COMPARISON OF SEVERAL DIFFERENT TRAPPING METHODS FOR *CULICOIDES VARIIPENNIS* (DIPTERA: CERATOPOGONIDAE)

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ABSTRACT. When battery operated CDC miniature incandescent and black light traps (with and without light bulbs) were operated with and without CO_2, the rank of trap effectiveness for total numbers of female *Culicoides variipennis* caught was: black light plus CO_2; CO_2-baited trap without light bulb; black light without CO_2; incandescent light plus CO_2 and incandescent light without CO_2. In 1983, the black light trap plus CO_2 caught significantly more males and females than any other traps, and the incandescent light trap without CO_2 caught significantly fewer females than any other traps. There were significant differences also in times gnats were collected, as well as in the gonotrophic condition of females caught in different traps. Comparative catches with a vehicle-mounted net revealed that few males were caught in traps and that different traps caught different physiological/reproductive segments of the population. All catches revealed that gravid females began flying only a few min before sunset and peaked in the 1st h after sunset. Because it caught significantly larger numbers of females than other traps and because it was selectively attractive to gravid and parous females, the black light trap would be the trap of choice when large numbers of parous females are desired in arbovirus isolation studies.

INTRODUCTION

Light traps commonly have been used for collecting species of Ceratopogonidae since first used by James (1943), but they also have been criticized for not providing an unbiased estimate of insect flight activity and the gonotrophic state of the population sampled. When estimates of population age structure were the objective, various workers (Barnard 1979, Barnard and Jones 1980, Bidlingmayer 1961, Nelson and Bellamy 1971, Rowley[2]) used such other sampling methods as suction traps and vehicle-mounted net catches.

Although it is known that certain kinds of light are more attractive than others to several *Culicoides* species (e.g., Belton and Pucat 1967, Rowley and Jorgenssen 1967), there is little information on whether the difference is only numerical or whether light sources of different wavelengths might exert a selective attraction to females in different gonotrophic states or at different times in a diel. The primary objectives of this study, therefore, were to determine the relative effectiveness (= attractiveness) of different kinds of light traps for female *Culicoides variipennis* (Coq.) and to determine the gonotrophic condition of females caught in different traps and at different times. Since vehicle-mounted sweep nets and nonbaited suction traps are thought to provide an unbiased sample of the flying population of many *Culicoides* species (e.g., Barnard and Jones 1980, Lewis and Taylor 1965, Nelson and Bellamy 1971, Reuben 1963, Rowley,[2] Service 1971, 1973), gnat catches from different traps were compared with vehicle-mounted net catches to assess potential trap bias.

MATERIALS AND METHODS

Study site and trapping of adults: A dairy located 15 km northwest of Santa Rosa in western Sonoma County (ca. 80 km north of San Francisco) was selected for trapping adults. This dairy had a wastewater holding pond (ca. 100 × 40 × 3 m) positive for larvae of *Culicoides variipennis* (Linhares and Anderson, unpublished data).

From August 26 through September 30, 1982, the following 7 types of traps (Table 1) were exposed 10 m apart along an unobstructed north-south pasture fence located 1 km from the lagoon breeding site:

Type 1: A 6-V CDC miniature light trap[3] with incandescent light bulb.

Type 2: Same as type 1 and baited with CO_2.

Type 3: Same as type 2, but without a light bulb (= suction trap).

Type 4: A 12-V CDC miniature light trap with a 4-W black light bulb (ca. 320–420 nm).

Type 5: Same as type 4 and baited with CO_2.

Type 6: A 25 × 38 cm white plywood panel covered with clear Mylar,® a transparent plastic material. The Mylar sheet was coated with TangleTrap,® a sticky substance used to catch insects.

Type 7: Same as type 6 and baited with CO_2.

Dry ice® was used as the source of CO_2. In 1982, ca. 1 kg was placed on the ground beneath

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[2] Rowley, W. A. 1965. The occurrence and bionomics of bloodsucking midges in the Central Columbia Basin. Ph.D. Dissertation, Washington State University, 92 pp.

[3] All light traps were manufactured by the John W. Hock Co., P.O. Box 12582, Gainesville, FL 32604.

Table 1. Number of *Culicoides variipennis* collected in 1982 by 7 different trap types, from 2 h before to 1 h after sunset.

