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Temperature and Photoperiodic Regulation of the Postembryonic Development of the Cigarette Beetle, *Lasioderma serricornes* (Coleoptera: Anobiidae)

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ABSTRACT

The life cycle characteristics of a stored product-household pest, the cigarette beetle, *Lasioderma serricornes* (F.) was investigated by individually rearing under various photoperiod and temperature conditions. Two stocks (E and S) were used for comparison. The insect responded to a short-day rearing by extending the period of ultimate larval instar, undergoing supernumerary molts. The period of last larval instars under LD 12:12 varied between 30 and 205 days at 23°C in the S stock and between 24 and 208 days at 25°C in the E stock. The frequency of supernumerary molts under LD 12:12 was the highest at 23°C of the 4 temperatures investigated, 20, 23, 25 and 30°C in the S stock and at 25°C in the E stock. The E stock extended the second instar period of larval development also which occurred under LD 16:8. The short day effect was more prominent at 23°C and 25°C. 30°C overrode photoperiodic effect producing all fast developing individuals. The extension of larval period did not result in the larger body size. This indicates that the extension of larval period is due to stationary molts in diapause, not to the extension of feeding period. The two stocks had different threshold temperatures that were very high to compare with outdoor insects, 15.3 and 14.9°C for the S and E stocks, respectively. The number of eggs found in the ovary of newly emerged females that were reared at 20°C was less than half that of females reared at higher temperatures, 23, 25 and 30°C in the S stock. Grading of developmental speed seems therefore to be controlled at multiple check points in this species that supplies founders of new colony continuously after population collapses due to occasionally occurring environmental hazards. Artificial selection for slow developing individuals showed a plasticity of this trait, which means the versatility in the life cycle regulation is supported not only by a rich repertoire of physiological adaptations but also a genetic variability.

Key words; *Lasioderma serricornes*, Larval diapause, Photoperiodic response, Stored product pest, Cigarette beetle, Supernumerary molt

Introduction

The tobacco beetle, *Lasioderma serricornes* (F.) is an important stored product pest. It has been found all over the tropical and subtropical as well as in most parts of temperate regions (Howe, 1957). Since its infestation sometimes causes large economic losses, this species occupies a rank of the most important pests especially on stored tobacco leaves (Takaoka and Nakazawa, 1956). The biology and the control methods of this species have, therefore, been studied in many countries.

L. serricornes infests on a wide range of foodstuff. When Howe (1957) reviewed the biology of this beetle, he listed

the products that had records of infestation by this beetle. A typical poly- or omni-phagy has been shown in this list including almost all kinds of stored products such as grains, beans, nuts, flour, dry woods, as well as tobacco. Not only plant materials but also animal materials are listed.

Recently, this beetle has attracted much attention in Japan since its parasitoid, *Cephalonomia gallicola* (Bethyliidae) causes a serious medical problem of stinging residents in the ferro-concrete apartments. In such buildings larvae of the host beetle damage tatami mats made of imported rice straws. Therefore, the ultimate solution of this problem is to eradicate the beetle

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stinging residents in the ferro-concrete apartments. In such buildings larvae of the host beetle damage tatami mats made of imported rice straws. Therefore, the ultimate solution of this problem is to eradicate the beetle larvae (Imoto and Momoi, 1992; Momoi and Tanioka, 1994).

The beetle somehow succeeded to adapt themselves from forest dwelling, first to store-house situation and then to residences, changing their original life-cycle parameters to more extensively colonize urban situations that are characterized as more buffered conditions from the fluctuation in environmental factors. Urban environment provides the beetle with not only more stable buffered environment but also with warm and more humid conditions that favor reproduction to produce more generations annually.

The present investigation aims to clarify the life cycle regulation of this beetle not only to solve these sanitary and medical problems but also to characterize urban environment for insect colonization by observing a larva individually reared in a vial.

Materials and Methods

Stock colonies of *Lasioderma serricorne* (F.) used in this experiment have been cultured in our laboratory for more than 8 years. The experiments were conducted in our laboratory between 1987 and 1991. One stock (E) is derived from the Health Research Institute of Nagoya City, and the other (S) from the Central Research Institute of Japan Tobacco and Salt Public Corporation (Now JT Industry Co., Ltd). The insects were reared in mass at 25°C under LD 16:8. Three walk-in constant temperature rooms (3 m² floor area and 1.8 m high each) set at 20, 25 and 30°C, 70% R.H. and two incubators (NK model, capacity more than 400 liters) set at 23°C, ca.50% R.H. were used for rearing. Two photoperiods, LD 16:8 and 12:12 were used as representative long-day and short-day conditions, respectively. In each walk-in room, set at LD 16:8, a wooden cabinet of 45×70×50 cm with electric timer controlling a fan and a 10 W fluorescent light was placed to make LD 12:12.

