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COMPARATIVE EFFECTIVENESS OF THREE ADULT MOSQUITO SAMPLING METHODS IN HABITATS REPRESENTATIVE OF FOUR DIFFERENT BIOMES OF CALIFORNIA

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ABSTRACT. The effectiveness of New Jersey (NJ) light, dry ice baited, and gravid female traps for collecting adult mosquitoes was compared at representative habitats in the Coachella, San Joaquin, and Sacramento valleys and the Los Angeles basin of California. The NJ light traps effectively sampled *Anopheles freeborni, Culex tarsalis, Psorophora columbiae,* and several *Aedes* when abundance was high in rural areas with minimal competitive illumination. Dry ice-baited encephalitis virus surveillance or CDC style traps collected significantly more females of most species at most localities than did NJ light traps, regardless of background illumination. The Cummings modification of the Reiter gravid female trap baited with a bulrush (*Schoenoplectus*) infusion was the best method for collecting *Culex pipiens* complex females in most habitats. In the Los Angeles basin, gravid traps baited with bulrush infusion collected, on average, 4.5 times more *Culex quinquefasciatus* females than did traps baited with the Reiter infusion. The bulrush infusion in combination with the Cummings trap design seemed to provide resting site cues and collected males as well as empty and bloodfed females. Mosquito surveillance programs in California should include the systematic operation of dry ice-baited and gravid female traps to improve surveillance sensitivity for selected species in appropriate habitats.

KEY WORDS Adult collection methods, California, *Culex tarsalis, Culex pipiens* complex

INTRODUCTION

The accurate measurement of adult mosquito abundance is critical in evaluating control programs and in forecasting encephalitis virus activity. California mosquito and vector control districts currently participate in a statewide mosquito surveillance program that provides weekly Mosquito Occurrence Reports averaging the catch of adult *Culex tarsalis* Coquillett and other mosquito genera in New Jersey (NJ) light traps (Mulhern 1942) within urban, suburban, and rural habitats. Originally, light traps were deployed to monitor *Cx. tarsalis* abundance in relation to enzootic virus transmission activity (Longshore 1960, Loomis and Meyers 1960) and replaced labor intensive resting catches in natural shelters and red boxes (Loomis and Green 1959) as a method of monitoring adult abundance.

The NJ light trap samples nocturnal, phototactic mosquitoes such as *Cx. tarsalis* with minimal collection effort; however, catch size is reduced markedly by competing light sources (Milby and Reeves 1989). Decreased sensitivity of NJ light traps in conjunction with the progressive urbanization of California have led most control agencies to incorporate supplemental sampling methods into their mosquito surveillance programs, including CDC (Sudia and Chamberlain 1962) or encephalitis virus surveillance (EVS) (Pfuntner 1979) traps augmented with dry ice (hereafter, CO_2 traps) and CDC (Reiter 1987) or Cummings (Cummings 1992) gravid female traps baited with alfalfa infusion (Reiter 1983). The CO_2 traps rely on a CO_2 chemotaxis by host-seeking females and therefore are less influenced by background illumination. Gravid female traps baited with the standard alfalfa infusion (alfalfa, lactalbumin, and yeast) attract mostly *Culex quinquefasciatus* Say and are most effective in urban habitats (Reisen and Pfuntner 1987, Reisen and Meyer 1990).

The current research compared the effectiveness of NJ light, CO_2, and gravid female traps for sampling *Cx. tarsalis* and other potential vector and pest mosquitoes in representative habitats in 4 different ecological areas of California. This research extends the results of previous trap effectiveness studies (e.g., Hayes et al. 1958, Milby et al. 1978, Meyer et al. 1984, Reisen and Pfuntner 1987, Milby and Reeves 1989, Reisen et al. 1990) that compared these and other methods in specific habitats. An increasing human population encroaching on formerly rural areas, expanded and effective mosquito control, and improved flood and irrigation water management have combined to markedly alter the landscape of California as well as mosquito abundance and diversity (Reeves and Milby 1989). Our research evaluated the effectiveness of 3 sampling methods for monitoring mosquito abundance in this altered landscape.

