

Ecology of Vector Mosquitoes of Japanese Encephalitis,
Especially of *Culex tritaeniorhynchus*. 2. Nocturnal activity
and host preference based on all-night-catches by different
methods in 1965 and 1966 near Nagasaki City.*

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Abstract

All-night-catches of mosquitoes were made four times at human huts, by human-baited-traps, at animal sheds, and by dry-ice-traps, two times in June and once in September, 1965 and once in August, 1966. The hourly distributions of the collected females of *Culex tritaeniorhynchus* usually had a high post-sunset peak, and occasionally a low peak before or around sunrise. It was also shown that the order of mosquito species in the appearance of the post-sunset peak, early to late, is as follows: *Aedes vexans nipponii*, and *Armigeres subalbatus* > *Anopheles sinensis*, *Culex neovishnui*, and *C. tritaeniorhynchus* > *C. pipiens pallens*. As for the host preference of mosquitoes, it was shown from the percentage compositions of mosquitoes collected by various methods that *C. tritaeniorhynchus*, *An. sinensis*, *Ae. vexans nipponii*, and *Ar. subalbatus* are zoophilic; *C. neovishnui* is ornithophilic and zoophilic; and *C. pipiens pallens* is ornithophilic and anthropophilic.

Introduction

The nocturnal activity of the females of *Culex tritaeniorhynchus*, and other mosquitoes, has been studied in Japan by some investigators, but the hourly pre-

valence of the females has been shown not always in the same pattern. With *C. tritaeniorhynchus* females, for example, a post-sunset peak was observed each in the

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collections by dry-ice-traps by Kato *et al.* (1966) and Takeda *et al.* (1962), and at a horse-shed by Kato and Toriumi (1950); a predawn peak was observed in addition to a post-sunset peak at a horse-shed by Kato and Toriumi (1951); and the females were collected almost constantly throughout the night at a pigsty by Ogata *et al.* (1968) and Yoshitake Wada (1969); while all such patterns as stated above were observed on different nights by light traps by Nakata (1962). Although such meteorological factors as temperature, humidity, and wind will ex-

plain partly the difference in the nocturnal activity of mosquitoes, it seems that they are not enough for the explanation. As for the host preference of nocturnal mosquitoes, all-night-catches will give more accurate information than limited-time catches, because the hourly prevalence of mosquitoes often differs markedly between species. In this paper, therefore, the results obtained by four all-night-catches of mosquitoes by various methods are presented for their activity pattern and host preference.

Place and method

All-night-catches of mosquitoes were made by various methods on June 12-13 (Exp. 1), 1965 in Tomachi, and on June 19-20 (Exp. 2) and September 1-2 (Exp. 3), 1965 and August 5-6 (Exp. 4), 1966 in Kaizu, as shown in Table 1. The sites of mosquito collections in Tomachi

are given in Fig. 1. Tomachi is a semi-farm village surrounded by small hills. There are paddy fields between residential quarters and hills. Fig. 2. gives the collection sites of mosquitoes in the grounds of Nagasaki Agriculture and Forest Experiment Station the main building

Table 1. Plan of all-night-catches of mosquitoes.

| Exp. No. | Village & date | Site or method of mosquito collection | Host animals |
|----------|--|---|--|
| 1 | Tomachi (cf. Fig. 1) Jun. 12-13, '65 | at pigsty at cowshed at henhouse by human-baited-trap by dry-ice-trap | 18 pigs 1 cow 250 hens 1 man (dry ice) |
| 2 | Kaizu (cf. Fig. 2) Jun. 19-20, '65 | at pigsty at cowshed at hut by dry-ice-trap | 30 pigs 12 cows 4 men (dry ice) |
| 3 | Kaizu (cf. Fig. 2) Sep. 1-2, '65 | at pigsty at hut by dry-ice-trap | 51 pigs 4 men (dry ice) |
| 4 | Kaizu (cf. Fig. 2) Aug. 5-6, '66 | at pigsty at cowshed by dry-ice-trap | 62 pigs 4 cows (dry ice) |