The experiments were started with eggs collected on corrugated sheets of filter papers of 10 cm² on which a tea-spoonful of dry yeast powder ("Ebiosu", Asahi Beer Co., Ltd.) was placed. The sheets were kept with ca. 200 adults in a cylindrical plastic container of 13 cm across and 5 cm deep with a lid. The adults were allowed to oviposit on the sheet for 24 hours. The next day, the sheet was cut to provide an equal number of eggs.

A 5 ml glass tube of 1.5 cm across and 4 cm length was used for each individual. Sixty individuals were used for each experimental replica. Development was individually

recorded subsequently in various environmental conditions and food (dry yeast) consumed was compensated at each observation. Dates of egg hatching, larval molts, pupation, pupal eclosion, and adult emergence from the cocoons, as well as the width of adult prothorax and the number of eggs carried by a newly emerged female were observed under a binocular microscope with a scored eye piece. Newly emerged adults stay inside the cocoon until cuticular hardening and sexual maturation (Howe, 1957; Niiho, 1982).

Forty earliest emerging adults of the S stock were selected every generation that were kept in mass under LD12:12 at 25°C to examine the plasticity in the rate of development. Offspring was reared individually for developmental test at the third and sixth generation.

Results

Figure 1 depicts developmental events that mark stages of development. Each bar represents records of an individual for hatching, each of three larval molts, supernumerary molts, pupation, pupal eclosion and adult emergence. The individual recordings for each event are connected vertically. Two such events designate a specific stage (a-g). **Figures 2–5** show the developmental profiles of individuals at different temperatures under LD 12:12 and 16:8. Photoperiodic effect appeared clearly in the period of fourth instar larva except at 30°C. **Table 1** summarizes the developmental characteristics at a mature larval stage, while **Table 2** for total post-embryonic period.

Under LD 16:8 at 20°C, mature larvae, fourth and supernumerary instars, of the S stock developed uniformly fast but under LD 12:12 development was retarded significantly, i.e., 20-29 vs. 24-184 days respectively (**Fig. 2** a vs. b). In the E stock, photoperiodic effect was not so apparent as in the S stock (**Fig. 2** cd). When development was retarded, they very often underwent supernumerary molts under both photoperiods. The period of the 4th instar larva was longer under LD 12:12 than under LD 16:8, while the period of the 2nd instar was longer under LD 16:8 than under LD 12:12, though the retardation in the 2nd instar is much smaller than in the 4th instar. **Figure 6** illustrates this condition. Under LD 12:12 the distribution of 2nd larval period is uniformly short and independent of the total larval period but under LD 16:8 distribution of relative length of second instar differed from the pattern obtained under LD 12:12 where some individuals had longer second instar period than others. Individuals having short 2nd instar had short 4th instar and the other having long 2nd instar had long 4th instar. The two periods were dependent. The figures were plotted against total period of larval development.

Under LD 16:8 at 23°C, mature larvae of the S stock

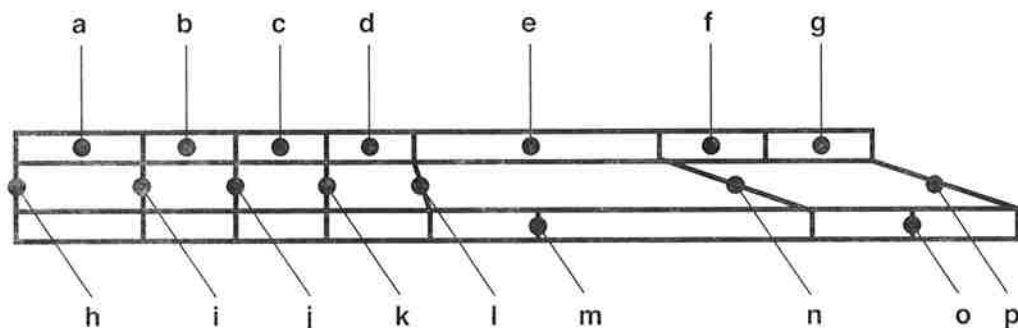


Fig. 1 Developmental events and the stages delineated by them, depicted in Figs. 2-5. a, egg; b-e, 1st-4th larval instars; f, pupa; g, adult inside the cocoon; h, egg-laying; i, hatching; j-l, 1st-3rd larval-larval molt; m, supernumerary molt; n, pupation; o, pupal eclosion; p, adult emergence.

developed fast but under LD 12:12 development was retarded significantly, i.e., ca 17-41 vs. 30-205 days, respectively (**Fig. 3** a b). When development was retarded, they underwent supernumerary molts. In the E stock, photoperiodic effect was apparent but it was less clear-cut than in the S stock (**Fig. 3** c d). Not only the rate of development in the E stock was faster than in the S stock under LD 16:8, but also the degree of extension in developmental time under LD 12:12 was much smaller in the E stock than in the S stock. Under LD 12:12, the extension of larval period was greater at 23°C than at 20°C. Also, the number of larvae undergoing multiple supernumerary molts was higher than at 20°C. The incidence of supernumerary molts was very low in the E stock compared to the S stock under LD 16:8.

