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Population Dynamics on Vector Mosquitoes in Kyungpook, Korea*

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- Abstract -

In order to determine the seasonal prevalence and population dynamics of vector mosquitoes in Kyungpook Province, Korea, a survey based on the average number of female mosquitoes per trap-night, were carried out during the period from 1992 to 1995.

A.sinensis first appeared between late March and early May, and were trapped in a large number between 29th June and 8th July. The number of trapped mosquitoes began to decrease from early September, and a few were collected until mid-October, each year. In the general patterns of seasonal prevalence, *C.tritaeniorhynchus* was first collected in June between 8th and 23th, and trapped in large numbers during the period from late July to late August, and showed a simple sharply pointed one-peaked curve, while, *C.pipiens pallens* was found to be active through almost the entire season showing irregular curves with several peaks. The average number of *A.sinensis* in July rapidly decreased after 1992, and the number became particular low in 1994. The number of *C.tritaeniorhynchus* in August was 164.1 per trap-night in 1992, but in 1993 decreased abruptly to 46.1, and then increased to 689.4 in 1993. The total number of *C.pipiens pallens* progressively decreased during the initial 3 years from 1992, followed by a increase. A marked decrease on MPI was obtained in 1994.

In the trend of nocturnal activities of *C.pipiens pallens,* with oncoming darkness they become very active, gradually decreasing in activity toward mid-night, but slightly increasing toward dawn, while, *C.tritaeniorhynchus* and *A.sinensis* were rather constantly active all through the night with more or less inconspicuous peaks twice a night.

The immature stage of *A.sinensis* in the rice paddies was first found in the correlation pattern with peak adult densities in early July. The total number of larval *C.tritaeniorhynchus* in rice paddies was highest in mid-August, and its number progressively decreased in early September because of insecticide spray. After late September, the larval mosquitoes were rarely found until rice plants were harvested.

The larval *C.tritaeniorhynchus* and *C.pipiens pallens* showed high resistance levels and resistance ratios against 5 kinds of organophosphorus compounds, but low resistance against 2 synthetic pyrethroides.

The present results indicated that the population density of *A.sinensis* and *C.pipiens pallens* in Kyungpook Province were decreasing over the four years from 1992 to 1995, while, *C.tritaeniorhynchus* was progressively increasing after 1993.

Key Words : Population dynamics, vector mosquito, *Anopheles sinensis, Culex tritaeniorhynchus, Culex pipiens pallens*

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* The result of this study were presented at the 38th annual meeting of the Korean Society for Parasitology(1996).

Introduction

Vector mosquitoes have been known from the early part of this century as a public health pest not only to cause serious nuisance in many areas, but also to act as the transmitter of malaria, filariasis, viral encephalitis and others endemic in tropic, subtropic, and temperate countries.

In those days a considerable number of patients seriously suffering from malaria, filariasis, Japanese encephalitis and their vectors in Korea had been reported by Hasegawa (1913), Watanabe (1916), Nagai (1925), Osawa (1927), Tanabe (1927), Kobayashi (1921, 1926a & b, 1928) and Yamada (1936 a&b).

Hasegawa (1913) made a survey on the adult and larval Anopheline mosquitoes collected from several locations in Korea, and ascertained their ability to transmit malarial parasites. From his studies on the seasonal prevalence of mosquitoes in Korea, Kobayashi(1929) noted that *A.sinensis* was the most predominant species between July and August, and that biting habits of the species appeared to be active throughout the whole night, but were more active during darkness, after sunset to mid-night.

The first comprehensive survey of mosquito fauna of Korea was made by Yokoo(1944), in which altogether 14 species were recorded. He also reported that *A.sinensis* seemed to serve as a vector of setariasis in domestic animals.

During the 15 years from the World War II to the Korean War, the concentration of population in urban areas and unsanitary conditions increased the prevalences of various insects and other arthropod-borne diseases to such extent that they became the major public health problems of nation-wide significance

After the Korean War, as a consequence of increased interest in the mosquito-borne diseases, such as malaria, filariasis and Japanese encephalitis, a disease borne by mosquitos, investigations on *A.sinensis, A. togoi* and *C.tritaeniorhynchus* were carried out intensively by a number of medical parasitologists and public health officials in Korea and other countries.

Whang (1962) studied the biological observations on Anopheline mosquitoes in Korea, and reported that *A. sinensis* had mainly zoophilic habits, and since its man-biting rate was rather low, it would cause a low infection rate of malaria. From their studies on the JE virus isolation from mosquitoes of Korea in the summer of 1965, Lee et al.(1969) found that *C. pipiens pallens* was the most prevalent species and next in order were *A. sinensis, A.. vexans nipponii,* with *C.tritaeniorhynchus* taking 4th place, and also claimed that the main vector of JE virus in its season in Korea was *C. tritaeniorhynchus.*

A study of Shin et al.(1971) described the seasonal prevalence of mosquitoes throughout the country, with particular references to JE vector mosquitoes.

Since the beginning of the Saemaul movement in the third five-year Economic Development Plans, the Korean government has made plans to attain self- sufficiency in rice production due to practicing land reclamation and cultivating hilly areas in combination with the establishment of irrigation system, improvement of agricultural technique, and intense use of agricultural chemicals.

These operations inevitably resulted in the expansion of mosquito larval habitats, and introduced important changes in the agroecosystems which determined the distribution and abundance of mosquitoes. Furthermore, rice fields and various types of impounded water but relatively clear water, also stream pools or sluggish streams produced important vectors of malaria, filariasis, Japanese encephalitis and others.

To establish effective control measures of mosquito-borne diseases, epidemiological, ecological and entomological studies on these diseases such as malaria, filariasis and Japanese encephalitis in Kyungpook, Korea have been carried out since 1975 (Kanda et al. 1975 a & b ; Joo and Wada, 1985 ; Lee et al. 1986 ; Baik and Joo, 1987 and 1991 ; Joo and Kang, 1992 ; Kang and Joo, 1993 ; Joo and Kang, 1994 ; Joo and Lyuh, 1994).

As for the seasonal prevalence and population dynamics of *A.sinensis* in relation to the epidemics of malaria and the ecology of these vector mosquitoes in Kyungpook Province, Korea, Joo and Kang(1992) and Kang and Joo(1993) reported that the population density of *A.sinensis* in the province was decreasing over the five-year period from 1987 to 1991.

In recent year a few cases of malaria, filariasis and Japanese encephalitis in Korea have been noted. Even though these diseases are considered to have disappeared spontaneously in the past few decades along with improvements in general sanitation, it is considered that there still exists a number of small isolated foci in rural parts, and to lack of attention given to the problem of mosquito-borne diseases.

This study has proceeded as a part of our investigation in the epidemio-entomology and control of mosquito-borne diseases, and attempts to estimate the population dynamics of vector mosquitoes in Kungsan city, Kyungpook Province from 1992 to 1995.

Materials and Methods

Surveyed areas : Kyungpook Province is located in the southeast part of the Korean peninsula, covering an area of 19,700 square kilometers(Fig.1). Keimyung University training farm in Kyungsan city was selected as the main survey station. Nine rural villages situated in the surrounding rice paddies in the Province were selected as other study areas because of the presence of the main breeding places for the vector mosquitoes. More detailed geographical features were presented by Baik and Joo (1991), Kang and Joo(1993), and Joo and Lyuh (1994).

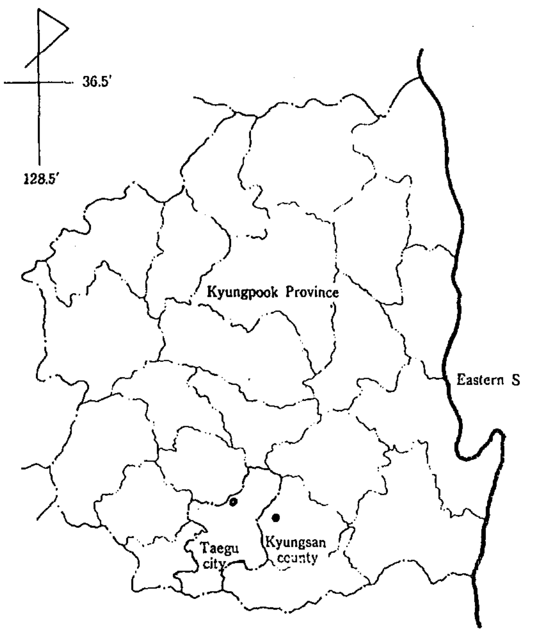

Fig. 1. Surveyed areas(●) in Kyungpook Province, Korea.