	Trap type[1]															
	Black light trap + CO_2		Black light trap + CO_2		Incandescent light + CO_2		Suction trap[2] + CO_2		Sticky trap + CO_2		Black light trap only		Incandescent light trap only		Total	
Date	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Aug. 26	7	310	—	—	3	183	0	21	0	25	0	0	0	0	10	539
Sept. 2	0	31	—	—	0	5	0	19	0	0	0	1	0	2	0	58
Sept. 9	3	46	—	—	0	0	0	9	0	0	2	50	0	0	5	105
Sept. 16	0	3	—	—	0	0	0	15	0	27	0	0	0	0	0	45
Sept. 23	21	167	—	—	6	151	4	173	2	59	1	15	0	0	34	565
Sept. 30	9	152	—	—	4	18	3	250	0	1	1	3	0	0	17	424
Oct. 7	13	41	43	324	0	22	0	39	0	3	0	11	0	0	56	440
Oct. 14	6	118	21	158	0	11	12	120	2	69	0	2	0	0	41	478
Oct. 21	23	126	11	57	3	100	0	21	0	7	0	0	0	0	37	311
Oct. 28	8	69	9	127	16	113	33	161	0	0	0	0	0	0	66	470
Nov. 4	14	134	35	193	6	195	4	179	0	0	0	0	0	0	59	701
Nov. 11	0	2	0	7	0	58	0	30	0	0	0	0	0	0	0	97
Total	104 (a)[3]	1,199 (a)	119 (a)	866 (a)	38 (a)	856 (a)	56 (a)	1,037 (a)	4 (a)	191 (a)	4 (a)	82 (b)	0 (a)	2 (b, c)	325	4,233

[1] For all trap types except black light trap plus CO_2 above, 1 kg of dry ice was exposed in a perforated container set on the ground beneath each baited trap. The unbaited sticky trap caught no *C. variipennis*.

[2] A CDC miniature light trap operated without light bulb.

[3] Results of Kruskal-Wallis' one way ANOVA test applied for female catches were significant at $P < 0.001$ ($\chi^2_6 = 47.59$) and for male catches at $P < 0.001$ ($\chi^2_6 = 30.99$). For each sex, trap catches followed by at least one similar letter did not differ significantly when Bonferroni's inequality multiple comparisons test was used for 21 comparisons (overall error rate $\alpha = 0.05$), for pairwise comparisons of different trap types.

each baited trap at the start of trapping. Each block of dry ice was exposed in a 1.9 liter waxed cardboard container with eight 1–2 cm holes near the bottom. Each sticky panel trap was staked with the bottom of the panel about 0.5 m from the ground, and light traps were hung from a fence with entrances ca. 0.5 m from the ground. Prevailing W, SW or NW winds blew across the north-south oriented trap line so that CO_2-baited traps were not exposed upwind of non-baited traps. On each collection date, the traps' relative positions were randomly assigned along the fence line. The 10-m spacing was selected so that insects attracted into the vicinity of the traps being compared could perceive and respond to any of several traps. Most traps were nearly equally visible from most orientations. Trapping was conducted weekly from 2 h before to 1 h after sunset, from August 26 through November 11, for a total of 12 collection dates. On October 7, a CDC miniature black light trap baited with CO_2 was added to the design (Table 1). With this trap, 1 kg of dry ice was placed in a perforated plastic bag on top of the trap. Collection bags for all traps were replaced hourly. The dry ice supply for each trap was monitored and supplemented as necessary so that each trap had at least 0.25 kg at the end of the last period.

Each light trap had an identical motor and fan mounted in the same size cylinder. Voltages at the motor terminals (with or without the lights operating) are 6.1 for the CDC incandescent trap and 6.3 for the UV trap (John W. Hock, personal communication). On each night of exposure all light traps were operated with fully charged batteries. Each light trap was equipped with a removable nylon mesh collecting bag into which insects were blown after passing through the fan located beneath the light. Collection bags for all traps were replaced hourly, as were gnat-positive Mylar sheets.

Temperature data for the Santa Rosa meteorological station was obtained from the Climatological Data for California, Vol. 87, National Climatic Data Center, Asheville, NC. Times of sunset on collection dates were obtained from annual issues of the American Ephemeris and Nautical Almanac (U.S. Government Printing Office, Washington, DC). Wind velocity and direction, temperature, RH and light intensity were also recorded at half-hour intervals at the sampling site.

