Arbovirus infections in the mosquitoes of Fukuoka area, Kyushu, Japan

4. The epidemiological relations among the seasonal prevalence of the vector mosquitoes of Japanese encephalitis virus, the natural infection of the mosquitoes and the epidemic sizes of Japanese encephalitis

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Abstract: Light-trap studies on the seasonal prevalence of Culex tritaeniorhynchus Giles were conducted during the period from 1963 to 1972 in specified study sites of the Fukuoka area. The results of the studies are subject to the inquiries into the relations with the natural infection patterns of the mosquito with Japanese encephalitis virus and the epidemic sizes of Japanese encephalitis. The vector populations had been infected in their increasing phases in the severe epidemic period before 1967 but often in their decreasing phases in the mild epidemic period after 1966. The period changes in mode of vector infection and epidemic size might be attributed to a chronic tendency towards decline of vector populations. Despite of the above facts, the annual variation in the onset time of vector infection was responsible for year-to-year fluctuation in epidemic size in the mild epidemic period as well as in the severe epidemic period.

The epidemics of Japanese encephalitis (JE) had yearly broken out among residents of Fukuoka area with a wide variation in size in the period from the middle 1950's to the middle 1960's, but the epidemics were extremely reduced in size in the area as well as in the other areas of Japan since the late 1960's. It might be of epidemiological importance to manifest what factors took part in the annual variation in epidemic size in the past.

The 3rd paper of this series (Yamamoto, 1981) revealed the annual patterns of Japanese encephalitis virus (JEV) infection of Culex tritaeniorhynchus Giles in the Fukuoka area during the period from 1963 to 1972, and suggested that the field patterns of mosquito infection might have to be discussed in relation to the population dynamics of the mosquito. The present paper describes the annual variation in seasonal prevalence of the mosquito along with those in mosquito infection with JEV and JE epidemics in the area during that period, making an inquiry into epidemiological correlation among the 3
phenomena.

**Study Sites**

The perennial observations on seasonal prevalence and JEV infection of *C. tritaeniorynchas* mosquitoes were conducted in 2 series. The study sites were the same as those described in Yamamoto (1981): study series I (Ser. I) was made in Uchihashi-Aé and Shime of Kasuya-gun throughout the 1963–1967 period; study series II (Ser. II) was made in Iimori, Nishiyama and Shika of the Kanatake district (Fukuoka City) (Fig. 1) in the 1968–1971 period, and supplemented with the study in Maebara (Itoshima-gun) in 1972. The group of study sites in Kasuya-gun and that in the Kanatake district are separated at a distance of about 20 km. The former lies on northeast of Fukuoka City and the latter occupies the southwest suburban zone of the city. Maebara stands at a distance of 22 km from the center of Fukuoka City.

Two to 3 trapping spots were arranged in the Uchihashi-Aé, Iimori, Nishiyama and Maebara study sites (multi-spot study sites), and a single trapping spot was placed in the Shime, Kanatake and Shika study sites (uni-spot study sites). The trapping spots were cattle, cow, pig and fowl sheds.

![Fig. 1 A map showing the trapping spots of the Kanatake district. Solid circles represent trapping spots, and areas encircled with dotted line show study sites.](image-url)

**Materials and Methods**

Light-trap operation: Light-trap catches of *C. tritaeniorynchas* were periodically conducted at the selected trapping spots during a period from May or June to October in every study year. A light trap was fixed at 1.5 m above the ground indoors at a trapping spot (an animal shed), and operated from dusk to dawn on a 1-night per week schedule in Ser. I and on a 2-night per week schedule in Ser. II.

Sorting and counting of mosquito specimens: All the mosquito specimens were individually examined for species under a stereoscopic microscope and counted in the 1963–1968 studies. Mosquito species and mosquito numbers were estimated by a weighing method in larger catches in the 1967–1972 studies. The method was as follows: 1) Light-trap catches were weighed by a balance after ridding themselves of large insects. 2) In the catches above 5 g weight, 3 to 10 subsamples (0.5 g weight each) were taken out according to the sample weight and examined for the species composition. 3) The number of a mosquito species in the whole catch was estimated from the mean of subsamples. In mass sorting of light-trap specimens, the discrimination between *C. tritaeniorynchas* and *Culex pseudovishnui* Colless was not made owing to heavy damage of upright forked scales on the vertex. The proportion of the latter to the former was considered to be negligible for seasonal prevalence studies in all the study sites (Yamamoto, 1979).