MATERIALS AND METHODS

During 1997, representative habitats were studied concurrently in 4 major biomes of California:

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the southern Coachella Valley in Riverside County, the Bakersfield area of the southern San Joaquin Valley in Kern County, the Sacramento Valley in Sacramento and Yolo counties, and the Los Angeles basin in Orange County. Selection of localities within each biome was based on the presence of a NJ light trap and habitat type. Habitats included urban premises, suburban residences, urban parks, riparian corridors, managed marshland, irrigated agriculture, and golf courses. Differentiation between urban and suburban areas was based on the extent of vegetation and human population density. Urban parks often were located along water courses but usually were isolated by surrounding housing areas, whereas rural riparian habitat presented an extensive vegetative continuum transecting agricultural habitat. All agriculture was irrigated and included row crops (Coachella, San Joaquin, Sacramento), date orchards (Coachella), citrus (San Joaquin), grapes (San Joaquin, Sacramento), rice (Sacramento), and pasture (Sacramento).

Three trap types were compared at 8–10 localities within each of the 4 biomes on 1 night per week from July through October 1997. Standard NJ light traps were hung at 2.4 m (8 ft.) height and fitted with 25-watt incandescent or 5-watt fluorescent lamps (Sacramento and Yolo counties) that yielded comparable brightness (≈250 lumens). The CO_2 traps (CDC style in Coachella, San Joaquin, and Sacramento; EVS style in Los Angeles) were operated concurrently without lights at fixed standards of 1.5 m height positioned within 50 m of the NJ light trap and baited with dry ice presented in modified 3.7-liter (1-gal.) insulated cans (≈2.5 kg) or styrofoam holders (Coachella, ≈1.5 kg). All gravid traps were constructed following the revised design of Reiter (1987) upgraded by Cummings (1992) and were operated at fixed locations on the ground within 50 m of the NJ light trap. Gravid traps were baited with 1-wk-old bulrush (*Schoenoplectus* [=*Scirpus*]) infusion consisting of 4.5 g of chopped and dried bulrush stems per liter of tap or well water (Walton and Workman 1998). The bulrush infusion attracted a broad range of species (especially *Culex stigmatosoma*) in field tests (Walton and Workman 1998) and attracted *Cx. tarsalis* in laboratory experiments (J. Millar, personal communication).

Attractiveness of the bulrush infusion was compared with the original alfalfa infusion (Reiter 1983) at 8 sites in the Los Angeles basin during a 10-wk period. Traps were operated at 2 fixed positions at the same locality within 50 m of each other. Infusions were prepared fresh each week and rotated between positions to account for any spatial effects.

Mosquitoes were returned to the laboratory where they were sorted to species, sex, and female abdominal condition (empty, bloodfed, gravid) and counted. Abdominal conditions were comparable with Sella's (1920) stages 1, 2–5, and 6–7, respectively. Counts were transformed by $\ln(y + 1)$ to control the variance and normalize the distribution. Separate multiway classification analyses of variance (ANOVA) were conducted on data from each of the 4 biomes, with collection method and habitat as main effects (GLM procedure for fixed effects with 1st-order interactions, NCSS software version 6.0.22). Data initially were blocked by weeks ($n = 10 - 12$), but time accounted for <5% of the total variance at all biomes and was deleted in the final ANOVAs. In the Los Angeles basin, counts from gravid traps baited with alfalfa infusion were not included in the general ANOVA but rather were compared with counts from traps baited with the bulrush infusion in separate ANOVAs with media, position, and habitat as main effects. Throughout, posteriori Newman–Keuls multiple comparison tests were used to group means that were not significantly different ($P > 0.05$). Means in text and tables were backtransformed or geometric means expressed as numbers per trap per night. Initially, product moment correlations were calculated for transformed and untransformed female counts of the abundant species collected in NJ light, CO_2, and gravid traps at each biome. However, $\ln(y + 1)$ transformations did not appreciably improve the fit and only untransformed values are shown.

RESULTS

Fauna: A total of 37,601 female and 4,787 male mosquitoes comprising 19 species in 5 genera were collected by all methods (Table 1). *Culex pipiens* complex species were most abundant and widespread, followed by *Cx. tarsalis. Culex pipiens* complex specimens from the Sacramento and San Joaquin valleys were a mixture of *quinquefasciatus* and *pipiens* genotypes, whereas specimens from the Los Angeles basin and Coachella Valley south of the Tehachapi Mountains were only *quinquefasciatus* (Urbanelli et al. 1997). *Aedes* species were associated with irrigated pasture and were most abundant in the Coachella and Sacramento valleys. *Anopheles freeborni* Aitken was abundant in the rice growing areas of the Sacramento Valley. *Culiseta incidens* (Thomson) was abundant in residential areas in the Los Angeles basin and Sacramento Valley. *Psorophora columbiae* (Dyar and Knab) was found only in the Coachella Valley. Statistical analyses were limited to the abundant species (total ≥200) indicated by bold font in Table 1.

