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Survival Rates of Immature Stages of *Culex tritaeniorhynchus* (Diptera, Culicidae) in Rice Fields under Summer Cultivation*

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Abstract: Survival rates and mortality factors were examined on immature *Culex tritaeniorhynchus* released in experimental frames or cages set in rice fields in July, because this period following transplantation of young rice plants is the most active breeding season of the species in Nagasaki, Japan. Emergence rates were low during the period when agricultural chamicals (insecticides, herbicides) applied to rice fields remained lethal to *tritaeniorhynchus* larvae. Even when the effect of chemicals disappeared, emergence rates were generally very low in frames with a natural complex of predators. However, emergence rates in a few frames were much higher than those observed in fallow rice fields in May. This high emergence rate was due not to the increased daily survival rate but primarily to the shortened developmental period under high temperatures of midsummer. Predator density was lower in rice fields treated with agicultural chemicals than in untreated ones. Emergence rates increased remarkably in enemy-free cages. Fishes were considered to be very effective predators for eggs and larvae. Also, predacious insects appeared to make a large contribution to mortality during aquatic stages. Based on the results, there was analysed the process of population growth of *tritaeniorhynchus* in summer under the strong pressure of predation and agricultural chemicals. It was concluded that the heterogeneity in the condition of rice fields is a very impor-

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tant factor ensuring the continuous growth of *tritaeniorhynchus* populations in summer. Emphasis was put on the positive use of natural enemies to suppress *tritaeniorhynchus* populations in summer.

Culex tritaeniorhynchus is a main vector of Japanese encephalitis (JE) virus in Japan and some other countries, where rice fields are most important as its breeding place. In the preceding paper of this series (Mogi et al., 1980), survival rates of immature *tritaeniorhynchus* were examined in fallow rice fields in May. The purpose of the present report is to clarify survival rates and mortality factors in July, a period immediately following transplantation of rice plants, when conditions of rice fields are most favorable for the reproduction of this mosquito (Mogi, 1978, Section 6.6.19). This good period leads to the peak abudance of adult *tritaeniorhynchus* in midsummer (Yamada′s peak), which is proportional to the yearly total number of human JE cases (Wada et al., 1975, Fig. 6). Therefore, understanding the process of population growth in July is essential to prevent JE epidemics in Japan through the efficient control of this mosquito.

METHODS

Three series of experiments were done in rice fields of Nagasaki Agricultural and Forestry Experiment Station. *Experiment-1* and *2* were done in 1972 and *Experiment-3* in 1973. Herbicides, insecticides and fungicides were applied following the regular schedule of rice culture in the Nagasaki district except a few ″untreated″ rice fields where chemicals other than fertilizers were not applied. Rice culture procedures, experiments and other significant events were in the following order.

1972	June	29	Transplanting
	July	2–12	*Experiment-1*
		4 & 5	Herbicide (granules of benthiocarb plus CNP)
		6	Bioassay on water samples
		13	Heavy rain
		18	Insecticide (PHC dust)
		27–Aug. 11	*Experiment-2*
	July	29	Bioassay on water samples
1973	June	28	Transplanting
		30	Herbicide (granules of benthiocarb plus CNP)
	July	9–17	*Experiment-3*
		12	Insecticide (dust of fenitrothion plus carbaryl)

The experiment was done with the Nagasaki strain of *tritaeniorhynchus* which had been maintained in the laboratory for 85 generations or more. The fundamental procedure was identical with that of the fallow field experiment reported (Mogi et al., 1980), therefore the procedure will be described briefly.

Experiment-1. Egg rafts laid at the previous night were released into frames of 1 m^2 with a natural complex of predators. Larval density was examined by the dipper every day as a rule, and the number per dip was converted to the absolute number in the frame with conversion coefficients (Wada and Mogi, 1974, Table 3; Mogi et al., 1980, Table 1). The bioassay on the water sample from each frame was done with first instar larvae of *tritaeniorhynchus* at the room temperature.

Experiment-2. Two procedures were added to those of *Experiment-1*. First, hatch and survival rates were observed in enemy-free cages of 10×10 cm floated in frames. Secondly, all predators in frames were collected at the end of the experiment by filtering the water through nets of fine meshes. Although the position of frames remained unchanged between *Experiment-1* and *2*, the predator fauna in frames was renewed by the heavy rain on July 12 which increased the water level beyond the height of frames.

Experiment-3. Survival rates were observed with larvae released into enemy-free floating cages of 30×30 cm in untreated rice fields.