In 1982, trapping was terminated on November 11 because regular sampling of immatures at the lagoon breeding site revealed that pupation had ceased about 3 weeks previously. Preliminary sampling in previous years also had shown that, at the onset of winter, all larvae disappeared from the shoreline and pupation ceased.

In 1983, we modified the experimental design by: 1) operating 2 replicates of trap types 1–5 (Table 2) and eliminating trap types 6 and 7; 2) placing the dry ice above all traps; and 3) operating traps from 2 h before to 2 h after sunset (Table 3).

Trap types 2, 3 and 5 each had the bottom of a styrofoam insulated pail (20 cm diam × 15 cm deep) bolted to the topframe located 8–10 cm above the trap entrance. At the beginning of each trapping night each pail was baited with 1 kg of dry ice and covered with a styrofoam lid. The CO_2 escaped through ten 1–1.5 cm holes punched in the bottom of the pails. In 1983 traps were operated from June 9 through November 3. Trapping stopped after November 3 because, as in 1982, samples of immatures revealed that pupation had ceased a few weeks previously. In both years, the collecting bags were checked at hourly intervals and changed if gnats were present. The dry ice supply was monitored and supplemented as in 1982.

In addition to the regular operation of light traps in 1983, a vehicle-mounted sweep net (115 cm diam × 150 cm long), similar to that of Nelson and Bellamy (1971), was attached to the top of a station wagon and used to catch insects on 8 collecting dates between August 18 and September 29. On each date multiple samples

Table 2. Number of male and female *Culicoides variipennis* collected in 1983 by 5 different trap types, from 2 h before to 2 h after sunset.[1]

	Trap type											
	Black light trap + CO_2		Incandescent light + CO_2		Suction trap[2] + CO_2		Black light trap only		Incandescent light trap only		Total	
Date	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
June 9	21	204	4	114	0	81	0	7	0	0	25	406
June 16	13	239	0	13	1	111	0	3	0	0	14	366
June 23	4	116	0	82	0	127	0	8	0	0	4	333
June 30	0	13	0	8	0	7	6	49	0	0	6	77
July 7	0	57	0	13	0	57	4	16	0	0	4	143
July 14	0	31	0	2	0	12	1	9	0	0	1	54
July 21	3	94	0	12	0	15	21	131	0	0	24	252
July 28	3	145	0	16	0	10	14	146	0	0	17	317
Aug. 5	34	256	0	28	0	40	3	43	0	2	37	369
Aug. 12	7	85	0	10	0	2	6	40	0	0	13	137
Aug. 18	149	1,085	0	90	6	468	1	24	0	1	156	1,668
Aug. 25	13	68	2	126	0	39	1	21	0	0	16	254
Aug. 29	21	351	0	34	0	40	0	24	0	0	21	449
Sept. 2	71	386	0	10	0	34	5	72	0	1	76	503
Sept. 9	21	129	0	20	0	31	7	152	0	0	28	332
Sept. 16	0	84	0	21	0	17	1	21	0	0	1	143
Sept. 19	17	273	1	138	0	32	69	650	0	0	87	1,093
Sept. 22	31	318	0	15	0	18	31	565	0	0	62	916
Sept. 29	6	135	0	31	0	12	2	19	0	0	8	197
Oct. 5	2	138	0	48	0	46	0	15	0	3	2	250
Oct. 13	22	659	0	170	7	202	0	37	0	0	29	1,068
Oct. 20	81	812	6	316	13	276	6	70	0	2	106	1,476
Oct. 27	67	1,404	1	71	17	583	13	192	0	0	98	2,250
Nov. 3	14	362	0	55	2	118	4	50	0	1	20	586
Total	600	7,444	14	1,443	46	2,378	195	2,364	0	10	855	13,639
	(a)[3]	(a)	(b)	(b)	(b, c)	(b)	(a, c)	(b)	(b)	(c)		

[1] Two replicates of each trap type were operated each date. For each trap 1 kg of dry ice was exposed in a perforated container suspended over the entrance to the trap.

[2] A CDC miniature light trap operated without light bulb.

[3] The results of Friedman's two way ANOVA test were significant for female catches at $P < 0.001$ ($\chi^2_4 = 66.89$), and for male catches at $P < 0.001$ ($\chi^2_4 = 53.82$). For each sex, trap catches followed by the same letter did not differ significantly, when Bonferroni's inequality multiple comparisons test was used for 10 comparisons (overall error rate $\alpha = 0.05$), for pairwise comparisons of different trap types.