At 25°C, photoperiodic effect appeared in the same way as at 23°C in both the stocks, though a small proportion of the population took longer time to pupation than at 23°C except under LD 16:8 in the E stock (**Fig. 4** a d). Photoperiodic effect was most dramatic at this temperature of the three low-intermediate temperatures used. This temperature suppressed the incidence of supernumerary molts under LD 16:8. Adult emergence of the S stock under LD 12:12 occurred at nearly the same time as at 23°C though developmental period to reach the 3rd instar was shortened. In the E stock under LD 12:12, some adults emerged earlier than at 23°C but many emerged later than at 23°C. Under LD 12:12, the extension of larval period was again greater at 25°C than at 20°C.

At 30°C, photoperiodic effect was no longer apparent in the S stock and they developed at nearly the same rates under both photoperiods, while the E stock was not investigated (**Fig. 5**). Supernumerary molts was not observed under both photoperiods except one individual under LD 12:12.

Table 1 shows that mature larval diapause was most intense at 25°C where photoperiodic effect was most clearly expressed. It also shows that high incidence of

supernumerary molts occurred under both photoperiods at intermediate temperatures, 23 and 25 °C, in the S stock. Contrarily, in the E stock the percentage increased when temperature rose under LD 12:12 but decreased when temperature fell under LD 16:8. Developmental thresholds from egg to adult emergence (t_0) were calculated from the data collected under LD 16:8 (**Table 2**) as 15.3°C for the S stock and 14.9°C for the E stock. **Table 3** shows that females are larger than males and that differences between the two stocks and between the two photoperiods are slight. **Table 4** shows that the numbers of eggs found in the ovary of newly emerged females seems not different between the stocks and at temperatures between 23 and 30°C but that the number greatly decreased at 20°C, especially in the S stock. Whether the number will increase to an equivalent level to that at higher temperatures during adult life remains uncertain.

Artificial selection for fast development induced a significant reduction in developmental period before pupation in 3 generations (**Fig. 7**). Cumulative percentage of pupation 60 days after egg-laying was 14, 43 and 69 % in generations 0, 3 and 6, respectively. Medians of larval period were 164, 70 and 51 days for generations 0, 3 and 6. This demonstrates the plasticity of this trait.

Discussion

The two laboratory stocks of *L. serricorne* responded to short photoperiods and intermediate temperature by extending the period of mature larval stages. Both stocks showed a long-day type response at mature larval stage where short-days retard development. Although temperatures higher than 30°C suppressed the incidence of diapause, photoperiodic response is clearly expressed at other temperatures, particularly 23°C and 25°C in this species. Development took longer time at higher temperature below 30°C under LD 12:12 more typically in

