Sci. Rep. Lab. Amphibian Biol., Hiroshima Univ. 2: 165–185 (1977)

Two-spotted Crickets, *Gryllus bimaculatus* De Geer, as an Excellent Diet for Terrestrial Anurans

By

Midori Nishioka and Ichiro Matsuura*

Laboratory for Amphibian Biology, Faculty of Science, Hiroshima University, Hiroshima, Japan

(With 17 Text-figures)

INTRODUCTION

Until quite recently, it was not an easy task to raise terrestrial anurans from completion of metamorphosis to sexual maturity. Kawamura (1939) reared several pond frogs, *Rana nigromaculata*, produced by artificial parthenogenesis on mosquitos and flies. Mosquito larvae or pupae collected from small ditches were introduced into the containers with metamorphosed frogs. Froglets fed on mosquitos which emerged one after another from the water. In recent years young pond or brown frogs were principally reared on domestic flies cultured in the laboratory, while older ones were reared on bagworms collected from bushes and occasionally given small pieces of liver of cattle or domestic fowl by force-feeding (Kawamura and Nishioka, 1972). Four or five years ago when ant-cows increased eruptively in the neighborhood, they were utilized as the best diet for froglets of some species, such as *Rana japonica*, at the stage soon after metamorphosis. In order to raise froglets, Nace (1968) used birdmosquitos, *Culex pipiens*, greenbottle flies or immature crickets. Adult frogs were alternately given meat flies or greenbottle flies and field crickets. The crickets used by Nace as food for juvenile and adult frogs were *Acheta domestica*. Browder (1968) reported that the diet of his juvenile frogs was changed from *Drosophila* and meal worms to crickets obtained from a cricket farm in Louisiana, as the frogs grew.

Differing from flies, crickets with incomplete metamorphosis can be used as food for both juveniles and adults even of the species in which the froglets immediately after metamorphosis are very small. As a result of search for crickets suitable as diet for frogs, Matsuura, one of the present authors, found that the two-spotted cricket, *Gryllus bimaculatus* De Geer, is the best among the many cricket species reared in his laboratory, including *Acheta domestica*. This is one of the most common gryllids in tropical Asia and Africa (Chopard, 1969). In Japan, crickets of this species are abundantly found in southern islands of the Southwestern Archipelagos, such as Ishigaki-jima, Iriomote-jima and Kikai-shima, while they are not distributed in four main islands of Japan.

* Tokyo Onkyo Co., Audio Lab.

Gryllus bimaculatus is a rather large and stocky cricket. The body is usually black and has two yellow spots at the base of the tegmen after the final molt. MATSUURA ascertained by himself that the crickets of this species are insensible, slow-moving and so robust that they scarcely contract disease and can be reared in high density. Moreover, they breed at all times of the year if kept at about 30°C. On the basis of these characteristics, in 1973 NISHIOKA examined in a medium-sized scale with her staff the adequacy of this species as diet for both juveniles and adults of several anuran species. As the result was good, they re-examined the adequacy in a larger scale the following year, and at the same time devised the simplest method for the mass culture of this species. On the basis of results obtained in 1974, all the metamorphosed frogs and toads, more than 20000 in number, kept in the breeding rooms of the Laboratory for Amphibian Biology, Faculty of Science, Hiroshima University, have been fed on crickets of this species alone since the spring of 1975. It was necessary to carry out some experiments clarifying the reproductive capacity of this cricket species in the laboratory condition, in order to establish the most pertinent plan for raising a definite number of anurans. The results of such experiments are presented in this paper.

MATERIALS AND METHODS

Males and females of *Gryllus bimaculatus* DE GEER were collected by one of the present authors, MATSUURA, from Ishigaki-jima in 1970 (Fig. 1). Their offspring were abundantly produced for generations in MATSUURA's laboratory situated in Tokyo. A part of the offspring were transferred in the autumn of 1972

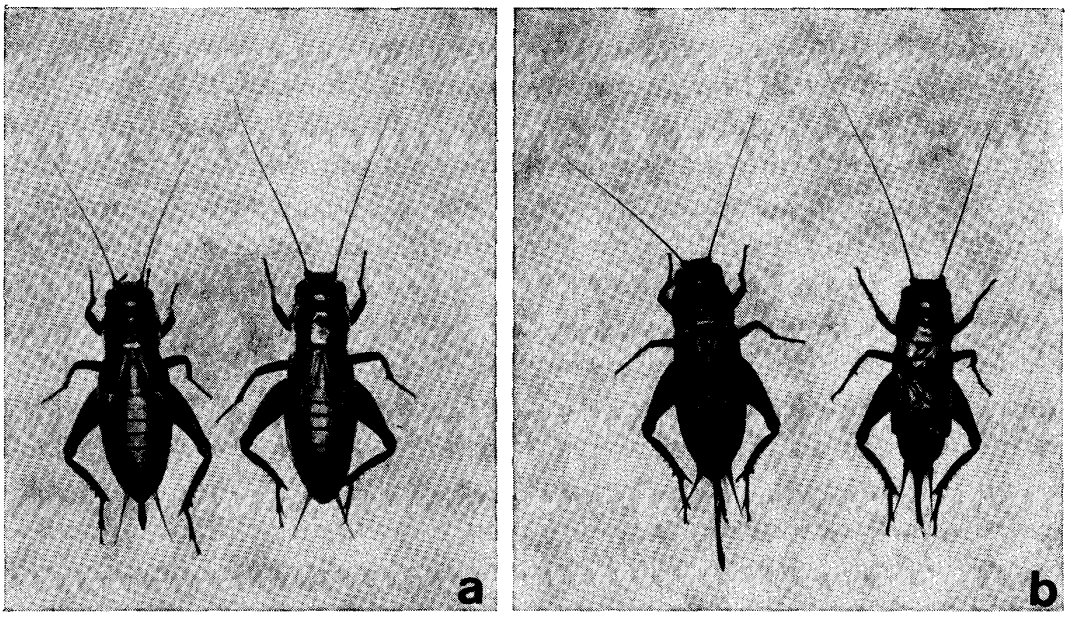

Fig. 1. *Gryllus bimaculatus* DE GEER.
a, Female and male nymphs before the final molt. × 1. b, Female and male adults. × 1.

by KAWAMURA and NISHIOKA to the Laboratory for Amphibian Biology, Hiroshima University. They were increased in number to utilize them as the diet of anurans. Two experiments were carried out in this Laboratory by making use of the crickets.

Cricket rearing cages were colorless, transparent plastic boxes available on the market as vessels for raising small fish (Fig. 2). They were 22 cm long, 17 cm

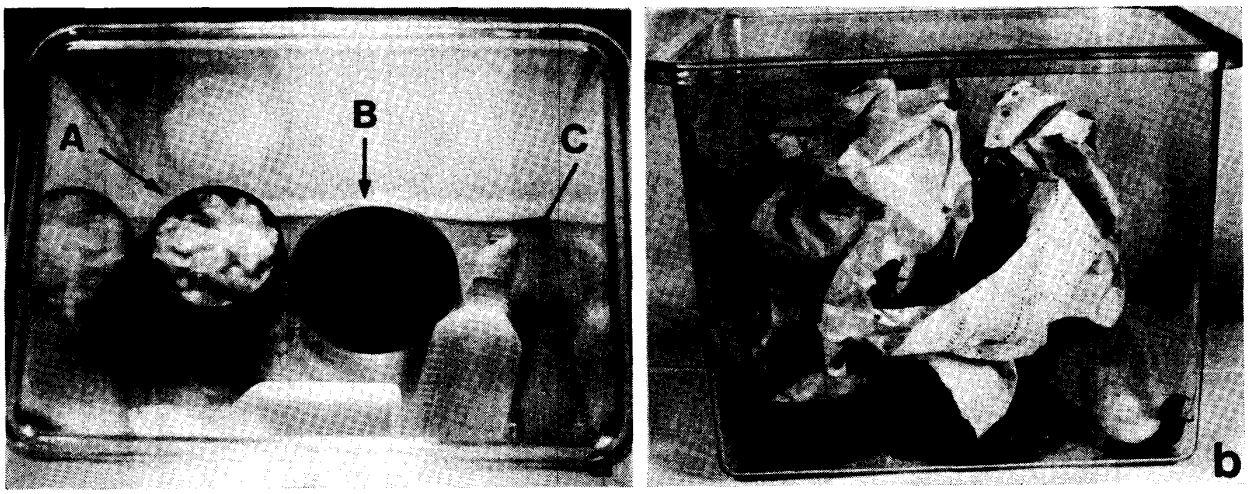

Fig. 2. Cricket rearing cage.

a, Inside equipped with a ovipositing vessel (A), a food dish (B) and a water bottle (C). b, Cage containing 10 pairs of crickets.

wide and 21 cm high. Their inner surfaces were so smooth that crickets could not crawl up. Each cage had a latticed plastic cover. As cricket food, the powdered food R for experimental animals commercially available from Oriental Ferment Industry Co. was used. This powder is said to be the same in component as the solid rabbit food RC4 produced from the same company. Food was spread on a shallow dish, 10 cm in diameter and 0.5 cm in depth, and supplied once or twice a week. The layer of deposits consisting mainly of cricket feces on the food was removed before supplying food. Water was given by a small bottle with a loose stopper of absorbent cotton. Crickets drank water from the cotton stopper. As the water-bottle, a 100 ml plastic vial with flat surfaces was suitable. The water in the bottle was replaced once a week, even if the bottle had some water left.