Meteorological data : The surveyed areas are under the influence of a typical continental climate of the eastern coast affected by both high atmospheric pressure from the cold continent and a low one from the Pacific Ocean in the summer season. Therefore, seasonal fluctuation of air temperature and precipitation, which is of fundamental importance to understand the population dynamics of vector mosquitoes is very great. Meteorological data for the period of the present survey was provided by the Taegu branch of the Korea Meteorological Agency.

Light trap operation : In order to record changes in abundance of vector mosquitoes, and to compare seasonal and annual fluctuation in population size, light trap collections were performed as follows: A light trap was fixed at 1.5m above the ground at trapping spots, such as the piggery A, cow-shed B, and dwelling- house C, and operated from dusk to dawn on one-night per week schedules. Mosquitoes collected at each station were counted by species.

The census of adult populations was done from 1984 to 1995, and a part of the results was published already (Joo and Kang, 1994: Joo and Lyuh, 1994).

Indices of Mosquito abundance : In order to compare the seasonal and annual abundance of vector mosquitoes, mean percent index(MPI), which was proposed by Maeda et al.(1978), was used. MPI is calculated by the following procedure. If the total numper of mosquitoes collected by m-time collection at a station of i in a year of k is given by

$$X_{ik} = \sum_{j=1}^{m} X_{ijk},$$

where X_{ijk} is the number of mosquitoes collected at each station, MPI is shown in the following equation :

$$MPI_k = \frac{100}{n} \sum_{i=1}^{n} (Xik/Xio),$$

Where n is the number of station and X_{io} is the total number of mosquitoes collected at each station in the standard year(1986), when the stations for the collection were being fixed.

Seasonal prevalence can be also expressed in MPI from the data of light trap collections as follows :

$$MPI_{jk} = \frac{MPI_k}{n} \sum_{i=1}^{n} (X_{ijk}/X_{ik}).$$

Human baited catches : In order to determine the relative population size and species of mosquito which were attracted by human beings, human baited catches were performed as follows: A man was allowed to lie on the floor of a tent 2.6 X 1.5m and 1.5m in height. An open window 2.0 X 1.5m permitted entry of mosquitoes.

All mosquitoes biting or attempting to bite were collected between 19:00 and 06:00 hours on one night in July and August in 1992, 1993 and 1995.

Dissection of mosquitoes : In order to identify the stages of the development of ovarian follicles for a precise analysis of the gonotrophic conditions, all the mosquitoes biting or attempting to bite were collected either on the skin with a sucking tube or with on insect net, and killed with ethyl ether. They were transferred into a glass tube and kept in an ice box until they were individually identified and dissected in the laboratory. Dissection of mosquito specimens were made usually the next morning. After each mosquito was identified and number recorded, it was transferred on a slide glass with a drop of 0.6% saline solution. They were examined for the determination of the ovarian age using the methods described by Detinova(1962). Records were made for each mosquito whether it was nulliparous or parous, and if parous, the number of follicular relics was determined. After this all other body parts, especially salivary glands, were examined for malarial and filarial larval parasites.

Collection of adult resting mosquitoes : Inorder to determine the resting places of mosquito species in daytime, oral aspirators and hand nets, about 40 cm in diameter, made of fine mosquito netting were used to catch adult resting populations in man-made shelters, and/or in natural shelters, such as amongst vegetation, in hollow trees, anamial burrows, crevices in the ground and others. All the mosquito specimens were individually examined for species under a binocular dissecting microscope and counted.

Collection of larvae : In order to determine the species and density of larval mosquito population, 30 fixed rice paddies were dipped from June to October at one week intervals in 1992. The dipper was 15 cm in diameter and 5 cm in depth with a wooden handle of 60 cm in length. At the outset a collector stood at a point on the side of the rice paddies, and took a dip on the water surface, which was thought to be most favorable for the breeding of the larvae and pupae within the reach of the dipper. In each rice paddy, the dipping was made ten times which was thought to be necessary to estimate the distribution pattern of the numbers of larval population in a rice paddy. The total number of larval population size in this study areas was determined according to the methods reported by Wada and Mogi(1974).

Insecticide susceptibility test : In order to estimate the insecticide resistance on vector mosquitoes, blood-fed females were collected from man-made and/or natural shelters with an insect net and/or a sucking tube in the summer of 1995. Approximately 300 mosquitoes were collected in each sample collection and sent to the laboratory.

The mosquitoes were allowed to oviposit in an insectary at 28±1℃ and of 70-80% relative humidity with 16 : 8 (L:D) photoperiod, and were fed on 5% sugar solution. The approximately 300 first instars were transferred to a separate insectary at 28±1℃ and 16 : 8 photoperiod and were reared to the fourth instar on crushed powders of laboratory mouse pellets in pans measuring 50 X 40 cm filled to 2 cm depth of water. The larvae were identified in each sample under a stereoscopic microscope for conspecificity. Some larvae were allowed to pupate and emergence as adults. The adults were maintained and mated in wire screen cages in which 5% sugar solution was provided. Adult females were given opportunity to feed on laboratory mice. Insecticide resistance was modified from those described by Yasutomi (1971), Yasutomi et al.(1986), Takahashi and Yasutomi (1987), and Yasutomi and Takahashi (1944 & 1987). Twenty fourth instars were continuously held for 24 hours in 200 ml of various concentrations of each chemical, diluted in a 2-fold succession. Plastic cups 8 cm in diameter and 6.5 cm high were used for the tests, which were carried out at 25±1℃. Larval mortality was judged after immersion for 24 hours. Lc_{50} values were obtained from the regression lines between log dosage and mortality.

Results

Table 1 gives the earliest dates when vector mosquitoes began to be collected by light traps and the air temperature and humidity at that time in Kyungsan city, Kyungpook Province. *A.sinensis* began to be collected in April, between 6th and 8th days in 1992 and in 1994, but on May 6 in 1993 and March 22 in 1995. At that time the air temperature ranged from 8.3-26.8℃ and humidity from 58-84 per cent. The average number of *A.sinensis* per trap-night was 0.3 to 6.0.

From 1992 to 1995, *C.tritaeniorhynchus* first appeared consistently in the light traps in June, between the 8th and 23th days. The air temperature at that time ranged from 17.4-27.3℃ and humidity from 67-80 per cent.

C.pipiens pallens was first collected in the light traps from 1992 to 1994 in April, between the 6th and 14th days, but on March 22 in 1995. The temperature ranged from 6.3-26.8℃ and humidity from 45-80 per cent. The average number of *C.pipiens pallens* per trap-night was 0.3 to 0.7.

Table 1. Four years' observations of the earliest dates three main vector mosquitoes begin to appear in Kyungsan, together with meteorological data

Species	Year	Earliest date when mosquito appeared		Temperature (Range℃)	Humidity (%)	Average No./ trap-night
A.sinensis	1992	April	8	9.2-22.1	66	0.7(2/3)*
	1993	May	6	15.1-22.1	84	6.0(18/3)
	1994	April	6	12.2-26.8	58	2.3(7/3)
	1995	March	22	8.3-11.5	80	0.3(1/3)
C.tritaeni-orynchus	1992	June	17	17.4-26.0	71	0.3(1/3)
	1993	June	23	18.3-27.3	80	1.0(3/3)
	1994	June	8	18.3-26.4	74	0.3(1/3)
	1995	June	21	18.5-23.1	67	0.3(1/3)
C.pipiens pallens	1992	April	8	9.2-22.1	66	0.3(1/3)
	1993	April	14	6.3-22.4	45	0.7(2/3)
	1994	April	6	12.2-26.8	58	0.3(1/3)
	1995	March	22	8.3-11.5	80	0.3(1/3)

* Number in parentheses means the total number of female mosquitoes per trap-night.

The appearance of a new generation of vector mosquitoes is indicated by males, since only females overwinter. The dates in each year for the first apperance of newly-emerged males in Table 2 are based on the collection by light traps.