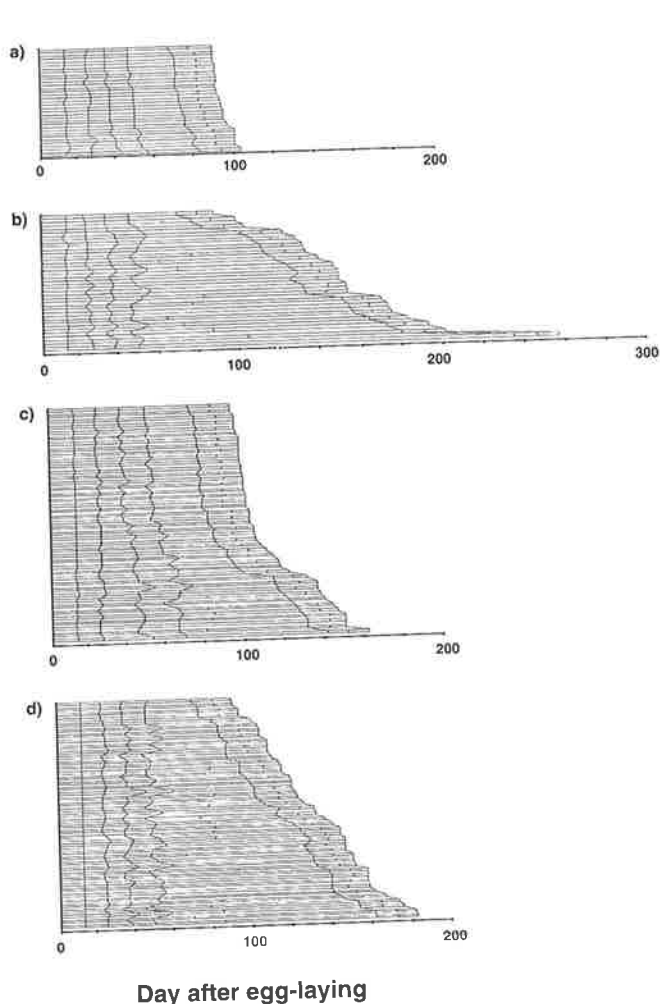


Fig. 2 Developmental profile of *L. serricorne* at 20°C. a) LD 16:8; b) LD 12:12 of the S stock; c) LD 16:8; d) LD 12:12 of the E stock.

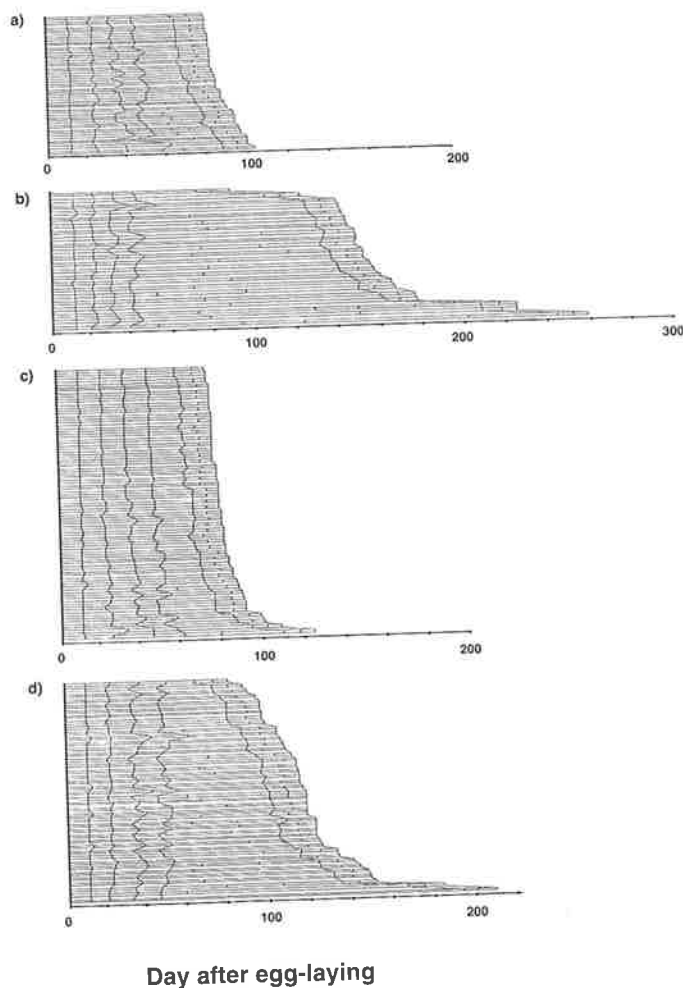


Fig. 3 Developmental profile of *L. serricorne* at 23°C. a) LD 16:8; b) LD 12:12 of the S stock; c) LD 16:8; d) LD 12:12 of the E stock.

the S stock (**Table 1**) which is unusual among long-day species. Developmental check-points occur not only at larval stages but also at adult stage in this species. The number of eggs in the ovary of newly emerged females raised at 20°C was less than half that of the numbers found in females reared at high temperatures (**Table 4**). This could be an incipient adult diapause induced by low temperature signals.

Each stock was clearly characterized based on its response to photoperiod and temperature conditions. The S stock shows more straight-forward responses than does the E stock. The E stock, however, showed a developmental retardation also at the 2nd instar under LD 16:8 at 20°C (**Fig. 6**) that was not observed in the S stock. The response is a short-day type that is frequently observed as an adaptation for dormancy for estivation. This type of photoperiodic response is usually intensified at higher temperatures but not in this species. Therefore, adaptive significance of this response remains uncertain. The effect of temperature on the response to short-days in the E stock is also difficult to understand. More individuals

extended larval period responding to a short-day at 25°C than at 23°C (**Figs. 3, 4**). Response to short-day in the long-day type photoperiodic response is usually intensified at lower temperatures but that is not the case in this species.