A small glass vessel packed with absorbent cotton containing a little water was prepared for oviposition of crickets. This ovipositing vessel was 8 cm in diameter and 3 cm in depth. Female crickets laid eggs in the wet cotton. These eggs were exactly counted with a counting machine by loosening the cotton into pieces with a pincette. The eggs laid in the cotton stopper were also counted by the same way. After all the eggs laid in the cotton of the ovipositing vessel and the cotton stopper were counted, they were transferred into a new cricket rearing cage together with the pieces of cotton which were put back in the ovipositing vessel. This rearing cage was loosely covered with a piece of vinyl cloth and

kept in an incubator at 32°C. As either dryness or submersion kills embryos, special attention was paid to maintain at a moderate level the water content of the cotton pieces having the eggs. The piece of vinyl cloth was removed four days after oviposition. The nymphs hatched 7~8 days after oviposition. They were counted after anesthetizing with ether. Fifty nymphs were reared in each cage. The body length of each nymph was measured on alternate days until the final molt. Hardly any difference was found in growth rate among the 50 nymphs.

OBSERVATION

I. Reproductive capacity of two-spotted crickets

1. Experiment 1

Three groups (A, B and C) of nymphs which hatched on October 10th, 23rd and 28th, 1975 were separately put in three large plastic boxes, 52 cm×65 cm×44 cm, and reared until the stage of emergence in a room kept at 24~27°C (Figs. 3, 4). Although each of the three groups consisted of about 5000 nymphs at the start, it gradually deceased in number and became a group of about 1000 adults. The nymphs of group A which hatched on October 10th began to reveal fully differentiated wings on December 14th, 65 days after hatching and became mature adults. Of the latter, 10 females and 10 males were reared in a transparent plastic cage, 22 cm×17 cm×21 cm, at 30±2°C. The nymphs of groups B and C which hatched on October 23rd and 28th began to emerge on December 15th and 28th, 53 and 60 days thereafter, respectively. Ten females and 10 males of groups B and C were reared under the same condition as those of group A. The eggs laid by the females of each group were counted every day. The number of nymphs obtained from among these eggs was counted one week later. The number of eggs per female laid every day after the final molt as well as that of nymphs obtained from these eggs is shown in Fig. 5~7. Actually, it was unclear how many females kept in a cage laid eggs on each day.

a. Group A.

The females of this group began to oviposit on the third day after their fully differentiated wings appeared (Fig. 5). The oviposition continued for 32 days, although there were two breaks on the 11th and the 22nd day after the final molt. During this period a total of 54754 eggs were laid. The number of eggs per female laid every day during the period of the 32 days presented two parabolas before and after the first break of oviposition. The number of eggs per female laid in a day at the peak of the first parabola was 261, while that of the second parabola was 320. Two females died on the 23rd day, that is, the day after the second break of oviposition. Two, two, three and one of the remaining eight females died on the 35th, 36th, 37th and 38th days after the final molt, respectively.

In group A, a total of 42809 nymphs hatched. Their rate to the total of eggs laid by all the females was 78.2 percent. During the period from the fourth to the 31st day after the final molt, more than 72 percent of the eggs laid each day hatched and became nymphs, while 50~56 percent of eggs hatched in the subse-

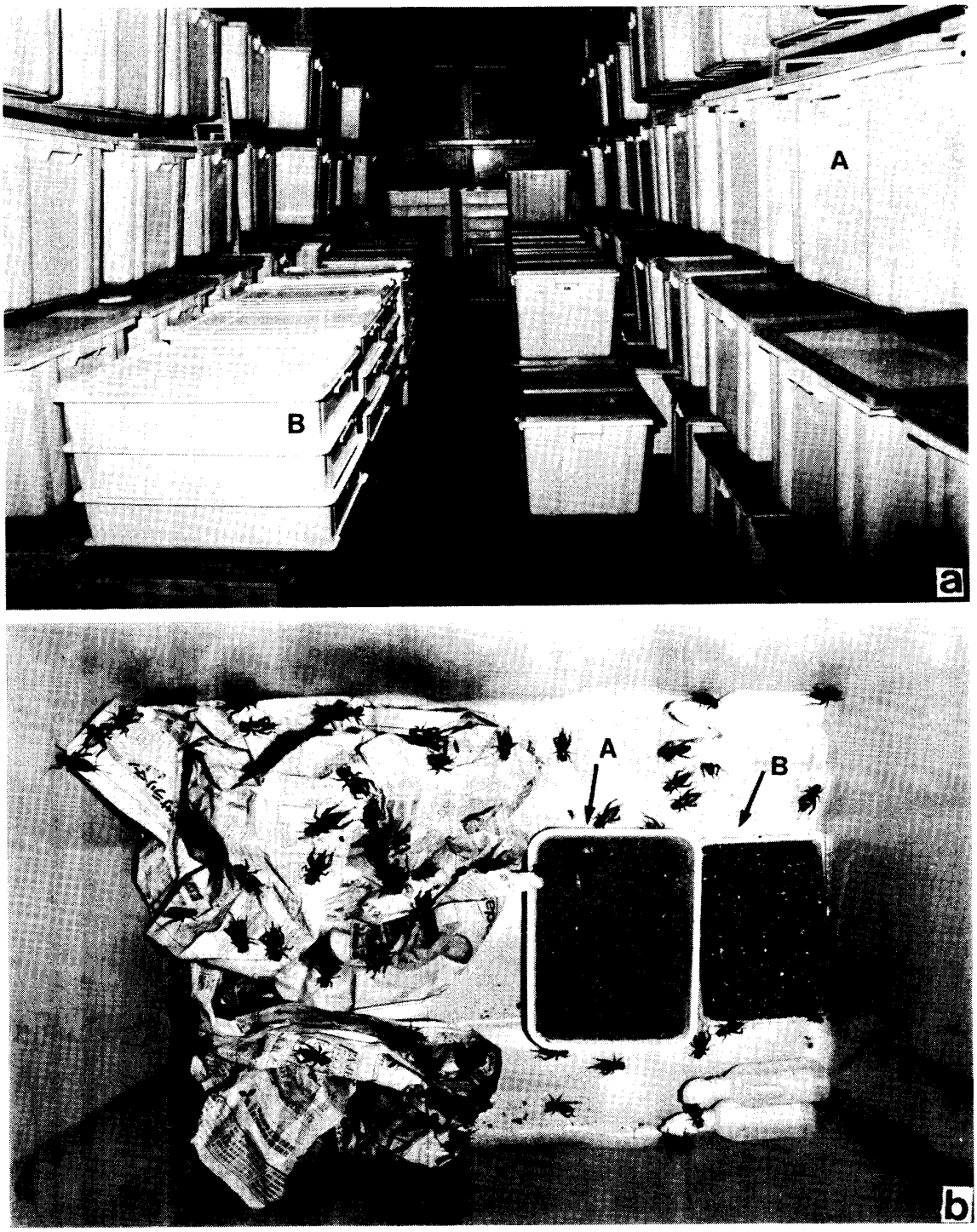

Fig. 3. Mass culture of crickets.

a, Cricket room filled with large deep plastic boxes (A) containing growing crickets and large shallow plastic boxes (B) containing cricket eggs. b, Inside of a large deep plastic box equipped with a food dish (A), a ovipositing dish (B) and water bottles (C).

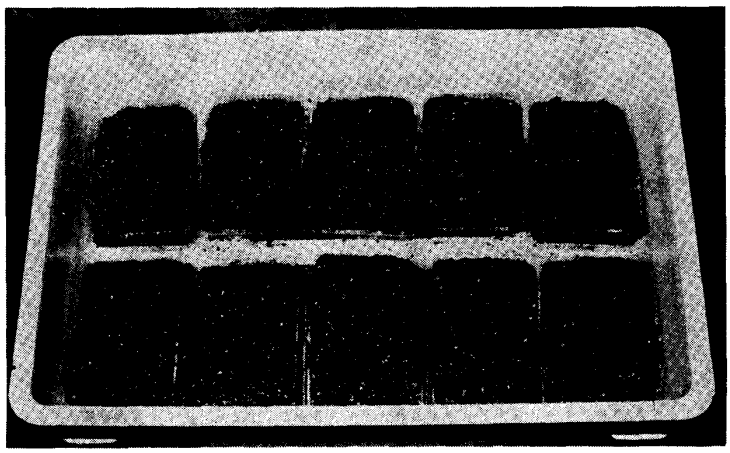

Fig. 4. Inside of a large shallow plastic box. Many dishes filled with vermiculite including innumerable eggs are arranged.