Coachella Valley: Gravid traps collected significantly more *Cx. quinquefasciatus* females and males than did either NJ light traps or CO_2 traps (Table 2). The interaction between method and habitat was significant; catch in CO_2 traps was greatest in agricultural habitat, whereas catch in gravid traps was greatest in agricultural and golf course habitats. Catch of *Cx. tarsalis* females was greatest in CO_2 traps in suburban and agricultural habitats. Interestingly, gravid traps collected significantly more

Table 1. Total female (F) and male (M) mosquitoes of each species collected by all methods during 1997.[1]

Species collected	Coachella		San Joaquin		Los Angeles		Sacramento		Total	
	F	M	F	M	F	M	F	M	F	M
Aedes melanimon	0	0	27	0	0	0	1,075	33	1,102	33
Aedes nigromaculis	0	0	53	0	0	0	11	3	64	3
Aedes vexans	121	0	0	0	0	0	384	8	505	8
Anopheles hermsi	0	0	0	0	110	3	0	0	110	3
Anopheles franciscanus	1	0	5	1	6	4	27	8	39	13
Anopheles freeborni	0	0	4	0	0	0	**4,776**	**1,008**	4,780	1,008
Anopheles punctipennis	0	0	0	0	0	0	2	0	2	0
Culex apicalis	0	0	0	0	2	0	0	0	2	0
Culex boharti	0	0	0	0	1	1	0	0	1	1
Culex erythrothorax	1	0	2	0	142	0	186	0	331	0
Culex pipiens/quinquefasciatus	**3,054**	**1,235**	**9,415**	**801**	**2,879**	**224**	**2,956**	**2,912**	18,304	2,564
Culex stigmatosoma	4	0	12	1	79	0	140	23	235	24
Culex tarsalis	**1,771**	195	**1,924**	50	**394**	5	**7,784**	**865**	11,877	1,115
Culex thriambus	0	0	0	0	61	0	0	0	61	0
Culiseta incidens	0	0	0	0	93	1	95	27	188	28
Culiseta inornata	0	0	0	0	1	0	2	0	3	0
Culiseta particeps	0	0	0	0	1	0	0	0	1	0
Psorophora columbiae	**8,509**	30	0	0	0	0	0	0	8,509	30
Total	13,461	1,460	11,442	853	3,769	238	17,438	2,266	37,601	4,787

[1] Data in bold were used for trap evaluations.

Table 2. Backtransformed mean number of adult mosquitoes per trap night, Coachella Valley.[1,2]

			Habitat				
Species	Sex	Method	URB (TN = 72)	SUB (TN = 71)	AGRI (TN = 141)	GOLF (TN = 72)	Mean (TN = 356)
Culex quinquefasciatus	F	NJLT	0.09	0.00	0.22	0.22	0.14c
		CO2T	1.65	3.87	6.18	2.11	3.12b
		Gravid	4.87	5.23	7.97	14.53	7.46a
		Mean	1.57bc	2.15abc	3.28ab	2.89ab	2.41
Cx. quinquefasciatus	M	NJLT	0.00	0.00	0.15	0.11	0.01b
		CO2T	0.00	0.33	0.01	0.11	0.13b
		Gravid	1.15	1.69	5.97	8.70	3.45a
		Mean	0.29b	0.53b	1.07a	1.29a	0.75
Culex tarsalis	F	NJLT	0.00	0.57	1.25	0.09	0.41c
		CO2T	0.22	8.78	5.88	0.01	2.09a
		Gravid	0.22	2.13	1.86	0.32	0.86b
		Mean	0.15b	2.63a	2.53a	0.01b	1.01
Cx. tarsalis	M	NJLT	0.00	0.18	0.67	0.00	0.19a
		CO2T	0.00	0.13	0.00	0.00	0.00b
		Gravid	0.00	0.42	0.92	0.00	0.31a
		Mean	0.00c	0.24b	0.49a	0.02c	0.18
Psorophora columbiae	F	NJLT	0.00	0.35	6.67	0.28	0.91a
		CO2T	0.13	0.38	12.00	1.09	1.55a
		Gravid	0.00	0.00	0.01	0.00	0.00b
		Mean	0.00b	0.23b	3.74a	0.39b	0.70