Indices to mosquito abundance: The seasonal prevalence curves of *C. tritaeniorynchas* were presented by weekly abundance of females on the basis of 1 trap-night index in the 1963–1968 studies and on the basis of 2 trap-night index in the 1969–1972 studies. The trap-night indices were given by the method of Loomis and Hanks (1959) and expressed as $\log_{10} (x+1)$ transformation. The data were signified by the weighed mean of simultaneous catches at different trapping spots in multi-spot study sites. The weighed mean was calculated by the following equation:
Table 1  Amendments in the manner of light-trap catch in the present studies.

<table>
<thead>
<tr>
<th>Year</th>
<th>Study site</th>
<th>Trapping spot</th>
<th>Schedule nights (per week)</th>
<th>Light trap Type</th>
<th>Lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study ser. I in Kasuya-gun</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1963</td>
<td>Uchihashi-Aé</td>
<td>(Cattle sheds B, F, Fowl shed H)</td>
<td>1</td>
<td>NJ</td>
<td>FIL</td>
</tr>
<tr>
<td>1964</td>
<td>do.</td>
<td>(Cattle shed F, Fowl shed H)</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
</tr>
<tr>
<td>1965</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
</tr>
<tr>
<td>1966</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
</tr>
<tr>
<td>1967</td>
<td>Shime</td>
<td>Pig shed P</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
</tr>
<tr>
<td>Study ser. II in Kanatake dist. and Maebaru</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>Imori</td>
<td>Pig sheds A, O</td>
<td>do.</td>
<td>do.</td>
<td>DLFL</td>
</tr>
<tr>
<td>1969</td>
<td>Nishiyama</td>
<td>(Pig sheds J, K, Cattle shed L)</td>
<td>2nd and 3rd</td>
<td>NH 3</td>
<td>BLBFL</td>
</tr>
<tr>
<td>1970</td>
<td>do.</td>
<td>do.</td>
<td>1st and 4th</td>
<td>do.</td>
<td>do.</td>
</tr>
<tr>
<td>1972</td>
<td>Maebaru</td>
<td>(Cow sheds Q, R, Pig shed S)</td>
<td>do.</td>
<td>do.</td>
<td>do.</td>
</tr>
</tbody>
</table>

BLBFL, black light blue fluorescent lamp (30 W); DLFL, day light fluorescent lamp (20 W); FIL, frosted incandescent lamp (60 W); NH 3, Nozawa NH 3; NJ, New Jersey.

For the abbreviation of the trapping spots of the Uchihashi-Aé study site see Yamamoto and Manako (1968).

\[
\bar{x}_m = \frac{\sum_{k=1}^{f} (x_{mk} / T_k) / \sum_{k=1}^{f} (1 / T_k)}
\]

where \( T_k = \sum_{m=1}^{f} x_{mk} \), \( x_{mk} \) is a mosquito catch at a trapping spot \((k)\) on a night \((m)\).

There were some amendments in light-trap operations during the 10-year study. The changes are summarized in Table 1.

Mosquito infection patterns with Japanese encephalitis virus: The techniques for virus isolations from field-caught mosquitoes and the methods for estimating the infection rate of mosquito populations (IRMP) were presented in the preceding papers of this series (Yamamoto, 1978, 1980, 1981). The 95 per cent confidence belts of IRMP's were roughly estimated from the tables by Chiang and Reeves (1962).

Incidence of Japanese encephalitis patients: The data were taken from the official reports by the Department of Health of the Fukuoka Prefectural Government. The JEV patients referred to were restricted to the cases with serological confirmation and/or successful isolation of JEV from autopsied specimens.

**Results**

Year-to-year variations in seasonal prevalence curve and JEV infection pattern of *C. tritaeniorhynchus* during the 1969–1972 period are graphically presented on the same-scaled abscissa in Fig. 2 along with the yearly numbers of patients in Fukuoka Prefecture. In Fig. 2, the epidemic pattern is given by the daily incidence of JEV patients, and the vector population indices and the vector infection rates are plotted at the intervals of 7 days throughout a study season. The results in the 1963–1967 period (Ser. I) and 1968 (a part of Ser. II) were presented in a former paper (Yamamoto, 1971).