Table 3. The number and gonotrophic/physiologic status of female *Culicoides variipennis* collected in 1983 by 4 different trap types.

		Gonotrophic/physiologic status				
Trap type	Hour[1]	Nulliparous	Parous	Gravid	Engorged[2]	Total
Black light	I	387	269	3	0	659
+ CO_2	II	1,782	763	3	0	2,548
	III	1,213	1,458	639	2	3,312
	IV	263	387	274	1	925
	Total[3]	3,645 (a)	2,877 (a)	919 (b)	3	7,444 (a)
Incandescent light	I	48	20	1	0	69
+ CO_2	II	600	236	1	0	837
	III	211	160	2	0	373
	IV	66	89	9	0	164
	Total	925 (b)	505 (b)	13 (c)	0	1,443 (b)
Suction trap	I	155	88	0	0	243
+ CO_2	II	969	409	2	0	1,380
	III	463	236	2	1	702
	IV	23	30	0	0	53
	Total	1,610 (a, b)	763 (b)	4 (c)	1	2,378 (b)
Black light	I	0	0	0	0	0
	II	0	0	0	0	0
	III	22	214	1,209	2	1,447
	IV	29	118	766	4	917
	Total	51 (c)	332 (b)	1,975 (a)	6	2,364 (b)
Grand totals		6,231	4,477	2,911	10	13,629

[1] There were two 1-h trapping periods before, and two after, sunset.

[2] All females appeared nearly fully engorged with blood.

[3] The two way ANOVA (SAS GLM procedure) for differences in numbers of nulliparous, parous, gravid and engorged females caught in the different traps was highly significant ($F = 15.55$, $P < 0.001$). Total trap catches in vertical columns followed by the same letter did not differ significantly when Bonferroni's inequality multiple comparisons test was used for 6 comparisons (overall error rate: $\alpha = 0.05$), for pairwise comparisons of different trap types.

were taken as the vehicle was driven over a 2.9 km route. The collecting route followed an off-road track leading through a hayfield and an unused field around 3 sides of a cornfield. The cornfield was adjacent to and N and ENE of where the light traps were operated. During each hour that light traps were operated, vehicle net collections were started 15 min into the hour and 15 min before a trap hour ended. These two collections were combined to represent hourly catches for comparison with the light trap catches. During the collecting trips the vehicle was driven at 16–25 km/h. It took about 8 min to complete the route, after which the collecting bag was replaced. Each trip started and ended at a point about 40 m from the fence supporting the light traps. Driving lights on the vehicle were operated on low beam when it became too dark to follow the route safely without their use.

Flies collected in the light traps and vehicle-mounted net were held in ice-cooled insulated containers until taken to the laboratory. Here, they were anesthesized with CO_2, placed in snap cap glass vials, sealed in polyethylene bags and frozen at −30°C until they could be dissected and examined for determination of their gonotrophic state. For several of the collections, hourly catches of females were very large (several hundred/trap) for some of the traps. For practical reasons, therefore, a maximum of 50 females/trap/h was randomly selected and examined to determine their gonotrophic state. The results were then used to estimate the proportion of flies in different gonotrophic states for those specific traps and hourly catches.

Determination of gonotrophic condition: Collected females were examined with a dissecting microscope and classified into 4 categories: a) nulliparous, b) parous, c) gravid and d) blood engorged. If a female was neither gravid nor engorged, the parity status was determined by the absence of abdominal pigment as described by Dyce (1969) and Potter and Akey (1978), and by the pattern of abdominal tergites II and III (Akey and Potter 1979).

Since flies had been frozen at −30°C for several weeks before they were examined and dissected, it was not possible to check for the possible occurrence of multiple oviposition cycles by using the method of Polovodova (Detinova 1962). Loss of elasticity in the ovarian tissues of frozen flies made it too difficult to stretch the ovarioles to check for degenerative follicles or oviposition scars in the ovaries as described by Mullens and Schmidtmann (1982).

We were not able to determine the parity status of gnats collected by sticky traps in 1982 because the sticky material permeated the cuticle and obscured color differences. These flies, therefore, were not included in the following analysis.

Data analysis: The Kruskal-Wallis one-way ANOVA test (Zar 1974) was used to determine if differences existed in the numbers of gnats caught among the several trap types used in 1982. The Friedman two-way ANOVA test (Zar 1974) was used for the 1983 data. In both years, Bonferroni's inequality multiple comparisons test (Miller 1981) also was used to look for specific pair-wise differences among the traps. The Kruskal-Wallis test was used instead of the Friedman test for the 1982 data because of the smaller number of replicate nights for the black light trap baited with CO_2 above. The unequal number of replicates in 1982 precluded the use of the Friedman test.