[1] Means within each species/sex followed by the same letter were not significantly different by N-K multiple range test ($P > 0.05$).
[2] URB = urban, SUB = suburban, AGRI = agriculture, GOLF = golf course, TN = total trap nights for 3 methods at 10 sites for 12 wk, F = female, M = male, NJLT = New Jersey light trap, CO2T = CO_2 trap, Gravid = gravid trap.

Cx. tarsalis females than did NJ light traps. No significant difference was found between the catches of male *Cx. tarsalis* in NJ light and gravid traps, both of which were greatest in agricultural habitat. No significant difference was found in the catches of female *Ps. columbiae* between the NJ light and CO_2 traps, both of which were significantly greatest in agricultural habitat. Practically all *Aedes vexans* (Meigen) were collected by CO_2 traps in agricultural habitat (data not shown).

San Joaquin Valley: Catch of both *Cx. quinquefasciatus* females and males was greatest in gravid traps operated in agricultural and riparian habitats (Table 3). Catch of *Cx. tarsalis* females was greatest in CO_2 traps operated in riparian and agricultural habitats. The riparian locality along the Kern River was adjacent to citrus orchards irrigated with a drip system that pooled excessive water at the tree bases, providing extensive larval habitat.

Los Angeles basin: Gravid traps baited with bul-

Table 3. Backtransformed mean number of adult mosquitoes per trap night, San Joaquin Valley.[1,2]

			Habitat				
Species	Sex	Method	URB (TN = 99)	SUB (TN = 66)	AGRI (TN = 131)	RIP (TN = 33)	Mean (TN = 329)
Culex quinquefasciatus	F	NJLT	0.01	0.00	0.63	0.48	0.27c
		CO2T	3.77	1.56	58.97	6.40	7.60b
		Gravid	10.79	12.24	28.80	5.04	11.95a
		Mean	2.91c	2.27c	13.27a	6.15b	4.21
Cx. quinquefasciatus	M	NJLT	0.00	0.01	0.01	0.35	0.12b
		CO2T	0.00	0.00	0.02	0.46	0.12b
		Gravid	2.02	1.72	5.49	2.35	2.66a
		Mean	0.48b	0.43b	0.91a	0.87a	0.66
Culex tarsalis	F	NJLT	0.01	0.00	0.74	0.17	0.97b
		CO2T	0.33	0.22	10.35	32.12	3.96a
		Gravid	0.11	0.16	0.17	0.42	0.21c
		Mean	0.17c	0.12c	1.85b	6.20a	1.28

[1] Means followed by the same letter within species/sex were not significantly different by the N-K range test ($P > 0.05$).
[2] URB = urban, SUB = suburban, AGRI = agriculture, RIP = riparian, TN = total trap nights for 3 methods at 10 sites for 11 wk, F = female, M = male, NJLT = New Jersey light trap, CO2T = CO_2 trap, Gravid = gravid trap.

Table 4. Backtransformed mean number of adult mosquitoes per trap night, Los Angeles basin.[1,2]

Species	Sex	Method	Habitat URB (TN = 144)	Habitat MAR (TN = 93)	Habitat PARK (TN = 36)	Mean (TN = 273)
Culex quinquefasciatus	F	NJLT	0.14	0.09	0.86	0.32c
		CO2T	4.09	0.81	0.19	1.22b
		Gravid	24.87	2.68	20.43	11.68a
		Mean	4.32a	0.94c	2.62b	2.34
Cx. quinquefasciatus	M	NJLT	0.01	0.28	0.19	0.17b
		CO2T	0.01	0.00	0.00	0.00b
		Gravid	1.53	0.27	1.61	1.03a
		Mean	0.43a	0.17b	0.46a	0.35
Culex tarsalis	F	NJLT	0.14	0.16	0.67	0.30b
		CO2T	0.40	5.29	1.63	1.85a
		Gravid	0.33	0.13	0.12	0.19b
		Mean	0.28b	1.02a	0.70a	0.64