1. **The descriptions of the 1969–1972 results**

The 1971 seasonal prevalence curve of the mosquito showed an irregularity: the curve
The seasonal prevalence curves and the natural infection patterns with Japanese encephalitis virus in *Culex tritaeniorhynchus* and the incidence of the patients with Japanese encephalitis in the period from 1969–1972.

The period of a study year is marked out at 7-day intervals on the internal side of an abscissa. Open circles signify vector infection rates (%) with 95% confidence belts (vertical bars). The capitals in parentheses are the symbols of the trapping spots for the mosquitoes.

rose in early July and continued steady increase up to late July without a sharp peak. The continuous pattern of mosquito infection was found in the decreasing phase of mosquito populations in 1969, 1970 and 1972 but in the increasing phase in 1971 in which a relatively large epidemic of JE followed the mosquito infection. The 1972 mosquito infection took an extreme irregularity of pattern although the seasonal prevalence curve of the mosquito was rather normal in the year. In 1972 the mosquito infection started in mid-August and continued down to early September, and scattered occurrence of only 2 JE patients was reported. The termination of the 1972 mosquito infection could no longer be verified owing to the scarcity of mosquitoes in the field.

The results of light-trap catches of *C. tritaeniorhynchus* varied much in absolute size from spot to spot. However, the general trend of seasonal prevalence curve was not much varied by spots within a study site and even by those of neighbouring study sites. The correlation coefficients were calculated as 0.55–0.96 (on the real number basis) at the different trapping spots of the Kanatake district (Fig. 3).

2. **A summary of the 1963–1972 results**

The data throughout the 1963–1972 studies are schematically illustrated in Fig. 4 to facilitate a comparison between the results of different epidemic period and summarized as follows:

Seasonal prevalence of *C. tritaeniorhynchus* populations. In a former paper (Yamamoto, 1971), the seasonal prevalence curve of the mosquito in a multi-spot study site was represented by the single results at the trapping spot which produced the largest mosquito collection through a season in a study site. A little difference existed between the seasonal prevalence curves given in the former paper and the revised curves on weighed mean basis in the present study. In each study series, seasonal prevalence curves of the mosquito, although varied in curvature, showed a mid-summer peak with often increase in early autumn. The outstanding mid-summer peak was usually found in a range from late July to early August in both Ser. I and Ser. II with a few exceptions: the 1964 curve attained to the peak in earlier season, and the 1971 curve was as described in the preceding paragraph. The seasonal prevalence curves
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Fig. 3 Spot-to-spot variation in the seasonal prevalence curve of *Culex tritaeniorhynchus*. The 1970 results: The data were obtained at 3 trapping spots of the Nishiyama study site. The solid curve signifies the result at the pig shed J, the chain that at the pig shed K, and the broken that at the cattle shed L. Correlation coefficients*: J-K 0.9147 (0.9554), J-L 0.7381 (0.9612), K-L 0.5536 (0.9195). The 1971 results: The data were obtained at 3 trapping spots of different study sites of the Kanatake district. The solid curve signifies the result at the pig shed J (Nishiyama), the chain that at the pig shed M (Kanatake), and the broken that at the cow shed N (Shika). Correlation coefficients*: J-M 0.9627 (0.9632), J-N 0.8805 (0.9426), M-N 0.8532 (0.9270).

* The values without parentheses were calculated on the real number basis, and those in parentheses on the \(\log_{10}(x+1)\) transformation basis.

of the mosquito were similar to each other in the fundamental trend throughout the results of 2 study series, despite of the fact that 2 series of studies were established in different districts. Local differences in the fundamental trend of seasonal prevalence curves were, thus, hardly recognized between the respective series of studies.

The relation between the seasonal prevalence and JEV infection in *C. tritaeniorhynchus* populations. Full data of JEV infection of the mosquito were presented in the 3rd paper of this series. Since the JEV infection and seasonal prevalence studies were simultaneously made in the same study sites, the results of the 2 studies may have been obtained from the same populations of the mosquito. As shown in the preceding papers, JEV infection of the mosquito showed a continuous phase in a limited period of summer in every year with premonitory signs in some years. The evidences for premonitory mosquito infections are not shown in Fig. 4 and not discussed in the present paper since they had probably been obtained by chance.