A Log linear analysis (Fienberg 1977) using a three dimensional table (trap type vs. trapping time vs. gonotrophic status) was used for simultaneous testing for complete independence, partial independence and conditional independence among the 3 variables for both 1982 and 1983. The analysis was performed on a computer using either the $SPSS_X$ Loglinear Procedure (SPSS Inc. 1983) or the SAS Catmod Procedure (SAS Institute 1985).

The ANOVA was conducted with the SAS GLM program (SAS Institute 1985) to test for significant differences in numbers of nulliparous, parous, gravid and engorged females caught in the different traps and to determine if there were significant differences in numbers of nulliparous, parous, gravid and engorged females caught in each trap during different trapping periods. The same procedure was used to test for differences in numbers of nulliparous, parous and gravid females caught in the vehicle mounted sweep net during different trapping periods. In all analyses, the dependent variable was Log $(n + 1)$.

RESULTS AND DISCUSSION

Analysis of trap catches: Total trap catches for 1982 and 1983 are shown in Tables 1 and 2, respectively. In 1982, few males were caught in any traps. In the more extensive 1983 study, black light traps caught significantly more males than any other traps. Unlike females, males were not attracted to CO_2; only small numbers of males were caught in CO_2-baited incandescent light traps, and none were caught in nonbaited incandescent light traps. However, in southern California, Nelson and Bellamy (1971) caught much greater numbers of males in CO_2-baited incandescent light traps than were caught in this study. Since male swarms have a nonrandom distribution (Zimmerman et al. 1982), it is possible that some of the Nelson and Bellamy traps were located near swarming sites or that males may have been attracted to females in the traps.

For females, statistical analyses showed a significant difference in effectiveness (= attractiveness) among the several types of traps used. As the identical motors and fans on all traps provided equal suction we conclude, in all analyses, that the differences in numbers of females caught were directly related to the attractiveness of the light source and to the presence or absence of CO_2. For 1982, multiple comparison tests revealed that CO_2-baited traps were significantly more attractive to females of *C. variipennis* regardless of the kind of light source used. However, no significant difference was found among the CO_2-baited light traps even though, on average, the black light trap with CO_2 above collected many more gnats/trapping night than the other traps (Table 1).

The more extensive operation of traps in 1983 revealed clear differences in attractiveness among the different types of traps tested. The CO_2-baited black light trap was significantly more effective than all other traps in catching females of *C. variipennis* (Table 2). About 55% of all trapped females in 1983 were collected by this type of trap. The other 2 types of CO_2-baited traps (incandescent light trap and suction trap) collected, respectively, 10% and 17% of the flies caught. Of the 2 types of nonbaited traps, the one with a black light bulb was as effective as the CO_2-baited light trap without a light bulb, at least in numerical terms. It caught about 17% of the total flies collected. The nonbaited incandescent light trap was by far the least attractive; it caught only 10 of 13,639 female gnats in 1983 and only 2 of 4,248 females in 1982. Incandescent light, in fact, appeared to have a repellent effect on females (compare catches in suction trap plus CO_2 with incandescent light plus CO_2 in Tables 1–3).

Although the black light trap was very effective in catching females of *C. variipennis*, its attractiveness was enhanced when CO_2 was used as an additional attractant. The positive attractive effect of CO_2 is well-known for mosquitoes (Gillies and Wilkes 1969; Reeves 1951, 1953), as well as for other blood sucking flies (Anderson and Hoy 1972, DeFoliart and Morris 1967), including Ceratopogonidae (Birley and Boorman

1982, Mullens and Rutz 1984, Nelson 1965, Nelson and Bellamy 1971).

Host-seeking females of *C. variipennis* were first caught in large numbers in CO_2-baited traps by Nelson (1965), who suggested that CO_2 played a role in directing host-seeking female gnats to hosts. Nelson based this interpretation on the fact that nearly all females collected were neither gravid nor engorged. The results of this study support that interpretation. However, our results also revealed that the type (color) of light used with the traps also influenced the nature of the catch. The greater effectiveness of the black light traps in this study confirms the findings of Belton and Pucat (1967) and Rowley and Jorgenssen (1967), who found that black light traps were much more efficient than incandescent light traps for catching females of several *Culicoides* species, including *C. variipennis*. However, these researchers did not use CO_2 as bait, and they did not determine the gonotrophic state of the females collected. Significant biological differences related to these factors are discussed below.