[1] Means followed by the same letter within each species/sex were not significantly different by the N-K range test ($P > 0.05$).
[2] URB = urban, MAR = marsh, PARK = urban park, TN = total trap nights for 3 methods at 8 sites for 12 wk, F = female, M = male, NJLT = New Jersey light trap, CO2T = CO_2 trap, Gravid = gravid trap.

rush infusion collected the most female *Cx. quinquefasciatus* in urban and park habitats in Orange County; CO_2 traps were most effective in urban habitats (Table 4). Similar to females, most *Cx. quinquefasciatus* males were collected in gravid traps operated in urban and park habitats. In contrast, most *Cx. tarsalis* females were collected by CO_2 traps in marsh habitat. Gravid traps baited with bulrush infusion collected significantly more *Cx. quinquefasciatus* females and males and *Cs. incidens* females than did gravid traps baited with the alfalfa infusion (Table 5). Position effects were significant for *Cx. quinquefasciatus* males but not females, indicating that males were influenced more by trap placement than were females. Habitat effects also were significant in the ANOVAs for *Cx. quinquefasciatus* but not for *Cs. incidens.*

Sacramento Valley: Catch size of *An. freeborni* females was significantly greatest in CO_2 and NJ light traps operated in agricultural habitat (Table 6). Catch of *An. freeborni* males was greatest in NJ light traps, followed by gravid traps. Catch of *Cx. pipiens* females and males was greatest in gravid traps operated in urban and suburban residential habitat. Catch of *Cx. tarsalis* females was greatest in CO_2 traps, followed by NJ light traps, operated in agricultural habitats.

Female abdominal condition: The 3 sampling methods targeted different portions of the female *Culex* population (Table 7). The NJ light and CO_2 traps collected mostly empty females (i.e., no visible blood or eggs), whereas gravid traps collected more gravid females. Proportionately more gravid female *Cx. pipiens* than *Cx. tarsalis* were collected in gravid traps. In contrast, most (>95%) females of species such as *Aedes* and *Psorophora* were unfed, regardless of the sampling method used (data not shown).

Correlation analysis: Correlation coefficients among sampling methods were calculated over both time and space for species collected abundantly by more than 1 method (Table 8). Catch of *Cx. tarsalis* females collected by NJ light trap was significantly correlated ($P < 0.01$) with females collected by CO_2 trap in all biomes except for urban Los Angeles basin, where catch was low overall. Catch of *Cx. tarsalis* in gravid traps was correlated with NJ light traps at 2 of 4 sites and with CO_2 traps at 1 of 4 sites. In contrast, catches of *Cx. pipiens* in gravid and CO_2 traps were correlated at 3 of 4 sites, but NJ light trap data was correlated with CO_2 and gravid traps at only 1 each of 4 sites. Although abundance of *An. freeborni* varied significantly among methods (Table 6), patterns measured by all 3 methods were well correlated over time and space in the Sacramento Valley. Similarly, the catch of

Table 5. Backtransformed mean number of females collected in gravid traps baited with bulrush or alfalfa infusions.[1]

Species	Sex	Bulrush (TN = 94)	Reiter (TN = 87)	P^2
Culex quinquefasciatus	F	11.01	2.44	<0.001
	M	1.09	0.31	<0.001
Culiseta incidens	F	0.35	0.01	<0.001

[1] TN = trap nights, F = female, M = male.
[2] *P*, means significantly different.

Table 6. Backtransformed mean number of adult mosquitoes per trap night, Sacramento Valley.[1,2]