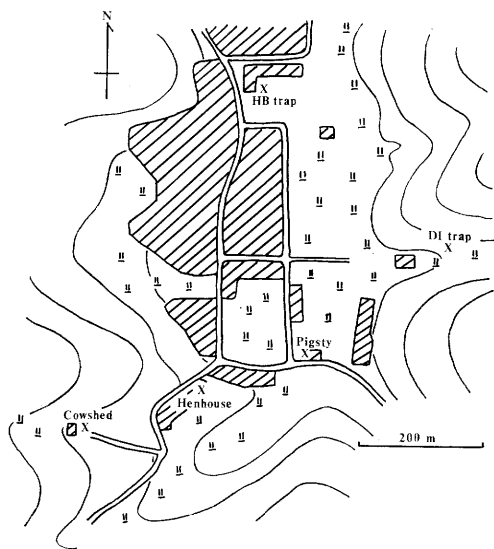


Fig. 1. Map of Tomachi showing the sites of all-night-catches of mosquitoes (Exp. No. 1 in Table 1). X: The site of catch. ▨: Paddy field. ▩: Residential quarter. HB trap: Human-baited-trap. DI trap: Dry-ice-trap.

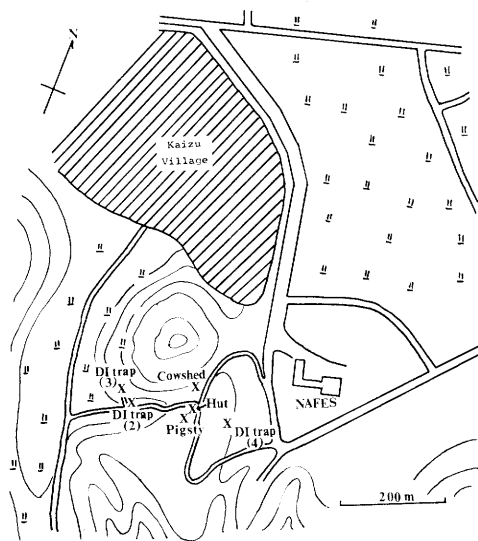


Fig. 2. Map of the grounds of Nagasaki Agriculture and Forest Experiment Station (NAFES) in Kaizu Village, showing the sites of all-night-catches of mosquitoes (Exp. No. 2-4 in Table 1). X: The site of catch. The sites, in the case of DI traps, (2), (3), and (4) were selected respectively in Exp. 2, 3, and 4. ▨: Paddy field. ▩: Residential quarter.

Table 2. Meteorological conditions on the date of each Experiment.

| Exp. No. & place of observation | Weather ¹⁾ , temperature (°C), and wind force ²⁾ at | | | | | | | | | | | | Mean |
|---------------------------------------|---|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------|
| | 7 PM | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 AM | |
| Exp. 1, in human- baited-trap | r 22.0 0 | c 20.4 0 | r 20.4 0 | c 20.2 0 | r 20.2 0 | r 20.0 0 | r 19.8 0 | r 19.6 1 | c 19.4 1 | r 19.4 1 | r 19.3 2 | c 19.4 0 | 20.0 |
| Exp. 2, outdoors | | r 19.6 2 | r 19.2 2 | c 19.1 3 | r 19.1 2 | r 18.9 3 | r 18.9 2 | r 19.0 2 | r 19.5 1 | R 19.2 3 | R 19.2 4 | R 19.2 0 | 19.2 |
| Exp. 3, outdoors | | c 22.8 0 | c 21.2 1 | f 20.4 0 | f 19.8 0 | f 19.2 1 | f 18.8 0 | f 18.4 0 | f 17.8 0 | f 17.8 0 | f 17.0 0 | f 17.0 0 | 19.1 |
| Ex. 4, outdoors | | f 27.0 | f 26.5 | f 26.2 | f 26.5 | f 25.9 | f 25.2 | f 24.8 | f 24.5 | f 24.0 | f 23.6 | f 24.5 | 25.3 |

0-1 throughout the night

Remarks: 1) f: fine. c: cloudy. r: rainy. R: heavy rain.

