CORRELATION OF *AEDES SIERRENSIS* CAPTURES AT HUMAN SENTINELS WITH CO_2-BAITED FAY-PRINCE AND DUPLEX CONE TRAPS

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ABSTRACT. The efficiency of the duplex cone and Fay-Prince traps for monitoring adult male and female *Aedes sierrensis* was evaluated at 3 field sites in California. The numbers of females captured by both types of traps were significantly correlated with human sentinel collections. The Fay-Prince trap captured more *Ae. sierrensis* females than the duplex cone trap and was a better tool for estimating female activity levels. There was no significant correlation between the number of males captured in Fay-Prince traps and at humans. Male numbers in duplex cone trap collections explained only 27% of the variation in the number of males collected at sentinels, suggesting that neither trap is a robust tool for estimating male activity around humans.

INTRODUCTION

Mechanical collection devices such as the Fay trap (Fay 1968) and the CDC light trap (Sudia and Chamberlain 1962) have proven to be effective tools for sampling adult mosquitoes. Traps are an appealing alternative to human sentinels for collecting mosquitoes and assessing population densities because: 1) they eliminate the bias from differences in attractiveness among sentinels, 2) they can be used to sample many populations simultaneously, 3) they may reduce labor costs, and 4) they lower the risk of workers acquiring mosquito-borne diseases. Since mosquitoes differ in their habitat choice, host-seeking behavior and temporal activity, selection of the appropriate design, placement and attractant for traps is crucial for accurate mosquito surveillance. For some diurnal species such as *Aedes albopictus* (Skuse) that are not attracted to light sources, population assessment using passive traps has been problematic. Recently, Freier and Francy (1991) described a new passive trapping device, the duplex cone, which utilizes both dry ice and visual stimuli as attractants. This trap collected large numbers of *Ae. albopictus* in field trials in eastern Orleans Parish, LA.

In this report, we present data on the efficacy of CO_2-baited duplex cone and Fay-Prince traps for monitoring adult populations of the western treehole mosquito, *Aedes sierrensis* (Ludlow), a species that is widely distributed in western North America from British Columbia to Baja California (Bohart and Washino 1978). In forested habitats of the coastal range and in lower elevation (<1,500 m) sites in the Sierra Nevada of California, *Ae. sierrensis* can be a serious nuisance species; it is also suspected to be an important vector of canine heartworm, *Dirofilaria immitis* (Weinmann and Garcia 1974). While female and male *Ae. sierrensis* are attracted to mammalian hosts which are used as blood sources and mating sites, determining the relative abundance of adults has been hampered by the lack of a suitable trapping system (Garcia et al. 1988). Previously, Garcia et al. (1988, 1989) found that *Ae. sierrensis* were captured in modified Magoon traps (Rudnick 1986) baited with rabbits and CO_2 alone and in combination; adult *Ae. sierrensis* were also collected in large numbers using CO_2-baited Fay-Prince traps (Garcia et al. 1989). Neither study, however, correlated trap catches with *Ae. sierrensis* activity at human sentinels. In the latter study, the rabbit-baited and Fay-Prince traps captured similar numbers of female *Ae. sierrensis*, but more males were collected using the Fay-Prince trap. Monitoring male activity is potentially useful because *Ae. sierrensis* males emerge on average 2–4 wk before females (Hawley 1985, Woodward 1988, Washburn et al. 1989, Garcia et al. 1989), and accurate assessment of male populations could theoretically be used to anticipate female emergence and provide a means for timing effective control measures. In our study, we evaluated the numbers of both male and female *Ae. sierrensis* captured by duplex cone and Fay-Prince traps and compared these collections with those made at human sentinels.

MATERIALS AND METHODS

We constructed 5 duplex cone traps following the illustration and description provided in Freier and Francy (1991). Three forested field sites (one each in Marin, Lake and El Dorado counties, CA) with previous records of *Ae. sierrensis* activity were selected for trap tests. At each field site, we designated 5 (Lake) or 7 (Marin and El Dorado) stations separated from one another by a minimum distance of 25 m.