The results of the Log linear analysis were highly significant ($P < 0.001$) for both the 1982 and 1983 data, revealing that the type of trap, time of gnat collection and gonotrophic status were not partially, conditionally nor totally independent.

The nonbaited black light trap: This trap was highly selective for gravid females and, to a certain degree, for parous females (Table 3). It also was effective only after sunset with no gnats being collected during the first 2 h of trapping. Results for 1982 were similar (Linhares[4]). Overall, this trap caught significantly fewer nulliparous females than any other type of trap (Table 3).

The CO_2-baited black light trap: Combining CO_2 with this trap resulted in a highly attractive synergistic effect (Tables 2 and 3; see Table 6). This trap caught significantly more nulliparous and parous females than the other types of traps (Table 3), and it caught significantly more gravid females than the other 2 types of CO_2-baited traps (incandescent light plus CO_2 and suction plus CO_2). However, it caught significantly fewer gravid females than the black light trap without CO_2 (Table 3), indicating that CO_2 had a general repellent effect on gravid females (Table 3). Nevertheless, the general effectiveness of this trap appeared to be due to release of CO_2, which attracted host-seeking nulliparous and parous females both before and after sunset, and to the attraction of gravid females to black light after sunset. As the non-CO_2-baited black light trap caught no gnats during the first two exposure periods (Table 3), it was surprising to see that the CO_2-baited black light trap caught so many more host-seeking females than the other 2 types of CO_2-baited traps.

The CO_2-baited incandescent light trap and CO_2-baited suction trap: Catches in these traps for both 1982 and 1983 were similar (Tables 1–3). As the non-CO_2-baited incandescent light trap rarely caught *C. variipennis* (Tables 1 and 2) we conclude that the CO_2-baited incandescent light trap and the CO_2-baited suction trap (Table 3) both functioned essentially as CO_2-baited traps in this study. Although there is an indication that incandescent light had a repellent effect on some females, there was no significant difference in numbers of females caught in these 2 types of traps (Table 3). Except for nullipars caught in the suction trap, both types of traps caught significantly fewer females than the CO_2-baited black light trap (Table 3). Results for the 1982 catches were similar (Linhares[4]). The most interesting result was the poor attractiveness of both trap types for gravid females. Hence, in contrast to black light, incandescent light provided little attraction, if any, to females of *C. variipennis*, regardless of their gonotrophic state.

Gonotrophic state in relation to trapping time: The results for all 1983 traps combined (Table 3) showed that significantly fewer nulliparous, parous and gravid females were caught during the first hour of trapping, and that significantly greater numbers of gravid females were caught during period III (Table 3). All engorged, and most gravid females, were collected after sunset,

Table 4. The number and gonotrophic status of *Culicoides variipennis* caught in 1983 in vehicle-mounted sweep net collections.

Date	Males	Gonotrophic status of females[1] Nulliparous	Parous	Gravid	Total
Aug. 18	2,150	30	6	14	50
Aug. 25	3,632	60	6	14	80
Sept. 2	2,991	39	4	53	96
Sept. 9	4,860	16	3	33	52
Sept. 16	2,147	26	14	13	53
Sept. 19	9,563	95	27	23	145
Sept. 22	3,799	75	20	19	114
Sept. 29	342	15	3	2	20
Total	29,484	356	83	171	610
Percentage		(58.36)	(13.61)	(28.03)	

[1] No blood engorged females were caught.

[4] Linhares, A. X. 1984. The biology of *Culicoides variipennis* (Coquillett) (Diptera: Ceratopogonidae) in Northern California. Ph.D. Dissertation, University of California, Berkeley, 153 pp.

and the vast majority of both were caught in black light traps (Table 3). The 10 gravid females caught prior to sunset (Table 3) may have been prematurely stimulated to undertake a host-seeking flight when CO_2-baited traps were placed near their resting sites. Since it is not unusual to collect small numbers of gravid and engorged females of haemotophagous species in host biting collections, it does not seem unusual that a few such *C. variipennis* females would be attracted to CO_2.