RESULTS

Experiment-1

Table 1 shows the survival and development of immature *tritaeniorhynchus* in experimental frames. No larvae were collected from *Frame-1*, and only a small number of first or second instar larvae were collected from *Frame-3*, *7*, *8* and *9*. From the other five frames (*2*, *4*, *5*, *6* and *10*), old larvae were recovered, but no pupae were found from *Frame-10*. Although tendencies in the decline of numbers were variable, it is clear that mortality in immature stages was very large in general.

In the preceding paper of this series (Mogi et al., 1980), a regression method was employed to estimate hatch, emergence and daily survival rates in fallow rice fields. However, the same method could not be applied to the present data satisfactorily because of the following reasons. First, the number of census times was often too small to follow the process of declines owing to rapid extinction of released larvae compared with the census interval. Secondly, daily survival rates were not necessarily regarded to be constant throughout the aquatic stages. Therefore, we obtained rough estimates of hatch and emergence rates by a very simple method based on freehand survivorship curves fitted smoothly to observed points including the number of released eggs (Fig. 1)*. The number of hatched larvae was estimated by reading the height

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* Lakhani and Service (1974) estimated the number of *Aedes cantans* entering each stage from freehand survivorship curves.

Table 1. Survival and development of immature *Culex tritaeniorhynchus* in rice fields (*Experiment-1*)

Rice field	Frame	Developmental stage	Days after release							
			0*	2	4	5	6	7	8	10
Untreated	1	Egg	9400**							
		Total	9400	0						
	2	Egg	9400							
		1st instar		4890						
		2nd instar		470	2350	776	12			
		3rd instar			434	301	50			
		4th instar				71	44			
		Pupa					49			
		Total	9400	5360	2787	1148	155	0		
	3	Egg	1227							
		1st instar		128						
		2nd instar		116						
		Total	1227	244	0					
	4	Egg	1252							
		1st instar		436						
		2nd instar		302						
		3rd instar			75					
		4th instar			193	9	9			
		Pupa				94	21	7		
		Total	1252	738	268	103	30	7	0	
	5	Egg	1232							
		1st instar		333						
		2nd instar		674						
		3rd instar			25					
		4th instar			571	214				
		Pupa				162	430	63		
		Total	1232	1007	596	376	430	63	0	
	6	Egg	1243							
		1st instar		487						
		2nd instar		512	140	81				
		3rd instar			367	183	117	8		
		4th instar			9	259	304	268	9	
		Pupa				7			14	
		Total	1243	999	516	530	421	276	23	0
Treated	7	Egg	1273							
		1st instar		154						
		2nd instar		23						
		Total	1273	177	0					
	8	Egg	1269							
		1st instar		51						
		2nd instar		12						
		Total	1269	63	0					
	9	Egg	1365							
		1st instar		115						
		2nd instar		47	209	23				
		Total	1365	162	209	23	0			
	10	Egg	1368							
		1st instar		897						
		2nd instar			186	233				
		3rd instar					83			
		4th instar							89	
		Total	1368	897	186	233	83	***	89	0

* Egg rafts were released.
** No. released
*** Census was not done.

on curves at the mean hatch time (the time when half eggs hatched) observed in the outdoor insectary for eggs laid together with released ones. Similarly, the number of emerging adults was estimated from the height on curves at the mean emergence time (the time when half larvae pupated plus 2 days). As mentioned earlier, daily survival rates were not necessarily constant during the aquatic stages. However, daily survival rates were calculated from emergence rates under the assumption of constancy to compare the level of daily mortality in summer rice fields with that in fallow rice fields where developmental periods had been much longer under lower temperatures.

The results are presented in Table 2. Estimated hatch rates were variable among frames, ranging from the maximum of 0.95 to the minimum of 0.20, while the hatch rate in the insectary was 0.79. However, the census was not done on the day when larvae hatched, low hatch rates obtained for released eggs may have been the result of large mortality in first instar larvae. Adults were expected to have emerged from 3 untreated frames, but emergence rates appeared very low except *Frame*—5 where as