The mosquito infection continued regularly for 4–5 weeks showing a little variation in duration but a noticeable variation in the time of onset. The earliest onset of mosquito infection was in late June in 1964 in Ser. I and in mid-July in 1971 in Ser. II, and the latest was in the end of July in 1963 in Ser. I and in mid-August in 1972 in Ser. II. The mosquito infection always started at varied times in the increasing phase of mosquito population in Ser. I, but more often in the decreasing phase in Ser. II. The mosquito populations at the peak of mosquito infection were yet small in the years of Ser. I when mosquito infections occurred earlier, while those were already reduced in the years of Ser. II when mosquito infections occurred in later season. They attained to their largest size at the peak infection in the years in which the mosquito infection started in late July in Ser. I. The growth rate of mosquito populations at the peak of mosquito infection varied from year to year according to the onset time of mosquito infection. The infection rates at the peaks were higher in mosquito infections in later season than in those in earlier season.

Figure 4 shows atypical patterns of mosquito infection in certain years. For the explanations of those patterns, readers are referred to the 3rd paper of this series. Although the 1965 mosquito infection showed 2 peaks, the earlier peak probably represented the extensive amplification of JEV. The 1967 mosquito infection showed a delay and depression of the peak, and the 1972 mosquito infection took a noticeable irregularity of pattern.

Epidemics of Japanese encephalitis. JE
epidemics, although varied from year to year in size and time, underwent a drastic change of size in 1967. The yearly number of JE patients attained to the figures more than 80 in the 1963–1966 period and fell to those less than 46 in the 1967–1972 period with virtual extinction in 1972. The 2 periods, thus, are designated as the severe and mild epidemic periods, respectively. JE epidemics sometimes occurred in a wide range of period with a prolonged premonitory phase of scattered patient occurrence; however, the majority of the patients appeared concentrically in a limited period, which indicated the concentative phase of epidemic. The duration of the concentative phase of epidemic approximated to that of mosquito infection in most cases. The pattern of epidemic was discernible with an outstanding peak in severe epidemics, but it was often interrupted and did not exhibit the outline of the concentative phase in mild and moderate epidemics. The peak of patient occurrence was recognized around the middle of the concentative phase in most cases but not in 1964 and 1967 epidemics. There appeared to be a time lag between the concentative phases of patient occurrence and mosquito infection. However, it was difficult accurately to determine the length of the time lag. The concentative phase of patient occurrence could not be defined in mild and moderate epidemics and even in severe epidemics because of the scattered occurrence of a few patients in early and late stages of the phase.

**Discussion**

The epidemics of JE declined abruptly in 1967 and have remained very small up to the present in the Fukuoka area. Considerable irregularities in pig-mosquito cycles of JEV were demonstrated in 1967 in both the swine and mosquito infection studies (Otsuka et al., 1969; Yamamoto, 1971).

As shown in a former paper (Yamamoto, 1971), the historical data of JE epidemics in the area manifested that large-sized epidemics of JE had repeatedly broken out before the present study was initiated. In view of this, the 1963–1966 results (Ser. I) may represent a part of the severe epidemic period.
continued from the preceding years, and the 1967 (Ser. I) and 1968–1972 (Ser. II) results the mild epidemic period.

Recent decline of JE epidemic has been taken as a general tendency all over Japan, and considered to be ascribable to the marked decrease of vector populations (Kamimura and Watanabe, 1973; Maeda et al., 1978b). The results, however, did not bear positive evidence for the population decrease of vector mosquitoes in the mild epidemic period. Although some of the factors other than vector decrease (e.g., changes in vector competence) may have been responsible for the recent reduction of JE epidemics, those cannot be justified owing to the paucity of knowledge. The mosquito collections might have failed to represent the general tendency of vector populations by virtue of the peculiarities at the specified trapping spots in the regular study sites. Under the circumstances it seems likely that vector populations did not attain to a sufficient density to prevail intensive JEV dissemination in urban areas in the years of mild epidemic. On the other hand, it might be also probable that the delay in vector infection markedly reduced the number of infected mosquitoes in the mild epidemic period except for 1967 and 1971.