2) Beaufort's wind force scale.

of which stands on the foothill area in Kaizu Village. The collection sites are accordingly settled on rather hilly places near paddy fields. All-night-catches of mosquitoes were made every one hour from sunset to sunrise for 20 minute by a man. At the pigsty, cowshed, hen-house, and human hut, mosquitoes resting on the walls before or after feeding were randomly collected. In the cases of catches by the human-baited-trap or the dry-ice-trap, mosquitoes were naturally collected as unfed ones, while in

rare cases fed ones were collected when they strayed into the traps after having fed on animals at some other places.

Table 2 shows the meteorological conditions, i.e., the weather, temperature, and wind force on the nights when all-night-catches of mosquitoes were made. It was rainy on the nights of Exp. 1 and 2, and fine on those of Exp. 3 and 4. Temperatures were around 20°C in the first three Experiments, and around 25°C in Exp. 4. It was rather windy in Exp. 2 and quiet at the others.

Results obtained

The species composition of mosquitoes collected by various methods is presented in Table 3. In total, 26,180 female mosquitoes belonging to 12 species were collected. Of those, *Culex tritaeniorhynchus* was the most dominant species, 73.55% of the total. *Aedes vexans nipponii* formed

9.74%, *Anopheles sinensis* 9.36%, *Culex neovishnui* 3.97%, *Culex pipiens pallens* 1.59%, *Armigeres subalbatus* 1.24%, while the other six species were very small in number. Strictly speaking, however, the composition differs with locality, site and method as seen in each Experiment.

Table 3. The species composition of mosquitoes by all-night-catches by various methods. The number of females and the percentage (in parentheses) to the total catch are given for each Experiment.

| Experiment No. | 1 | 2 | 3 | 4 | Total |
|-----------------------------|--------------------|--------------------|---------------|---------------|----------------|
| Village | Tomachi | Kaizu | Kaizu | Kaizu | |
| Date | Jun. 12-13, '65 | Jun. 19-20, '65 | Sep.1-2, '65 | Aug. 5-6, '66 | |
| <i>An. sinensis</i> | 468 (5.22) | 595 (6.78) | 464(38.63) | 923(12.76) | 2,450 (9.36) |
| <i>An. sineroides</i> | 37 (0.41) | 14 (0.16) | | | 51 (0.19) |
| <i>Ar. subalbatus</i> | 23 (0.26) | 239 (2.72) | 29 (2.41) | 34 (0.47) | 325 (1.24) |
| <i>Mans. uniformis</i> | | | 5 (0.42) | | 5 (0.02) |
| <i>Ae. vexans nipponii</i> | 2,479(27.65) | 45 (0.51) | 22 (1.83) | 5 (0.07) | 2,551 (9.74) |
| <i>C. bitaeniorhynchus</i> | 21 (0.23) | 1 (0.01) | 7 (0.58) | 7 (0.10) | 36 (0.14) |
| <i>C. hayashii</i> | 1 (0.01) | | | | 1 (0.00) |
| <i>C. p. pallens</i> | 333 (3.71) | 69 (0.79) | 11 (0.92) | 2 (0.03) | 415 (1.59) |
| <i>C. neovishnui</i> | 254 (2.83) | 142 (1.62) | 352(29.31) | 292(4.04) | 1,040 (3.97) |
| <i>C. sinensis</i> | 3 (0.03) | 1 (0.01) | | | 4 (0.02) |
| <i>C. tritaeniorhynchus</i> | 5,331(59.46) | 7,674(87.39) | 298(24.81) | 5,953(82.31) | 19,256(73.55) |
| <i>C. whitmorei</i> | 16 (0.18) | 1 (0.01) | 13 (1.08) | 16 (0.22) | 46 (0.18) |
| Total | 8,966(100.00) | 8,781(100.00) | 1,201(100.00) | 7,232(100.00) | 26,180(100.00) |

With the six dominant mosquito species, the percentage composition to the total number of mosquitoes collected in each Experiment is given in Table 4. As the number of host animals were not necessarily the same by method and Experi-

ment, and the daytime resting places seemed not uniform around or from the collection sites, the numbers of mosquitoes collected seem to be not directly comparable for the host preference. However, the percentage species compo-

