FLIGHT CAPACITY OF BLOOD-ENGORGED MOSQUITOES[1]

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INTRODUCTION

There exists little factual data concerning the dispersal of blood-engorged mosquitoes. Nonetheless, it is seemingly a widely held view that engorged individuals do little if any flying. Presumably, this stems from the assumptions that: (1) fully-engorged mosquitoes are physically incapable of extended flight, and (2) blood-engorged mosquitoes have no need to fly any great distance.

During the course of studying blood-feeding behavior of mosquitoes in different habitats in Indian River County, Florida, we were immediately impressed by the number of mosquitoes containing blood from hosts (primarily cattle) not present in the areas where collections were made. This was particularly evident among mosquitoes obtained from an island surrounded by marsh. Because of the unusual geography of the area, and the variety of mosquito species taken, information on the flight capacity of engorged mosquitoes was obtained and is herein presented. Data from truck trap and suction trap collections made during two other, independent investigations of mosquito activity are included to provide preliminary evidence concerning the motive for flight by engorged mosquitoes and the probable time when such flight occurs.

METHODS

A complete description of the study habitat, a wooded island of about 100 acres, has been published (Kale and Webber, 1968). Briefly, it consists of a dense oak-hickory-palm hammock bordered by a band of maple trees and surrounded by freshwater marsh. The entire marsh-maple swamp portion of the habitat is normally covered by shallow water.

Blood-engorged mosquitoes were collected weekly throughout the year using a tractor-powered aspirator (Bidlingmayer and Edman, 1967) operated over a 3-mile trail in the hammock. Engorged specimens were identified, their blood meals classified and they were then placed immediately in cold storage (−34° C) where they remained until tested. Criteria of color and size were used to indicate the stage of digestion of the blood meal and, by inference, the approximate age of the meal was obtained. The following classification was used: (A) red, any size (B) dark, $>\frac{3}{4}$ full (C) dark, $\frac{1}{2}$–$\frac{3}{4}$ full (D) dark, $<\frac{1}{2}$ full. Mosquito blood meals are normally digested in 2–3 days with some variation depending on the species, temperature, size of the meal, and other factors (Downe *et al.*, 1963; O'Gower, 1956; Shlenova, 1938). Blood meals classified (A) or (B) were considered <24 hours old and those classified (C) or (D) >24 hours old. Questionable meals were not classified.

The precipitin techniques used to identify the vertebrate sources of mosquito blood meals have been described (Tempelis and Lofy, 1963; Edman and Downe, 1964). Data were obtained on more than 20 species of mosquitoes but only the 9 species with at least 100 identified feedings on mammals are here included and only the feedings on bovine hosts will be considered in detail.

Cattle were numerous in the pastures beyond the marsh but they were restricted from the area within a 1-mile radius of the island except for two small protrusions of

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pastureland at the perimeter (Figure 1). Mosquitoes containing bovine blood and collected on the island were consequently assumed to have flown at least 1 mile between the time of blood-feeding and complete digestion of the blood meal. The distance of 1 mile only provides an estimate of the minimum distance flown, since most non-migratory flights are probably not uni-directional.

Deer blood was found to react with our bovine antisera so it was not possible to separate feedings on deer and cattle serologically. Initially this caused some concern, since white-tailed deer occur in this area. However, continual census of mam-