The first time appearance of males varied greatly from year to year. The earliest date for the first appearance of male *A.sinensis* was May 4 in 1994 and the lastest one was June 11 in 1992. The first appearance of male *C.tritaeniorhynchus* was June 29 in 1994 and the latest one July 14 in 1993. The dates of the first appearance of male *C.pipiens pallens* in the

Table 2. Date for the first appearance of newly-emerged male vector mosquitoes and the meteorological data at that time

Species	Year	Dates of first appearance		Temperature (Range℃)	Humidity (%)
A. sinensis	1992	June	11	14.0-27.3	50
	1993	May	6	15.1-22.1	84
	1994	May	4	12.5-18.8	53
	1995	May	24	15.1-29.6	43
C.tritaeni-orhynchus	1992	July	8	22.6-37.8	63
	1993	July	14	20.6-32.3	77
	1994	June	29	21.2-31.4	66
	1995	July	5	21.4-28.9	84
C.pipiens pallens	1992	May	13	14.3-21.3	85
	1993	May	12	15.7-28.5	71
	1994	May	11	15.2-17.8	86
	1995	May	10	9.3-26.6	74

Table 3. Date of peak population of three main vector mosquitoes and the meteorological data at that time

Species	Year	Date of peak population		Temperature (Range℃)	Humidity (%)	Average No./ trap-night
A.sinensis	1992	July	8	22.6-37.8	63	1,223.3(3,670/3)
	1993	July	7	19.2-31.9	71	1,074.0(3,222/3)
	1994	June	29	21.2-28.0	66	832.7(2,498/3)
	1995	July	5	13.6-28.0	63	890.3(2,671/3)
C.tritaeni-orynchus	1992	August	5	21.9-25.2	82	178.0(534/3)
	1993	August	25	24.5-31.9	79	255.7(767/3)
	1994	July	27	24.8-31.4	80	887.7(2,663/3)
	1995	August	24	24.3-31.7	83	535.3(1,606/3)
C.pipiens pallens	1992	July	15	21.1-28.5	82	722.0(2,166/3)
	1993	July	7	19.2-31.9	71	1,096.7(3,290/3)
	1994	June	29	21.2-31.4	66	768.0(2,304/3)
	1995	July	5	21.4-28.8	64	843.0(2,529/3)

Table 4. Date of disappearance of three main vector mosquitoes and the meteorological data

Species	Year	Date of disappearance of vector mosquito		Temperature	Humidity
A.sinensis	1992	October	21	8.6-20.1	69
	1993	October	20	7.3-22.6	66
	1994	October	26	4.9-21.1	65
	1995	October	25	8.8-20.2	59
C.tritaeni-orynchus	1992	October	21	8.6-20.1	69
	1993	October	6	16.3-17.9	63
	1994	October	19	11.4-18.9	71
	1995	October	25	8.8-20.2	59
C.pipiens pallens	1992	November	21	-3.3-3.5	63
	1993	November	20	11.0-17.4	78
	1994	November	9	3.6-23.6	60
	1995	November	29	-0.25-12.7	70

light traps was consistently in mid-May, between the 10th and 13th days. The air temperature ranged from 9.3 to 28.5℃.

In Table 3, the dates that the maximum number of the three main vector mosquitoes were collected in the light traps are listed according to the year studied. The highest population density of *A.sinensis* from 1992 to 1995 was observed during the period from early June to early July. The air temperature was between 13.6 and 37.8℃ and relative humidity from 63 to 71 per cent. The maximum number of *A.sinensis* in 1992 was 1,223 per trap-night. In 1993, the number decreased to 1,074.0 and 832.7 in 1994. In 1995, the number increased again to 890.3. In the case of *C.tritaenio-rhynchus,* the maxium number in 1992 was 178.0 per trap-night. In 1993, the number increased to 225.7 and 887.7 in 1994. The highest population density of *C.pipiens pallens* was encountered during the period from late June to mid-July. The maxmium number of *C.pipiens pallens* in 1992 was 722.0 per trap-night. It showed a marked increase and reached a maximum of 1,096.7 in 1993, followed by a decrease. In 1995, the number increased again to 843.0.

Table 4 presents the dates vector mosquitoes were not collected in the surveyed area and the meteorological data at that time. *A.sinensis* and *C.tritaeniorhynchus* were not observed from the area in early and late October, while, *C.pipiens pallens* was not collected in early and late November, between the 9th and 29th. The air temperature at that time ranged from -3.3 to 23.6℃ and humidity from 60 to 78 per cent. The monthly changes of three main vector mosquitoes collected by the light traps in Kyungsan city, Kyungpook Province, from 1992 to 1995, are summarized in Table 5.

In general, *C.pipiens pallens* was collected in 7 or 8 months, from April to October or November, every year. *A.sinensis* was collected in 6 or 7 months, and *C.tritaeniorhynchus* was collected in 4 or 5 months. The general patterns of monthly and yearly changes of the vector mosquitoes were found to vary greatly by species. For instance, the average number of female *A.sinensis* per trap-night in April, 1992 was 0.5, it increased to 1.0 in May, 59.1 in June, and reached the maximum number, 650.6 in July. In August, the average decreased to 113.5, in September to 91.2, and in October to 1.7. The general patterns of monthly changes of *A. sinensis* in the other years are similar to those for 1992. The average number of female *A. sinensis* in July, 1992 was 650.6, whereas the average in 1993 decreased to 489.8 and dropped abruptly to 282.0 in 1994. The number increased again to 423.7 in 1995. *C.tritaeniorhynchus* first appeared in June with the average number of 0.1-2.2, it subsequently increased and reached a maxmium of 46.1-689.4 in August,

Table 5. Monthly changes of vector mosquitoes by average number collected in each trap during four years in Kyungsan

Species	Year	Average No. of female mosquito per trap-night							
		Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
A.sinensis	1992	0.5	1.0	59.1	650.6	113.5	91.2	1.7	0
	1993	0	2.5	84.2	489.8	132.4	89.4	1.3	0
	1994	0.8	0.8	211.9	282.0	64.4	16.3	1.3	0
	1995	0.2	3.3	119.1	423.7	66.9	18.2	2.0	0
C.tritaeni-orhynchus	1992	0	0	0.1	38.5	164.1	80.2	0.8	0
	1993	0	0	0.7	13.1	46.1	33.8	0	0
	1994	0	0	2.2	284.2	689.4	79.8	0	0
	1995	0	0	0.2	21.8	322.3	92.8	2.5	0
C.pipiens pallens	1992	0.1	12.8	201.0	507.8	371.2	122.8	1.9	0.5
	1993	0.8	23.2	720.5	671.3	351.5	74.6	1.9	0
	1994	0.6	10.6	280.5	576.7	242.2	62.8	4.5	0.3
	1995	0.3	14.9	315.3	708.4	377.0	154.1	11.3	0.2

followed by a decrease. The trend of seasonal distribution of female *C.pipiens pallens* was similar to that of *A.sinensis,* but the earliest dates of appearance and disappearance differed from that of *A.sinensis.*

The results of relative abundance and MPI calculation for three main vector mosquitoes in successive years after 1984 are shown in Table 6 and illustrated by Fig.2. This expression is useful for showing the annual pattern of vector

Table 6. Relative abundance of three main vector mosquitoes in successive years after 1984

	At the 3-stations located in Kyungsan city					
Year	*A.sinensis*		*C.tritaeniortynchus*		*C.piens pallens*	
	Total	MPI	Total	MPI	Total	MPI**
Standard year*	10,242	100.0	2,398	100.0	24,126	100.0
1992	13,236	126.8	3,760	175.4	16,509	82.3
1993	8,378	75.3	1,087	45.6	22,292	82.7
1994	7,706	73.8	14,516	462.8	15,488	64.2
1995	7,800	66.7	6,242	189.8	18,502	81.3

* Data of standard year reported by Joo and Kang(1992) and Baik and Joo(1991).
** MPI means mean percent index.

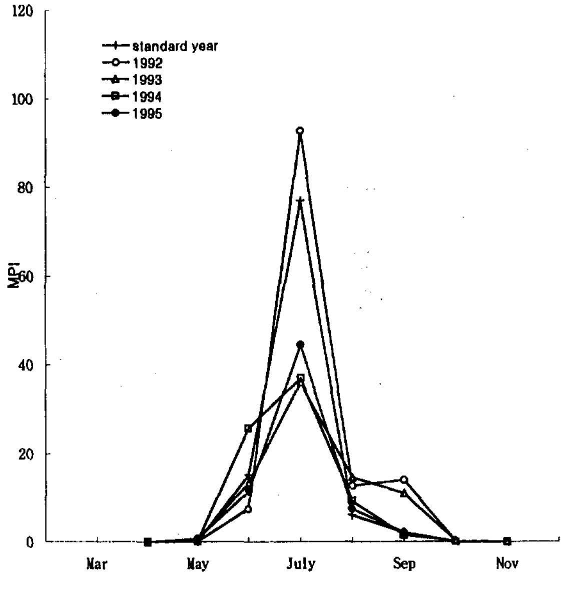

Fig. 2-1. Annual prevalence of *Anopheles sinensis* as shown in MPI calculated from the date of mosquito collection at 3 satations.

