

Model for Use in Mass-Production of *Acheta domesticus* (Orthoptera: Gryllidae) as Food

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ABSTRACT A production model was developed that simulates the harvest of a predetermined number of eggs of house cricket, *Acheta domesticus* (L.), per day by regulating the numbers and ages of adults in the breeding colony. With a discard age of 24 d, the production model predicted a sustainable harvest of $\approx 4,000$ (4,440) and 6,000 (6,660) crickets per day when four or six pairs, respectively, of newly emerged adults were added per day to an initial breeding colony of 50 pairs. Natalivity was based on the number of nymphs surviving to 7 d per surviving female, after which little nymphal mortality occurred. Ovipositional surface area availability was not a limiting factor in egg production.

KEY WORDS *Acheta domesticus*, human food, mass-production

THE HOUSE CRICKET, *Acheta domesticus* (L.), is a cosmopolitan, omnivorous insect that is easily reared under confined conditions (Patton 1978). Previous research (Jordan & Baker 1956; Patton 1963, 1967; Polt 1971; Clifford et al. 1977; McFarlane 1985; Parajulee & DeFoliart 1993) described the rearing methods and emphasized the widespread use and suitability of house crickets for laboratory studies. In the United States and Canada it is widely used as fish bait and for maintaining insectivorous vertebrates in captivity. Finke et al. (1989) found that the house cricket is of high protein quality and slightly superior to soy protein at all levels of feeding when fed to weanling rats, and Nakagaki et al. (1987) found that dried house crickets are a source of high quality protein for broiler chicks. The cricket is recommended by Taylor & Carter (1976) as an ingredient in gourmet recipes. Nakagaki & DeFoliart (1991) have shown the cricket to be competitive compared with other livestock on the basis of food conversion efficiency. Because of its palatability, protein quality, and high food conversion efficiency, the cricket is a promising candidate for wider promotion as food and animal feed (DeFoliart 1989).

We designed a mass-rearing system which involves a breeding colony and 32 rearing units, each unit providing enough space (50 by 44 by 20.5 cm) to rear $\approx 6,000$ crickets to harvestable size (eighth instar). One cage is seeded each day with enough eggs to allow for mortality, and the 6,000-cricket cohort is harvested 32 d later. Following harvest, each cage is reseeded (one cage per day) with 9-d-old eggs (ready to hatch) from the breeding colony. Thus, 6,000 crickets per day

are harvested on a continuing basis. The system is expandable depending upon the daily production desired.

Previously, it has been difficult to determine proper number of eggs to seed per cage without sorting and counting thousands of eggs from the oviposition medium each day. The two objectives of our study were to (1) develop and test a production model based on age-specific natalivity and cumulative net maternity of crickets that would accurately predict the number and ages of crickets needed in the breeding colony to produce the desired number of eggs per day, and (2) to determine whether the area of ovipositional surface available was limiting to daily egg production.

Materials and Methods

Developing the Production Model. To determine cricket natalivity and cumulative net maternity, we used net reproductive rate (R_0) as defined as $\sum_x l_x m_x$ (Andrewartha & Birch 1954), where survivorship (l_x) is the probability of an individual female attaining age x (days) and natalivity (m_x) is the number of female nymphs produced by a female between ages $x-1$ and x . We define cumulative net maternity as $2(R_0)$ to include male offspring.

Three simultaneous replicates of 50 pairs of newly emerged adult crickets were confined in glass terraria (50 by 30 by 26 cm) covered with a perforated aluminium lid to prevent crickets from escaping. We started the experiments with 50 pairs because of aberrations in cricket behavior at low population densities (McFarlane

1962). The crickets were fed the Animal Nutrition Research Council Reference Chick diet (National Research Council 1977) for broiler-type chicks, modified by the addition of 0.5% NaCl and 3% fish protein (McFarlane 1964). Observations were made daily to determine survival of females and to remove dead crickets. Feed and water were provided ad libitum. The feed was provided in a petri dish at one end of the terrarium. Fresh tap water was supplied to the breeding colony using a standard chick watering device consisting of a 0.9-liter glass jar with a screw-on plastic pan base. Aluminum screening under the water outlet prevented the crickets from crawling into the opening and drowning. The water bottles were emptied, washed, and refilled every 3 d to prevent crickets from drinking fouled water. Three pieces of cardboard chicken egg cartons (30 by 15 cm) were placed in each terrarium to provide resting and hiding surfaces for the crickets.