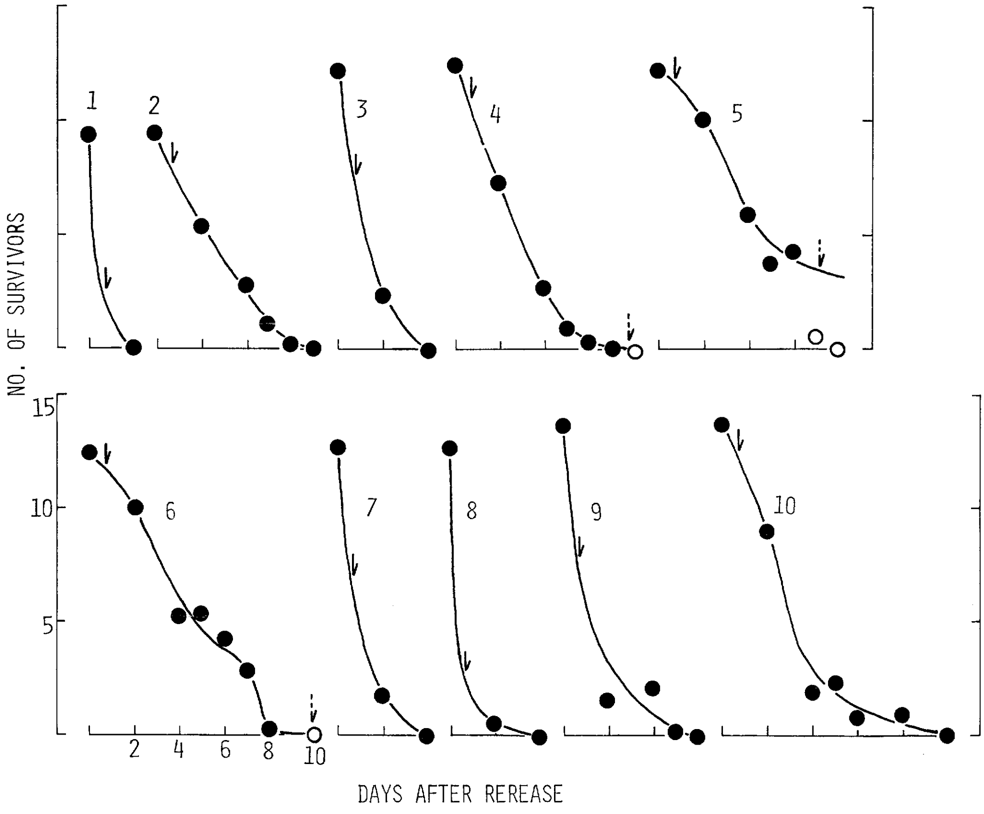

Fig. 1. Survivorship curves of immature *Culex tritaeniorhynchus* in rice fields (*Experiment-1*). Open circle: Period of adult emergemce. Arrow: Hatch time. Broken Arrow: Emergence time. Scale: $1=10^3$ for *Frame-1*, *2*, and $1=10^2$ for the others.

Table 2. Estimation of hatch, emergence and daily survival rates of *Culex tritaeniorhynchus* in rice fields (*Experiment-1*)

Rice field	Frame	No. of released eggs (A)	No. of hatched larvae (B)	Hatch rate (B/A)	No. of emerging adults (C)	Emergence rate (C/B)	Larval daily survival rate
Untreated	1	9400	2100	0.22	0	0.00	
	2	9400	7800	0.83	0	0.00	
	3	1227	720	0.59	0	0.00	
	4	1252	1070	0.85	10>	0.01>	0.52>
	5	1232	1170	0.95	350	0.30	0.83
	6	1243	1170	0.94	10>	0.01>	0.60>
Treated	7	1273	600	0.47	0	0.00	
	8	1269	250	0.20	0	0.00	
	9	1365	740	0.54	0	0.00	
	10	1368	1210	0.88	0	0.00	

many as 0.3 of hatched larvae were estimated to have become adults. High emergence rates of this level was not observed in fallow fields (Mogi et al., 1980, Table 3). It should be remarked that this high emergence rate is equivalent to the daily survival rate of 0.83 which is comparable to the level of daily survival rates in fallow rice fields in May. This means that the high emergence rate of 0.3 observed in summer rice fields was not attributed to the increased daily survival rate but primarily to the shortened duration of the larval stage under high temperatures in midsummer. Pupal duration does not vary greatly within the temperature range of 20—30°C (Mogi, 1978, Section 5.3). Adult emergence was not expected from treated frames. This agrees with the results of bioassay (Table 3). Survival rates of larvae were distinctly lower in water samples from frames treated with benthiocarb plus CNP than in water from untreated frames or in tap water. The herbicide was clearly an important mortalty factor for *tritaeniorhynchus* larvae in treated frames. Predator density, on the other hand, appeared higher in untreated frames than in treated ones (Table 4). Dytiscidae (Predacious water beetle) was an only predator detected by the dipper from treated frames, and no predators were dipped from *Frame—7* and *8*. From untreated frames, Agrionidae (damselfly: larva), Nepidae (water scorpion: adult), Notonectidae (back swimmer: larva) and Cyprinodontidae (*Oryzias* medaka fish: young) were collected in addition to Dytiscidae. It is highly probable that predation was a most important mortality factor in untreated frames because no other probable factors of great importance were recognizable.