In the former papers (Yamamoto, 1968, 1971; Yamamoto and Manako, 1970), I attached an epidemiological importance to the difference in mode of vector infection between the western and eastern regions of Japan, referring to the vector infection patterns in the increasing phase of vector population and those in the decreasing phase as "western type" and "eastern type," respectively. The vector infection pattern had been changed from the western type to the eastern type in the western regions in and after 1968, yet it is a matter of epidemiological importance whether vector populations were infected in their increasing phases or in their decreasing phases. Subsequently, Wada (1972) discussed this problem on the mathematical basis and demonstrated that the vector infections in the decreasing phases of vector populations made smaller the number of infected mosquitoes. In fact, JE epidemics had a tendency towards decline in the eastern regions while the epidemics had broken out in larger scales in the western regions, and the change from the western type to the eastern type was accompanied with the decline of JE epidemic also in the western regions. Notwithstanding the difference of locality between Ser. I and Ser. II, it seems likely that the mode change of vector infection from Ser. I to Ser. II meant annual transition but not local difference. Local variation was hardly recognized among the results of vector infection studies simultaneously conducted in different localities (Yamamoto, 1981), which fact lend a strong support to the above interpretation.

As pointed out in the former papers, annual variation in the onset time of vector infection was the major factor which determined yearly size of epidemic in the severe epidemic period. In the years of ultra-large epidemic such as 1963 and 1966, the peaks in vector infection rate coincided with the peak densities of vector populations. The peak of vector infection undoubtedly indicates the extensive amplification of the virus through pig-mosquito cycles. Simultaneous appearance of a vast number of infected mosquitoes rapidly causes exhaustive scarcity of susceptible amplifying hosts, which results in the termination of pig-mosquito cycles of the virus in the subsequent times. Then the total number of infected mosquitoes through an epidemic season depends largely on the density of vector populations at the peak infection. This inevitably means extraordinary swell of the number of infected mosquitoes in the years in which the peak infection and the peak density were coincident in vector populations.

The above explanation can be accepted also in the mild epidemic period. In 1971 the peak of vector infection was found within the peak phase of vector populations, and JE epidemic attained to the largest of those in the mild epidemic period. The largest epidemic in the 1967–1972 period, however, was smaller than the smallest epidemic in the 1963–1966 period. This may have been attributed to the chronic tendency towards decrease of vector population in the period after 1966.

The infection rates of vector populations had no bearing themselves on epidemic sizes
in the present study. The infection rates took extraordinarily high values in mild epidemic years such as 14.60 and 11.69% in 1970 and 1972, respectively. The absolute values of infection rates may correspond to the fluctuation of physiological age composition of vector populations (Yamamoto, 1981).

From what has been mentioned above, it is evident that JEV activity had maintained among mosquitoes throughout the mild epidemic period in spite of the marked decline in JE epidemic, and it should be emphasized that the coincidence of peak infection and peak density in vector populations was the major factor giving rise to a larger epidemics also in the mild epidemic period. This speculation is compatible with those by recent authors (Wada et al., 1975; Maeda et al., 1978a, b) in basic rationale. However, the results of the present study have a notable disagreement with those of Maeda et al. (1978a) which demonstrated no relationship between the time of vector infection peak and the epidemic size in Kyoto. Geographical condition in Kyoto may not allow a wide range of annual variation in the peak time of vector infection.

In conclusion, it may be said that the change of epidemic period and year-to-year variations in epidemic size within a period were controlled by different factors, respectively: chronic reduction of vector populations took part in the former, and annual variation in onset time of mosquito infection in the latter.

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References


福岡地方における蚊のアルボウイルス感染に関する研究

福岡地方における日本脳炎ウイルス媒介蚊の出現消長と
野外感染パターン及び日本脳炎流行
規模との疫学的関連

福岡地方における日本脳炎流行は、1966年以前の激甚流行期と1967年以後の流行衰退期とに区別される。このうち、1963～1972年間の媒介蚊野外感染状況は前報に詳述した。本報では、同期間における年ごとの媒介蚊出现消長を明らかにし、媒介蚊出現消長、同蚊野外感染状況及び日本脳炎流行規模の年次変動の関連を検討した。その結果、流行衰退期における流行規模の年ごとの変動をもたらした。激甚流行期における媒介蚊野外感染開始時期と同蚊個体群密度の季節的消長との関係の年ごとの変動と、また激甚流行期から流行衰退期への転換は、全国的な慢性的媒介蚊減少傾向に起因する可能性が大きいと考えられた。なお、本研究では、流行衰退期における媒介蚊減少を通じて証明できなかったので、コガタアカイエカの媒介資質の変化による流行衰退を考慮する余地はあら

摘 要

Giles and Culex pseudovishnui Colless in Fukuoka area. Relative abundance of C. pseudovishnui to C. tritaeniornynchus in field samples. 