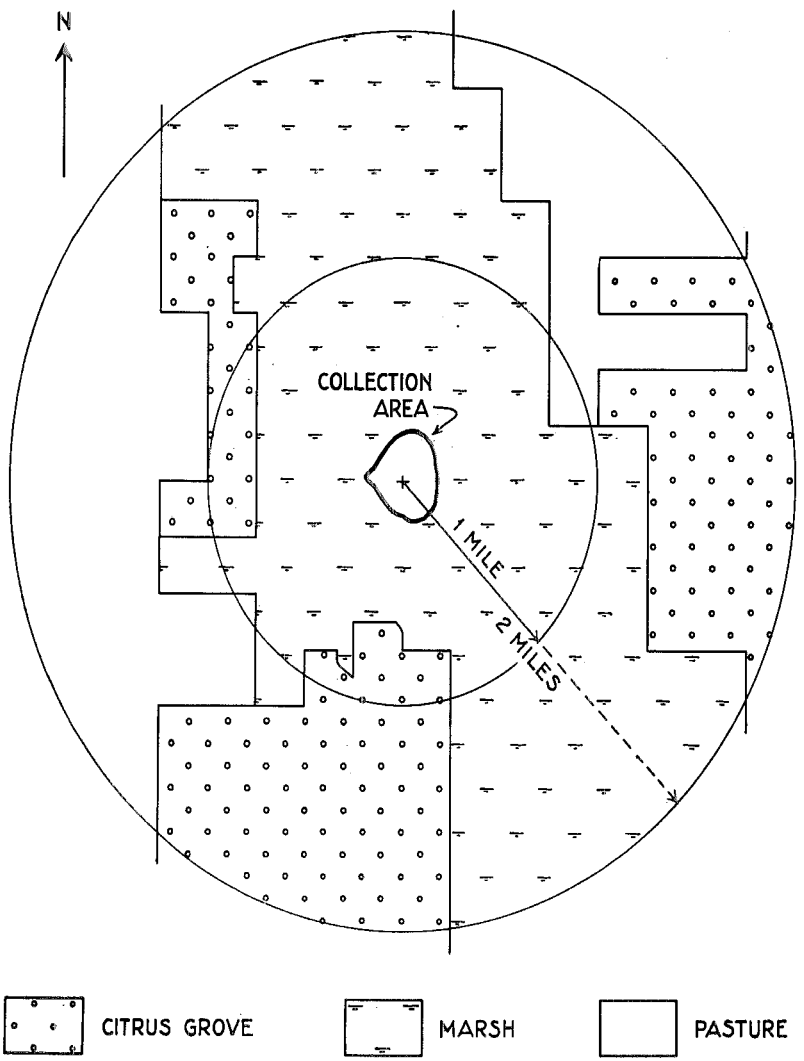

FIG. 1.—Diagram of the area within a 2-mile radius of the island hammock where engorged mosquitoes were collected.

mal populations indicated that the presence of deer on or near the island was so sporadic and their numbers (2–3) so small, that bovine blood could be considered, for all practical purposes, synonymous with cattle blood. This conclusion was challenged by comparing engorged mosquitoes collected during periods when deer had visited the island with those from periods when deer were absent. The percentage of bovine blood meals was approximately the same during both periods. In addition, the blood sources of mosquitoes collected from the portion of the island favored by deer during their visits showed little variation with those collected from other parts of the island.

RESULTS

BLOOD MEAL STUDIES. As evidenced by the feedings on bovines, some engorged individuals of all nine species were found to fly at least 1 mile, the minimum distance from pasture to hammock (Table 1—Part A). The frequency of the flights varied considerably among species, with primarily on mammalian hosts except *Culex nigripalpus*. Approximately one-half of the engorged *C. nigripalpus* collected had fed on birds (Edman and Taylor, 1968).

Recent (<24 hrs. old) blood meals were separated from older meals and the incidence of bovine blood among the two groups was calculated independently (Table 1—Part B). Only the feedings on mammals were included in this grouping and meals which proved difficult to classify were excluded. Thus, the total number of individuals represented in Part B is usually less than in Part A. It is apparent that most engorged mosquitoes arrived on the island less than 24 hours after taking blood since the percentages of bovine bloods among recent feedings is similar to that found in the older meals. However, it appears that some *Psorophora confinnis* may not arrive until the second day after feeding, since there was a 60 percent increase (from 36–56 percent) in bovine bloods among the older meals in this species.