Frame—1 and *2* were prepared to examine the overcrowding effect on survival rates, but the result was inconclusive. Also, it ended in failure to find factors responsible for the peculiar survivorship curve in *Frame—6* where only a small number of pupae were recovered after the suspended presence of numerous fourth instar larvae. A

Table 3. Survival of first instar *Culex tritaeniorhynchus* in water from each frame (*Experiment-1*)

Rice field	Frame	No. of introduced larvae	No.* of survivors 1 day after	Survival rate
Untreated	1	20	18.5	0.925
	2	20	12.5	0.625
	3	20	17.0	0.850
	4	20	18.0	0.900
	5	20	17.5	0.875
	6	20	13.0	0.650
Treated	7	20	4.0	0.200
	8	20	3.5	0.175
	9	20	7.5	0.375
	10	20	4.0	0.200
Control**		20	15.5	0.775

* Average of two replicates except *Frame-10*

** Tap water

Table 4. Predators dipped from each frame (*Experiment*-1)

Rice field	Frame	Insecta				Osteichthyes
		Agrionidae L	Nepidae A	Notonectidae L	Dytiscidae A,L	Cyprinodontidae L
Untreated	1		+			
	2			+	+	
	3		+		+	
	4			+	+	+
	5	+			+	+
	6	+	+		+	
Treated	7					
	8					
	9				+	
	10				+	

L : Larva or young, A : Adult

possible explanation is the unsuitable quality of water in the broadest sense including the low concentration of food available to *tritaeniorhynchus* larvae ; water in this frame was clean throughout the experiment.

Experiment—2

Survival rates in frames with a natural complex of predators were analysed following the same procedure as in *Experiment—1* (Tables 5, 6 and Fig. 2). General tendencies agreed with those in the first experiment ; emergence rates were very low except a few frames, higher emergence rates than in fallow rice fields were attributed

Table 5. Survival and development of immature *Culex tritaeniorhynchus* in rice fields (*Experiment-2*)

Rice field	Frame	Developmental stage	Days after release													
			0*	1	2	3	4	5	6	7	8	9	10	11	12	13
Untreated	1	Egg	1093**													
		1st instar		615	51											
		2nd instar			465	47										
		3rd instar				433	33									
		4th instar					536	339	54							
		Pupa							70	70						
		Total	1093	615	516	480	569	339	124	70	0					
	2	Egg	1069													
		1st instar		641	38											
		2nd instar			12											
		Total	1069	641	50	0										
	3	Egg	1114													
		1st instar		13												
		Total	1114	13	0											
	4	Egg	1064													
		1st instar		26												
		Total	1064	26	0											
	5	Egg	1087													
		1st instar		26												
		Total	1087	26	0											
	6	Egg	1335													
		1st instar		980	667											
		2nd instar			256	744	116									
		3rd instar				33	367	83								
		4th instar				18	71	732	411	357						
		Pupa						28	127	14	394					
		Total	1335	980	923	795	554	843	538	371	394	0				
Treated	7	Egg	1002													
		1st instar		410	26											
		Total	1002	410	26	0										
	8	Egg	1080													
		1st instar		1256	821											
		2nd instar			395	698	47									
		3rd instar					333	125	17							
		4th instar						98	89	89	36	54	17	36	36	
		Pupa									14	14	42	14	14	
		Total	1080	1256	1216	698	380	223	106	89	50	68	59	50	50	0
	9	Egg	1063													
		1st instar		1026	103											
		2nd instar		47	395	1209										
		3rd instar				133	383									
		4th instar						518	325	214						
		Pupa								113	197	85	70	14		
		Total	1063	1073	498	1342	383	518	325	327	197	85	70	14	0	
	10	Egg	1030													
		1st instar		115	13											
		Total	1030	115	13	0										

* Egg rafts were released.