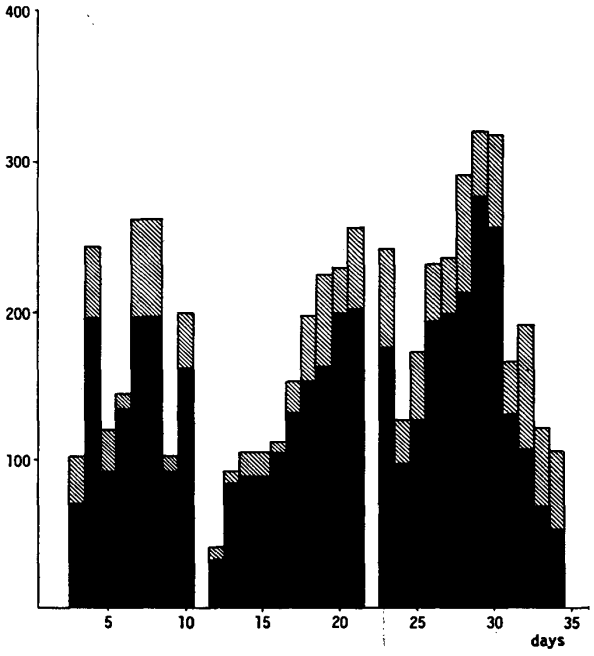

Fig. 5. Numbers of eggs and hatched nymphs (solid bars) per day per female after the final molt in group A.

quent three days. On the first day of oviposition, 68 percent of the eggs hatched.

b. Group B

The females of group B began to lay eggs on the eighth day after the final molt and continued to do for 37 days, although four of the ten females died on the 29th day and the oviposition of the remaining females became intermittent (Fig. 6). The number of eggs laid per female every day during the period of the first 26 days presented a hyperbola. The number of eggs per female laid in a day at the first peak of oviposition was 397, while that at the second peak was 360. Two, two, and two of the remaining eight females died on the 34th, 44th and

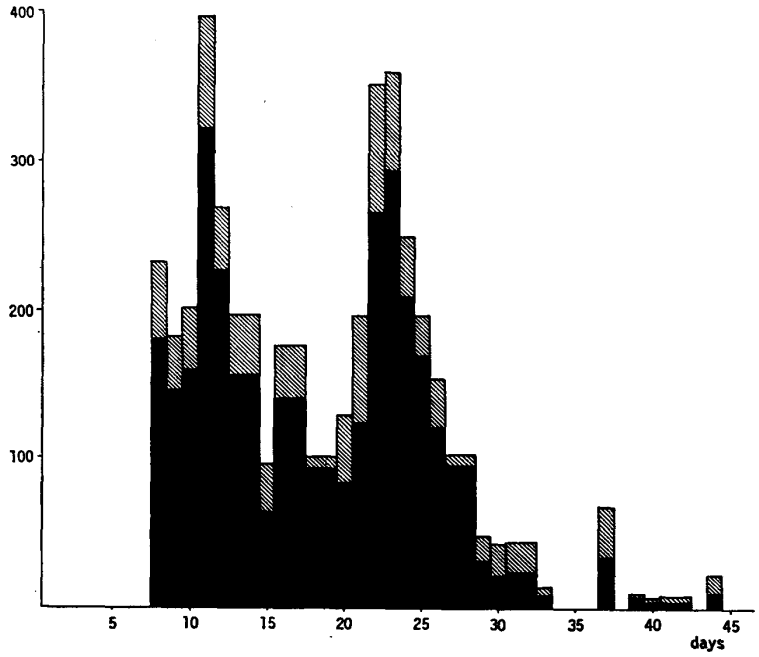

Fig. 6. Numbers of eggs and hatched nymphs per day per female after the final molt in group B.

48th days after the final molt, respectively. The eggs laid by the females of group B were 44942 in total number.

Of the total number of eggs, 35265 (78.5%) hatched and became nymphs. Hatching usually occurred in more than 76 percent of the eggs laid by all the females on each of the first 21 days, except the 15th, 20th and 21st days after the final molt. After this period, hatching usually occurred in 50~54 percent of the eggs laid on each day.

c. Group C

The females of this group began to oviposit on the ninth day after the final molt and continued to do for 41 days. Although there were no breaks of oviposition during the first 34 days from the ninth to the 42nd day, there were four drops about the 11th, 20th, 27th or 28th and 38th days after the final molt (Fig. 7). At these deepest drops, 88~147 eggs per female were laid in a day. At the peaks before the drops, 401, 384, 366 and 257 eggs per female were laid on the 10th, 18th, 25th and 30th days after the final molt, respectively. On the 42nd day, four females died; no oviposition occurred on the next day. After 62 eggs per female were laid on the 44th day, no oviposition occurred on the next two days. Four, two, two and two females died on the 42nd, 46th, 47th and 52nd day, respectively. The eggs laid by the ten females of group C were 75074 in total number.

A total of 57704 nymphs hatched in this group. Their rate to the total number of eggs was 76.9 percent. Hatching usually occurred in more than 70 percent of the eggs laid by all the females on each of the 29 days from the ninth to

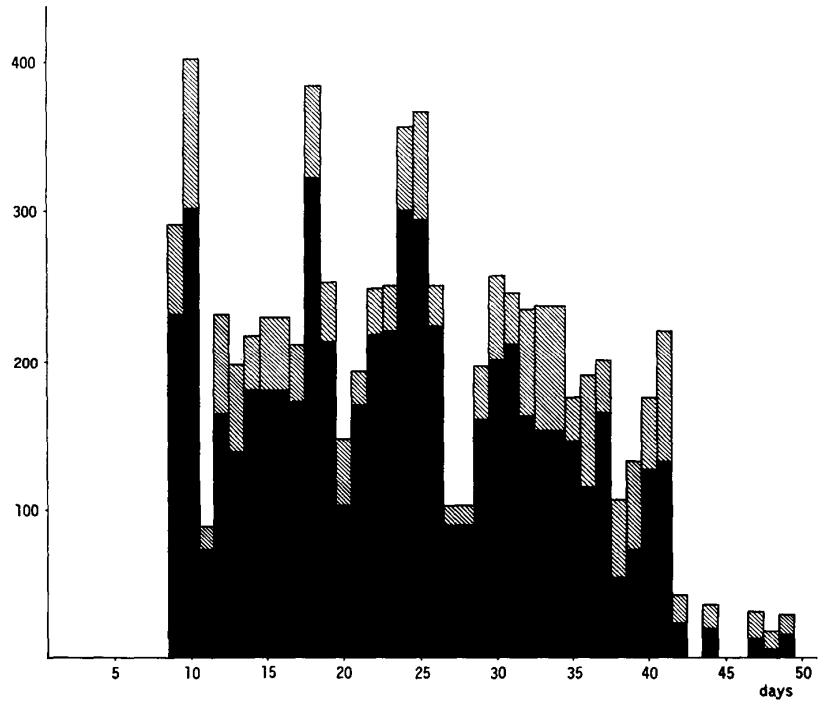

Fig. 7. Numbers of eggs and hatched nymphs per day per female after the final molt in group C.

the 37th day except the 33rd, 34th and 36th after the final molt. After this period, the percentages of nymphs decreased remarkably; 40~55 percent of eggs produced nymphs in seven days, although 72 and 60 percent of eggs did on the 40th and 41st days.

2. Experiment 2

Eggs of the females of group C were utilized in this experiment. Fifty or one hundred nymphs that hatched on the 5th, 6th, 7th, 8th, 9th, 10th, 12th and 13th, January were removed immediately after hatching and raised in plastic boxes, 22 cm × 17 cm × 21 cm, at 30±2°C. Fifty nymphs were kept in each box. The eight groups differing in the date of hatching were designated D, E, F, G, H, I, J and K in the order given. All the nymphs finished the final molt to reveal fully differentiated wings during the period between the 40th and 48th days after hatching.

a. Growth

For the purpose of clarifying the growth rate of nymphs kept in the boxes, the body length of nymphs belonging groups D, E and F was measured. As each of these three groups consisted of 100 nymphs, 50 of them were utilized for the measurements. The remaining 50 nymphs of each of these groups were raised until the adult stage without making measurements, for the purpose of examining their reproductive capacities.