Table 4. Host preference of mosquitoes represented by the percentage species composition by all-night-catches. Percentages are calculated to the total number of mosquitoes collected in each Experiment (cf. Table 3).

| Mosquito species | Exp. No. | Attractive animals | | | | | |
|--------------------------------|----------|--------------------|-------|-------|------|-----------|--------|
| | | Pigs | Cows | Hens | Men | (Dry ice) | Total |
| <i>Anopheles sinensis</i> | 1 | 0.37 | 2.30 | 0.56 | 0.14 | 1.85 | 5.22 |
| | 2 | 2.37 | 4.08 | | 0.02 | 0.31 | 6.78 |
| | 3 | 6.83 | | | 0.08 | 31.72 | 38.63 |
| | 4 | 6.00 | 5.20 | | | 1.56 | 12.76 |
| <i>Armigeres subalbatus</i> | 1 | 0.01 | 0.13 | 0.02 | 0.00 | 0.09 | 0.26 |
| | 2 | 0.23 | 2.45 | | 0.03 | 0.01 | 2.72 |
| | 3 | 1.75 | | | 0.00 | 0.67 | 2.41 |
| | 4 | 0.11 | 0.30 | | | 0.06 | 0.47 |
| <i>Aedes vexans nipponii</i> | 1 | 0.59 | 2.91 | 0.16 | 0.01 | 23.98 | 27.65 |
| | 2 | 0.14 | 0.33 | | 0.00 | 0.05 | 0.51 |
| | 3 | 0.08 | | | 0.00 | 1.75 | 1.83 |
| | 4 | 0.00 | 0.03 | | | 0.04 | 0.07 |
| <i>Culex pipiens pallens</i> | 1 | 0.26 | 0.42 | 2.78 | 0.21 | 0.04 | 3.71 |
| | 2 | 0.38 | 0.05 | | 0.16 | 0.20 | 0.79 |
| | 3 | 0.75 | | | 0.08 | 0.08 | 0.92 |
| | 4 | 0.03 | 0.00 | | | 0.00 | 0.03 |
| <i>Culex neovishnui</i> | 1 | 0.14 | 0.72 | 1.04 | 0.12 | 0.80 | 2.83 |
| | 2 | 0.13 | 1.10 | | 0.05 | 0.34 | 1.62 |
| | 3 | 6.33 | | | 0.42 | 22.56 | 29.31 |
| | 4 | 2.83 | 0.39 | | | 0.82 | 4.04 |
| <i>Culex tritaeniorhynchus</i> | 1 | 9.41 | 21.90 | 7.13 | 5.07 | 15.94 | 59.46 |
| | 2 | 18.21 | 42.75 | | 0.39 | 26.04 | 87.39 |
| | 3 | 3.75 | | | 0.67 | 20.40 | 24.81 |
| | 4 | 16.81 | 31.66 | | | 33.84 | 82.31 |
| Others | 1 | 0.01 | 0.08 | 0.03 | 0.03 | 0.71 | 0.87 |
| | 2 | 0.00 | 0.18 | | 0.00 | 0.01 | 0.19 |
| | 3 | 0.17 | | | 0.17 | 1.75 | 2.08 |
| | 4 | 0.17 | 0.03 | | | 0.12 | 0.32 |
| Total | 1 | 10.80 | 28.47 | 11.71 | 5.60 | 43.42 | 100.00 |
| | 2 | 21.44 | 50.94 | | 0.65 | 26.97 | 100.00 |
| | 3 | 19.65 | | | 1.42 | 78.93 | 100.00 |
| | 4 | 25.95 | 37.61 | | | 36.44 | 100.00 |

sition shown in Table 4 is considered, in general, to reflect the difference in host preference.

It is seen from Table 4 that *An. sinensis* is zoophilic and also well attracted to dry ice; *Ar. subalbatus* is rather zoophilic; *Ae. vexans nipponii* is well attracted to dry ice and rather zoophilic; *C. p. pallens* is ornithophilic; *C. neovishnui* is ornithophilic and zoophilic and also well attracted to dry ice; and *C. tritaeniorhynchus* is strongly zoophilic and also greatly attracted to dry ice.