** No. released

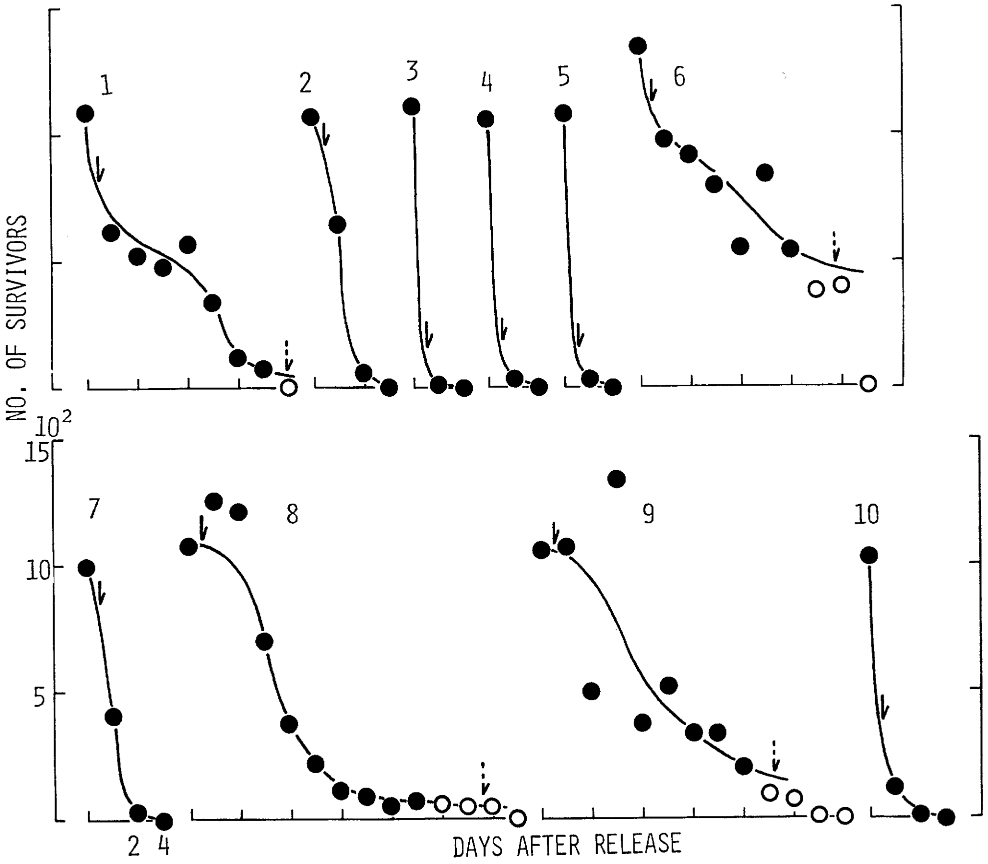

Fig. 2. Survivorship curves of immature *Culex tritaeniorhynchus* in rice fields (*Experiment-2*). For symbols, see Fig. 1.

Table 6. Estimation of hatch, emergence and daily survival rates of *Culex tritaeniorhynchus* in rice fields (*Experiment-2*)

Rice field	Frame	No. of released eggs (A)	No. of hatched larvae (B)	Hatch rate (B/A)	No. of emerging adults (C)	Emergence rate (C/B)	Larval daily survival rate
Untreated	1	1093	780	0.71	50	0.06	0.68
	2	1069	900	0.84	0	0.00	
	3	1114	80	0.07	0	0.00	
	4	1064	110	0.10	0	0.00	
	5	1087	100	0.09	0	0.00	
	6	1335	1070	0.80	470	0.44	0.90
Treated	7	1002	780	0.78	0	0.00	
	8	1080	1070	0.99	50	0.05	0.76
	9	1063	1050	0.99	160	0.15	0.80
	10	1030	300	0.29	0	0.00	

primarily to shortened developmental periods, and daily survival rates were not necessarily constant from hatch through adult emergence. The bioassay on water samples indicated that at least acute toxity against *tritaeniorhynchus* larvae of PHC treated 10 days before had disappeared at the start of this experiment (Table 7). Although larval periods were prolonged in *Frame–8* and *9*, there was no evidence indicating that the residual effect of PHC was responsible for this delay.