The body length from the anterior end of the head to the posterior end of the abdomen of each nymph was measured every second day during the period of 42

TABLE 1
Body length of nymphs

Age (days)	Group D (mm)	Group E (mm)	Group F (mm)
0	2.54±0.12	2.24±0.11	2.21±0.10
2	3.51±0.19	3.20±0.19	2.75±0.20
4	4.53±0.14	4.23±0.20	3.43±0.18
6	5.44±0.16	4.70±0.21	3.81±0.19
8	6.23±0.13	5.32±0.20	4.47±0.20
10	7.13±0.15	6.22±0.26	5.63±0.21
12	8.02±0.17	7.21±0.28	7.19±0.23
14	10.54±0.17	8.07±0.23	7.94±0.20
16	11.50±0.16	8.76±0.11	8.94±0.25
18	12.89±0.32	11.57±0.24	9.84±0.30
20	13.45±0.42	12.79±0.34	10.64±0.35
22	14.21±0.32	14.49±0.53	11.38±0.34
24	15.66±0.42	16.54±0.57	12.88±0.39
26	16.60±0.38	18.20±0.55	14.25±0.36
28	17.44±0.36	20.82±0.64	16.15±0.41
30	18.82±0.31	21.61±0.62	18.46±0.42
32	19.61±0.37	22.31±0.31	19.83±0.45
34	22.44±0.35	23.50±0.35	22.43±0.36
36	25.25±0.37	25.70±0.30	25.64±0.35
38	27.30±0.61	27.14±0.37	27.50±0.34
40	29.64±0.36	28.14±0.36	29.85±0.37
42	30.79±0.33	30.32±0.46	32.64±0.35

days (Table 1). Although nearly all the 50 nymphs of each group were in good health for the first 28 days or more, some of them afterwards fell ill or died. Accordingly, about 30 healthy nymphs were measured on the 30th day and later. On the 42nd day, only about 10~20 adults were measured, while nymphs which had not yet made the final molt were not measured. The growth curves of the nymphs of groups D, E and F are shown in Fig. 8.

Newly hatched nymphs averaged 2.2~2.5 mm in body length. They were characterized by a pale color of the first and second thoracic segments. Their first molt occurred one day after hatching, while the subsequent three or four molts took place at intervals of two or three days. Since then, it was very difficult to observe their molting except the final molt. The nymphs averaged 5.6 ~7.1 mm, 10.6~13.5 mm, 18.5~21.6 mm and 28.1~29.9 mm in length, when measured 10, 20, 30 and 40 days after hatching, respectively. When they became adults 42 days after hatching, the length was 30.3~32.6 mm on the average.

The three groups of nymphs were somewhat different from one another in growth rate. While the nymphs of groups D and E increased twofold in body length five days after hatching, those of group F did eight days. While the nymphs of group D increased fourfold 14 days after hatching, those of groups E and F did 16 days. The nymphs of groups D, E and F increased eightfold 32, 26 and 29 days after hatching, respectively. They then increased tenfold 36, 32 and 34 days after hatching. The body lengths of the adults of groups D, E and

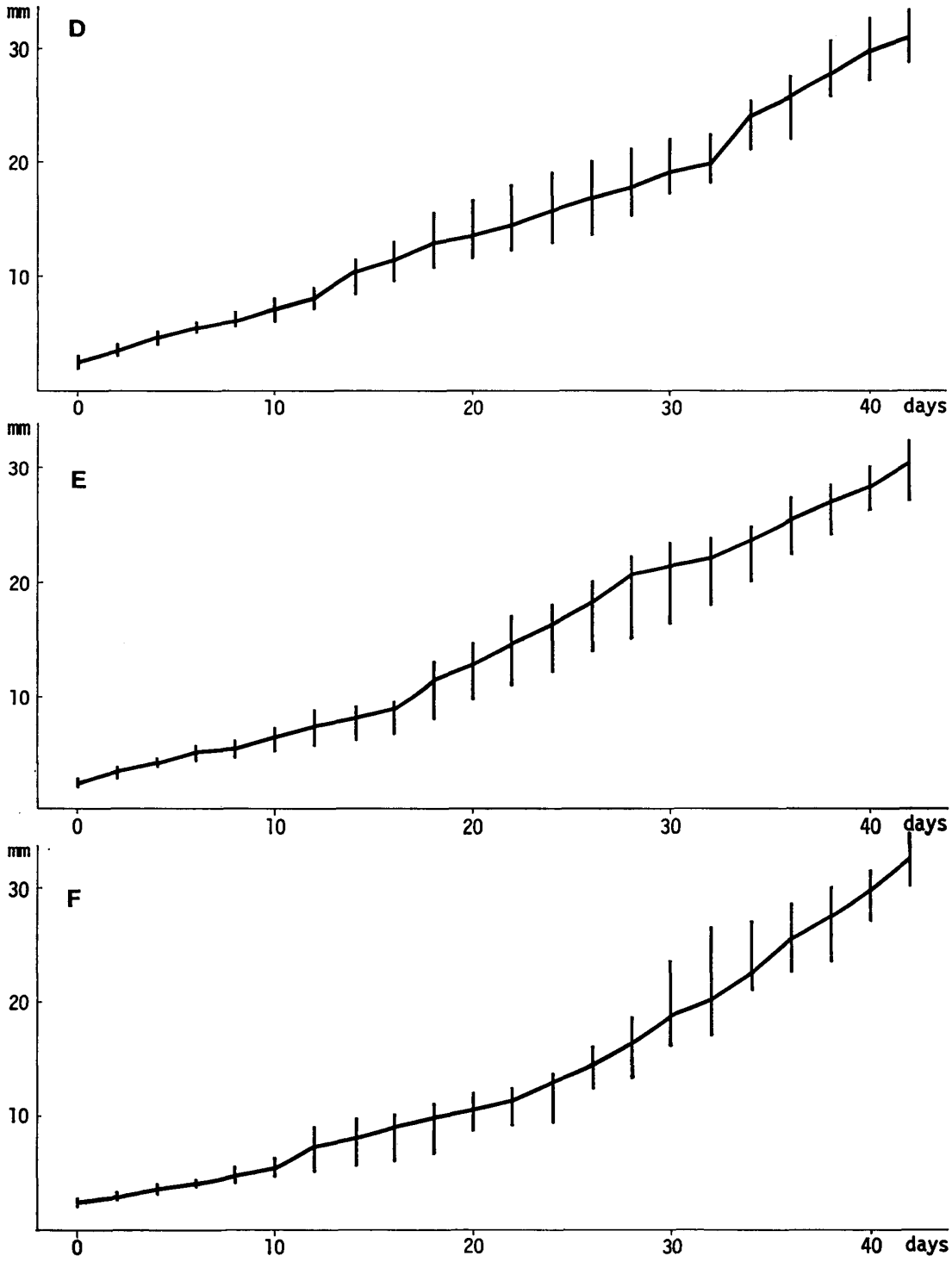

Fig. 8. Growth of nymphs after hatching in each of three groups D, E and F. Range (vertical line) and the mean of body lengths were obtained from 50 nymphs.

F were 12.1, 13.5 and 14.8 times as large as those of newly hatched nymphs, respectively. As all the three groups of nymphs, D, E and F, were derived from group C in experiment 1 and, moreover, they hatched on the 5th, 6th or 7th day, January, they were considered genetically similar to one another. Accord-

ingly, the differences in growth rate as well as in the body size of adults among the three groups seemed to be attributable to differences in rearing conditions.

b. Reproductive capacity

When the nymphs of the eight groups D~K began to make the final molt, 10 females and 10 males of each group were selected from among the adults which molted simultaneously; those of groups D, E, F and H became adults on the 42nd, those of group G on the 45th, those of group J on the 46th and those of groups I and K on the 48th day after hatching. Each group consisting of 10 females and 10 males was kept in a transparent plastic cage, 22 cm × 17 cm × 21 cm, at 27±1°C. The eggs laid by the females of each group were counted every day except legal holidays. One half of the eggs found on the day following a holiday was counted as those laid on that day for convenience' sake. All the eggs were kept at 34°C. At this temperature, nymphs hatched on the 7th day after oviposition without exception. The number of eggs per female laid on each day after the final molt as well as that of nymphs produced from these eggs is shown in Figs. 9~16.

i) Group D

The females of this group began to lay eggs on the sixth day after the final molt and continued to do for 44 days (Fig. 9). The number of eggs per female laid