This conforms generally the results of the host preference of mosquitoes which have been reported in Japan. Sasa (1949) and Sasa *et al.* (1950) gave the attraction order of animals to mosquitoes by using animal-baited-traps as follows: chicken > horse > goat > rabbit for *C. pipiens pallens*; horse > goat > chicken > rabbit for *C. tritaeniorhynchus*; horse > goat > rabbit > chicken for *An. sinensis* and *Ae. vexans nipponii*. Wada (1966) stated from the comparison of mosquito catches at dwelling houses and cowsheds that *C. pipiens pallens* is strongly anthropophilic, *Ae. togoi* rather zoophilic, and *Ar. subalbatus* strongly zoophilic. Wada *et al.* (1967) collected mosquitoes at various animal sheds and dwelling houses and by dry-ice-traps and said that *C. tritaeniorhynchus* is strongly zoophilic and probably in a lesser extent ornithophilic, *C. neovishnui* is ornithophilic and also zoophilic, *An. sinensis* and *Ae. vexans nipponii* are zoophilic, and *C. pipiens pallens* is anthropophilic and also ornithophilic.

From the present data and the literature mentioned above, it may be concluded that *C. tritaeniorhynchus*, *An. sinensis*, *Ae. vexans nipponii*, and *Ar. subalbatus* are

zoophilic, *C. pipiens pallens* is ornithophilic and also anthropophilic, and *C. neovishnui* is ornithophilic and zoophilic.

Hourly distributions of *C. tritaeniorhynchus* females collected by various methods in Exp. 1 are shown in Fig. 3. The hourly distribution was different

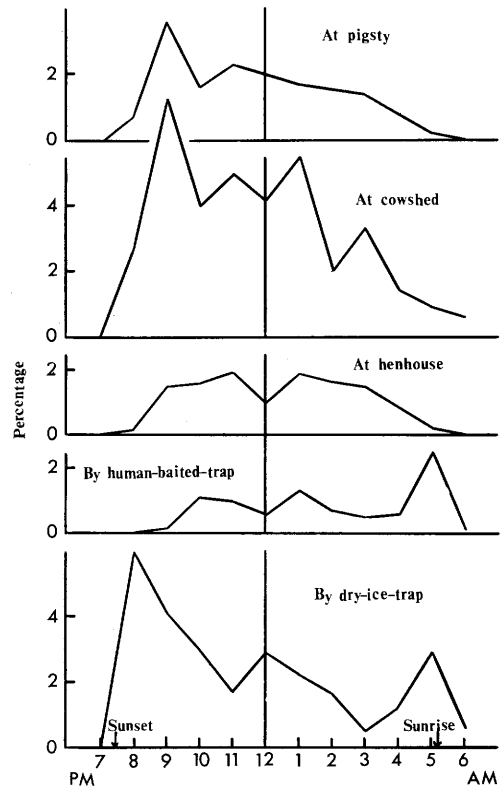


Fig. 3. Nocturnal activity of *C. tritaeniorhynchus* females represented by percentage hourly distribution, Tomachi, June 12-13, 1965. Hourly percentage is calculated to the total number of the females collected by all methods in Exp. 1.

considerably by collection method. The peak was seen just after sunset at the pigsty, cowshed, and in the dry-ice-trap, and a small peak was formed slightly before sunrise in the case of the dry-ice-trap. At the henhouse, there was no peak, but gradual increase and then

gradual decrease. The hourly distribution in the human-baited-trap was rather similar to that at the henhouse, but a small peak was seen slightly before sunrise.

Hourly distributions of *C. tritaeniorhynchus* in Exp. 2 are given in Fig. 4.