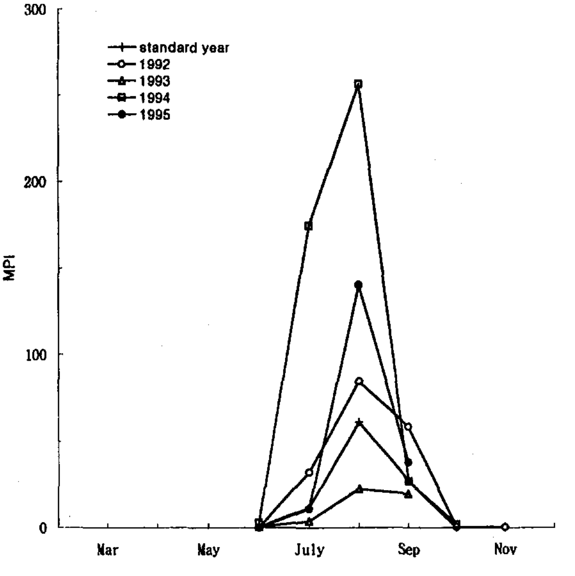

Fig. 2-2. Annual prevalence of *Culex tritaeniorhynchus* as shown in MPI calculated from the date of mosquito collection at 3 satations.

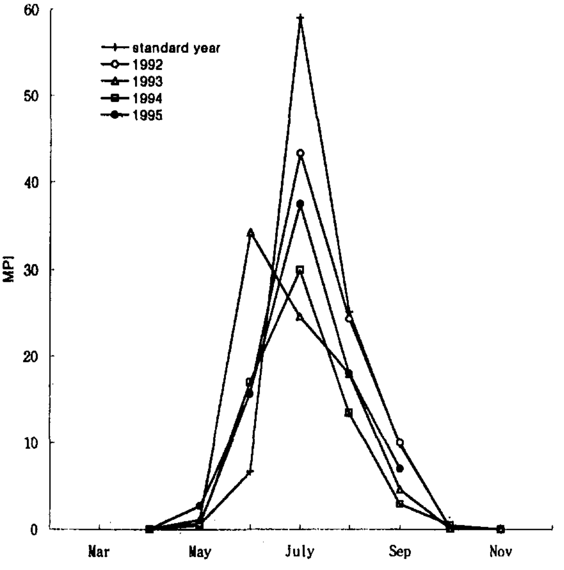

Fig. 2-3. Annual prevalence of *Culex pipiens pallens* as shown in MPI calculated from the date of mosquito collection at 3 satations.

mosquitoes prevalence from the data of collection at several stations. A marked decrease in MPI was obtained in successive years with respect to *A.sinensis* and *C.pipiens pallens*; the reduction was more marked in the latter rather than in the former. However, MPI of *C. tritaeniorhynchus* varied greatly from year to year.

The data presented in Table 7 are to compare the number of total and engorged female mosquitoes by the light traps collected at three locations during four years from 1992 to 1995. The overall rate of engorgement, as calculated by dividing the number engorged with the total, which reflect the efficiency of blood-sucking activity on vector mosquitoes, varied greatly by different species.

The overall engorgement rates of the three main vector mosquitoes in 1994 were in the

Table 7. Comparison of total and engorged number of three main vector mosquitoes collected by light traps at piggery A, cow-stall B, and house-dwelling C during four years, 1992-1995

Year	Location	*A.sinensis*		*C.tritaeniorhynchus*		*C.pipiens pallens*	
		No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged
1992	A	4,731	917(19.4)*	1,579	515(32.6)	7,784	55(0.7)
	B	6,741	2,852(42.3)	1,901	1,144(60.2)	5,772	67(1.2)
	C	1,764	26(1.5)	280	41(14.6)	2,953	23(0.8)
	Subtotal	13,236	3,795(28.7)	3,760	1,700(45.2)	16,509	145(0.9)
1993	A	4,330	1,268(29.3)	583	235(40.3)	14,806	90(0.6)
	B	3,543	1,422(40.1)	446	192(43.0)	5,803	20(0.3)
	C	505	5(1.0)	58	9(15.5)	1,683	15(0.9)
	Subtotal	8,378	2,695(32.2)	1,087	436(40.1)	22,292	124(0.6)
1994	A	3,366	980(29.1)	3,283	1,357(41.3)	8,208	53(0.6)
	B	3,445	1,213(35.2)	11,043	6,109(55.3)	5,852	20(0.3)
	C	895	9(1.0)	190	6(3.2)	1,428	13(0.9)
	Subtotal	7,706	2,202(28.6)	14,516	7,472(51.5)	15,488	86(0.6)
1995	A	3,544	1,390(39.2)	2,132	1,003(47.0)	6,819	28(0.4)
	B	3,867	1,796(46.4)	4,044	2,198(54.4)	10,074	49(0.5)
	C	365	3(0.8)	36	3(8.3)	1,471	6(0.4)
	Subtotal	7,776	3,189(41.0)	6,212	3,204(51.6)	18,364	83(0.5)

* Number in parentheses means the percentage of engorged females.

order of 35.2 per cent, 55.3 per cent, and 0.3 per cent on the cow-stall, 29.1 per cent, 41.3 per cent and 0.6 per cent on the piggery, and 1.0 per cent, 3.2per cent, and 0.9 per cent on the house-dwelling, respectively. The general patterns of engorgement rates in the other years weresimilar to those of 1994.

Table 8 summarizes the monthly fluctuation of engorgement rates of the three main vector mosquitoes collected by light traps in each year from 1992 to 1995. The engorgement rates vared greatly by different species and by different months in every year. Of the vector mosquitoes, the blood-sucking rates of *A. sinensis* were 14.3-33.3 per cent in May, 14.2-43.5 per cent in June, 25.0-41.6 per cent in July, 21.2-38.5 per cent in August, 18.3-25.7 per cent in September, and 4.2-15.0 per cent in October, respectively. The rates of *C.tritaeniorhynchus* were 19.5-64.1 per cent in July, 41.2- 52.9 per cent in August and 43.8-47.4 per cent in September. Although the rates decreased in October, it was kept on a level of 30.0 per cent.

The engorgement rates of *C.pipiens pallens* in 1992 were at the highest rate in May with 2.0 per cent, followed by June with 1.5 per cent and July with 1.2 per cent. The rates in the other years were similar to those for 1992.

The numbers of the three main vector mosquitoes collected by light trap in a pigsty and on human-baited method are listed by the order of the date in Table 9.

Each collection started from 1900 and was continued all through the night until 0600, and the results are tabulated by the numbers pooled for each hour.

In the light trap collection in a pigsty, *A.sinensis* and *C.tritaeniortynchus* attempted to feed from 1900-2000 onward, and the peak numbers of the mosquitoes showed two peaks, respectively. In general, on becoming dark *A.sinensis* and *C.tritaeniortynchus* become very active, gradually decreasing in activity towards midnight, hower, slightly increasing towards

Table 8. Monthly flucatuation of total and engorged number of vector mosquitoes

Species	Year	April		May		June		July		August		September		October		November	
		No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged	No. collected	No. engorged
A.sinensis	1992	7	0	12	4(33.3)*	709	241(34.0)	9,759	3,007(30.8)	1,362	289(21.2)	1,368	251(18.3)	20	3(15.0)	0	0
	1993	0	0	30	6(20.0)	1,263	179(14.2)	4,408	1,818(41.2)	1,589	443(27.9)	1,073	248(23.1)	15	1(6.7)	0	0
	1994	9	0	7	1(14.3)	3,178	1,075(33.8)	3,384	846(25.0)	966	242(25.1)	147	36(24.5)	15	2(13.3)	0	0
	1995	2	0	50	12(24.0)	1,417	617(43.5)	5,084	2,117(41.6)	1,004	387(38.5)	218	56(25.7)	24	1(4.2)	0	0
C.tritaeni-	1992	0	0	0	0	1	0	577	211(36.6)	1,969	879(44.6)	1,203	570(47.4)	10	5(50.0)	0	0
orhynchus	1993	0	0	0	0	10	7(70.0)	118	23(19.5)	553	228(41.2)	406	178(43.8)	0	0	0	0
	1994	0	0	0	0	33	30(90.9)	3,410	1,650(48.4)	10,341	5,461(52.8)	718	327(45.5)	14	4(28.6)	0	0
	1995	0	0	0	0	2	0	262	168(64.1)	4,834	2,557(52.9)	1,114	478(42.9)	30	12(40.0)	0	0
C.pipiens	1992	2	0	153	2(2.0)	2,412	36(1.5)	7,617	93(1.2)	4,454	8(0.2)	1,842	5(0.3)	23	0	6	0
pallens	1993	10	0	278	0	10,808	77(0.7)	6,042	13(0.2)	4,218	24(0.6)	895	11(1.2)	23	0	0	0
	1994	7	0	95	0	4,207	21(0.5)	6,920	56(0.8)	3,633	9(0.2)	565	0	59	0	2	0
	1995	4	0	571	0	3,783	18(0.5)	8,501	20(0.2)	5,655	42(0.7)	1,849	3(0.2)	135	0	3	0

* Number in parentheses means the percentage of engorged females.