These unusual features may represent the intermediate steps of adaptations in the process of colonization of urban habitat or storehouse environment. One of the most complex modes of diapause regulation and the variability is found in the Indian meal-moth, *Plodia interpunctella* which is also a stored product pest (Tsuji, 1963). This species responds to three distinct cues to arrest larval development, short-days, temperature-fall and crowding. The types of diapause induced by different cues were different, and required different cues to resume development. The complicated responses found in this species may be due to artificial indoor lighting and heating, or even cooling unlike more regular change in seasonal stresses prevailing outdoors.

The extension of the mature larval stage is accompanied with supernumerary molts typically observed in larval

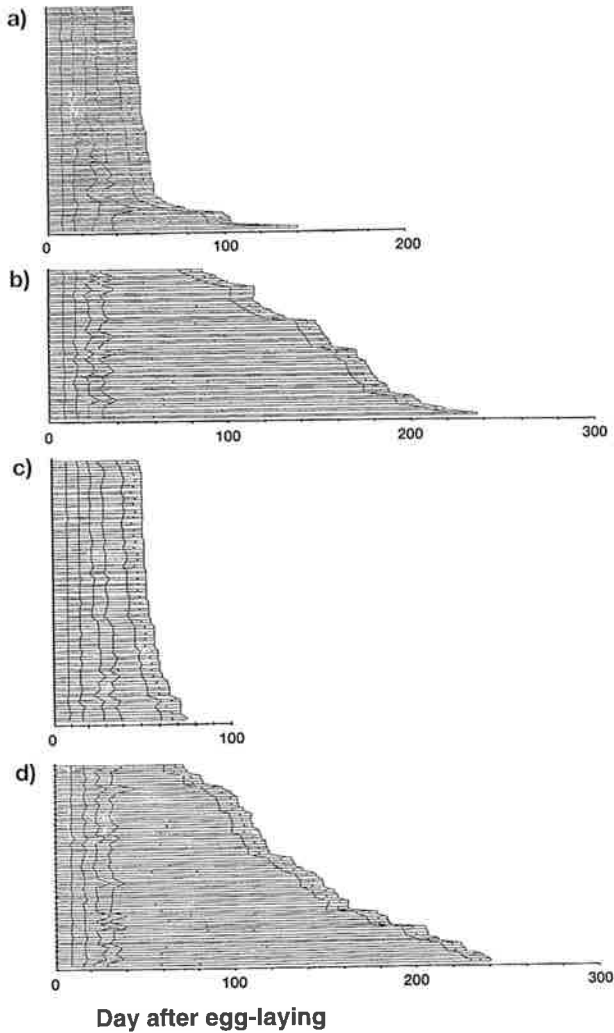


Fig. 4 Developmental profile of *L. serricorne* at 25°C. a) LD 16:8; b) LD 12:12 of the S stock; c) LD 16:8; d) LD 12:12 of the E stock.

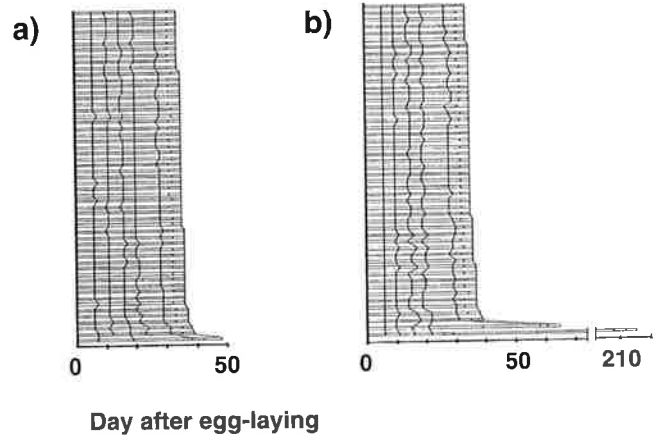


Fig. 5 Developmental profile of the S stock of *L. serricorne* at 30°C. a) LD 16:8; b) LD 12:12 of the S stock.