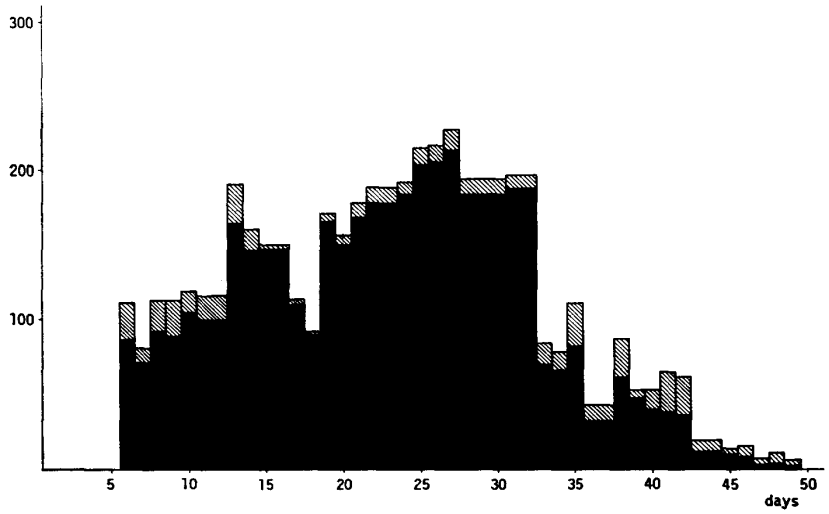

Fig. 9. Numbers of eggs and hatched nymphs per day per female after the final molt in group D.

every day during this period presented roughly a hyperbola with a drop of oviposition. At the first peak of spawning, 191 eggs per female were laid in a day, while 227 eggs per female were at the second peak. At the deepest drop, 92 eggs per female were laid. On the 33rd day and later, the number of eggs per female laid in a day decreased sharply. Two, four, two and two of the ten females died on the 40th, 43rd, 47th and 52nd days after the final molt, respectively. A total of 50829 eggs were laid by the females of group D.

Of the total number of eggs, 45851 (90.2%) hatched and became nymphs.

The rate of nymphs to the number of eggs per female laid in a day was usually more than 86 percent during the 28 days from the seventh to the 34th day after the final molt. After this period, the rates were generally lower, being 47~76 percent with an exception.

ii) Group E

The females started to oviposit on the seventh day after the final molt and continued to do for 45 days, although there were two breaks of oviposition on the 39th and 45th day (Fig. 10). The number of eggs per female laid every day during

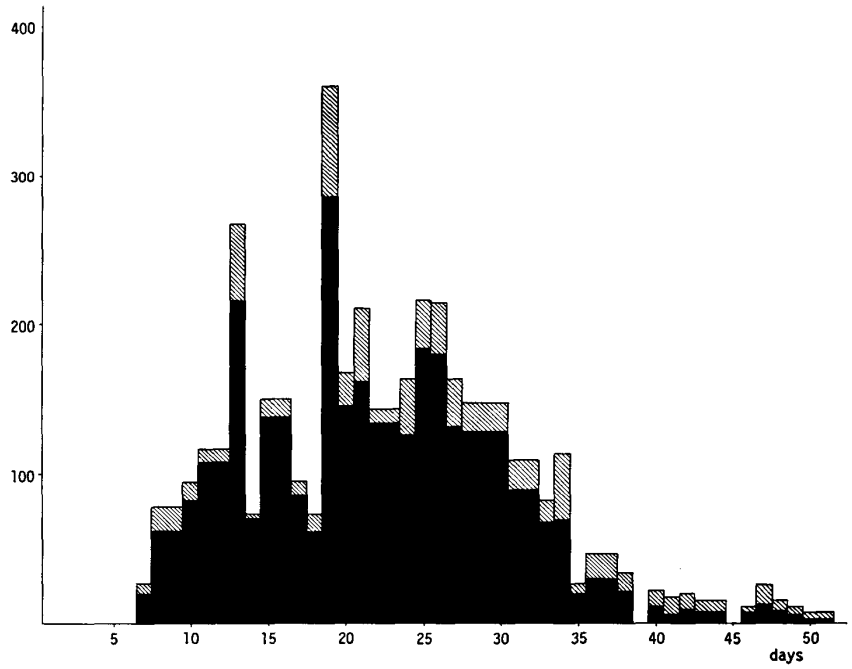

Fig. 10. Numbers of eggs and hatched nymphs per day per female after the final molt in group E.

this period presented a parabola with a peak on the 19th day, when 360 eggs per female were laid. However, there were two deep drops of oviposition before this peak; 71 eggs per female were laid on the 14th and 18th day. At the two breaks of oviposition, five and one of the ten females died. The remaining females died on the 52nd day. A total of 42732 eggs were laid by the females of this group.

Of these eggs, 35314 (82.6%) hatched and became nymphs. Hatching occurred in more than 77 percent of the eggs laid on each of the 26 days from the eighth to the 33rd day after the final molt, while thereafter the rate of nymphs was remarkably low, 50~65 percent in 13 of 16 days. In the remaining three days, it was 69~74 percent.

iii) Group F

Oviposition began to occur on the sixth day after the last molt and continued for 48 days, although there were intervals of four days. The number of eggs per female laid every day during this period presented an irregular parabola having

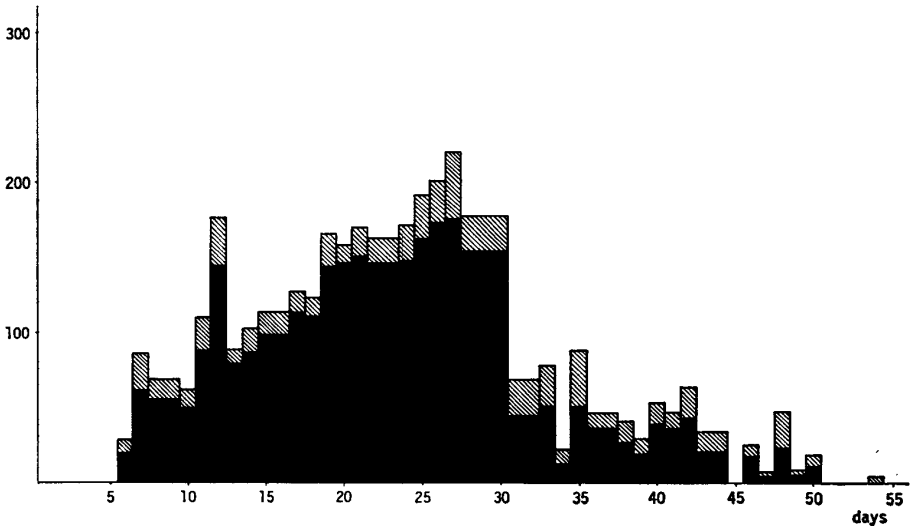

Fig. 11. Numbers of eggs and hatched nymphs per day per female after the final molt in group F.

a peak on the 27th day after the final molt (Fig. 11). At this peak, 219 eggs per female were laid. The number of eggs per female laid in a day decreased sharply on the 31st day and later. Five, four and one of the ten females died on the 45th, 51st and 55th days, respectively. A total of 41800 eggs were laid by the females of group F.

From these eggs, a total of 34359 (82.2%) nymphs hatched. Hatching occurred in more than 80 percent of the eggs laid by the females on each of the 23 days from the eighth to the 30th day after the final molt. Thereafter, the rates of nymphs to eggs decreased remarkably, being 50~70 percent on 15 of 20 days.

iv) Group G

The females of this group started to lay eggs on the fifth day after the final molt. The eggs laid in a day gradually increased and then decreased in number during the period of 33 days from the fifth to the 37th day. After this period, the females oviposited actively again and continued to do for 15 days until the 52nd day at intervals of four days (Fig. 12). During the first period, the number of eggs per female presented a hyperbola; 178 and 180 eggs per female were laid with two peaks being observed on the 18th and 24th day after the final molt, respectively. During the second period, the number of eggs per female presented an irregular parabola with three breaks. As the peak, 204 eggs per female were laid on the 46th day, while no oviposition occurred on the 43rd, 47th, 50th and 51st day. On these days most of the females died; two, three and two females died on the 43rd, 47th and 50th days. The remaining three died on the 53rd day after the final molt. A total of 45715 eggs were laid by the females of group G.