SUCTION TRAP COLLECTIONS. The effect

TABLE 1.—*Part A.* Incidence of bovine blood in mosquitoes collected in Schwey's island hammock during 1967 and 1968. *Part B.* Occurrence of bovine blood in recent vs. older blood meals. *Part C.* Comparison of habitat preferences during night-time flight.

	A		B				C[1]
			Meals with mammal blood				
	All blood meals		<24 Hours old		>24 Hours old		Ratio caught
Species	(No.)	% bovine	(No.)	% bovine	(No.)	% bovine	Woods:open
Aedes vexans	(906)	82	(264)	81	(626)	83	1:2.0
Aedes taeniorhynchus	(205)	73	(91)	75	(112)	73	1:3.0
Mansonia perturbans	(117)	53	(34)	50	(75)	57	1:2.0
Psorophora confinnis	(785)	50	(293)	36	(471)	56	1:16.0
Culex nigripalpus	(4302)	28	(922)	49	(1131)	56	1:0.3
Psorophora ferox	(139)	19	(66)	18	(72)	19	1:0.3
Anopheles crucians	(118)	18	(81)	16	(33)	21	1:4.0
Aedes infirmatus	(277)	15	(112)	19	(155)	12	1:0.6
Psorophora howardii	(108)	7	(30)	7	(76)	8	1:0.7

[1] These data are from night-time suction trap collections made in and near Neville swamp during 1968.

Aedes vexans (82 percent) and *Psorophora howardii* (7 percent) representing the two extremes. All species listed in Table 1 feed

of environmental influences on mosquito flight behavior is currently being investigated in an isolated maple swamp approxi-

mately 3 miles east of the island hammock area. This densely wooded habitat (Neville Swamp) of about 30 acres is also surrounded by relatively open terrain. In one test, collections from replicated pairs of large suction traps (described in Bidlingmayer, 1964) were used to compare the numbers of mosquitoes flying at night within the wooded swamp with those flying in the adjacent open area. The proportions captured in each situation are presented as ratios in Table 1—Part C. Five of the species were found to prefer open areas for night-time flight with *P. confinnis* showing the strongest preference for the open. Predictably, the four woodland species (Bidlingmayer, 1967) were more abundant in the swamp collections. Nonetheless, appreciable numbers were taken in traps located in the open.

TRUCK TRAP COLLECTIONS. The truck trap has proved to be a useful device for measuring the flight activity of mosquitoes (Bidlingmayer, 1966). Figure 2 compares collections made at different periods of the night, along the same 3 miles of road near Oslo. The road bisects relatively open terrain about 10 miles east of the island hammock.

Period 1 extends from sunset to astronomical twilight, a duration of about 80–90 minutes. Three periods of similar duration (2, 3, and 4) followed, representing the time between evening astronomical twilight and midnight. Periods 5, 6, and 7 occupied the time between midnight and morning astronomical twilight while period 8 began at twilight and ended at sunrise. Collections taken during periods 2, 3, and 4 and also periods 5, 6, and 7 were summed and a mean value for both groups obtained.

The number of females captured during the different periods indicates that in each species the greatest flight activity takes place during twilight, thus causing the formation of U-shaped curves in Figure 2. There is considerable variation between