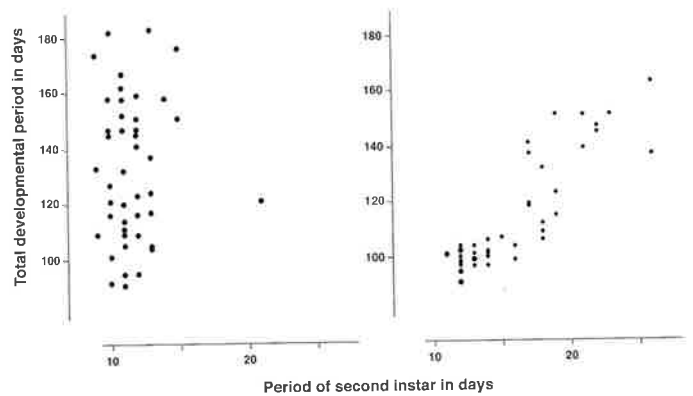


Fig. 6 The duration of 2nd larval instar relative to the duration of total postembryonic development of the E stock of *L. serricorne* at 20°C. Left, LD 12:12; right, LD 16:8.

diapause regulated by the titer of juvenile hormone (Yin and Chippendale, 1973). Whether larval diapause of this species is also regulated by JH remains as a subject of future study. The supernumerary molts usually occur once but in some conditions it occurs in multiple times such as under LD 12:12, 23°C (Table 1). Some of the S stock larvae underwent stationary molts four times at mature larval stage. This species can therefore change various developmental properties such as the fate of larval development at second and fourth larval instars, the rate of development, the rate of egg maturation and the number of stationary molts to fine-tune their life cycle, responding to various photoperiodic and temperature conditions. The present results also showed an extensive degree of variability between the stocks and within the stock in these properties. Such a multiplicity of check points for developmental determination may be general characteristics to stored product pests. Plasticity of the rate of larval development seems to be characteristics shared with other stored product insects such as *P.*

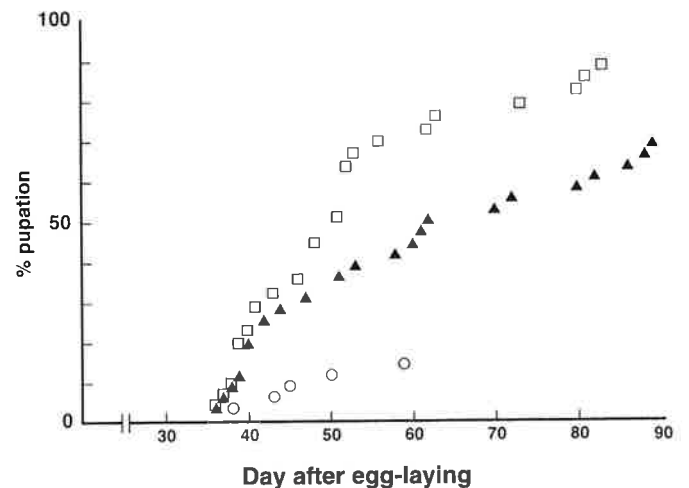


Fig. 7 Effect of artificial selection for fast development from the S stock of *L. serricorne* reared in mass under LD 12:12 at 25°C. Circles, unselected. Triangles, third generation of selection. Squares, sixth generation of selection.

Table 1 Period of mature larvae, i.e., fourth and supernumerary instars, from two stocks of *L.serricorne* reared under LD 16:8 and 12:12 at 20, 23, 25 and 30°C

Temperature	LD	Min	Max	Mean	SD	N	%Spn.molts ^a	%Msn ^b
<i>S stock</i>								
20	16:8	20	29	23.8	2.11	17	0	0
	12:12	24	184	81.9	38.9	20	50	0
23	16:8	17	41	23.7	5.72	28	32.1	0
	12:12	30	205	102	36.2	23	82.6	26.1
25	16:8	10	91	16.7	15.1	45	6.7	0
	12:12	43	192	110	37.4	28	71.4	0
30	16:8	7	19	7.9	1.62	55	0	0
	12:12	7	186	13.2	25.6	49	2.0	0
<i>E stock</i>								
20	16:8	22	71	34.5	15.2	42	14.3	0
	12:12	22	112	61.6	26.0	47	40.7	0
23	16:8	14	48	19.2	6.7	47	6.4	0
	12:12	14	140	52.2	24.4	41	51.2	9.5
25	16:8	10	33	13.9	4.75	45	0	0
	12:12	24	208	100	50.8	38	57.9	0

^a %Spn.molts refers to % larvae that underwent supernumerary.^b %Msn refers to the percent larvae that underwent multiple supernumerary molts.**Table 3** The width of prothorax of newly emerged adults of *L. serricorne*