Of these eggs, 33853 (74.1%) hatched and became nymphs. Hatching always occurred in more than 74 percent of the eggs laid by the females on each

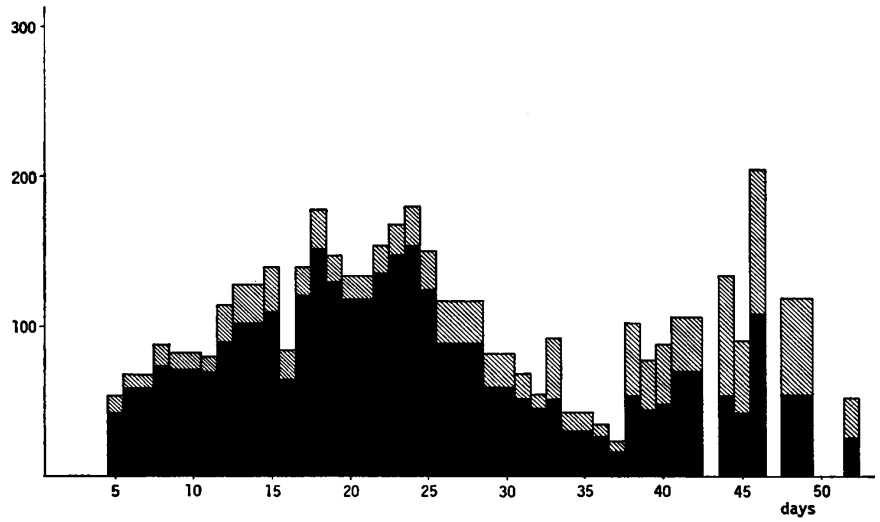

Fig. 12. Numbers of eggs and hatched nymphs per day per female after the final molt in group G.

day of the first period, except the 33rd day. Differing from this, it occurred in 42~55 percent of the eggs during the second period, except the 41st and 42nd day.

v) Group H

Oviposition began to occur on the sixth day after the final molt and continued for 43 days without breaks. The number of eggs per female laid during this period presented an irregular parabola (Fig. 13). As the peak, 268 eggs per female were laid on the 22nd day. Four, one, three and two of the ten females died on the 28th, 43rd, 47th and 49th days, respectively. A total of 42495 eggs were laid by the females of group H.

A total of 35421 (83.4%) nymphs hatched in this group. Hatching always

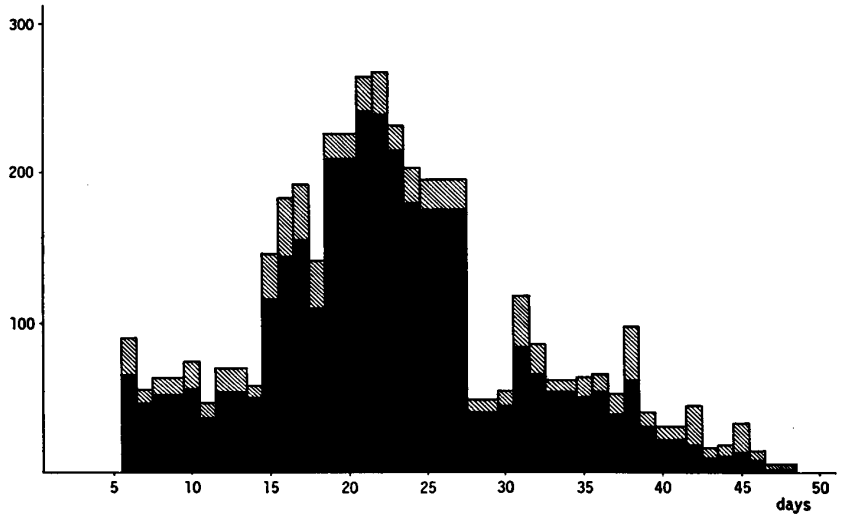

Fig. 13. Numbers of eggs and hatched nymphs per day per female after the final molt in group H.

occurred in more than 71 percent of the eggs laid on each of the 36 days from the sixth to the 41st after the final molt, except the 38th day when 63 percent of eggs hatched. In the subsequent seven days, hatching always occurred in 40~60 percent of the eggs laid on each day.

vi) Group I

The females of this group started to oviposit on the third day after the final molt and continued to do for 43 days, although there were three intervals without oviposition during the last several days (Fig. 14). The number of eggs per female

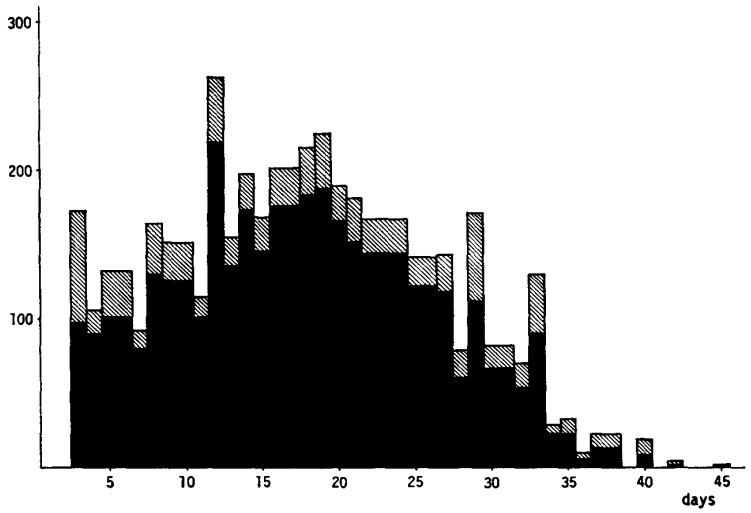

Fig. 14. Numbers of eggs and hatched nymphs per day per female after the final molt in group I.

laid every day presented roughly a parabola. As the peak of this parabola, 225 eggs per female were laid on the 19th day. While 263 eggs per female were laid on the twelfth day as the largest oviposition, this number did not appear as the peak, since the number of eggs per female laid on the previous day was 116. Four, four, one and one of the ten females of this group died on the 34th, 39th, 41st and 48th day after the final molt. On the latter three days, no oviposition occurred. A total of 49013 eggs were laid by the females of group I.

Of these eggs, 40085 (81.8%) hatched and became nymphs. Hatching usually occurred in more than 70 percent of the eggs laid in each day during the period from the fourth to the 36th day, except the 29th and 36th day when about 65 percent of eggs hatched. After this period, 31~58 percent of the eggs laid in a day became nymphs. On the third day when oviposition began, 57 percent of eggs hatched.

vii) Group J

The females of group J began to oviposit on the fourth day after the final molt and continued to do for 55 days. During this period, the number of eggs per female laid every day roughly presented a low parabola with three distinct drops about the 26th, 30th and 39th days (Fig. 15). The largest number of eggs, 172

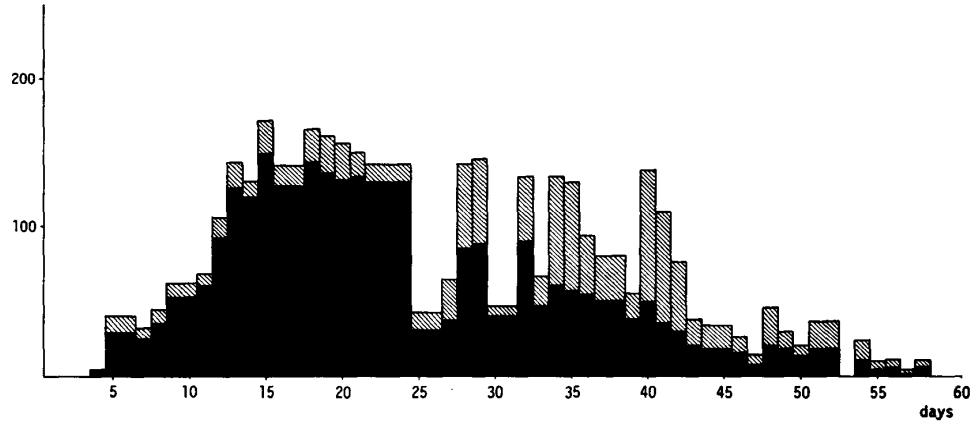

Fig. 15. Numbers of eggs and hatched nymphs per day per female after the final molt in group J.

per female, were laid on the 15th day. At the three drops, 42, 46 and 54 eggs per female were laid. Two, two, one, two, one and two of the ten females of this group died on the 43rd, 53rd, 57th, 58th, 59th and 61st day, respectively. On the 53rd day, no oviposition occurred. A total of 42373 eggs were laid by the ten females of this group.

A total of 30881 (72.9%) nymphs hatched from the above eggs laid during the 55 days from the fourth to the 58th after the final molt. While the rate of nymphs to the eggs laid in a day was more than 73 percent on each of the 23 days from the fourth to the 26th, it was generally low, that is, 31~67 percent on each of the subsequent 31 days, except four days when 69~87 percent hatched.

viii) Group K

The females of this group laid the most numerous eggs during the longest period among those of the eleven groups. They began to oviposit on the fifth day after the final molt and continued to do so for 66 days with an interruption on the 69th day, although there were several drops in oviposition (Fig. 16). The number of eggs per female laid every day during this period presented an irregular parabola. As the peak of oviposition, 216 eggs per female were laid on the 16th day. Although 274 eggs were laid on the 25th day, this number did not appear to be the peak, since only 37 eggs were laid on the previous day. The number of eggs per female laid thereafter presented nearly a plateau until the 58th day, and then decreased remarkably. Two, four, two and two of the ten females of this group died on the 60th, 65th, 69th and 72nd day, respectively. A total of 77807 eggs were laid by the ten females of group K.

