Life Table Descriptions of *Tetrastichus* sp. (Hymenoptera: Eulophidae) on *Hyphatria cunea* Drury

Jang-Hoon Lee*, **Ki-Sang Lee**[1], **and Hai-Poong Lee**[2]

Research Institute for Natural Science, Dongguk University, Seoul 100-715, Korea;
[1]IPM Team, Sesil Corporation, Koyangsi 411-380, Korea;
[2]Department of Biology, College of Natural Sciences, Dongguk University, Seoul 100-715, Korea

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Life table studies were conducted in the laboratory for the eulophid gregarious pupal parasitoid, *Tetrastichus* sp., on *Hyphantria cunea* Drury at a constant temperature of 28.2±2℃, 50-60% RH to evaluate their impact on the host and their potential biological control. Development of immature stage took 20.1±2.7 d; adult females lived for 23.2±2.2 (range, 16-27) d and produced a mean of 53.6±26.6 adult progeny per female, with a sex ratio of 1: 9.5 (M:F). The intrinsic rate of natural increase (r_m) was 0.178/female/day; the net reproductive rate (R_0), 46.74; the capacity for increase (r_c) 0.177; the finite rate of increase (λ) 1.195/female/day; thus each female contributed 46.74 individuals to the population in a mean generation time of 21.6 d. Biological factors in determining the life history trait variation of the parasitoid were discussed.

Fall webworm, *Hyphantria cunea* Drury, was first detected in Korea in 1958. It has spread from the initial infestation in Seoul to all over Korea and it continues to be one of the most serious pests of deciduous trees (Kim, 1983). Ichneumonid, Pteromalid and chalcid wasp appeared to check the fall webworm population (Kim and Lee, 1982; Lee, Jang-Hoon, unpublished data). Identification of biological control agents and evaluation of their effectiveness are important toward major integrated pest management effort against pest insects, and the knowledge in the parasitoid is essential in intensification of alternative control measures such as biological control (Van Driesche and Bellows, 1996). New parasitoid - host association was obtained from field collection in Seoul in 1997 (Lee et al., 1999); the eulophid, *Tetrastichus* sp., gregarious pupal endoparasitoid was reared from *Hyphantria cunea* Drury and its life history traits and morphological characteristics were reported.

The aim of the studies presented here was to give life table and intrinsic rate of natural increase (r_m) of *Tetrastichus* sp, together with other population growth parameters, using the fall webworm as a host in order to assess its ability as biological control agent.

Materials and Methods

A laboratory colony was established at Dongguk University in the winter of 1997 from parasitized, field-collected fall webworm, *Hyphatria cunea* Drury pupae at Sinsa-dong, 16 km SE of Seoul. The rearing of the parasitoid and the host was conducted at a constant temperature of 27±2℃ and 40-50 RH in an insectary. Host pupae were kept at 4℃ and were used within two weeks from initial pupation for the experiment.

Fall webworm pupae reared in laboratory varied in size. Pupae about 1.1×0.5 cm in length and width (0.62 mL in volume) were used because the host size would influence fecundity and sex ratio of parasitoid (Quicke, 1997).

The life table data of *Tetrastichus* sp. were obtained from cultures of the parasitoid on *H. cunea* at a constant temperature of 28.2±2℃ and 50-60 RH in growth chamber. A thermo-hydrograph was placed in the growth chamber to record temperature. Newly emerged female parasitoids were obtained from parasitized pupae in the laboratory. Emerging females were placed individually in plastic vials (3.0×5.5 cm) along with a single male and allowed to mate. After copulation, each pair of parasitoid (n = 16) was exposed to the host pupa. Every 24 h, the parasitized pupae (i.e, pupae exposed overnight for parasitoid oviposition) and honey/water solution were removed and replaced with fresh material until the female died. The parasitoids were fed, by streaking a 10% honey/water solution inside the vials. The series of parasitized pupae collected daily from each vial containing the parasitoid were kept singly in the vial in the growth chamber from the immature stages to complete development. On emergence, the progeny was counted daily and the sex

* To whom correspondence should be addressed.
Tel: 82-2-2260-3511, Fax: 82-2-2269-4560
E-mail: ecojhl@dongguk.edu