Predator density appeared generally higher in untreated frames than in treated ones (Table 8), but the difference was not very distinct. Larval Hydrophilidae (water scavenger beetle) were more abundant in treated frames. Therefore, 1 % PHC dust treated at the dosage of 4 kg per 10 a, which killed most *tritaeniorhynchus* larvae (Mogi, 1978, Table 15), may have been not highly toxic to some aquatic predators, since it is unlikely that all the predators were newcomers following the disappearance of the lethal effect of PHC. A comparison between hatch rates and predator density suggests strongly that young crucian curps (Cyprinidae, *Carrasius*) were efficient predators against *tritaeniorhynchus* eggs; hatch rates were 0.1 or less in frames with more than 10 individuals of this fish, the rate in the insectary being 0.74. Also, larvae in these frames disappeared rapidly. Three of four frames where adults emerged were free from fishes. Fishes including *Carrasius* appeared very efficient predators for *tritaeniorhynchus* eggs and larvae in rice fields following transplanting where activities of fishes are not restricted in contrast with fallow rice fields with dense weeds (Mogi et al., 1980). On the other hand, the correlation was unrecognized between the density of insect predators and adult emergence rates. However, this does not necessarily mean that predation due to aquatic insects was a minor mortality factor. Hatch and

Table 7. Survival of first instar *Culex tritaeniorhynchus* in water from each frame (*Experiment-2*)

Rice field	Frame	No. of introduced larvae	No.* of survivors 1 day after	Survival rate
Untreated	1	20	20.0	1.000
	2	20	20.0	1.000
	3	20	19.5	0.975
	4	20	20.0	1.000
	5	20	20.0	1.000
	6	20	20.0	1.000
Treated	7	20	19.5	0.975
	8	20	20.0	1.000
	9	20	20.0	1.000
	10	20	19.0	0.950
Control**		20	20.0	1.000

* Average of two replicates
** Tap water

Table 8. Numbers of predators in each frame (*Experiment-2*)

Rice field	Frame	Insecta				Osteichthyes		
		Agrionidae L	Libellulidae L	Hydrophilidae L	Dytiscidae A	Cyprinidae L	Cobitidae L	Cyprinodontidae L
Untreated	1	3	1	2		2		1
	2	22		11	2	3		
	3	3		2	13	12		
	4	9	1	1	23	11		
	5	11		2		15		
	6	43	9		4			
Treated	7	4	1	10	8		1	
	8	2	3	15	1			
	9	15		57	1			
	10	4		2	1		1	

L : Larva or young, A : Adult

Table 9. Hatch and survival rates of *Culex tritaeniorhynchus* in enemy-free cages in experimental frames (*Experiment-2*)

Rice field	Frame	No. of released eggs (A)	No. of hatched larvae (B)	Hatch rate (B/A)	No. of survivors* (C)	Survival rate (C/B)	Daily survival rate
Untreated	1	101	61	0.60	43	0.69	0.95
	2	107	55	0.51	40	0.73	0.96
	3	119	110	0.92	106	0.96	0.99
	4	107	66	0.62	53	0.80	0.97
	5	141	84	0.60	68	0.81	0.97
	6	136	33	0.24	16	0.48	0.91
Treated	7	114	62	0.54	44	0.71	0.96
	8	134	76	0.57	62	0.82	0.97
	9	105	45	0.43	25	0.56	0.93
	10	91	49	0.54	46	0.94	0.99

*8 days after hatch

larval survival rates in enemy—free cages revealed the effect of insect predators as well as of fishes (Table 9). Hatch rates observed were generally low owing probably to the low insemination rate, but it appeared meaningful that such extremely low rates as 0.1 or less were not observed in contrast with egg rafts exposed to the attack of fishes. Also, larval survival rates were much increased. As more than 30 individuals were reared in small cages, the development was very slow owing probably to food shortage. Therefore, survival rates 8 days after hatch was compared with emergence rates under the presence of predators. The minimum survival rate in cages was 0.48, which was equivalent to the constant daily survival rate of 0.91. These values approximated the maximum in frames with only insect predators (*Frame—6*). Survival rates in the other two fish-free frames (*8* and *9*) were much lower. Considering that the lethal effect was not recognized for water samples from experimental frames (Table 7), insect predators can properly be regarded most responsible for mortality not due to predation by fishes.

Experiment—3

This experiment was done to confirm the increase in adult emergence rates under the absence of predators with floating cages larger than in *Experiment—2* to diminish the overcrowding effect. The results demonstrated high emergence rates in the condition where both predation and overcrowing effect were excluded (Fig. 3). A total of 93 pupae out of 200 released larvae were counted on the day immediately preceding the start of adult emergence. In addition to the invasion of Dytiscidae indicated by arrows, influx of insecticides (dust) on the wind from neighbouring treated rice fields may have been responsible for relatively low emergence rates in some cages.