Species	Sex	Method	Habitat URB (TN = 88)	SUB (TN = 77)	AGRI (TN = 239)	Mean (TN = 404)
Anopheles freeborni	F	NJLT	0.01	1.59	6.26	1.71a
		CO2T	0.27	1.52	7.97	2.06a
		Gravid	0.35	0.00	0.98	0.40b
		Mean	0.22c	0.89b	4.05a	1.27
An. freeborni	M	NJLT	0.00	0.37	1.72	0.57c
		CO2T	0.00	0.00	0.00	0.00c
		Gravid	0.21	0.00	0.72	0.28a
		Mean	0.08b	0.11b	0.69a	0.26
Culex pipiens	F	NJLT	0.65	0.69	0.41	0.58c
		CO2T	1.28	5.41	1.68	2.39b
		Gravid	23.06	9.98	2.26	8.51a
		Mean	3.49a	3.92a	1.31b	2.71
Cx. pipiens	M	NJLT	0.24	0.98	0.30	0.47b
		CO2T	0.00	0.00	0.00	0.00c
		Gravid	1.86	0.78	0.19	0.82a
		Mean	0.53a	0.54a	0.16b	0.40
Culex tarsalis	F	NJLT	0.87	0.84	6.33	1.93b
		CO2T	2.10	12.78	36.83	10.74a
		Gravid	2.46	0.16	1.17	1.05c
		Mean	1.72b	2.08b	7.49a	3.13
Cx. tarsalis	M	NJLT	0.19	0.37	2.62	0.81a
		CO2T	0.00	0.00	0.00	0.00c
		Gravid	0.63	0.00	0.84	0.46b
		Mean	0.26b	0.13b	0.90a	0.40

[1] Means followed by the same letter within each species/sex were not significantly different by the N-K range test ($P > 0.05$).
[2] URB = urban, SUB = suburban, AGRI = agriculture, TN = total trap nights for 3 methods at 10 sites for 12 wk, F = female, M = male, NJLT = New Jersey light trap, CO2T = CO_2 trap, Gravid = gravid trap.

Ps. columbiae in NJ light traps was correlated significantly ($P < 0.01$) with catch in CO_2 traps ($r = 0.591$) in the Coachella Valley; too few were collected in gravid traps for analysis.

Model II regression equations then were calculated for significantly correlated pairs of data to estimate the catch in NJ light traps (NJLT) from catch in CO_2 traps (CO2T). These regressions may be useful in sampling programs replacing NJ light with CO_2 traps and having historical data limited to NJ light traps. For *Cx. tarsalis* equations for each biome were as follows: Coachella, NJLT = 0.876 + 0.139CO2T, $R^2 = 0.138$; San Joaquin, NJLT = 0.179 + 0.103CO2T, $R^2 = 0.615$; and Sacramento, NJLT = 4.780 + 0.050CO2T, $R^2 = 0.163$. With the exception of the San Joaquin Valley, these regressions explained <20% of the variability observed among NJ light trap counts. In the Los Angeles basin, the regression coefficient did not differ significantly from 0 ($P > 0.05$).

DISCUSSION

Catch sizes by different sampling devices varied markedly among species and habitats. The NJ light traps worked well for *An. freeborni, Cx. tarsalis,* and *Ps. columbiae* in agricultural and riparian habitats where competing illumination was minimal. Catch size at NJ light traps was greater in agricultural habitats in the Sacramento Valley than in the Coachella and San Joaquin valleys. Differences in catch were not attributed to incandescent vs. fluo-

Table 7. Percent abdominal condition composition of *Culex tarsalis* and *Culex pipiens* complex females collected at 4 biomes by 3 sampling methods.[1]

Method	*Cx. tarsalis* *n*	GR	BF	MT	*Cx. pipiens* complex *n*	GR	BF	MT
NJLT	1,224	7.7	1.1	91.2	249	11.2	1.6	87.1
CO2T	9,804	0.7	0.5	98.8	9,071	0.4	0.7	98.8
GRAV	240	56.5	9.5	34.0	1,475	77.1	6.3	16.6

[1] NJLT = New Jersey light trap, CO2T = CO_2 trap, GRAV = gravid trap, GR = gravid, BF = bloodfed, MT = empty.

Table 8. Correlations over both time and space among untransformed counts of females per trap night.

Species and site	df	Trap comparison[1] 1 vs. 2	1 vs. 3	2 vs. 3
Culex tarsalis				
Coachella	115	0.28*	0.37*	0.54*
San Joaquin	108	0.78*	−0.05	0.15
Sacramento	108	0.40*	0.34*	0.18
Los Angeles	92	−0.06	0.02	−0.02
Culex pipiens complex				
Coachella	115	−0.02	0.17	0.33*
San Joaquin	108	0.09	0.44*	0.36*
Sacramento	108	0.40*	0.16	0.12
Los Angeles	92	0.09	0.16	0.51*
Anopheles freeborni				
Sacramento	108	0.78*	0.75*	0.71*