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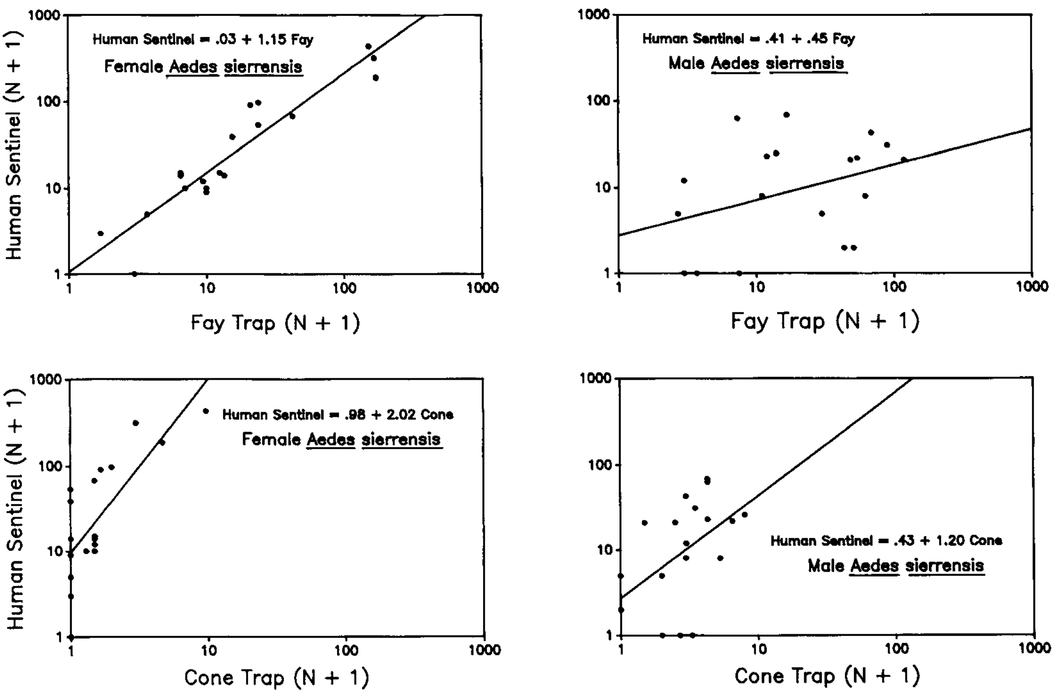

Fig. 1. Correlation between numbers (n + 1) of male and female *Aedes sierrensis* captured by Fay-Prince and duplex cone traps and numbers caught at sentinel humans. Each point represents data from one date of testing.

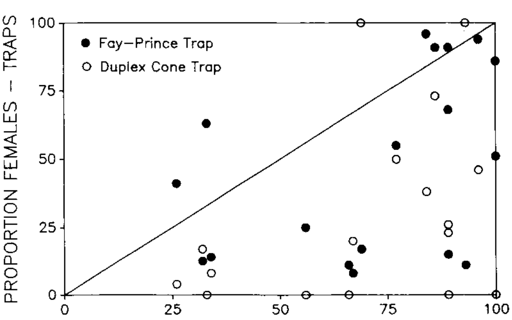

Fig. 2. Scatter plot showing the relationship between the proportions of females in collections from Fay-Prince and duplex cone traps and from collections made by sentinel humans. Each point represents the proportion from total catches in 2 or 3 trap collections and a single sentinel collection. The solid line is an isocline representing identical sex ratios in trap and sentinel collections. Points above and below the line reflect trap catches that are female and male biased, respectively, compared with sentinel collections.

Within sites, we attempted to choose stations that were similar in vegetation type, canopy cover, and other habitat characteristics. Traps were deployed and operated a total of 19 evenings [Lake Co. (n = 10), Marin Co. (n = 6), and El Dorado Co. (n = 3)] between June 5 and July 24, 1991. On each evening, we randomly assigned 2 (Lake) or 3 (Marin and El Dorado) stations for Fay-Prince and duplex cone trap placement; the remaining station at each site was used for the sentinel collection. Each trap was baited with 1 kg of dry ice and operated for 4 h between 1700 and 2100 h. Dry ice was placed on the ground inside the inner cone of the duplex traps. For Fay-Prince traps, the dry ice was placed in a foam box positioned above the intake fan; boxes were fitted with a small hole (approx. 2.5 cm) that allowed CO_2 to escape (see Garcia et al. 1989). Temperatures during tests ranged from 17 to 38°C, and cloud cover varied from 0 to 100%. Because *Ae. sierrensis* rarely fly under windy conditions, all tests were conducted during periods when winds were light or absent. At the end of each sample period, we collected the traps, transferred the mosquitoes to holding containers, and weighed the remaining dry ice (Marin site only). Traps were collected in the same order they were deployed to minimize differences in operation time. Sentinel collections were made between 1930 and 2030 h using 2 people wearing white clothing. All individuals used as sentinels provided statements of informed consent prior to participating in this study. Human sentinels remained seated at the designated station and were instructed to cap-

Table 1. Mean numbers of female and male *Aedes sierrensis* collected in duplex cone and Fay-Prince traps. Means for each sex were compared with a *t*-test for paired observations ($n = 19$).

