estimated to be 8%.

2006

The failure of reactive ground applications in 2004 and the surprisingly rapid spread of WNV in 2005 prompted the CVMVCD to implement proactive aerial and ground ULV treatments at

FIG. 8. Mean mortality of sentinel mosquitoes along four transects within the Mecca Avenue community as a function of sentinel cage distance from the ultra-low volume (ULV) ground application truck route.

FIG. 9. Geometric mean abundance of *Cx. tarsalis* females trapped at replicate CO2Ts located in the core or center, middle, and edge of the area treated by ground equipment with ultra-low volume (ULV) adulticide and at CO2Ts placed 1 (in) and 2 miles outside (out) the treated area, May 2005. Triangles show nights of treatment.

North Shore at the end of April 2006 after WNV was detected (Fig. 10). Although the aerial trials at North Shore in 2005 had disappointing results, the dependence of ground applications on access roads and prevailing winds and the ability to cover large areas by air, during the period of maximum host seeking just after sunset (Reisen et al. 1997), supported the decision to use aerial applications. The initiation of treatment was based upon an average abundance of >70 *Cx. tarsalis* in CO2Ts in and around North Shore, which was considered a risk for rapid WNV amplification. From 24 April through 2 June, ULV adulticides were applied by ground and air. Ground applications covered 26 hectares inside the Salton Sea Stare Park on each of 31 treatments during this period. Aerial applications covered 150 hectares for the first seven treatments, were extended westward to cover 180 hectares for the next seven treatments, and then continued on the western 78 hectares of the overall treated area for the last 12 treatments. Adjustments to the course and height of the flight path used in 2005 were made to better target the upland edge of shore-

line vegetation. Slide spinners were placed along this line of vegetation to document droplet dispersal at an area where prevailing winds tended to carry the droplets away from the target area. This was considered to be the most difficult area to reach and was used as the worst case scenario. As with all our aerial trials, due to landscape and atmospheric influences, there were gaps in coverage as measured by droplet impingement and/or sentinel mortality. The average densities of droplets of $<40\ \mu$ in diameter on slides at five spinners on 4 nights sampled during April ranged from 0 to 275 droplets per cm^2 , documenting variability among sites and applications. Mortality for sentinel mosquitoes deployed in 10 cages on 26–27 April averaged 24%, ranging from 0% to 86%. Percent control for *Cx. tarsalis* abundance based on CO2Ts operated pretreatment and on 26 April, 11 May, and 25 May post-treatment was estimated to be an encouraging 70%, 45%, and 69%, respectively.

Results from mosquito pools collected in April just prior to treatment showed that applications had begun just after the onset of WNV activity and that dispersal out of this focus may have been in progress. The CVMVCD responded by extending the treatment area further west to stay ahead of the presumed path of dispersal. Primary emphasis was placed on aerial ULV treatments along the shoreline with ground ULV filling in areas such as the Salton Sea State Park to the southeast of North Shore (Fig. 10). These treatments were concluded when results from surveillance indicated the continued absence of virus activity. Although WNV appeared at the North Shore focus and began to spread westward, it did not follow the expected seasonal pattern (Fig. 1) and was detected in only one sentinel chicken and two *Cx. quinquefasciatus* pools in the upper valley (Fig. 11 and Table 1). Late season activity was limited to the lower valley and primarily associated

FIG. 10. Area treated by ground and aerial ultra-low volume (ULV) along the northern shore of the Salton Sea during 2006. Aerial spray swath is shown in white.

FIG. 11. Distribution of positive mosquito pools, sentinel chicken flocks, dead birds, and human cases, Coachella Valley, 2006.

with duck club flooding and local increases in *Cx. tarsalis* abundance (Fig. 11).

DISCUSSION

Effective vernal suppression of *Cx. tarsalis* population abundance at North Shore appeared to effectively delay WNV amplification and subsequent dispersal to the rest of Coachella Valley. Parameters used to assess the interruption of virus transmission included seroconversion rates among sentinel chickens and infection rates in *Cx. tarsalis* and *Cx. quinquefasciatus* mosquitoes (Figs. 12 and 13). Too few dead birds or human cases were detected for meaningful statistical analyses. Figures 12 and 13 summarize all surveillance sites in the Coachella Valley and three sites in the Imper-

ial Valley. WNV initially entered the Coachella Valley in August 2003, but remained limited to the lower valley (Reisen et al. 2004). The first full season of WNV activity was during 2004, and although WNV enzootic activity was most intense within the *Cx. tarsalis* populations in the rural lower valley, the seven human cases in the upper valley point to *Cx. quinquefasciatus* involvement, because *Cx. tarsalis* is largely absent from this area. These results indicated a failure to contain WNV at its North Shore focus using reactive ground ULV adulticiding. Although evaluations of ground trials in 2005 (Lothrop et al. 2007a) indicated that this method can effectively reduce abundance, the dependence on wind to disperse the fog and the unfavorable direction of the prevailing winds may have prevented the droplets from reaching large portions of *Cx. tarsalis* popula-

FIG. 12. Seroconversion rates in sentinel chickens (proportion of negative chickens seroconverting per 2-week interval) deployed in Coachella Valley and Imperial Valley along the southern shore of the Salton Sea plotted as a function of disease weeks during 2004–2006 (for flock locations, see Fig. 2).

tion hunting along ecotonal vegetation at North Shore. It is also important to note that these treatments commenced almost one month after the initial detection of WNV activity at North Shore, and although not detected by our surveillance program, virus had apparently broken out of the North Shore target area.

In 2005, virus was not detected until 29 May, more than 1 month later than in 2004. Most likely, the virus was active prior to this date of initial detection and had already dispersed throughout the Coachella Valley. In agreement, WNV was detected in the upper valley immediately after detection at North Shore, precluding any attempt at containing dispersal. Enzootic surveillance in the upper valley was enhanced during 2005 by extensive use of gravid female traps, and their use contributed to the increased infection rates recorded in Table 1. Five human cases were reported during 2005, similar to the seven reported during 2004.

Timely aerial ULV treatments at North Shore in 2006 appeared to interrupt the early season amplification, contained early dispersal of WNV out of the North Shore area, limited the involvement of *Cx. quinquefasciatus*, and may have prevented tangential transmission to humans. Factors contributing to the success of the aerial treatments included the ability of the aircraft to reach large acreage not accessed by road, especially the shoreline vegetation, treatment of large acreage ahead of the dispersal track of the virus, and repeated 26 treatments, weather permitting, over a period of 40 nights. Although the calculated percent control averaged only 61%, repeated treatments apparently compensated for gaps in coverage and missed targets. Surveillance data from our comparison areas in the Imperial Valley that did not receive adulticide treatments indicated that WNV activity was greater during 2006 than in previous years, in marked contrast to the decrease reported in the Coachella Valley. Because the two valleys are close in proximity and similar in climate and seasonal mosquito-borne virus activity (Reisen et al. 1996), we feel that these results support our contention that intensive early season aerial treatments during 2006 were successful in delaying the amplification of virus in the rural lower valley and thereby prevented virus dispersal to the upper valley. An understanding of the landscape ecology of arboviruses in Coachella Valley provided us with an early season target for focused intervention that resulted in a long term and widespread impact upon virus amplification during the en-

FIG. 13. Maximum likelihood estimates of West Nile virus (WNV) infection per 1,000 females tested plotted by month for populations of *Cx. tarsalis* in Coachella and Imperial valleys and *Cx. quinquefasciatus* in Coachella Valley, 2004–2006.

suing season. These unique data show the value of long term ecological studies and early season intervention.

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DISCLOSURE STATEMENT

No conflicting financial interests exist.

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