Petri dishes (15 cm diameter) were used as egg trays and filled with moistened peat moss as an ovipositional substrate. For 45 d, individual egg trays were exposed to the crickets for 24 h-periods, allowing for oviposition. The trays were then removed, covered with a lid, and incubated at $34 \pm 2^\circ\text{C}$ (Roe et al. 1980). Just before egg hatch, the trays were placed in vented plastic storage boxes (34 by 21 by 9 cm) to rear the nymphs. Condensed water on the undersurface of the lid was removed by paper towels to prevent drowning of newly eclosed nymphs. After the eggs hatched (incubation period of 9 d at $34 \pm 2^\circ\text{C}$), the lid was removed from the egg tray and food and water were provided for the newly eclosed nymphs. A cotton dental wick (1 by 5 cm) was inserted into a vial containing water and laid on its side on the storage box floor to provide water for the nymphs. One or two folded paper towels were provided in each storage box to increase surface area and facilitate cricket molting. Finely ground feed was sprinkled over the paper towels. Nymphs were reared for 7 d, then killed by freezing and counted. Patton (1978) determined that at $32 \pm 1^\circ\text{C}$, *A. domesticus* molts occur at ≈ 3 -d intervals, thus at $34 \pm 2^\circ\text{C}$, most of our nymphs were in the third instar when killed for counting. Clifford et al. (1977) found that most *A. domesticus* mortality occurs in the first and second instars with essentially 100% survival thereafter; thus, the number of crickets surviving to 7 d should closely approximate the total number of crickets surviving to harvest. Our fecundity model, then, is based on the number of nymphs surviving to the seventh day.

The life-history statistics, such as net reproductive rate and cumulative net maternity, were calculated from the age-specific life-table analysis. These life-history statistics were then used to examine the dynamics of production for the addition of either 4 or 6 pairs of newly emerged

adults per day in an initial breeding colony of 50 pairs.

Testing the Production Model. The initial breeding colony consisted of 50 pairs of newly emerged adult crickets confined in an aluminum cage (50 by 44 by 20.5 cm), to which four pairs of newly emerged adults were added daily (hereinafter referred to as a four-pair colony). Petri dishes (15 cm diameter) were used as egg trays and moistened peat moss was provided as an ovipositional substrate as described above. For 50 d, individual egg trays were exposed to the breeding colony for a 24-h period, allowing for oviposition, then removed and incubated at $34 \pm 2^\circ\text{C}$ under continuous light. The egg trays were placed in vented storage boxes and nymphs were reared, killed, and counted as described previously.

In a second experiment under the conditions and procedures just described, six pairs of newly emerged adults were added daily to an initial breeding colony of 50 pairs (hereinafter referred to as a six-pair colony). Eggs were harvested and nymphs reared for 7 d, then killed by freezing and counted as before.

In both experiments, older adults were not removed from the breeding colony, but dead adults were removed when found.

Oviposition Substrate Area as a Limiting Factor. This experiment was conducted as described for the four-pair colony, except that the ovipositional surface area was reduced by 50%. A semi-circular wooden block of 5 cm thickness, ≈ 2 times the height of the petri dish rim, was fitted against the 15-cm-diameter petri dish to provide a barrier against oviposition in that half of the petri dish. The other half was filled with moistened peat moss. Eggs were harvested after exposing the modified egg trays to the breeding colony for a 24-h period for 46 consecutive days. Egg trays were incubated and the nymphs were reared for 7 d before freezing and counting as before. The mean production from this experiment was compared with that of the production achieved from the four-pair colony experiment by using *t* test statistics.