Trap type	Mean ± SE	*t* statistic	df	*P*
Female *Ae. sierrensis*				
Duplex cone	1.02 ± 0.47	2.738	18	<0.001
Fay-Prince	36.05 ± 13.16			
Male *Ae. sierrensis*				
Duplex cone	2.27 ± 0.43	3.887	18	<0.001
Fay-Prince	32.38 ± 7.67			

Table 2. Numbers of female and male *Aedes sierrensis* collected in duplex cone and Fay-Prince traps placed 1 m apart. Numbers of each sex were compared with a *t*-test for paired observations ($n = 12$).

Trap type	Mean ± SE	*t* statistic	df	*P*
Female *Ae. sierrensis*				
Duplex cone	0.73 ± 0.27	4.348	11	<0.001
Fay-Prince	30.64 ± 6.81			
Male *Ae. sierrensis*				
Duplex cone	5.64 ± 2.71	1.002	11	>0.16
Fay-Prince	3.18 ±1.09			

ture all incoming male and female *Ae. sierrensis* using a modified "AFS Sweeper" (Meyer et al. 1983). To account for the potential variation in the attractiveness to mosquitoes among sentinels, we used 11 different people in various combinations. Mosquitoes collected at sites in Marin and El Dorado counties were anesthetized with ether, sexed, counted and discarded. Those collected from traps and sentinels in Lake County were similarly processed except they were anesthetized with carbon dioxide and released at the field site the following day. For each night of collection, we calculated the mean numbers of males and females captured in each type of trap. We correlated the means from different nights with human collections using a simple linear model [least-squares regression (Sokal and Rohlf 1969)].

In previous tests, we observed that many *Ae. sierrensis* were attracted to, but not captured by CO_2-baited traps. We evaluated mosquito capture efficiency using paired CO_2-baited Fay-Prince and duplex traps placed 1 m apart; this protocol allowed us to evaluate capture rates of the 2 kinds of traps when sampling the same population of adult mosquitoes. For these tests, 2 pairs of traps were operated for 3–4 h during 3 mornings between 0500–1000 h and 3 evenings between 1600–2030 h at the El Dorado County site. After each sampling interval, mosquitoes were sorted and counted as described above and discarded. We combined data from morning and evening tests and compared the numbers of male and female *Ae. sierrensis* captured by the Fay-Prince and duplex cone traps using a *t*-test for paired observations (Sokal and Rohlf 1969).

RESULTS

The numbers of female *Ae. sierrensis* captured by the human sentinels were significantly correlated ($P < 0.001$) with adult activity level estimates from mosquitoes captured by both the duplex cone and Fay-Prince traps (Fig. 1). During the 19 sample dates, sentinels attracted between 0 and 433 female *Ae. sierrensis* in the 1 h collection periods. A total of 88 and 57% of this variation in population size was explained by the mean numbers of females captured by the Fay-Prince and duplex cone traps, respectively, during 4 h of operation. While the correlation between duplex cone and sentinel collections of male *Ae. sierrensis* was significant ($P < 0.03$), only 27% of the variation in numbers at sentinels was explained by trap catches; we did not find a significant correlation ($P > 0.65$) between male numbers in the sentinel and Fay-Prince trap collections. *Aedes sierrensis* samples from both types of traps contained smaller proportions of females compared to populations collected by the human sentinels (Fig. 2).

Overall, the Fay-Prince trap collections contained significantly greater numbers of *Ae. sierrensis* of both sexes compared with the duplex cone trap (Table 1). Similarly, in the paired trap tests we found that significantly fewer female

Ae. sierrensis were captured by the duplex cone trap compared with the Fay-Prince trap, but there was no significant difference in the numbers of males in the 2 traps (Table 2).