Table 9. The results of overnight vector mosquitoes collection by light trap in a pigsty and on human baited trap

Hour	*A.sinensis*		*C.tritaeniorhynchus*		*C.pipiens pallens*	
	Light trap	Human	Light trap	Human	Light trap	Human
July 29-30, 1992(Temperature: 35.1-24.7℃, Humidity:43-86%)						
1900-2000	4	0	1(1)	0	14	11
2000-2100	59(12)*	2	12(3)	1(1)	67	6
2100-2200	157(20)	5	49(11)	0	83(1)	13
2200-2300	31(5)	8(2)	7(2)	0	71	14
2300-2400	35(11)	3	8(1)	0	70(1)	3
2400-0100	29(4)	4	13(4)	1(1)	94(1)	16(1)
0100-0200	38(3)	4(1)	13(1)	1(1)	117(1)	5
0200-0300	20(5)	3	12(2)	2	55(0)	6
0300-0400	33(9)	1	8(3)	0	74(1)	7
0400-0500	5(1)	2(1)	6(1)	0	75(2)	14
0500-0600	42(13)	1	7	0	53(1)	1
Subtotal	463(83)	33(4)	36(29)	5(3)	773(8)	96(1)
August 18-19, 1993(Temperature: 26.8-20.0℃, Humidity:69-91%)						
1900-2000	18(1)	0	2	1(1)	56(2)	41
2000-2100	35(14)	1(1)	7(2)	5(5)	48	21
2100-2200	15(4)	5(3)	1(1)	2	57	31(1)
2200-2300	7(2)	5(1)	2(1)	1(1)	36	58(1)
2300-2400	6(4)	1	1(1)	1	32	41
2400-0100	3(2)	0	0	1	32(2)	44(1)
0100-0200	3(1)	0	0	1	56(2)	28
0200-0300	4(0)	0	0	0	39(2)	7
0300-0400	2(1)	0	2(1)	0	55(2)	10
0400-0500	12(2)	0	1	0	43(1)	11
0500-0600	11(3)	0	2(2)	0	26(1)	1
Subtotal	116(34)	12(5)	18(8)	12(7)	480(11)	293(3)
August 16-17, 1995(Temperature: 34.6-24.4℃, Humidity:71-75%)						
1900-2000	10(3)	0	16(5)	0	18(3)	9
2000-2100	48(25)	1	118(57)	3	58	2
2100-2200	18(9)	2(2)	29(12)	3(2)	14	18
2200-2300	14(5)	0	16(7)	4(4)	14	11
2300-2400	7(4)	0	11(2)	2(1)	12	13
2400-0100	4(1)	2	5(3)	2(1)	7(1)	13
0100-0200	1(1)	0	3	0	8	4
0200-0300	4(1)	0	5(2)	0	15(2)	1(1)
0300-0400	4(1)	0	16(3)	0	10	2(1)
0400-0500	8(4)	0	19(5)	0	14	2
0500-0600	6(4)	0	12(3)	1(1)	2	0
Subtotal	124(58)	5(2)	250(99)	15(9)	172(4)	75(2)

* Number in parentheses means number of engorged female mosquitoes.

dawn.

The biting activity of *C.pipiens pallens* was continued throughout the night. The peak number of this species was 117 between 0100-0200 hour on July 29-30, 1992 and 58 between 2000-2100 hour on August 16-17, 1995. In the human baited trap collection the peak hour of biting differed each month, for example between 2400-0100 hour in July, 1992. 2200-2300 hour in August, 1993 and 2100-2200 hour in August, 1995, when the air temperature was 34.6-24.4℃ and the humidity 71-75 per cent in the field.

The hourly distribution of *A.sinensis* and *C. tritaeniortynchus* was not apparent in the human baited trap, because a very small number were collected.

The frequency distribution and cumulative percentages of the three main vector mosquitoes collected on human baits at hourly intervals derived from the grand total are shown in Table 10 and illustrated in Fig.3-A and Fig.3-B. The grand total of the numbers of three main vector mosquitoes at Kyungsan city in 3 nights were 50, 32 and 464, as seen in the first columns of Table 10. The mean time and standard deviations of *A. sinensis* calculated from this figure were 23.22±2.15 hours. The theoretical number per each hour expected from the normal frequency distribution were computed, and were compared with the numbers observed. The value of Chi-square was 20.567 with the degrees of freedoms of 8, and thus probability was about 0.005.

The total number of *C.tritaeniorhynchus* and *C.pipiens pallens* collected on human baits were 32 and 464, respecively. The mean and standard deviations were 22.41±2.17 hours on *C.tritaeniorhynchus* and 23.13±2.31 hours on *C.pipiens pallens.* The values of Chi-square were 26.59 on *C.tritaeniorhynchus* and 73.60 on *C.pipiens pallens* with the degrees of freedoms of 8, and thus the probability were about 0.001.

These figures suggest that the biting rhythms of these mosquitoes observed under this method takes a pattern significantly different from a normal frequency distribution, though it looks somewhat similar. From Fig.3-B, the cumulative percentage distribution of the number of vector mosquitoes collected at hourly intervals derived from the grand total was roughly on sigmoid curves. Thus is seen that about 50 per cent of the mosquitoes attacking man in a night can be collected before midnight, or 80 per cent can be collected with five hours' work from 2000 to 0100.

In Table 11, the patterns of biting rhythms by the species as calculated from frequency distribution by the time of collections were listed. Significant differences were seen in the mean and standard deviation by different species and/or different traps. *A.sinensis* collected by light trap and on human baits in Kyungsan city with mean±standard deviations of 23.17±3.00 and 23.22±2.15, and *C.pipiens pallens* with similar values were found to represent the nocturnal activity more concentrated to midnight, while *C.tritaeniorhynchus* showed the values from 22.58±3.04 to 22.41±2.17.

The results of classification of female mosquitoes collected at hourly intervals by engorgement and ovarian development are listed in Table 12. The numbers listed for each hour's collection were arranged by the order A,B and C. A represented the mosquitoes which were looking for a host, while B were those which had a blood meal in the same night and C were those which were in the status of blood digestion and yolk developments, or of just before oviposition. As shown in Table 13, it was found that almost all mosquitoes collected on human baits during the hours 1900 to 0100 were in the status of searching for a host. The total number of *C. pipiens pallens* collected from 0100 to 0600 at Kyungsan station were

Table 10. Frequency distribution and cumulative percentages of three main vector mosquitoes collected on human baits at hourly intervals in Kyungsan city