Results and Discussion

Developing and Testing the Production Model. Fig. 1 shows the age-specific natality (mean number of offspring surviving for 7 d per surviving female) for the cricket cohorts. A peak of 90 offspring per female occurred on day 11, which represents 6.4% of cumulative net maternity, and declined to fewer than 3 offspring per female by day 45 (Fig. 1). No adult mortality was recorded before age 24 d, and survivorship declined to 71% by the termination of the experiment on day 45 (Fig. 2). Although the survivorship seems apparently high even on day 45 (70%), reduced competitive ability of older fe-

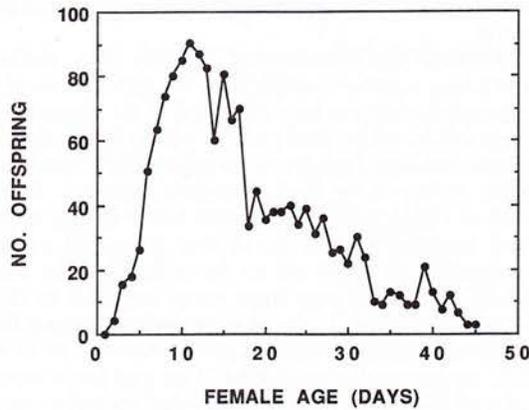


Fig. 1. Number of *A. domesticus* offspring (surviving for 7 d) produced per adult female per day at $34 \pm 2^\circ\text{C}$. Each data point represents the mean of three cohorts.

males contributes to very little effect on overall population growth (see below for the concept of discard age and the poor competitive ability of the older females). The mean cumulative net maternity for the generation (twice R_0) was 1,407.

Using the natality (Fig. 1) and survivorship (Fig. 2) data from the single-aged cricket cohorts, we developed a model to predict the harvest for a mass-rearing production system:

$$E_{t+1} = \sum_i (b_i N_{i,t})$$

$$N_{0,t} = p$$

$$N_{i,t} = s_{i-1} N_{i-1,t-1}, i > 0$$

where E represents the number of eggs, N is the number of adult females, i is adult age class, t is time, b is natality (male plus female offspring), p is the number of cricket pairs added daily, and s is survivorship. A production colony differs

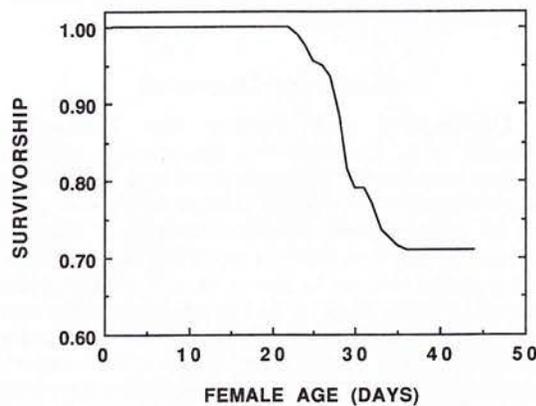


Fig. 2. Survivorship of female *A. domesticus* adults at $34 \pm 2^\circ\text{C}$.

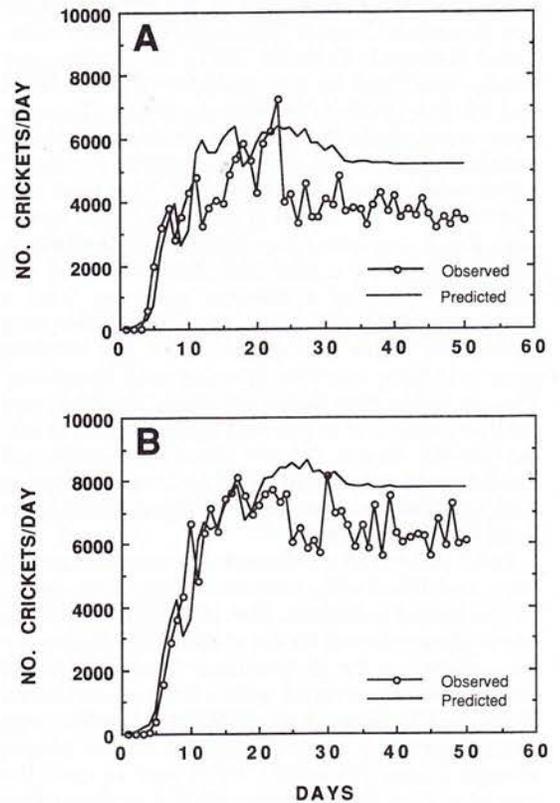


Fig. 3. Daily observed and predicted production of 7-d-old *A. domesticus* offspring from a breeding colony of 50 pairs with four pairs (A) and six pairs (B) of newly emerged crickets added daily.