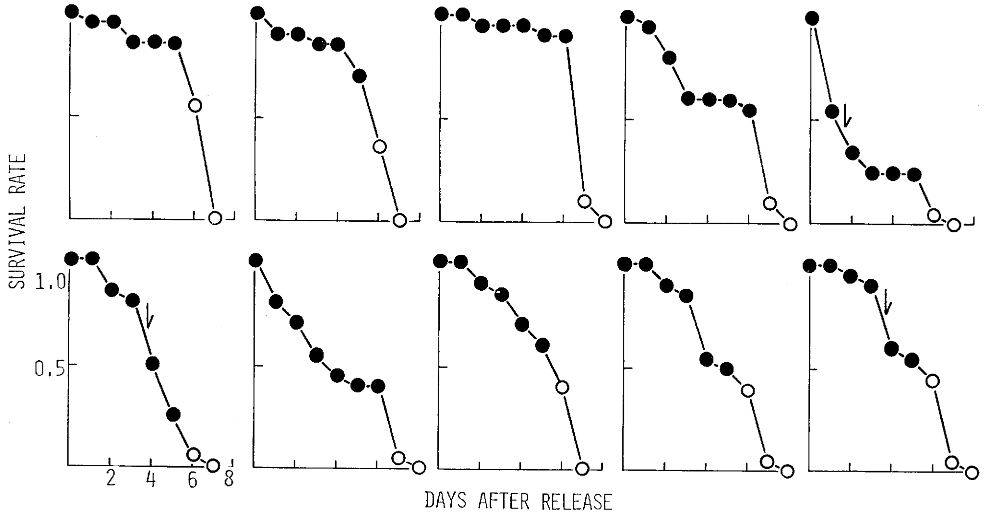

Fig. 3. Survivorship curves of *Culex tritaeniorhynchus* larvae in enemy-free cages in rice fields (*Experiment-3*). Open circle: Period of adult emergence. Arrow: Invasion of predacious water beetles.

DISCUSSION

Mortality factors for immature tritaeniorhynchus *in rice fields under planting*

There were evidenced two important mortality factors, predation and toxic agricultural chemicals. In addition to these, a large portion may be dried up by artificial drainage or be washed away by a flood due to heavy and/or successive rains. The former two are considered to be common to every year and region insofar as recent twenty years of Japan are concerned. On the other hand, the importance of the latter two appears to vary both yearly and locally. Roles of these factors in the population fluctuation of *tritaeniorhynchus* were discussed in detail (Mogi, 1978), and the nature of mortality caused by water currents and predation was analysed further in two separate papers (Mogi, 1979; Mogi et al., 1980). We shall take up a subject which has been little discussed in spite of its fundamental importance.

Heterogeneity in the condition of rice fields as an important factor determining the growth pattern of tritaeniorhynchus *populations in summer*

Present experiments were done in July when the average survival rate of *tritaeniorhynchus* larvae in rice fields is highest in the year at least in the Nagasaki district (Mogi, 1978, Section 6.3). This high survival rate, which leads to the annual peak of biting females at the end of July or the beginning of August, results from the concentration of several condition favorable to *tritaeniorhynchus* larvae (Mogi, 1978, Section 6.6.19). However, it should be also remembered that this summer growth of *tritaeniorhynchus* populations is accomplished under the strong pressure of both agricultural chemicals and predation as evidenced by the present study. How is this possible? This is our problem which needs to be explained.

Many of insecticides and herbicides to protect rice plants are also lethal to *tritaeniorhynchus* larvae, but their effects are usually not long-lived (Asahina et al., 1963; Ogata and Nakayama, 1963; Nishigaki, 1970; Mogi, 1978, p. 222). It is frequently observed that rice fields are recolonized by *tritaeniorhynchus* within 10 days after the treatment of effective chemicals. In the summer of Nagasaki, *tritaeniorhynchus* needs about 10 days for immature development (Mogi, 1978, Fig. 3 and Table 8). Therefore, adults can emerge if chemicals are not applied during 10 days after the disappearance of the effect of the previous application. When the effect persists 5 days, the 15-day-interval ensures the adult emergence of one generation. This requirement may not necessarily be satisfied easily in the Japanese rice culture system depending on the intensive use of chemicals. For instance, the standard schedule of chemical application in Nagasaki in the early 1970's included one herbicide and two insecticides in July (Mogi, 1978, p. 181). Therefore, if this schedule were kept rigidly by all farmers, rice fields in July would not allow the active breeding of *tritaeniorhynchus*. Even two times of chemical application may be sufficient to suppress the midsummer growth of the species population if they are arranged as follows.