Time of collection	f	Z	P	F	$(f-F)^2/F$	Cum.%
	Anopheles sinensis					
1900-2000	0	-1.51	0.0655	3.275	3.275	0
2000-2100	4	-1.06	0.0791	3.955	0.001	8.0
2100-2200	12	-0.61	0.1263	6.315	5.118	32.0
2200-2300	13	-0.17	0.1616	8.080	2.996	58.0
2300-2400	4	0.28	0.1778	8.890	2.690	66.0
2400-0100	6	0.72	0.1539	7.695	0.373	78.0
0100-0200	4	1.17	0.1148	5.740	0.527	86.0
0200-0300	3	1.61	0.0673	3.365	0.040	92.0
0300-0400	1	2.06	0.0340	1.700	0.288	94.0
0400-0500	2	2.50	0.0135	0.675	2.601	98.0
0500-0600	1	2.95	0.0046	0.230	2.578	100.0
0600-			0.0016	0.080	0.080	
Subtotal	50		1.0000	50.000	20.567	
	Culex tritaeniorhynchus					
1900-2000	1	-1.19	0.1170	3.744	2.011	3.1
2000-2100	9	-0.75	0.1096	3.507	8.604	31.3
2100-2200	5	-0.30	0.1555	4.976	0.000	46.9
2200-2300	5	0.14	0.1736	5.555	0.055	62.5
2300-2400	3	0.58	0.1633	5.226	0.948	71.9
2400-0100	4	1.02	0.1272	4.070	0.001	84.4
0100-0200	2	1.47	0.0830	2.656	0.162	90.6
0200-0300	2	1.91	0.0427	1.366	0.294	96.9
0300-0400	0	2.35	0.0187	0.598	0.598	96.9
0400-0500	0	2.80	0.0068	0.218	0.218	96.9
0500-0600	1	3.24	0.0020	0.064	13.689	100.0
0600-			0.0006	0.019	0.019	
Subtotal	32		1.0000	32.000	26.599	
	Culex pipiens pallens					
1900-2000	61	-1.28	0.1003	46.539	4.493	13.1
2000-2100	29	-0.89	0.0864	40.090	3.068	19.4
2100-2200	62	-0.49	0.1254	58.186	0.250	32.8
2200-2300	83	-0.09	0.1520	70.528	2.206	50.6
2300-2400	57	0.31	0.1576	73.126	3.556	62.9
2400-0100	73	0.70	0.1363	63.243	1.505	78.7
0100-0200	37	1.10	0.1063	49.323	3.079	86.6
0200-0300	14	1.50	0.0689	31.970	10.101	89.7
0300-0400	19	1.90	0.0381	17.678	0.099	93.8
0400-0500	27	2.29	0.0177	8.213	42.975	99.6
0500-0600	2	2.69	0.0074	3.434	0.599	100.0
0600-			0.0036	1.670	1.670	
Subtotal	464		1.000	464.000	73.601	

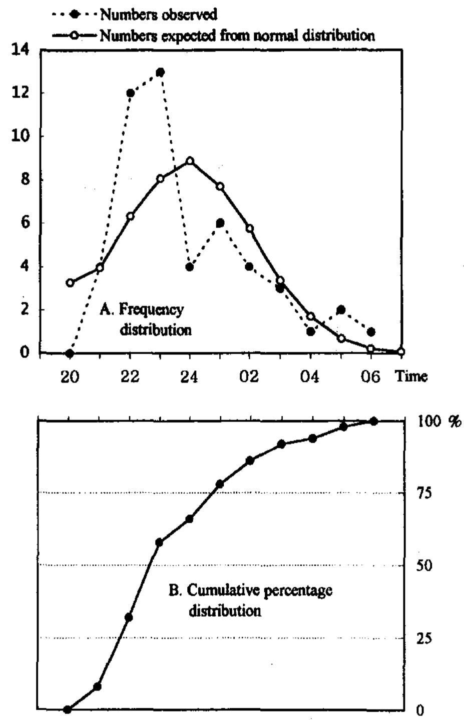

Fig. 3-1. Total numbers of *Anopheles sinensis* collected on human baits at hourly intervals at Kyungsan.

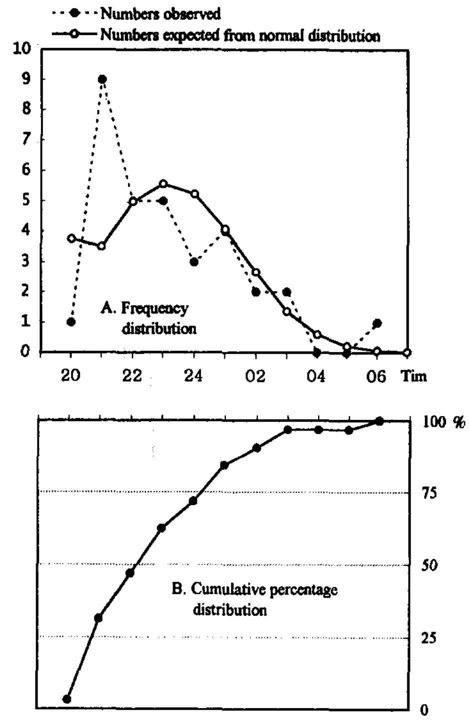

Fig. 3-2. Total numbers of *Culex tritaeiohynchus* collected on human baits at hourly intervals at Kyungsan.

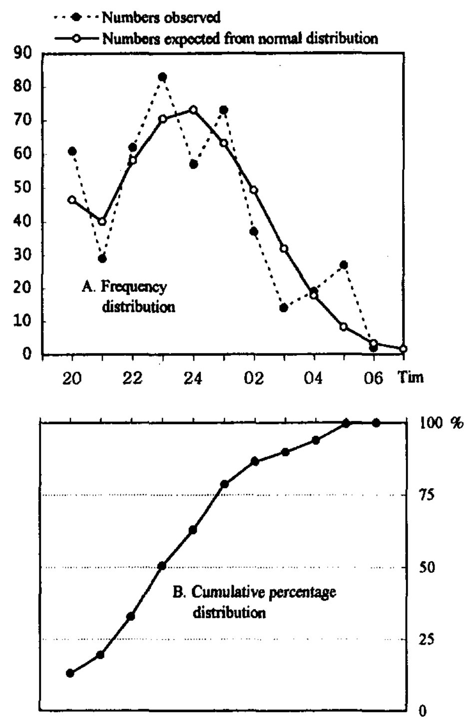

Fig. 3-3. Total numbers of *Culex pipiens pallens* collected on human baits at hourly intervals at Kyungsan.

composed of A:7, B:2 and C:0.

The data shown in Table 13 summarizes the age structure of immature stages of vector mosquitoes and the seasonal prevalence of the total number of larvae plus pupae in the study area. It is quite clear the *Anopheles* larval density is generally much higher than that of *Culex* species in cultivated fields. The highest average density of *Anopheles* species in the fields was 2,724 X 10^3 on July 24, 1992, while the highest larval density of *C.tritaeniorhynchus* was 264 X 10^3 recorded on August 14, 1992.

It is only about one tenth of *Anopheles* larval density in the fields. After late September, such density showed a marked decrease and the larvae and/or pupae of vector mosquitoes were rarely found until rice plants were harvested. Since few larvae and pupae had other mosquito species, no reliable age structure could be charted.

Table 11. Summary of patterns of biting rhythm of three main vector mosquitoes as calculated from frequency distributions by the time of collections

Species	Light trap			Human baited trap		
	Total No. collected	Mean of time collected	SD in hour	Total No.collected	Mean of time collected	SD in hour
A.sinensis	693	23:17	3:00	50	23:22	2:15
C.tritaeniorhynchus	404	22:58	3:04	32	22:41	2:17
C.pipiens pallens	1,396	24:21	3:02	464	23:13	2:31

Note : Mean and standard deviation were calculated from the frequency distribution by the class interval of an hour. The standard deviation is 2.15 hours or two hours and fifteen minutes.

Table 12. Classification of female mosquitoes collected at hourly intervals by engorgement and ovarian development

Time of collection	*A.sinensis*			*C.tritaeniorhynchus*			*C.pipiens pallens*		
	A	B	C	A	B	C	A	B	C
1900-2000	0	0	0	0	0	0	9	0	0
2000-2100	1	0	0	2	0	1	2	0	0
2100-2200	0	2	0	1	2	0	17	0	1
2200-2300	0	0	0	0	4	0	10	0	1
2300-2400	0	0	0	1	1	0	12	0	1
2400-0100	0	0	2	1	1	0	11	0	2
0100-0200	0	0	0	0	0	0	4	0	0
0200-0300	0	0	0	0	0	0	0	1	0
0300-0400	0	0	0	0	0	0	1	1	0
0400-0500	0	0	0	0	0	0	2	0	0
0500-0600	0	0	0	0	1	0	0	0	0
Total	1	2	2	5	9	1	68	2	5

Note: A: Unengorged and ovarian undeveloped B: Midgut engorged with fresh blood and ovaries undeveloped C: Unengorged and ovaries with yolk development.

Table 13. Age structure of immature stages of main vector mosquitoes in the study area

Date		Total No. in the study area at the median age of each stage($X10^3$)*									
		A.sinsensis					*C.tritaeniorhynchus*				
		L_1	L_2	L_3	L_4	Pupa	L_1	L_2	L_3	L_4	Pupa
Jul.	3	782	330	161	71						
	10	820	892	171	14	14					
	17	433	589	565	58						
	24	682	952	952	138						
	31	470	776	1,176	106						
Aug.	7	447	319	96	85	15	16	11	27	16	2
	14	897	410	95	28	7	4	115	107	20	18
	21	356	270	351	106			86	99	11	6
	28	484	1,362	551	155	25	24	24	24	38	14
Sep.	4	186	143	90	13	4		69	53	51	8
	18	549	401	326	53	6	47	72	21	10	12
	25	532	147	80	22		19	52			11
Total		6,008	6,591	4,614	849	71	110	429	331	146	71

* Total No. in the study area at the median age of each stage($X10^3$)=Total No. of each stage in the study area(=Average No.per dip X 186 X Total area with water in m^2)/ Mean period of the stage at the then temperature. Ten-day average temperatures were used here.