Temperature	LD	M/F	Mean(mm)	SD	N	
<i>S stock</i>						
20	16:8	F	1.48	0.085	9	
		M	1.30	0.074	9	
23	12:12	F	1.52	0.130	12	
		M	1.36	0.059	8	
	16:8	F	1.49	0.072	12	
		M	1.33	0.058	15	
25	12:12	F	1.57	0.119	11	
		M	1.37	0.059	11	
	16:8	F	1.44	0.081	26	
		M	1.34	0.087	19	
30	12:12	F	1.48	0.112	8	
		M	1.30	0.096	19	
	16:8	F	1.41	0.058	28	
		M	1.31	0.029	27	
30	12:12	F	1.46	0.059	25	
		M	1.33	0.056	25	
	<i>E stock</i>					
	20	16:8	F	1.41	0.087	22
M			1.30	0.056	20	
12:12		F	1.50	0.066	24	
		M	1.33	0.065	20	
23	16:8	F	1.41	0.053	23	
		M	1.30	0.057	24	
	12:12	F	1.55	0.077	21	
		M	1.35	0.095	20	
25	16:8	F	1.46	0.048	14	
		M	1.34	0.054	29	
	12:12	F	1.54	0.083	16	
		M	1.38	0.059	21	

Table 2 Total period of postembryonic development of *L. serricorne*

Temperature	LD	Min	Max	Mean	SD	N
<i>S stock</i>						
20	16:8	90	104	94.4	4.50	18
	12:12	89	258	158	38.8	20
23	16:8	79	104	87.5	7.83	27
	12:12	89	260	162	36.4	22
25	16:8	50	140	60.8	17.6	45
	12:12	87	324	157	39.1	27
30	16:8	34	48	35.5	1.99	55
	12:12	34	215	39.9	25.7	50
<i>E stock</i>						
20	16:8	95	163	114	19.3	41
	12:12	91	183	133	25.9	44
23	16:8	74	115	82.9	8.75	47
	12:12	82	210	120	24.4	41
25	16:8	50	70	57.0	6.53	43
	12:12	73	251	147	50.6	38

Table 4 The number of mature eggs in the ovary of newly emerged females of *L. serricorne*

Temperature	LD	Mean	SD	N
<i>S stock</i>				
20	16:8	14.1	8.8	9
	12:12	14.7	10.2	12
23	16:8	33.2	4.9	12
	12:12	30.3	9.9	11
25	16:8	31.2	9.3	26
	12:12	29.0	10.3	8
30	16:8	32.1	11.5	28
	12:12	31.7	12.3	25
<i>E stock</i>				
20	16:8	13.0	9.0	22
	12:12	15.0	7.9	24
23	16:8	20.5	8.6	23
	12:12	29.1	11.2	21
25	16:8	33.4	11.3	14
	12:12	36.9	8.0	16

interpunctella (Naeemullah and Takeda,1998).

The developmental thresholds were very high, 15.3 and 14.9°C for the S and E stocks, respectively, which also characterizes stored product pests especially coleopteran species (Kiritani, 2002). Artificial selection for slow developing individuals showed a plasticity of this trait (Fig. 7), which means the versatility in the life cycle regulation is supported not only by a rich repertoire of physiological adaptations but also a genetic variability. easiness to change developmental traits has been shown in *P. interpunctella* (Naeemullah and Takeda, 1998). This may be also a shared property by stored product pests that may contribute to a restoration of founders upon population catastrophe or sudden changes in environmental conditions.

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タバコシバンムシにおける後胚子発育の温度と光周期による制御

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家屋・貯穀害虫であるタバコシバンムシの生活史形質を2つの光周期 (LD 12:12と16:8) 及び4つの温度条件 (20, 23, 25, 30°C) で個体飼育することによって調べた。比較のために2つのストック (SおよびE) を用いたが, LD12:12で飼育すると, 両系統とも老齢期で過剰脱皮を繰り返して, 幼虫休眠に入った。LD12:12での老齢幼虫期間は, S系統で30~205日, E系統では24~208日であった。LD12:12での過剰脱皮の頻度は, S系統では23°C, E系統では25°Cで高かった。E系統ではこの他にLD16:8で2齢を延長して幼虫休眠する傾向も見られた。短日の効果は, 23-25°Cの中間温度でより顕著に見られ, 30°C高温では, ほとんどの個体が短期に発育を完了した。過剰脱皮は, 成虫のサイズの増加を伴わなかった。両系統の発育零点はS系統が15.3°C, E系統が14.9°Cと屋外の害虫に比べ両方とも高かった。20°CでのS系統の産卵数は, 23, 25, 30°Cに比べ, 半分以下であった。以上の結果から, この害虫の発育は, いくつかのチェックポイントで調節されており, この特性は絶滅にさらされたときに, 新たなコロニーの創設者を確保することができるという貯穀害虫の生活史に適応的なものと考えられる。人為淘汰の実験もこの形質の可塑性を示しており, 生理的な特性とともに, 遺伝的な多様性に富んでいることが示唆された。

住民の参加によるチョウ群集のモニタリング

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ABSTRACT

Monitoring of butterfly assemblages by nonprofessional citizens. Masashi Tashita¹⁾, Hiroshi Nakamura²⁾, Kiyoshi Maruyama³⁾, Masashi Fukumoto⁴⁾ (1) Amori 1863-1, Nagano, 380-0943 Japan; 2) Faculty of Agriculture, Shinsyu University, Minamiminowa 8304, Nagano, 399-4511 Japan; 3) Kashiwabara 1566-1, Hotaka, Nagano, 399-8304, Japan; 4) Oogou 3524-1, Kijimadaira, Nagano, 389-2301 Japan. *Jpn. J. Environ. Entomol. Zool.* : 16 : 9-16 (2005).