Table 1. Life history traits of *Teterastichus* sp on *Hyphatria cunea* pupae at 28.2±2℃ and 50-60%RH in the laboratory

Development period (days)	Longevity (days)	Oviposition period (days)	Realized fecundity[3]	%Sex ratio and male:female	n
20.1±2.7[1]	23.2±2.2[2] (16-27)	2.2±1.2 (1-5)	53.6±26.6 (86-6)	84±12 1:9.5	16

[1] Mean ±SD. [2] Range. [3] Mean numbers of adult progeny produced per female.

ratio was recorded to provide an index for parasitoid fecundity used in the (m_x) column (Table 1). The life tables were prepared from observed survival and fecundity (progeny production) rates. The intrinsic rate of natural increase was calculated from the life-fecundity table using methods described by Birch (1948) as follows:

$$\sum e^{-rm}x\ l_x m_x = 1 \text{ or } \sum e^{7-r_m x}\ l_x m_x = 1096.6\ (1097)$$

where (e) is the base of natural logarithm;(x), the age interval; (l_x), proportion of females alive at age (x); (m_x), the number of female offspring produced per female in the age interval (x).

Also calculated were the net reproductive rate (R_o) as given by the formula:

$$R_o = \sum l_x m_x$$

And the mean generation time (T) as given by the formula

$$T = \sum X\, l_x m_x \,/\, \sum l_x m_x$$

The capacity for increase (r_c) was calculated as:

$$r_c = \log_e R_o / T_c$$

The (r_c) gives an approximate value of the intrinsic rate of natural increase (r_m) (Laughlin, 1965) and is slightly lower than (r_m) for insects with overlapping generation (Southwood, 1976).

The mean generation time (T) was then computed from the formula:

$$T = \log_e R_o \,/\, r_m$$

And the finite rate of increase (λ) was computed from the formula:

$$\lambda = \text{antilog}_e\ r_m$$

This (λ) represents the number of individuals added to the population per female per day (Siddiqui et al., 1973)

Identification of the parasitoid was made by Dr. John LaSalle (Australia National Insect Collection, CSIRO). We deposited voucher specimens at the entomological collection of Dongguk University.

Results

At 28.2±2℃ and 50-60%RH, development of immature stages of *Tetrastichus* on *H. cunea* from oviposition to adult emergence took 20 d. Adult females lived for 23.2±2.2 (range, 16-27) d, produced a mean of 46.7±25.4 (81-5) female progeny per female, with a sex ratio of 1:9.5 (M:F) (Table 1). Oviposition started the day of adult emergence and continued for up to 5 d; mortality started on the 16th day of adult life but females lived for a maximum of 27 d on 10% honey/water solution (Table 2).

The intrinsic rate of natural increase was found to be 0.178 per female per day (Table 3). The net reproductive rate was 46.74; the capacity for increase was 0.177 (Table 2, 3). The finite rate of increase was calculated to be 1.195 per female per day, while mean generation time was computed to be 21.6 d (Table 3).

Table 2. Life-fecundity table for *Tetrastichus* sp. on *Hyphatria cunea* at a constant temperature of 28.2±2℃, 50-60RH in the laboratory

Age interval (days)	Proportion of female alive at age (x)	No. female progeny / female		
X	l_x	m_x	$l_x m_x$	$l_x m_x X$
0-20 d, immature stages				
21	1	22.41	22.41	470.61
22	1	21.23	21.23	467.06
23	1	2.19	2.19	50.37
24	1	0.26	0.26	6.24
25	1	0.65	0.65	16.25
26-35	1	0	0	0
36-37	0.89	0	0	0
38-42	0.56	0	0	0
43-44	0.449	0	0	0
45-46	0.227	0	0	0
47	0.5	0	0	0
Total			46.74	1010.5

Table 3. Life table statistics for *Tetrastichus* sp. reared on *Hyphantria cunea*

Mean generation time (T)	21.6
Net reproductive rate (R_0)	46.74
Finite rate of increase (λ)	1.195
Intrinsic rate of natural increase (r_m)	0.178 (0.005)[1]

[1] Number in parenthesis is standard error.