from a single-aged colony in that a fixed number of newly eclosed adult pairs are added each day, resulting in a population with mixed ages. However, once the adult age structure in such a colony becomes artificially "stable" (i.e., all age classes are represented with numbers relative to their survival expectations), the daily production of offspring should be sustainable and equal to a multiple of the cumulative net maternity (i.e., 1,407 per cricket pair added). Thus our model would predict a harvest of 5,628 and 8,442 nymphs per day from colonies in which four pairs and six pairs, respectively, were added daily.

The production-system results (Fig. 3) disagreed with our model predictions in that for both the four-pair and six-pair colonies, the actual sustainable cricket production was substantially less than predicted. These differences were probably caused by reduced competitive abilities of the older females in the mixed-age colonies. In the presence of younger females, older females tended to spend less time around the egg trays and more time in the egg carton resting places (M.N.P., unpublished data). The older females could be recognized by their dark,

rough, dirty wings compared with lighter, shiny, and cleaner wings of young females. However, it did not appear that older females experienced an increased mortality rate in the mass-rearing colonies compared with the single-aged colonies.

Carey & Vargas (1985) found that in mass rearing three species of tephritids, eggs laid after 3 wk of adult life contributed little to population growth. To compensate, they invoked an artificially imposed last day of reproduction, termed the adult discard age. Under our system of daily introducing new cricket adults into the breeding colony, the data from the four-pair colony show a sharp drop in cricket production on day 24 (Fig. 3A), indicating a reduction in oviposition by the females in the original 50-pair cohort and suggesting an adult discard age of 24 d. It would not be practical in our case to actually remove crickets from the colonies. However, assuming that reproduction in a mixed-age colony becomes negligible after age 24 d, we can impose an effective discard age, which results in a revised cumulative net maternity value of 1,110 offspring per female. With this discard age, our model thus predicts a harvest of 4,440 and 6,660 nymphs per day for the four-pair and six-pair colonies, respectively. In both cases, the experimental results were in general agreement with these predictions. Observed mean daily production was 3,995 (± 861) and 6,535 (± 688) nymphs for the four-pair and six-pair colonies, respectively, from days 25 to 50 of the experiments.

One issue our production experiment did not address directly is the sustainability of yields beyond 50 d. We assume that the daily yields we observed could be maintained indefinitely. However, although reproduction by older females appears to be reduced in mixed-age colonies, survivorship (Fig. 2) may not be similarly affected. It is possible that over time, old crickets could build up to levels at which they would interfere with colony productivity, but this is unlikely because old crickets and the young, productive crickets appear to compete only for the essentially unlimited number of resting places provided by the egg cartons.

Oviposition Substrate Area as a Limiting Factor. We detected no density-dependent depression in per-cricket production between the four-pair and six-pair cages. The area of oviposition substrate rather than overall cage volume could be the limiting factor for cricket mass-production, and increasing only this area might increase the adult cricket density in a cage beyond the recommended levels (Patton 1978). Our results, however, indicated that the oviposition substrate area was not limiting (Fig. 4). Nymph production was $3,737 \pm 1,555$ (mean \pm SD) when the ovipositional surface was reduced by half, and $3,773 \pm 1,459$ when the entire area of the petri dish was available.

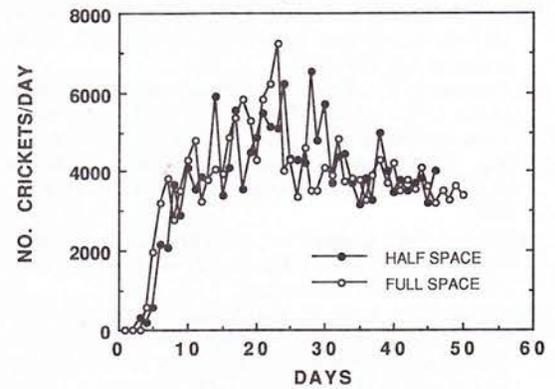


Fig. 4. Effect of reducing the oviposition substrate area by half on the daily production of 7-d-old *A. domesticus* offspring from a colony of 50 pairs with 4 pairs of newly emerged adults added daily.