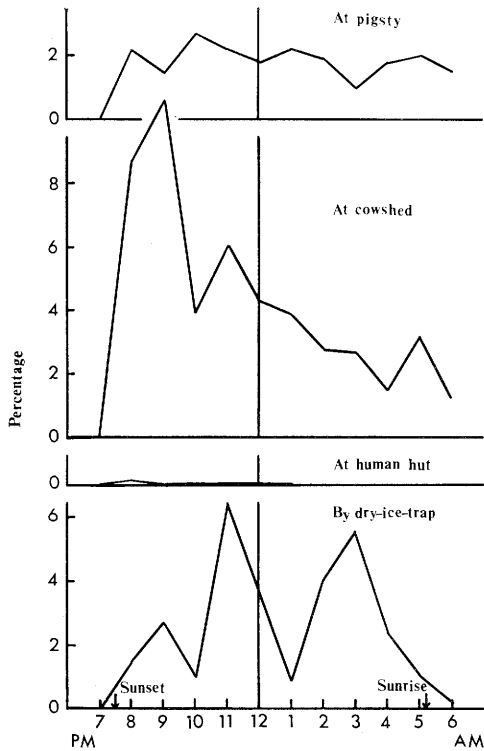


Fig. 4. Nocturnal activity of *C. tritaeniorhynchus* females represented by percentage hourly distribution, Kaizu, June 19-20, 1965. Hourly percentage is calculated to the total number of the females collected by all methods in Exp. 2.

The distributions were again different by methods. At the pigsty the mosquitoes were collected nearly constantly throughout the night. At the cowshed there was found a peak just after sunset. The distribution is not apparent at the human hut, because a very small number of mosquitoes were only collected.

The mosquitoes collected by the dry-ice-trap showed a peculiar distribution with three peaks. This is perhaps due to the weather conditions of rain and wind (see Table 2), which might affect more strongly the catches in the dry-ice-trap than the other catches made indoors.

Fig. 5 and 6 give the hourly distributions of the mosquitoes in Exps. 3 and

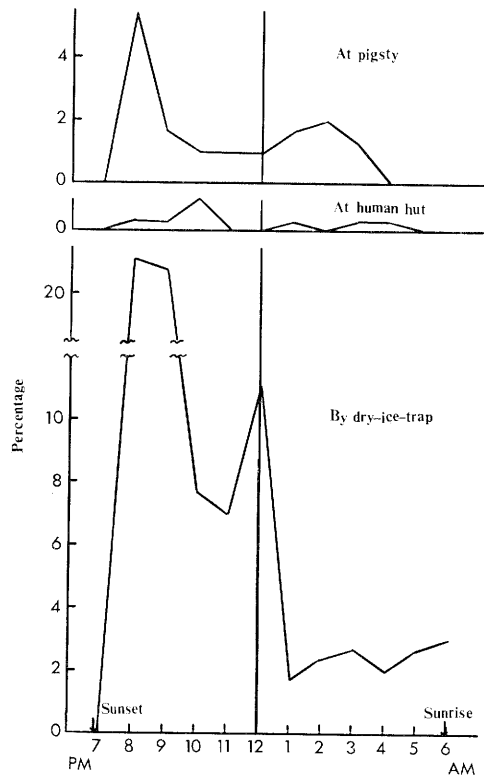


Fig. 5. Nocturnal activity of *C. tritaeniorhynchus* females represented by percentage hourly distribution, Kaizu, September 1-2, 1965. Hourly percentage is calculated to the total number of the females collected by all methods in Exp. 3.

4. The distributions showed rather similar trends to those in Exp. 1 (Fig. 3). At the human hut in Fig. 5, the trend is not clear, because a small number of mosquitoes were only collected. In all the other cases, the peak