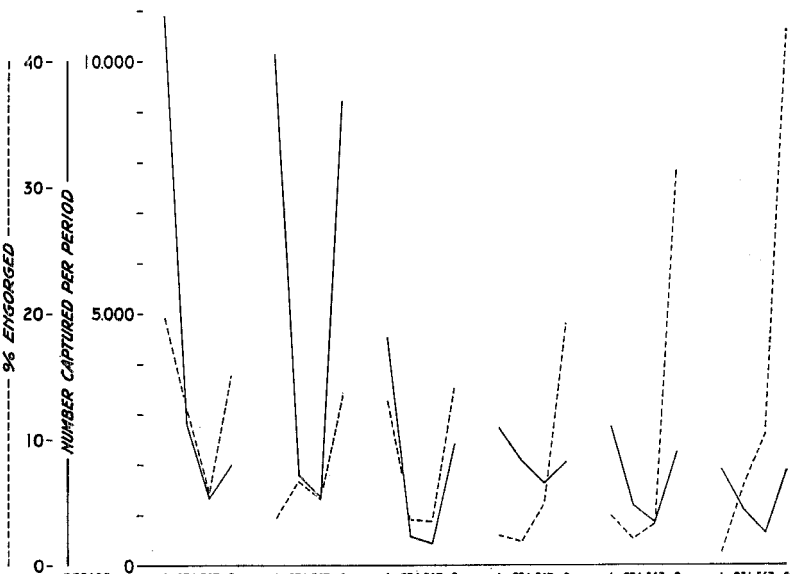

FIG. 2.—Number of flying female mosquitoes captured and percentage engorged during the night. Truck trap collections, Oslo, 1963–1965.

species. In *Psorophora* and *Aedes* most flight activity occurs during crepuscular periods. *Culex* and *Anopheles* show proportionately higher levels of activity during the dark periods of the night. These data are in agreement with the abundant literature on this subject but nonetheless are presented here to serve as a point of reference for engorged individuals.

The number of engorged mosquitoes for each species is represented as the percentage of the total numbers of females taken. If the number engorged were directly proportional to the number taken in each period, the broken lines in Figure 2 would appear as horizontal. It is apparent that the times of flight activity of engorged mosquitoes differ from those of the population as a whole. The activity of engorged mosquitoes throughout the night also tends to form a U-shaped curve, indicating that they favor crepuscular periods more strongly than unengorged individuals. Moreover, whereas females collectively show peak activity in the evening twilight, engorged females, except *P. confinnis,* preferred to fly during the morning twilight period. This was particularly true of the woodland species.

DISCUSSION

Anyone who has watched a mosquito feed is likely to have supported the contention that engorged individuals are physically incapable of extended flights. The fully-fed mosquito, appearing less than flightworthy, flies with apparent difficulty from the host (often just walking or gliding off), and settles on the nearest surface. Unfortunately, this is where most observations end. However, evidence that mosquitoes may excrete clear fluids equal to nearly one-half the weight of the blood meal within the first 2 hours after feeding (Wigglesworth, 1932; Boorman, 1961) indicates that excess bulk is eliminated quickly. In addition, calculations concerning the mechanics of flight (in terms of body form and weight) also indicate that the appearance of an engorged mosquito may give a misleading impression as to its ability to fly (Hocking, 1953).

The different levels of bovine blood encountered among the nine species (Table 1–A) could conceivably reflect different flight abilities, with *A. vexans* being the strongest flier, followed by *A. taeniorhynchus,* etc. However, our knowledge of these species suggests that their distribution in the environment may be regulated more by the behavior of the species than by flight ability. In general, the suction trap collections (Table 1–C) support this suggestion. Of the five species which were collected most frequently in the open, all except *An. crucians* also had a higher incidence of bovine blood meals than the four species which were caught most often in the woods. The low percentage of bovine blood in *An. crucians* may reflect searching habits which lead to more frequent contact with small mammals than with cattle. The comparisons in Table 1 are based on the assumption that all "mammal feeders" (Edman and Taylor, 1968) feed proportionately on the mammals available and this may not always be true.

Considering its stronger preference for open areas (e.g. pastures with cattle) during searching flight, *P. confinnis* might be expected to have the highest incidence of bovine blood meals. This incongruity may be due in part to the differing daytime resting habits of this species. *P. confinnis* is the only species in Table 1 which frequently spends the day in open areas (Bidlingmayer, unpublished data). Since our engorged mosquitoes were all collected in the woods during mid-morning, when about one-half of all *P. confinnis* are still in the open, our sample of blood meals for this species may not be as representative of the entire population as it is for the other species. The finding of lower percentages of *P. confinnis* with fresh bovine blood (Table 1–B) is further evidence that this species may inhabit open areas during the day.