When the oviposition substrate area was reduced, the increased density of crickets resulted in loss of both oviposition substrate and previously laid eggs by adults kicking substrate out of the trays (M.N.P., unpublished data). When a larger surface area was available, there also was kicking of the substrate, but it tended to occur near the center of the dish, resulting in less substrate being kicked out of the dish. The loss of oviposition substrate is negligible using a 15-cm-diameter petri dish filled to only three-fourths of its depth with moistened peat moss. Dry peat moss is light in weight, which increases the possibility of loss from disturbance.

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References Cited

- Andrewartha, H. G. & L. C. Birch. 1954. The distribution and abundance of animals. University of Chicago Press, Chicago.
- Carey, J. R. & R. I. Vargas. 1985. Demographic analysis of insect mass rearing: a case study of three tephritids. *J. Econ. Entomol.* 78: 523-527.
- Clifford, C. W., R. M. Roe & J. P. Woodring. 1977. Rearing methods for obtaining house crickets, *Acheta domesticus*, of known age, sex, and instar. *Ann. Entomol. Soc. Am.* 70: 69-74.
- DeFoliart, G. R. 1989. The human use of insects as food and as animal feed. *Bull. Entomol. Soc. Am.* 35: 22-35.
- Finke, M. D., G. R. DeFoliart & N. J. Benevenga. 1989. Use of a four-parameter logistic model to evaluate the quality of the protein from three insect species when fed to rats. *J. Nutr.* 119: 864-871.

- Jordan, B. M. & J. R. Baker. 1956. The house cricket (*Acheta domestica*) as a laboratory animal. *Entomologist* 89: 126-127.
- McFarlane, J. E. 1962. A comparison of the growth of the house cricket (Orthoptera: Gryllidae) reared singly and in groups. *Can. J. Zool.* 40: 559-560.
1964. The protein requirements of the house cricket, *Acheta domesticus* L. *Can. J. Zool.* 42: 645-647.
1985. *Acheta domesticus*, pp. 427-434. In P. Singh & R. F. Moore [eds.], *Handbook of Insect Rearing*, vol. I. Elsevier, Amsterdam.
- Nakagaki, B. J. & G. R. DeFoliart. 1991. Comparison of diets for mass-rearing *Acheta domesticus* (Orthoptera: Gryllidae) as a novelty food, and comparison of food conversion efficiency with values reported for livestock. *J. Econ. Entomol.* 84: 891-896.
- Nakagaki, B. J., M. L. Sunde & G. R. DeFoliart. 1987. Protein quality of the house cricket, *Acheta domestica*, when fed to broiler chicks. *Poult. Sci.* 66: 1367-1371.
- National Research Council. 1977. Nutrient requirements of domestic animals. No. 1: nutrient requirements of poultry. National Academy of Sciences, Washington, DC.
- Parajulee, M. N. & G. R. DeFoliart. 1993. A simple method of heat supplementation for cricket mass-rearing in the absence of controlled-temperature equipment in developing countries. *J. Inst. Agric. Anim. Sci.* (in press).
- Patton, R. L. 1963. Rearing the house cricket, *Acheta domesticus*, on commercial feed. *Ann. Entomol. Soc. Am.* 56: 250-257.
1967. Oligidic diets for *Acheta domesticus* (Orthoptera: Gryllidae). *Ann. Entomol. Soc. Am.* 60: 1238-1242.
1978. Growth and development parameters for *Acheta domesticus*. *Ann. Entomol. Soc. Am.* 71: 40-42.
- Polt, J. M. 1971. Experiments in animal behavior. *Am. Biol. Teach.* 38: 475-477.
- Roe, R. M., C. W. Clifford & J. P. Woodring. 1980. The effect of temperature on feeding, growth, and metabolism during the last larval stadium of the female house cricket, *Acheta domestica*. *J. Insect Physiol.* 26: 639-644.
- Taylor, R. L. & B. J. Carter. 1976. Entertaining with insects, or: the original guide to insect cookery. Woodbridge, Santa Barbara, CA.

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