Table 14. Lc_{50} and resistance ratios of several insecticides for fourth instars of vector mosquitoes

	C.tritaeniorhynchus		*C.pipiens pallens*	
	Lc_{50}	R/S*	Lc_{50}	R/S
Diazinon	23.3	1,553	0.113	7.53
Malathion	21.1	5,023	0.163	38.81
Fenitrothion	10.7	13,896	0.0296	34.44
Fenthion	12.9	9,084	0.01958	13.79
Temephos	71.3	91,410	-	-
Allethrin	0.0558	-	-	-
Phenothrin	0.0062	-	-	-

* The data of susceptable strain reported by Department of Medical Entomology, NIH, Japan.

Table 14 shows the insecticides resistance levels of larval *C.tritaenorhynchus* and *C.pipiens pallens* for one generation in the laboratory from collection at Kyungsan station and compared those of susceptible laboratory strains. The larval mosquitoes were highly resistant to O-P compounds and synthetic and synthetic pyrethroides.

Among the O-P compounds, *C.tritaeno-rhynchus* was found to have resistance ratios against diazinon and malathion in the Lc_{50} value of 23.3 ppm and 21.1ppm, respectively.

The Lc_{50} values to temephos and fenitrothion were about 91,400 and 13,900 times higher than that of susceptible strain. Of the synthetic pyrethroides, larval *C.tritaenorhynchus* were quite susceptible to allethrin and phenothrin, Lc_{50} were 0.0558 ppm and 0.0062 ppm, respectively. The Lc_{50} value of the *C.pipiens pallens* to malathion was about 38.81 times as high as that of susceptible strain. The low increased resistance of larval *C.pipiens pallens* to fenthion and diazinon were discovered in this survey, the Lc_{50} values 0.01958 ppm for fenthion and 0.113 ppm for diazinon, respectively.

Discussion

Of the many kinds of blood-sucking insects and arthropods which bite people, cause annoyance and irritating dermatitis, and transmit pathogenic microorganisms, mosquitoes have been known as the most closely associated with human beings since olden times. Little factual researches on Korean mosquitoes were done before the end of World War II, although Anopheline mosquitoes were thought to be the important vectors of malaria in Korea because some studies on the prevalence of tertian malaria in Japanese military personnel stationed in several locations of Korea and its vectors were made by several surgeons (Hasegawa, 1913; Watanabe, 1916; Nagai, 1925; Osawa, 1927; and Tanabe, 1927). After World War II, the biological, ecological, sero-epidemiological, and virological studies on the vector mosquitoes in Korea have made remarkable progress through the labors of medical parasitologists and entomologists serving with the American military services. During the JE epidemics among the residents in Korea in 1946-1949, Sabin et al. (1947) conducted a study in American soldiers in the Kunsan area, and successfully isolated JE virus from a patient who died. A study of Hullinghorst et al. (1951) reported that the Korean epidemic during the summer of 1949 was caused by the virus of JE and that sera of normal Koreans subjected to anamnestic evaluation and specimens from domestic animals indicated wide dissemination of the virus in Korea.

In the survey of the vector mosquitoes in Korea, with a consideration of their importance as human medicine, Lee et al. (1969) conducted a study for JE virus isolated from mosquitoes collected in the Seoul area in the summer of 1965, and reported that 5 strains of JE virus were isolated from *C.tritaeniorhynchus,* one strain from *A.vexans nipponii,* and two starins from overwintering *C.pipiens pallens.* They also commented that the principal vector of JE in Korea was *C.tritaeniorhynchus. A.vexans nipponii,* and *C.pipiens pallens* were equally susceptable and were capable of transmitting JE virus.

From their mosquito survey, it was found that *C. pipiens pallens* was the most prevalent species, and next in order was *A. sinensis, with C.tritaeniorhynchus* taking the fourth place. As for the monthly fluctuation in numbers of the vector mosquitoes in Korea, it has been reported previously in an attempt to estimate the population dynamics of *A. sinensis* (Whang, 1962; Hong, 1970; Lee et al., 1986; Joo and Kang, 1992; Kang and Joo, 1993), *C.tritaeniorhynchus* (Shin et al., 1971; Self et al., 1973 a&b; Frommer et al., 1977 & 1979; Joo and Wada, 1985; Baik and Joo, 1991; Joo and Kang, 1994), and *C.pipiens pallens* (Joo and Lyuh, 1994). In the general patterns of seasonal prevalences, *C.tritaeniorhynchus* first appeared in mid-June, and was trapped in large numbers during the periods from mid-August to early September, showing a sharply pointed one peak curve, while *C.pipiens pallens* was found to be active through almost the entire season showing irregular curve with several peaks. As for *A. sinensis,* the trend was similar to that of *C.tritaeniorhynchus,* but the earliest dates of appearance and disappearance differed from that of *C.tritaeniorhynchus.*

This is a report on a complete year's collection with one night per week schedules. Data on vector mosquitoes has partly been reported particularly for earlier years (Joo and Kang, 1994; Joo and Lyuh, 1994). However, they are differently arranged in this paper so that population dynamics of vector mosquitoes can be compared seasonally and yearly. It seems that the appearance time of female mosquitoes from hibernation depended on the time of awakening from winter diapause; and varied from year to year probably due to different air temperatures in the early spring of each year. The appearance of a new generation of vector mosquitoes was indicated by male mosquitoes, since only female mosquitoes overwintered. The earliest dates in each year for the appearance of newly-emerged male mosquitoes in Table 2 were based on the light trap collections. From the results shown in Table 2, the appearance time of the first male mosquitoes have differed greatly in years, depending on the time of oviposition by overwintering females and the condition, partcularly the temperature, during the immature stages.

The seasonal variations of vector mosquitoes have been shown usually in the numbers of mosquitoes collected, but the numbers were found to fluctuate by day and place, as well as by collection method. Therefore, the total or mean value seems to be unfit for comparison of the annual abundance of mosquito population.

On the basis of this point, Ishii and Karoji(1975) conducted a survey of population dynamics of vector mosquitoes by using trap collection, and proposed the use of collection index and trap index estimated from the data obtained by light trap collection, and calculated the relative error of these indices by Morisita's I_δ method (1959). However, it was indicated that the large variations among many stations in the number of vector mosquitoes collected should be taken into consideration for comparison of annual abundance of mosquitoes. In fact, most of the vector mosquitoes in rural and suburban areas had habitats, which were suitable for breeding the larvae of mosquitoes. Thus, the total number of mosquitoes of certain species collected at all stations may not always represent the relative number of that species. In order to solve such a problem, Maeda et al.(1978) proposed to use the mean percent index(MPI), being calculated from the data of mosquito collections, for comparison of the annual abundance of mosquitoes. They also reported that *C.tritaeniorhynchus* had decreased after 1965 and this decrease was correlated with the reduction of human patients of Japanese encephalitis in Japan. Entomological surveys of the mosquito population in Kyungpook Province, Korea in successive years since 1984 have been carried out by some investigators(Joo and Wada, 1985; Lee et al., 1986; Baik and Joo, 1987 and 1991; Joo and Kang, 1992 and 1994; Kang and Joo, 1993; Joo and Lyuh, 1994). These data are valuable, but not used for further analysis of the epidemic of Japanese encephalitis, malaria and filariasis. In these data, however, remarkable decrease of vector mosquitoes have been found in recent years and the tendency of the decrease in number of these vectors are likely to be the case not only in Kyungpook Province, but also all over Korea.

It seems that the decrease of these vector mosquitoes are an important factor in the reduction of human infection cases with Japanese encephalitis, malaria and filariasis in Korea.

The main reasons responsible for the decrease in the number of vector mosquitoes can hardly be explained, but there are several factors, possibly due to spraying of insecticides including other toxic chemicals, to the extensive uses of herbicides such as CNP and NIP for rice plant cultivation, and to the introduction of intermittent irrigation or the early planting of rice plants.

As for the host preference of vector mosquitoes, Sasa et al. (1950) reported the attraction order of animals to vector mosquitoes by using animal-baited traps as follows: horse> goat> rabbit> chicken for *A.sinensis* and *A.vexans nipponii*, horse> goat> chicken> rabbit for *C.tritaeniorhynchus*, and chicken> horse> goat> rabbit for *C.pipiens pallens*.