Of these eggs, 61921 (79.6%) hatched and became nymphs. Hatching always occurred in more than 74 percent of the eggs laid on each of the 40 days from the fifth to the 44th after the final molt. During the subsequent 20 days from the 45th to the 64th day, 61~72 percent of the eggs laid in a day hatched, with an exception of 74 percent on the 64th day. In the last five days from the 65th to the 70th, only 48~55 percent of the eggs hatched.

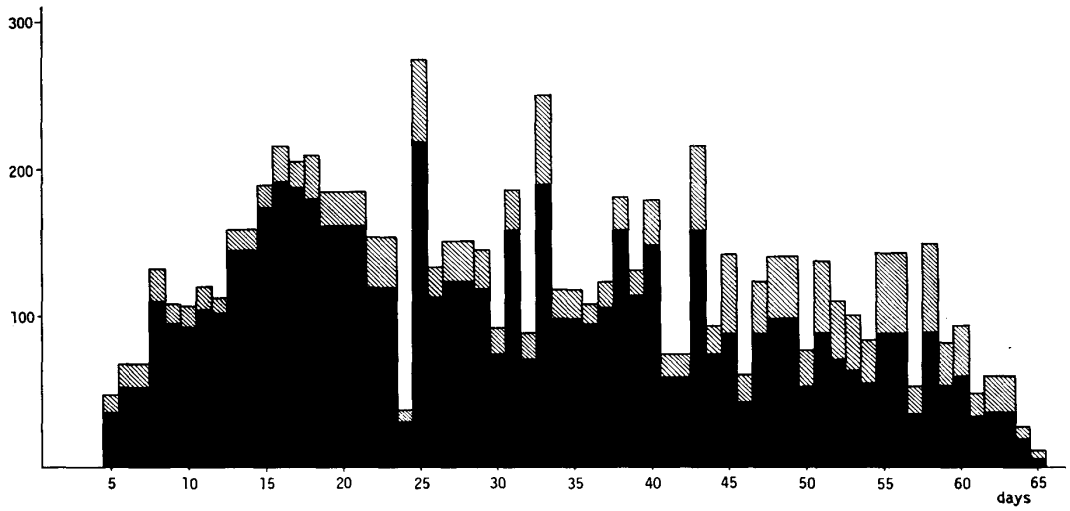

Fig. 16. Numbers of eggs and hatched nymphs per day per female after the final molt in group K.

II. Growth rates of different anurans fed on two-spotted crickets

Since the spring of 1975, all the frogs and toads kept in the Laboratory for

TABLE 2

Increase of the body length in each of 22 anuran species including 2 subspecies

Species	Time after metamorphosis			
	Immediately (mm)	3 months (mm)	6 months (mm)	One year (mm)
Rana nigromaculata	22.3	40.8	53.4	62.2
Rana brevipoda	18.5	35.1	47.6	51.4
Rana plancyi chosenica	17.8		37.6	47.5
Rana plancyi fukienensis	18.2		48.2	56.2
Rana lessonae	17.0			52.3
Rana ridibunda	16.7			57.4
Rana esculenta	17.5			64.2
Rana japonica	17.1	25.7	34.9	40.1
Rana ornativentris	17.8		46.2	56.9
Rana chensinensis	16.5		52.5	63.5
Rana dybowskii	16.5		50.5	58.3
Rana arvalis	17.2		42.1	50.0
Rana temporaria	16.7			65.8
Rana tagoi	6.0			31.5
Rana rugosa	19.0	35.2	46.7	48.2
Rana limnocharis	16.2			54.3
Bufo bufo bufo	13.4	71.4	82.5	100.1
Bufo bufo japonicus	9.2	85.2	100.3	125.4
Bufo americanus	8.7			100.5
Hyla arborea japonica	17.2	34.2	42.1	43.6
Microhyla ornata	7.4	25.2	29.1	30.5
Rhacophorus schlegelii	16.4	31.2	47.5	54.4
Rhacophorus arboreus	16.7		50.1	55.2
Bombina orientalis	16.5	30.2	45.9	49.2

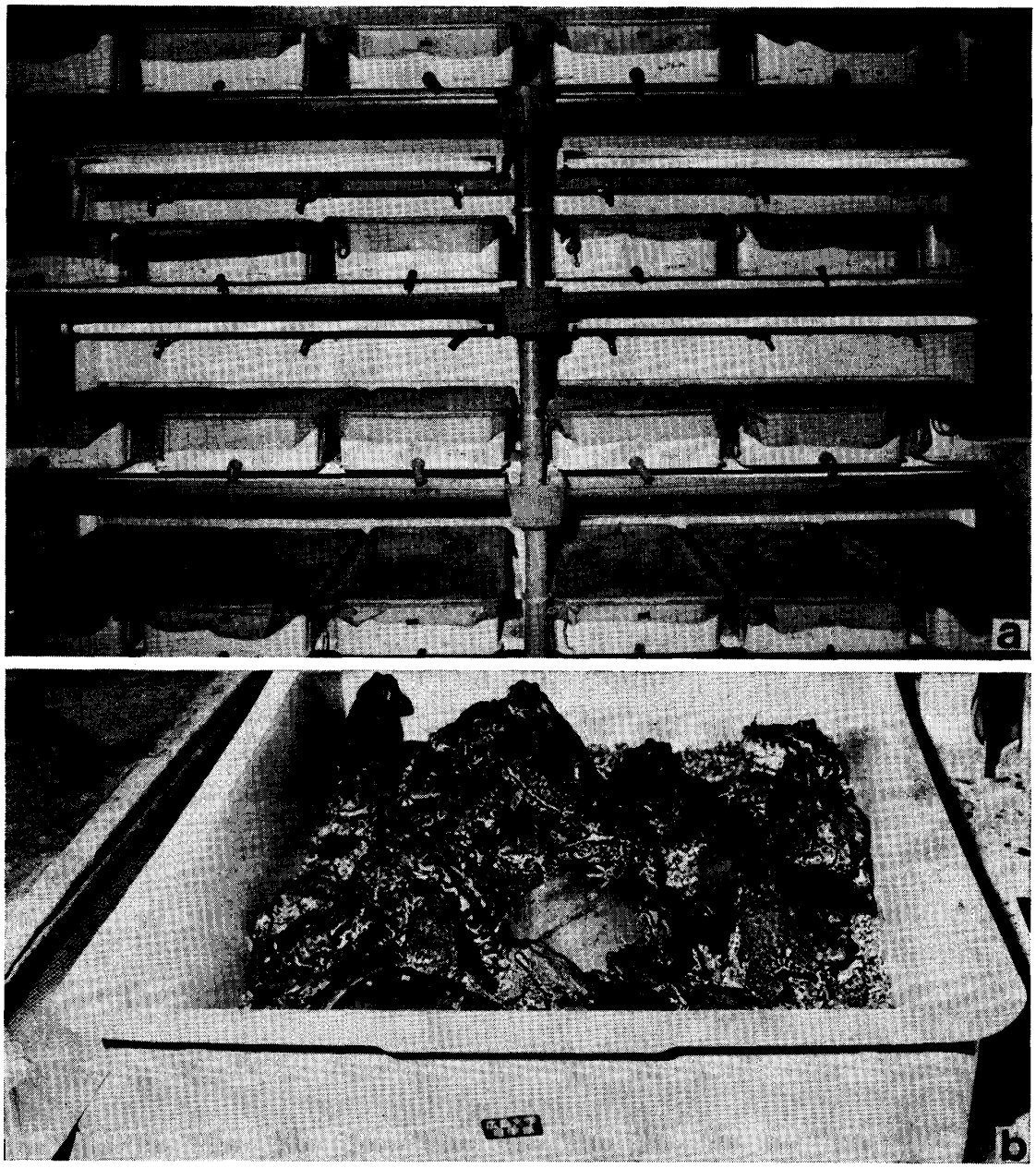

Fig. 17. Part of a rearing room for amphibians.
a. Rack of containers. b. Toad container.

Amphibian Biology have been fed on two-spotted crickets, *Gryllus bimaculatus*, alone after their metamorphosis. During the tadpole stage, they were given with soft vegetables, such as Japanese common kind of spinach (*Spinacia oleracea* L.) or leaf-beet (*Beta vulgaris* var. *cicla* L.), after thorough boiling. Though BERNS (1965) has reported that death is caused by kidney stones in spinach-fed frogs, Japanese spinach does not have such a harmful effect on various kinds of anurans including *Rana pipiens*.