Comparison of trap catches with vehicle-mounted net catches: Unlike the CO_2-baited light traps, the vehicle-mounted sweep net collected large numbers of males, greatly outnumbering females (Table 4). While making net collections with the vehicle, we noticed that, at times, the vehicle was driven through several large swarms of males. This occurred mainly around sunset, and we believe it accounts for the large catches of males.

In the case of females: 1) significantly fewer nulliparous individuals were caught during the first and last hours of collection, 2) significantly fewer parous individuals were caught during the first hour and 3) significantly more gravid individuals were caught during the third hour (Table 5).

Of the 610 females collected in the vehicle-mounted net catches, 28% were gravid, 58% were nulliparous and only 14% were parous (Tables 5 and 6). These results differ considerably from those of the different trap types operated during the same period (August 18 through September 29) (Table 6). During this time gravid females comprised only 14% of the total catch in CO_2-baited black light traps (Table 6). The two other types of CO_2-baited traps were even less effective in attracting gravid females, although they collected large numbers of nulliparous gnats. All 3 types of traps operated with CO_2 also attracted a higher percentage of parous females than was caught in the vehicle-mounted net (Table 6).

During the 8-day comparison of trap and vehicle net catches, 85% of the females caught in the non-CO_2-baited black light trap were gravid (Table 6), a percentage very close to that for this trap for the total trapping periods in 1982 (Linhares[4]) and 1983 (Table 3) and very different from the 28% caught by the vehicle-mounted net. Although gravid females comprised nearly 15% (24 out of 171) of the total catch in the vehicle-mounted net before sunset (Table 6), the data in Table 5 show that 23 of the 24 gravid females netted during the second hour of collec-

Table 5. The number and gonotrophic status of female *Culicoides variipennis* collected in 1983 with a vehicle-mounted sweep net in relation to hour of collection.

	Gonotrophic status[1]			
	Nulliparous	Parous	Gravid	Total
Collection 1[2]	0	0	0	0
Collection 2	3	0	0	3
Total, Hour I[3]	3 (b)	0 (b)	0 (c)	3 (c)
Percentage	(0.49)[4]	(0)	(0)	(0.49)
Collection 3	14	1	1	16
Collection 4	177	24	23	224
Total, Hour II	191 (a)	25 (a)	24 (b)	240 (a)
Percentage	(31.31)	(4.10)	(3.93)	(39.34)
Collection 5	145	26	116	287
Collection 6	10	10	21	44
Total, Hour III	155 (a)	36 (a)	137 (a)	328 (a)
Percentage	(25.41)	(5.90)	(22.46)	(53.77)
Collection 7	4	6	6	16
Collection 8	3	16	4	23
Total, Hour IV	7 (b)	22 (a)	10 (b, c)	39 (b)
Percentage	(1.15)	(3.61)	(1.64)	(6.40)
Total	356	83	171	610
Percentage	(58.36)	(13.61)	(28.03)	

[1] No blood engorged females were caught.

[2] Collections 1–4 (first 2 h) were before sunset and collections 5–8 (last 2 h) were after sunset.

[3] The two way ANOVA (SAS GLM Procedure) for differences in numbers of nulliparous, parous and gravid females caught in the different trapping periods was significant ($F = 9.50$, $P < 0.01$). Total catches in vertical columns followed by the same letter did not differ significantly when Bonferroni's inequality multiple comparisons test was used for 6 comparisons (overall error rate: $\alpha = 0.05$), for pairwise comparisons of different trap types.

[4] The numbers in parentheses reflect the percentages of the total number collected (610).

Table 6. The number of female *Culicoides variipennis* caught in relation to trap type and gonotrophic status on 8 dates when all traps and the vehicle-mounted net were operated.[1]

		Trap type					
Gonotrophic status		Vehicle-mounted sweep net	(A) Black light + CO_2	(B) Incandescent light + CO_2	(C) Suction trap + CO_2	(D) Black light only	Traps (A), (B), (C) and (D) combined
Nulliparous	Hour I	3	47	11	21	0	79
	Hour II	191	653	278	427	0	1,358
	Hour III	155	482	44	42	3	571
	Hour IV	7	235	15	3	14	267
	Total	356 (58.36)[3]	1,417 (a)[2] (57.23)	348 (b) (77.16)	493 (b) (76.55)	17 (c) (1.12)	2,275 (44.65)
Parous	Hour I	0	29	7	13	0	49
	Hour II	25	269	64	96	0	429
	Hour III	36	347	20	39	134	540
	Hour IV	22	76	11	3	74	164
	Total	83 (13.61)	721 (a) (29.12)	102 (b) (22.62)	151 (b) (23.45)	208 (b) (13.65)	1,182 (23.20)
Gravid	Hour I	0	0	0	0	0	0
	Hour II	24	1	0	0	0	1
	Hour III	137	258	0	0	931	1,189
	Hour IV	10	79	1	0	368	448
	Total	171 (28.03)	338 (b) (13.65)	1 (c) (0.22)	0 (c) (0)	1,299 (a) (85.24)	1,638 (32.15)
Total[4]		610	2,476	451	644	1,524	5,095