[1] 1 = New Jersey light trap; 2 = CO_2 trap; 3 = gravid trap.
* $P < 0.05$.

rescent lamp brightness (Barr et al. 1960) because both lamps purportedly output comparable lumens. Expanded use of security lighting at houses in many agricultural areas and the encroachment of suburban housing areas with home and street lighting have produced an "urban glow" and provided extensive competing background illumination (Milby and Reeves 1989). In addition, improved water management and mosquito control may have reduced mosquito population size in many areas of California. In combination, these factors reduced the catch in NJ light traps in many areas of the Coachella and San Joaquin valleys and essentially eliminated their effectiveness in the Los Angeles basin. Low catch size by NJ light traps throughout southern California during the current study agreed well with data trends summarized in unpublished Mosquito Abundance Reports during the past 10 years.

The CO_2 traps circumvented problems associated with competing background illumination and collected comparable or significantly greater numbers of all phototactic species than did NJ light traps, even in rural areas. The CO_2 traps also were advantageous in that they collected large numbers of *Cx. pipiens* complex females. Both NJ light and CO_2 traps sampled the same portion of the female population, collecting predominantly empty females. Previous studies in the Central Valley developed ratios between the catch size in NJ light and CO_2 traps in different habitats to estimate adult mosquito catch in NJ traps from that in CO_2 traps (Milby et al. 1978, Milby and Reeves 1989). We used linear regression to predict the number of *Cx. tarsalis* females per NJ light trap night from females per CO_2 trap night. However, these equations explained <20% of the variability in NJ light trap counts at 3 of 4 sites and generally were not considered useful in placing abundance measured by CO_2 traps into a historical context. Semi-log or log-log transformations did not markedly improve the R^2 values, indicating that the relationship between these 2 methods was linear over time and space within biomes.

Gravid traps baited with bulrush infusion collected the greatest numbers of *Cx. pipiens* complex females and males, especially in urban situations. The bulrush infusion also performed well in rural agricultural areas, where the alfalfa infusion previously was markedly less attractive and unable to compete with natural oviposition sites (Reisen and Pfuntner 1987, Reisen and Meyer 1990). The bulrush infusion collected significantly more females than did the alfalfa infusion in 3 habitats in Orange County and collected a greater diversity of species. Unfortunately, the bulrush infusion failed to collect large numbers of *Cx. tarsalis* gravid females when compared with concurrently operated CO_2 traps. Considering that the gonotrophic cycle of *Cx. tarsalis* is about 3 days long and that daily survivorship averages about 0.8 per day in most habitats (Reisen and Reeves 1990), then if equally effective, gravid traps should have collected about half the number of females as CO_2 traps, an effectiveness never achieved in the current study.

Interestingly, the gravid trap also collected males and nongravid females of several species that seemed to be responding to cues associated with resting sites, such as decaying *Schoenoplectus* odors, a plume of elevated humidity created as the fan moved air over the infusion, and/or the color of the black pan used to hold the infusion.

The present results indicated that the statewide mosquito surveillance program, which is based solely on NJ light trap data, should be expanded into an integrated mosquito surveillance program that utilizes the most sensitive sampling methods to measure the relative abundances of target species in specific habitats. Gravid traps should be used in urban and suburban environments to monitor *Cx. pipiens* complex species. The NJ light traps should be replaced by CO_2 traps in urban and suburban habitats and in those agricultural and rural areas where background illumination precludes the effective operation of NJ light traps. Because of the low sampling effort required and the phototactic response of the encephalitis virus vector species, *Cx. tarsalis* and *Aedes melanimon*, NJ light traps could be retained in rural areas of the Sacramento Valley where trap operation remains effective.

Additional research will be required to ensure adequate sensitivity and standardization. The CO_2 traps currently in use throughout California vary considerably in design (motor size, diameter, propeller configuration), light use, and dry ice presentation (pelletized or block ice placed in insulated cans with or without holes or in styrofoam holders). In addition, the frequency of operation and pattern of deployment should be optimized through conditional simulation experiments. The bulrush infusion improved catch size and species diversity in gravid traps over the alfalfa infusion but still did not collect sufficient numbers of *Cx. tarsalis,* the target of most surveillance and control programs in California. Improvement of oviposition attractants will be necessary before this trap can replace other sampling devices for most mosquito species.

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