June	30	Transplanting
July	8	Herbicide
July	22	Insecticide

However, chemicals are applied to rice fields usually without considering the joint control of mosquitoes, and *tritaeniorhynchus* can find a time to complete the aquatic life. Predator faunas reduced by agricultural chemicals would favor mosquito breeding further in rice fields where effects of chemicals has disappeared. Such periods, however, appear short and infrequent in view of the intensity of chemical application in the Japanese rice culture system. Therefore, if co-operative control is done in a large area, the *tritaeniorhynchus* population is expected to fluctuate irregularly under the strong influence of chemical control. The actually observed continuous growth in summer is certainly attributable to the heterogeneity in the condition of rice fields at least partly. Chemicals are applied by each farmer independently, therefore there are always rice fields free from the toxic effect of chemicals and with decreased predator faunas. Strong ability to fly of *tritaeniorhynchus* would make the effective use of this heterogeneity possible. It was also stressed that the heterogeneity in the condition of rice fields is a very important factor determining the mode of density effects in this mosquito (Mogi and Wada, 1973; Mogi, 1978, p. 231). Chubachi (1979) emphasized again this view. There have been developed mathematical models simulating the trend of mosquito populations to evaluate the effectiveness of various control measures (Cuellar, 1969; Miller et al; 1973; Weidaas, 1974; Haile and Weidaas, 1977)*. All these models treated the immature population as a whole without referring to the structure of breeding places. The concept of discrete and heterogeneous habitat units appears essential for models to mimic the population trend of *tritaeniorhynchus* breeding in Japanese rice fields. A very simple model described in an earlier paper (Mogi, 1978, Section 8.1) was based on this view.

Methods to suppress the summer growth of tritaeniorhynchus *populations in Japan*

A plan to increase the effectiveness of agicultural chemicals to *tritaeniorhynchus* populations was mentioned in the preceding section. Also, more comprehensive discussion on this problem was already presented (Mogi, 1978, Section 8). However, positive use of natural enemies may be added. Application of mass-produced parastites specific to mosquitoes including *tritaeniorhynchus* may become practical than formerly thought in view of the recent rapid progress in and the increasing attention to this fields (e.g., Laird, 1977; Chapman, 1978). Also in the area where predator density is low in early rice fields immediately after transplanting due to the cultivation of winter crops, it may be possible to reduce the population level by giving winter habitats to predators or by releasing appropriate predators into rice fields every summer. Collins (1980) found in California that the density of *Culex tarsalis* larvae was much higher in fields newly returned to rice after growing alternate crops than in fields under rice cultivation during two or more consecutive years. Also, positive correlation was recognized between the age of rice fields and the density of flatworms, an effi-

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* Models of Conway (1970) and de Figueiredo et al. (1975) were not seen.

cient predator for *tarsalis* larvae, although he carefully reserved to conclude that predation due to flatworms is a major factor reaponsible for low *tarsalis* density in aged rice fields. His recommendation of intensive allocation of biological control agents such as a mosquito fish *Gambusia affinis* to first year rice fields shares the same ecological basis as our consideration.

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水田におけるコガタアカイエカ未成熟期の生存率と死亡要因

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コガタアカイエカ未成熟期の生存率と死亡要因を明らかにするために，長崎の水田で7月上旬から8月上旬にかけて野外実験を行なった．6月末の田植に続くこの時期は，コガタアカイエカの増殖の最盛期にあたる．水田に施用された農薬（殺虫剤，除草剤）が有効な間は羽化率は低かった．農薬の影響がない場合でも，捕食性天敵が自然状態で存在する枠内での羽化率は一般に低かった．5月の休閑田で行なった同様の実験（Mogi et al, 1980）に比べてはるかに高い羽化率が観察された場合もあったが，これは日生存率の増加によるのではなく，主として，高温による発育期間の短縮に帰せられた．農薬を散布された水田の捕食性天敵の種類や密度は無散布水田に比べて少なかった．天敵除去区では生存率は顕著に高くなった．フナ等の魚類は，卵，幼虫，いずれにとってもきわめて有効な天敵だと考えられた．また捕食性の水生昆虫の働きもきわめて大きいと思われた．これらの結果にもとづき，農薬がしばしば散布されるにもかかわらずコガタアカイエカの数が夏に急増する過程を分析し，農薬散布が一斉にされないために，広い地域をとれば常に農薬によって天敵の減少した好適な水田があること，すなわち水田の条件の異質性がコガタアカイエカの連続的な増加を可能にしている重要な要因であると結論した．同種の防除に天敵を積極的に利用する可能性について触れた．

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