Crickets have been found to be much more suitable as nutrition for promoting the growth of frogs and toads than mosquitos and flies or bag-worms. Although the number of crickets raised in the Laboratory was not always enough

to satisfy the needs of the anurans kept there, the latter grew very rapidly (Fig. 17). In order to show how rapidly they grew by feeding on crickets, the growth rates of some anuran species are presented in Table 2. They were kept at a high density and not provided the food for many days, owing to shortage of crickets. There is no doubt that they would grow more rapidly, if they were reared in the best condition.

DISCUSSION

The results obtained from experiments 1 and 2 on the reproductive capacity of two-spotted crickets are summarized in Table 3. Oviposition in each of the eleven groups (A~K) began to occur 3~9 days, 5.6 on the average, after the final molt, and continued for 32~66 days, 45.6 on the average. The number of eggs per female laid every day during the ovipositing period in each group presented roughly a parabola or hyperbola. The eggs laid by ten females in each group were 41800~77807, 51594 on the average, in total number. In groups C and K, they were uncommonly large in number, that is, 75074 and 77807; 7644 eggs per female were laid in these two groups. In the other nine groups, 41800 ~54754 eggs were laid by ten females of each group, that is, 4607 eggs per female in these groups. Of the eggs laid in each of the eleven groups, 72.9~90.2%, 79.9% on the average, hatched about seven days after oviposition at 32°C. The percentage of nymphs to the eggs became remarkably lower toward the end of oviposition. Newly hatched nymphs became adults 40~48 days after hatching at 30±2°C. While nymphs were about 2.2~2.5 mm in body length at first, adults

TABLE 3

Summary of the results obtained from experiments 1 and 2
The most prolific period in each group is presented by the duration in which more than 80 nymphs per day per female were almost continuously produced.

Group	Period from final molt to oviposition (days)	Duration of oviposition (days)	Total number of eggs	The largest number of eggs per day per female	Hatched nymphs		Most prolific period
					Total number	Per-centage	
A	3	32	54754	320	42809	78.2	4~32 (29)
B	8	37	44942	397	35265	78.5	8~28 (21)
C	9	41	75074	401	57704	76.9	9~41 (33)
D	6	44	50829	227	45851	90.2	6~35 (30)
E	7	45	42732	360	35314	82.6	10~32 (23)
F	6	48	41800	219	34359	82.2	11~30 (20)
G	5	48	45715	204	33853	74.1	12~28 (17)
H	6	43	42495	268	35421	83.4	15~27 (13)
I	3	43	49013	263	40085	81.8	3~29 (27)
J	4	55	42373	172	30881	72.9	12~32 (21)
K	5	66	77807	274	61921	79.6	8~58 (51)
Mean	5.6	45.6	51594.0	282.3	41223.9	79.9	(25.9)

Parentheses present the number of days.

were about 30.3～32.6 mm. Although nymphs were in good health for about 28 days after hatching, some of them afterwards became ill or died. The period during which more than 80 nymphs per female were almost continuously produced every day in each group (Figs. 5～7, 9～16) is presented in the right column of Table 3. This period was 13～51 days, 25.9 on the average; it began 3～15 days, 8.9 on the average, and finished 27～58 days, 33.8 on the average, after the final molt. Accordingly, for the purpose of increasing crickets most efficiently, it seems preferable that male and female adults are prepared to oviposit 3 days after the final molt and allowed to do so for about one month. After this period, active oviposition does not seem to occur in most cases. However, this period may be substantially prolonged by obtaining more prolific adults. The excellent production in groups C and K seems to indicate the possibility of such improvement.

NACE (1968) has stated that froglets of some species, such as *Rana sylvatica* eschew flying insects and prefer immature crickets. Adult frogs were given flies and crickets alternately. However, as vitamin deficiency was found in these diets, the latter were given after dusted with a powdered preparation containing 10 vitamins and some other elements. The crickets, *Acheta domestica,* utilized as diet at the Amphibian Facility of the University of Michigan were mostly obtained commercially. Recently, GRUSCHOW (1976) described a raising method of this cricket species. This is identical in principle with that in this laboratory. As diet for froglets of *Megophrys nasuta,* SCHMIDT (1976) gave *Gryllus bimaculatus* and *Acheta domestica* alternately. These crickets were dusted with a powdered preparation containing vitamins, minerals and calcium in order to prevent the appearance of rickets.

As previously stated, all the terrestrial anurans kept in the Laboratory for Amphibian Biology, Hiroshima University, more than 20000 in number, feed on two-spotted crickets, *Gryllus bimaculatus,* alone. In spite of this single diet, all species grow rapidly and acquire the normal reproductive capacity. They have not revealed any definite defects in development nor abnormalities in reproduction, though the crickets were never dusted with a powdered preparation containing vitamins. No anuran species kept in the rearing rooms of the Laboratory have hitherto suffered from rickets, as they are illuminated with a fluorescent light. The authors believe that *Gryllus bimaculatus* is the best diet for most terrestrial anurans.

In this place, the authors want to make an additional remark that this cricket species is also suitable as diet for most kinds of terrestrial urodelans on the basis of their recent test done at the Laboratory for Amphibian Biology. Although the newts and salamanders reared on worms of Tubificidae by KAWAMURA (1950, 1953) attained sexual maturity, their growth after metamorphosis was not good. Differing from these urodelans fed on tubificids, the following three species made a strikingly rapid growth by feeding on crickets after their metamorphosis; *Hynobius nebulosus, H. dunni* and *Tylototriton andersoni* attained lengths of 118, 127 and 92.5 mm, respectively, just one year after insemination of the eggs.

SUMMARY

1. The reproductive capacity of two-spotted cricket, *Gryllus bimaculatus* DE GEER, was examined in order to utilize this species most effectively as a diet of terrestrial anurans.

2. Oviposition began to occur 3~9 days after the final molt and continues for 32~66 days in 11 groups each of which consisted of 10 females and 10 males. Ten females laid 51594 eggs on the average in total. Of these eggs, 79.9 percent on the average hatched about 7 days after oviposition at 32°C. Newly hatched nymphs became adults 40~48 days after hatching at 30±2°C. The former were about 2.2~2.5 mm in body length, while the latter were 30.3~32.6 mm.

3. For the purpose of increasing crickets most efficiently, it seems preferable that adults be prepared to oviposit 3 days after the final molt and be allowed to lay eggs for about one month.

4. Froglets of various anuran species fed on two-spotted crickets alone grew rapidly and acquired the normal reproductive capacity.

ACKNOWLEDGMENTS

The authors are especially indebted to Emeritus Professor Toshijiro KAWAMURA for his encouragement and guidance during the course of this work and his critical reading of the manuscript. This work was supported by grants from the Scientific Research Fund of Ministry of Education, Science and Culture.

LITERATURE

BERNS, M. W. 1965. Mortality caused by kidney stones in spinach-fed frogs (*Rana pipiens*). BioScience **15**(4): 297–298.

BROWDER, L. W. 1968. Pigmentation in *Rana pipiens*. I. Inheritance of the speckle mutation. J. Heredity, **59**: 163–166.

CHOPARD, L. 1969. Grylloidea. The fauna of India and the adjacent countries, edited by R. B. SEYMOUR SEWELL,, Orthoptera, Vol. 2, issued by the Zool. Survey of India, Calcutta.

GRUSCHOW, J. 1976. To raise crickets, *Acheta domestica*. A pamphlet issued from Amphibian Facil. of U. M. 1~4.

KAWAMURA, T. 1939. Artificial parthenogenesis in the frog. II. The sex of parthenogenetic frogs. J. Sci. Hiroshima Univ., Ser. B, Div. 1, **7**: 39–86.

KAWAMURA, T. 1950. Studies on hybridization in amphibians. III. Reciprocal hybrids between *Triturus pyrrhogaster* (BOIE) and *Triturus ensicauda* (HALLOWELL). J. Sci. Hiroshima Univ., Ser. B, Div. 1, **11**: 71–79.

KAWAMURA, T. 1953. Studies on hybridization in amphibians. V. Physiological isolation among four *Hynobius* species. J. Sci. Hiroshima Univ., Ser. B, Div. 1, **14**: 73–116.

KAWAMURA, T. and M. NISHIOKA 1972. Viability and abnormalities of the offspring of nucleo-cytoplasmic hybrids between *Rana japonica* and *Rana ornativentris*. Sci. Rep. Lab. Amphibian Biol., Hiroshima Univ., **1**: 95–209.

NACE, G. W. 1968. The Amphibian Facility of the University of Michigan. BioScience **18**: 767–775.

SCHMIDT, A. A. 1976. Erst-Nachzucht des Zipfelfroshes *Megophrys nasuta* (Amphibia, Salientia, Pelobatidae). Salamandra **12**(2): 55–68.