Discussion

The intrinsic rate of natural increase, as a measure of animal population growth rate, was first applied to insect populations by Birch (1948) and has since been used on several phytophagous insects (Hutchison and Hogg, 1984; Cho et al., 1988; Pinkham and Oseto, 1988; Nowierski et al., 1995), predators (Osawa 1992; Camporese and Duso, 1995) as well as parasitoids (Mendel et al., 1987; Löhr et al., 1989; Oloo, 1992).

Several criteria and diverse approaches exist for evaluation and selection of the best agents for controlling of a pest (Waage, 1990). One method considers life history characteristics as a component of population models for predator-prey interactions and their application to biological control. Demographic statistics that quantify life history attribute such as fecundity, survival, and developmental time under specific conditions are some parameters considered important in this approach (Reed et al. 1992). In particular, the intrinsic rate of increase (r_m) combines information on total fecundity, survival, and developmental time from birth to reproductive maturity in single statistics (Lewontin 1965). The (r_m) is strongly influenced by time from birth to first reproduction, and to a lesser extent, by survival and total reproduction (Lewontin 1965). Despite some limitation, differences in the values of (r_m) among species and strains can be compared statistically. To our knowledge, this is the first life table study conducted on *Tetrastichus* sp. attacking fall webworm although some biological information on this species was previously reported by Lee et al. (1999). The present study provides complementary data on *Tetrastichus* sp. which may prove useful in planning its utilization in biological control programs of fall webworm. From the (r_m) value of 0.178 per female per day, use of Verma and Makhmoor's (1988) formula: Days = $\log_e 2/r_m$ indicates that the parasitoid population had the potential to double in 3.9 d. The computed finite rate of increase of 1.2 per female per day shows that each female contributed 46.74 female offspring to the population over a mean generation of 21.6 d (as per definition of Siddiqui et al., 1973).

Under the experimental condition oviposition occurred for up to 5 d from adult emergence (mean of 2.2 $\pm$ 1.2) although females continued to live for a maximum of 27 d. Lee et al. (1999) observed oviposition period with a mean of 7.66 d greater than that of our study although a similar longevity of the parasitoid was obtained from both experiments. A considerable gap between our realized fecundity (53.6 adult offspring/ female) and the fecundity of Lee et al. (1999) (94.7 eggs laid/female) was found. Immature mortality would offer a potential explanation for such a difference because we observed a high larval mortality especially in a low egg loaded host (Lee, Ki-sang and Lee, Jang- Hoon, Unpublished data). On the contrary, Ode et al.'s study (1996) revealed a negative relationship between excess egg loads on hosts and the immature survival; in gregarious parasitoid *Bracon hebetor*, increasing clutch size decreased larval development time and they experienced higher rates of larval mortality when they developed in large clutches. In addition, adult size and host size variation would contribute to variable fecundity although we did not examine this in our experiments. Correlations between parasitoid fecundity and to its size were found in other gregarious chalcid parasitoids such as *Elachertus cacoeciae* (Hymenoptera: Eulophidae) (Fidgen et al. 2000), *Pteromalus pupaum* (Hymenoptera: Pteromalidae) (Takagi, 1985), and *Aprostocetus hagenowi* (Hymenoptera:Eulophidae) (Heitmans et al., 1992). The fecundity in this study was probably underestimated as compared to that in the field because the laboratory reared host pupae were usually smaller in size than field collected pupae. Kfir et al. (1993) also reported a positive correlation between the number of emergent parasitoids and the volume of the host from which they emerged. Similarly, a greater number of *Tetrastichus* sp. was emerged from a bigger volume of the host in a preliminary experiment; several hundred of adult progeny were reared from a single parasitized *Antheraea peryi* (Lepidoptera: Saturnidae) pupa.

In conclusion, various aspects of the host and parasitoid adults affected the life history trait including sex ratio and fecundity. Therefore our laboratory experiments do not reflect the multitude of factors encountered by the parasitoids in the field, and only the results of field release and field research on the population ecology of the parasitoids can unambiguously demonstrate their utility as biological control agents. Although the *Tetrastichus* does not currently control the fall webworm in Korea, we believe that *Tetrastichus* has a potential for augmentative and classical biological control agent. With minimal care and time expenditure, adult parasitoids were reared. The high production of female in the laboratory would greatly reduce the cost of production of *Tetrastichus* because no problems with sex ratio would arise. We believe that a long life span and high fecundity of the parasitoid would enhance its action in the field.

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