Wada et al.(1967) in their studies with vector mosquitoes of Japanese encephalitis reported that *C.tritaeniorhynchus* was strongly zoophilic and probably to a lesser extent ornithophilic, *A.sinensis* was a highly zoophilic species, and *C.pipiens pallens* was anthropophilic and ornithophilic species.

Blood-feeding success of vector mosquitoes observed was sometimes a reflection of relative mosquito abundance. In practice, *C.tritaeniorhynchus* abundance during 1994 was greater than in other years observed. The same relationship held true for the number of engorged mosquitoes collected during those years. However, monthly engorgememt success was not always linked to overall mosquito abundance. In 1992 *A.sinensis* was most abundant in July, but engorgement of females has the highest rate in June. On the basis of the previously reported data and our own figures, it is indicated that blood feeding was significantly associated with the rainfall, wind and humidity, etc. A study of Day and Curtis(1989) reported that *C.nigripalpus* abundance and blood feeding behaviour was tied closely with daily rainfall patterns. Similar results in vector mosquitoes have been obtained by Provost (1973), Olson et al.(1983), and Russel (1986). As for studies of the biting rhythm of vector mosquitoes in Korea, Kanda et al.(1975) found that *A.sinensis, A.vexans nipponii* and *C. tritaeniorhynchus* bit from 2000 onward, but *C.pipiens pallens* first appeared at 2200. Joo and Wada (1985) reported that *C.tritaeniorhynchus* and *A.sinensis* were rather constantly active all through the night with more or less inconspicuous peaks twice a night, while *C.pipiens pallens* exhibited an irregular curve. The numbers of *A.vexans nipponii, C.vagans* and *A.subalbatus* were very small and were not sufficient for estimating the bithing rhythm. In the present study *A.sinensis* appeared to be active throughout the wholenight, but more active during darkness, after sunset to midnight. *C.tritaeniorhynchus* had two peaks, one between 2000-2100 and the other between 0400-0500 on August, 16-17. *C.pipiens pallens* was the most active for one or two hours after sunset with a high peak at 2100-2200, decreasing gradually towards hours after midnight. These results indicate that the nocturnal activities of vector mosquitoes were not always similar by collection methods even on the same night. Although the environmental factors such as temperature, humidity, light and wind-borne stimuli, etc., should be essential in influencing the attraction of mosquitoes, this data can not be explained fully only by the hourly changes of these factors, because the meteorological conditions were considered nearly the same night at the sites where the collections were made. Further work along this line is needed. Joo and Lyuh(1994) in an epidemio-entomological survey of *C.pipiens pallens* in Kyungpook reported that this species was found to become most active during a few hours' period around midnight, with the standard deviation of about 3.27 hours. In this study the grand total of the numbers of three main vector mosquitoes collected by light traps in 3 nights were 693, 404 and 1,396, respectively. Significant differences were presented in the mean and standard deviations by the species and/or different collection methods. *A.sinensis* collected by light trap with the standard deviation of about 3:00 and on human-baited trap with 2:15,

C. tritaeniorhynchus and *C.pipiens pallens* showed the values from 3:04 and 3:02 in light trap to 2:17 and 2:31 on human-baited trap. The results given in Table 10 and Fig.3 indicate that about 60.0 per cent of vector mosquitoes attacking human beings in a night could be collected before midnight. The facts are useful in saving the labour of a collector in making comparative studies on the vector mosquitoes population between different location and/or by the seasons. Similar results were obtained by Sasa et al.(1964 and 1968), Kato (1955), Mogi (1984), Joo and Lyuh (1994), and Joo and Kang (1994). The larvae and pupae of the vector mosquitoes are found in a great variety of different habitats, ranging from large expanses of water such as swamps and rice fields to small collections of water as found in plant axils, snail shells and fallen leaves. Up to the mid 1940s larval collections formed an essential part of malaria surveys and control programmes, but with the the advent of DDT, and later other residual organochlorines, attention was focused on the biology and behaviours of the adult mosquitoes. Insecticidal spraying of larval habitats as in application of residual insecticides to houses, and larval surveys have consequently continued to be important in assessing population size and the impact of control measures. In the larval surveys of vector mosquitoes, Wada and Mogi (1974) undertook an instructive series of experiments to test the efficiency of a dipper in sampling the immature stages of *C.tritaeniorhynchus* and *C.pipiens pallens,* and reported that the efficiency of the dipper differed considerably for the different age classes of *C.tritaeniorhynchus* and also for 4th instar larvae of the two species. Mogi (1978) made population studies on mosquitoes in the rice field area of Nagasaki in southern Japan, and found that active reproduction occurred almost exclussively at suitable breeding places following transplanting of rice plants. From their studies on the Japanese encephalitis vectors in Korea, Baik and Joo (1991) reported that the density of *C.tritaeniorhynchus* in rice fields was the highest in mid-August, with an average number per m^2 of 14,900. Somboon et al.(1989) in a study on the Japanese encephalitis vector in Thailand stated that the average number of *C.tritaeniorhynchus* per m^2 in rice fields were the highest in July when the fields were ploughed, but in the period from transplanting to harvesting, the densities were very low. Joo and Kang (1992) conducted the epidemio-entomological survey on malrial vector mosquitoes in Korea, and concluded that the seasonal fluctuation in the larval population densities in paddy water was markedly different from paddy to paddy in the same area and/or from year to year in the same paddies.

In the present study, *A.sinensis* was a dominant species not only in this Anophelinae but also among mosquito species in this area. The number of larvae and pupae of *A.sinensis* was distinctly larger than that of *C.tritaeniorhynchus* without exception, with adult females of the latter not rarely exceeding the former in number. This interesting phenomenon was not restricted to this Province.

Mogi (1978), who studied rice field mosquitoes in Nagasaki, southern Japan, considered that four factors can be responsible for this phenomenon, but the truth was unknown. Larvae and pupae of *A.sinensis* were found in rice fields at least from July to September. A considerable number of adult females were not rarely attracted to baits in the earlier or the later season. *C.tritaeniorhynchus* was a dominant mosquito next to *A.sinensis.* From the data given in Table 13, it is noted that the average larval density of *Culex* species show one-tenth of *Anopheles* larval density in the fields. It is considered that the dipping method would not usually sample *Anopheles* and *Culicine* species equally, because whereas the latter often submerge for long periods to feed at the bottom of habitats *Anopheles* larvae rarely leave the surface unless disturbed. Apart from these difficulties, some larvae would escape capture by dipping by swimming away, and their ability to escape might differ between species and also instars.

In the studies on the insecticide resistance of vector mosquitoes and other arthropods of medical importance in Korea, there have been many investigations since World War II(Hurlbut et al., 1952; Hwang et al., 1965; Lee., 1969; Ree et al., 1979, 1980, and 1981; Shim et al., 1979; Shim and Kim, 1980 and 1981; Baik and Joo, 1987 and 1991; Joo and Kang, 1992 and 1994; Joo and Lyuh, 1994)

Hurlbut et al.(1952) conducted a survey of Korean body lice, and reported for the first time that the body lice was DDT resistant. Hwang et al.(1965) made a survey on insecticide susceptibility of *C.tritaeniorhynchus* collected from cow-sheds, and reported that this species was DDT susceptible and Dieldtin resistant. Ree et al.(1979) studied the control effects of agricultural pesticides against mosquitoes in rice paddies breeding species, and commented that *Culex* mosquitoes had developed a high degree of resistance to some insecticides. Baik and Joo(1991)reported that *C.tritaeniorhynchus* had developed high resistance to most of the insecticides as compared with the results of susceptible strains reported by Yasutomi and Takahashi(1987). Similar results in vector mosquitoes have been obtained by Shim and Kim(1980, 1981), Yasutomi et al.(1986), Takahashi and Yasutomi(1987), Kang and Joo(1993) who also reviewed published observations from other parts of the World.

In the study, the larval *C.tritaeniorhynchus* showed the highest resistance to diazinon and malathion with Lc_{50} values of 23.3 ppm and 21.1 ppm, respectively.

The more increased resistance to fenitrothion and fenthion were discovered in *C.tritaeniorhynchus* collected in Kyungsan County. Lc_{50} of temephos was extraordinarily higher resistant, but this insecticide has not been used in ricefields. Although the main reasons for the high resistance ratio of this insecticide are not readily apparent, it was considered to be due to cross-resistance resulting from exposure to one or more other agrochemicals with a similar mode of action.

The uniform susceptibility of mosquitoes to allethrin and phenothrin were anticipable, because pyrethroids have not been used as agrochemicals up to the present.

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