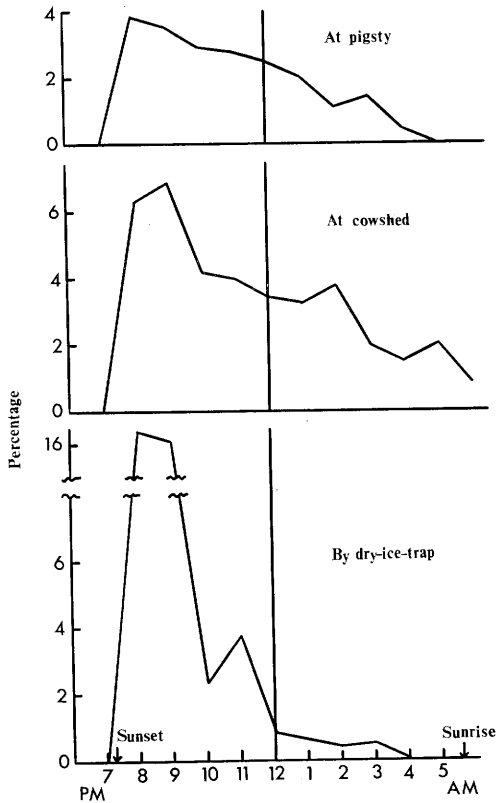


Fig. 6. Nocturnal activity of *C. tritaeniorhynchus* females represented by percentage hourly distribution, Kaizu, August 5-6, 1966. Hourly percentage is calculated to the total number of the females collected by all methods in Exp. 4.

was seen just after sunset, and in addition to this, in the dry-ice-trap in Fig. 5 and at the cowshed in Fig. 6 a small peak seemed to be formed slightly before sunrise.

From Figs. 3-6, the general pattern of the hourly distribution of *C. tritaeniorhynchus* females collected by each method will be given below. Although the hourly distributions at human huts, in human-baited-traps, or at henhouses are not very clear, because small numbers of females were only collected, it seems that the mosquito is attracted to these

hosts rather constantly throughout the night, without forming any remarkable peak. The hourly distributions at pigsties and cowsheds and by dry-ice-traps based on the total catches in Exps. 1-4 are given in Fig. 7. At pigsties and cowsheds, a post-sunset peak is apparently formed, though the mosquitoes are collect-

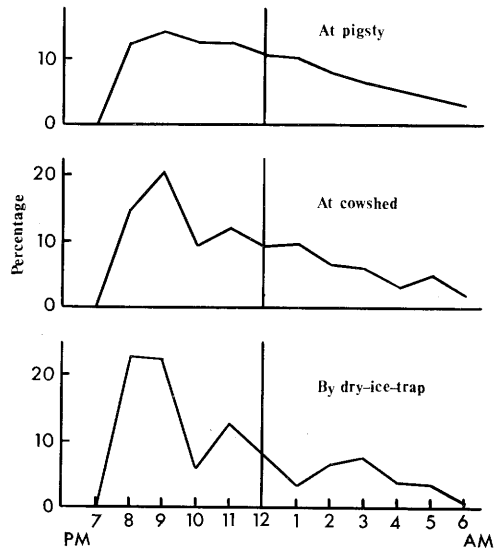


Fig. 7. The nocturnal activity of the female of *C. tritaeniorhynchus* based on the all catches carried out at the pigsties and cowsheds and by the dry-ice-traps throughout the Experiments, represented by the percentage hourly distribution of the female mosquitoes for each collection method.

ed throughout the night. In the catches by dry-ice-traps, the trend is generally similar to that at pigsties and cowsheds, though the distribution is more strongly subjected to the influences of unfavorable conditions than in the cases of catches made indoors or animal sheds.

To compare the general patterns of the female mosquitoes of six dominant species, the percentage distribution based on the all catches obtained in all the Experiments is given by species in Fig. 8.

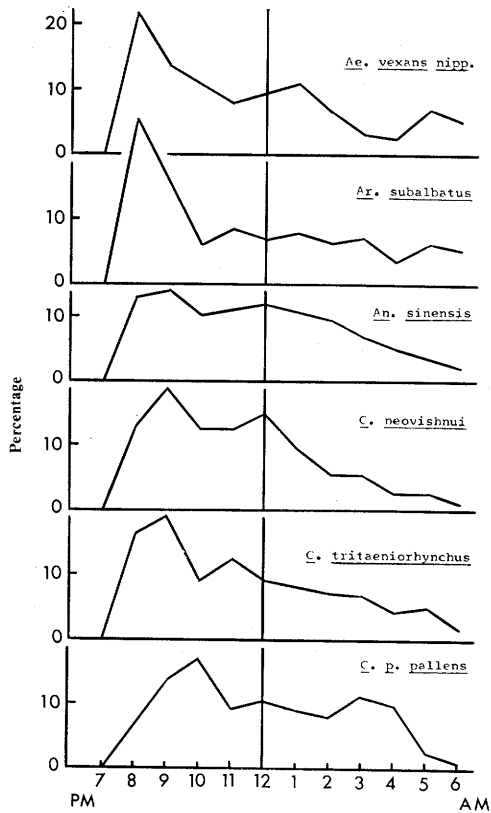


Fig. 8. The nocturnal activity of six dominant species of mosquitoes based on the all catches of the Experiments No. 1-4, represented by the percentage hourly distribution of the female mosquitoes for each species.