[1] Trapping dates are the same as those in Table 4. The two-way ANOVA (SAS GLM Procedure) for differences in numbers of females in each gonotrophic state caught in trap types A–D was highly significant ($F = 13.47$, $P < 0.001$).

[2] Total trap catches in horizontal rows followed by the same letter did not differ significantly when Bonferroni's inequality multiple comparisons test was used for 6 comparisons (overall error rate: $\alpha = 0.05$), for pairwise comparisons of different trap types.

[3] The numbers in parentheses reflect the percentages of the total collected by each kind of trap (column only).

[4] In addition to the flies accounted for in this table, 2 engorged females were caught in the black light trap plus CO_2; one was caught during hour III and one during hour IV.

tion were caught in the last of the two 8-min vehicle runs (completed only a couple of minutes before sunset). This confirms the results of trap catches that revealed that few gravid females were flying prior to sunset (Tables 3 and 6). In northeastern Colorado, Akey and Barnard (1983) also reported a large increase in gravid females caught in a vehicle net just after sunset.

A comparison of trapping results with vehicle-mounted net catches (Table 6) shows the nature of the bias for each trap type. Overall, the CO_2-baited black light traps overestimated the population of parous flies but underestimated the population of gravids. The CO_2-baited suction trap and CO_2-baited incandescent light trap overestimated both nulliparous and parous populations but greatly underestimated the gravid segment of the population. The nonbaited black light traps greatly overestimated the gravid segment of the population but exerted little attraction to host-seeking females. The flying activity of *C. variipennis* was overestimated by all CO_2-baited traps during the first hour. Because the vehicle net collections (Tables 5 and 6) and non-CO_2-baited traps (Tables 3 and 6) revealed that females in all gonotrophic states did not begin flying until a few minutes before sunset (e.g., Table 5, coll. 4), the small catches of females in CO_2-baited traps during the first hour may have been due to the fact that the CO_2 prematurely stimulated a host-seeking flight by females resting in the near vicinity of the traps. Overall, proportionately more nulliparous females were caught before sunset by all trap types with CO_2 and by the vehicle net. Akey and Barnard (1983) obtained similar results for vehicle net catches.

When catch results for all light and CO_2-baited traps are combined, the bias associated with individual trap types decreases considerably (Table 6). Hence, the percentages of gravid females caught in all trap types and the vehicle-mounted net are very similar (32% vs. 28%), as are the catches for the host-seeking segment of the population (68% vs. 72%). Parous females are still somewhat overrepresented when trap catches are combined, and nulliparous females somewhat underrepresented. Nevertheless, as judged by the nonattractive samples obtained in the vehicle-mounted net, combined data for all types of traps provides a better measure of the parity profile and the reproductive status of the population than the catch from any single type of trap. The biased nature of female catches in relation to their gonotrophic state limits the usefulness of certain types of light traps in studies of the population age structure of female *C. variipennis*. Bidlingmayer (1974) reported similar results for mosquitoes.

CONCLUSIONS

This is the first time that black light traps have been found to be selectively attractive to gravid and parous females of *C. variipennis*. Zimmerman and Turner (1983) previously reported high parous rates for *C. variipennis* caught in black light traps; but since only black light traps were used, it was not possible to make comparisons. Since our black light traps baited with CO_2 also caught significantly higher numbers of gnats than did other traps, this kind of trap should be the trap of choice when the objective is to catch large numbers of parous females, as in arbovirus isolation studies.

The ineffectiveness of black light traps for gravid females before sunset seemed related more to the fact that such females usually began flying only a few minutes before sunset (Tables 3 and 5) than to these traps not being visible to the flies prior to sunset. In 1983, the black light trap plus CO_2, in fact, caught 6 gravid females before sunset (Table 3), as well as catching more host-seeking females before sunset than the other types of CO_2-baited traps (Tables 3 and 6).

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