DISCUSSION AND SUMMARY

Data from these tests indicate the Fay-Prince trap is superior to the duplex cone trap for sampling adult populations of *Ae. sierrensis*. The tight correlation between Fay-Prince and sentinel collections of female *Ae. sierrensis* and because the y-intercept is not significantly different from 0 ($P > 0.74$, Fig. 1) suggest that the trap is an excellent surveillance tool even at low levels of mosquito activity. Importantly, our study revealed a strong correlation even though 11 different sentinels were used. The Fay-Prince trap is also economical to operate since only 2 or 3 traps were needed to accurately assess population densities around humans.

Overall, the Fay-Prince trap collected higher numbers of female *Ae. sierrensis* than the duplex cone trap both in the human sentinel tests (Table 1) and in the paired trap tests (Table 2). The lower numbers of *Ae. sierrensis* captured in the duplex cone were probably not due to differences in CO_2 emission between the 2 types of traps since significantly more residual dry ice remained in the Fay-Prince traps after operation (Fay-Prince, mean = 662 ± 39 g; duplex cone, mean = 356 ± 33 g; $t = 5.934$, $P < 0.0001$). This finding suggests that rates of carbon dioxide emission were greater for the duplex cone compared to the Fay-Prince trap.

Neither the duplex cone nor the Fay-Prince traps provided accurate estimates of male *Ae. sierrensis* activity at human sentinels. Interestingly, collections from both traps contained greater proportions of males than collections made at human sentinels (Fig. 2); this apparent bias for males may reflect behavioral differences between male and female *Ae. sierrensis*. During trap operation, we noted that males formed swarms around both kinds of traps, but many individuals did not fly close enough for capture. Carbon dioxide serves as an attractant that draws males into the vicinity of hosts where they can intercept and mate with females seeking blood meals. Unlike females, however, males need not land nor even closely approach hosts to successfully mate; they merely must remain active in areas where females are likely to be encountered. Male collections could have had higher random variation if they contained individuals that happened to fly close enough for capture. On the other hand, females might be underrepresented in trap collections because they are larger and stronger fliers that avoid capture or because they do not remain in the vicinity of traps after failing to locate a blood meal. These possibilities could be evaluated in careful behavioral studies in the field.

Behavioral differences between *Ae. sierrensis* and *Ae. albopictus* by themselves are unlikely to explain the apparently poorer performance of the duplex cone trap in our study compared with results published by Freier and Francy (1991). While sentinel and duplex cone trap catches appear to be correlated for *Ae. albopictus* as suggested by the authors (Freier and Francy 1991; Fig. 3, pp. 77–78), in reanalyzing their data, we found that actually only 6% of the variation in female *Ae. albopictus* catches at sentinels was explained by trap catches. Thus, while the duplex cone trap did capture high numbers of *Ae. albopictus*, its utility for estimating rates of human-vector contact for *Ae. albopictus* remains unproven. The weaker correlation between duplex cone traps and human sentinel collections for female *Ae. albopictus* compared with *Ae. sierrensis* ($r_{albopictus} = 0.25$; $r_{sierrensis} = 0.76$) may have resulted from differences in the sampling procedures used in the 2 studies. Freier and Francy (1991) collected only those *Ae. albopictus* landing on sentinels during a 5-min interval that was preceded by a 2-min baiting period. Thus, in their study mosquito activity at human sentinels was assessed over a 7-min sample period. In our study, we collected all *Ae. sierrensis* that approached or landed on hosts during a 60-min period. The longer sentinel monitoring time we used was closer to the duration of trap operation and resulted in higher mosquito numbers; such collections may more accurately reflect local population levels because of the larger sample size. The relationship between sentinel sample time and trap capture could be quantified by correlating the number of mosquitoes captured at sentinels during the first 10, 20, 30, etc. minutes of sampling with trap catches. We expect the correlation coefficient to approach an asymptote as the sample time increases. This technique could be useful for determining the minimum effective sentinel sample time.

In summary, our results show that the numbers of female *Ae. sierrensis* caught by the duplex cone trap and by human sentinels are significantly correlated. However, the stronger correlation and larger catches of the Fay-Prince trap indicate it is a superior surveillance tool for female *Ae. sierrensis*. Neither type of trap is a good predictor of male *Ae. sierrensis* activity at human sentinels.

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