In all the species, there was a peak in the early part of night, but the peak time was not always the same by species. The order in which the peak appeared, early to late, was as follows: *Ae. vexans nipponii*, and *Ar. subalbatus* > *An. sinensis*, *C. neovishnui*, and *C. tritaeniorhynchus* > *C. pipiens pallens*. This is generally consistent with the results reported by Bekku (1954), Kato and Toriumi (1950), Nagatomo (1960), Omori and Fujii (1953), Wada (1966), and Yoshida *et al.* (1947).

Discussions

It was shown from the results of the present experiments that the pattern of nocturnal activity of *Culex tritaeniorhynchus* females was not always similar by collection method even on the same night. It is well known that the flight activity of mosquitoes is influenced by many environmental factors such as light, temperature, humidity, wind, etc. (Clements, 1963; Kato & Toriumi, 1950 and 1951; Yoshida *et al.*, 1947). Although these factors should be important in regulating the pattern of nocturnal activity of mosquitoes reflected by the catches by traps baited with animals or dry ice, the present data can not be explained fully by only the hourly changes of these

factors, because the meteorological conditions were considered nearly the same at least on the same night at the sites, where the collections were made.

According to Clements (1963), it is generally assumed that mosquitoes are able to locate human settlements or animal sheds over considerable distances by an active process and do not arrive simply through random flight. It is considered that mosquitoes are attracted to a host by wind-borne stimuli, such as carbon dioxide, scent, heat, and moisture. However, it is not known over what distances these factors are effective from the host.

It is interesting to cite here a paper

by Giglioli (1965), who observed by using animal-baited traps the travel of *Anopheles gambiae melas* over 1-2 miles between its brackish breeding grounds and a village through orchard bush and open cultivated land. He said "The bulk of the mosquito population entering the town crossed the peri-urban cultivated area in 5 well defined and narrow avenues..... Wind direction did not determine the direction or pattern of mosquito approach to the village although it did determine the side on which mosquitoes made the final approach to the trap or habitation..... Mosquitoes approached the town by following the interface between bush and cleared land." This seems to indicate that there are two phases in the process of *An. gambiae*

melas to approach the host, i. e., in the first phase the mosquitoes direct to the village through the change of vegetational and topographical pattern, and in the second the mosquitoes are attracted to the host by wind-born stimuli when they approach to the host.

From the above statements, it seems probable for the present data that if the daytime resting place had been reasonably near to attractive hosts, the mosquitoes would have been attracted by wind-born stimuli from the hosts, while if the mosquitoes had rested quite far from hosts, they would have flied firstly through "mosquito avenue" and then would have been attracted to the hosts by wind-born stimuli.

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日本脳炎伝搬蚊、特にコガタアカイエカの生態

2. 終夜採集法による夜間吸血活動性と吸血嗜好性

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摘 要

1965年6月と9月及び1966年8月に、人またはドライアイスを用いたトラップにより、あるいは豚舎、牛舎または鶏舎において、計4回の蚊の終夜採集を行なった。コガタアカイエカ雌成虫の採集数の時刻的消長には、多くの場合には日没後にピークが見られ、ある場合には日出前後にも小さなピークが見られる。日没後のピーク出現の時刻は蚊の種類により違っていて、次の順序である：キンイロヤブカ、オオクロヤブカ>シナハマダラカ、シロハシイエカ、コガタアカイエカ>アカイエカ。種々の方法で採集した蚊の種類構成から、吸血嗜好性を判断すれば、次の通りである：コガタアカイエカ、シナハマダラカ、キンイロヤブカ、オオクロヤブカは大動物嗜好性；シロハシイエカは鳥類嗜好性及び大動物嗜好性；アカイエカは鳥類嗜好性及び人類嗜好性。