Non-migratory mosquito flight has been characterized as searching flight motivated by appetence (Provost, 1953), i.e., appetence for blood, sugar, a resting place, etc. Other authors (Eyles, *et al.,* 1945; Klingler, 1932) have correspondingly suggested that, at a given time and place, the distance and duration of appetential flight may largely depend on the local abundance and distribution of the items being sought (e.g. flowering plants, vertebrate hosts, and resting places). The requirement of a specific resting place (and possibly a sugar meal) certainly provides a motive for limited appetential flights, and in certain environments extended flights, by some engorged mosquitoes. Observations made on several anophelines (Thomson, 1941; Shannon, 1935) and *Mansonia perturbans* (Snow and Pickard, 1957) support this logic. Other observations show that some engorged anophelines move about extensively within and between suitable resting sites, and thus appear to fly without there being any *apparent* need to do so (Klingler, 1928, 1932).

The flight motive, of needing to find a suitable place to rest, seems tenable for the engorged mosquitoes in our study environment. Since most species do not spend the day in the open, it follows that individuals feeding on cattle in the open pastures at night probably attempt to find a wooded habitat before sunrise or soon after. Since dense woods are small and scattered in this area, mosquitoes may be forced to fly some distance to locate a suitable resting place. Also, the dark wooded islands, which stand out against the sky over the low, lighter marsh, may conceivably attract mosquitoes from a great distance. It is interesting to note that the first published observation of dispersive flights in mosquitoes made mention of the many mosquitoes with blood present in morning flights, and that morning flights took place higher above ground and were more directed than evening flights (Zetek, 1915). It would seem reasonable to suggest that light is the stimulus for early-morning flight, since neither temperature nor humidity normally change significantly until after sunrise.

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LABORATORY TESTS OF THE SUSCEPTIBILITY OF MOSQUITO LARVAE TO INSECTICIDES IN FLORIDA, 1968

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The surveillance program of the Florida State Board of Health for the detection of possible insecticide resistance in Florida mosquitoes was begun in 1963 (Rogers and Rathburn, 1964). Subsequently, two studies were made as a continuation of the program (Rathburn and Boike, 1967; Boike and Rathburn, 1968). This report deals with the further surveillance of Florida mosquitoes for their susceptibility to malathion, naled and fenthion. Initial data for Abate[1] and Dursban[2] are also included.

METHODS. The methods of collecting and handling the mosquitoes and testing procedures were generally the same as described by Rathburn and Boike (1967). With minor modifications the larval tests were performed according to procedures outlined by the World Health Organization (WHO, 1960). Rathburn and Boike (1969) showed that there was no significant difference between 600 ml. glass beakers and 400 ml. polypropylene beakers when using malathion, naled or fenthion; therefore, polypropylene beakers were used in most of the tests with these insecticides. However, they showed that there was a significant difference between the two types of test vessels with Abate; therefore, only glass beakers were used in tests with this insecticide. Tests of Dursban were conducted in glass beakers only.

One replication consisted of five insecticide dosages plus a check, 25 third instar larvae being used for each dosage. Tap water was used in testing all *Culex* species and *Aedes aegypti*, while 25 percent sea water was used with *Aedes taeniorhynchus*. Test beakers were washed with detergent, thoroughly rinsed and passed through two acetone baths after testing. The overall average water temperature was 74.0° F. with an average maximum temperature of 75.3° F. and an average minimum temperature of 72.8° F.

RESULTS. The results of tests with five insecticides against five species of mosquito larvae are shown in Table 1. Although the LC_{50} value of naled for *A. taeniorhynchus* from Mayport Naval Air Station (0.108 p.p.m.) is lower than reported in 1967 (0.196 p.p.m.), this may be due to species differentiation since the 1967 figure refers to tests with *A. taeniorhynchus* while the 1968 figure refers to a mixed population of 90 percent *A. sollicitans* and 10 percent *A.*

[1] American Cyanamid Co.
[2] The Dow Chemical Co.