Butterfly assemblages were monitored using the route census method at Saigawa River in Matsumoto City on 14 June and 13 September 2003 by professional researchers and nonprofessional citizens. On 14 June, 9.0 species and 63.1 individuals on average were recorded by 8 professional researchers. On 13 September, 12.0 species and 62.0 individuals on average were recorded by 4 professional researchers, while 6.7 species and 18.8 individuals on average were recorded by 10 nonprofessional citizens. The number of individuals, Shannon-Weaver's H' and RI-index recorded by the nonprofessional citizens differed from those recorded by the professional researchers. In contrast, the average values of Simpson's 1-λ, ER'-index and HI-index recorded by the nonprofessional citizens were the same as those recorded by the professional researchers. In total, 21 species were observed by the 14 researchers in September. The nonprofessional citizens were able to identify many more species after they were provided with brief information about the target butterflies.

Key words : Butterfly assemblage, Route census method, Citizen, Environmental assessment, Matsumoto City, Nagano Prefecture

筆者らは、2003年6月および9月に長野県松本市犀川の河川敷において、住民参加によるチョウを指標とした環境モニタリング調査を実施し、住民参加による調査の有効性や環境保全に対する住民の関心の向上対策について検討した。6月の調査では、熟練者が平均して9.0種63.1個体を確認した。また、9月の調査では、熟練者は平均して12.0種62.0個体、非熟練者は6.7種18.8個体を確認した。非熟練者による調査では、C.V.係数の値が熟練者より大きく、とくに、個体数の把握に大きな開きが生じ、その結果、平均多様度H'やRI指数に差が生じた。しかし、1-λやER'、HI指数の平均値は熟練者と非熟練者の間で差がなかった。非熟練者では、種の認識率は比較的高いが、正確な個体数のカウントはむずかしいことがわかった。9月調査では、熟練者と非熟練者の合計で21種が確認されているが、多くの調査者による調査では、生息種の発見確率が向上した。以上から非熟練者であっても多くの調査者による調査は、種の分布の確認には効果的であると判断した。なお、同じ調査サイトでも、わずかに調査ルートが異なると、確認種数に有意な差がみられた。

はじめに

近年、開発や地球温暖化の影響等による生物多様性の減少や希少動植物の減少が長野県においても危惧されている(長野県編, 2004; 田下, 2002; 信州大学山岳科学総合研究所編, 2003)。こうした自然環境の変化は、単に、動植物

そのものの生存を脅かすばかりではなく、私たちの生活にも、新たな病気の発生や異常気象に伴う災害の発生、作物の不作など様々な悪影響を及ぼすものと考えられている(環境省編, 1997)。

このような中で、生物群集を用いた環境モニタリングの調査資料は、環境の変化を敏感にとらえることにより、生

物多様性や希少種の保全、さらには、私たちの生活環境について考え、対応策を検討していくうえでの基礎資料として重要な役割を持つものと思われる。

近年、人口の分布が都市部に集中し、住民の生活サイクルは、中山間地域で自然と共生しながら暮らしてきた時代から急激に変化してきている。そのため、住民自らが参加し、環境問題を考えることのできる仕組みを作り上げていくことは重要である。このような中で住民によるビオトープ作りの試み(塩原, 1996)や住民の意見を反映した生物の生息に優しい工法による社会資本整備(桜井, 1991)等環境保全のための試みが活発化してきている。

チョウ類(チョウ目のうちアゲハチョウ上科, セセリチョウ上科)は、一般住民になじみが深いばかりではなく、種が翅の斑紋から識別し易いこと、昼間活動する大型の昆虫であり見つけやすいこと、種数が昆虫類の中では小規模なグループで扱いやすいこと、愛好者が多いこと等、他の生物群と比較して、一般市民の参加による環境モニタリングには良い材料であると思われる。さらに、チョウを指標とした環境モニタリングの調査手法やその精度、評価手法に関しては、田中(1988)、石井ら(1991)、Kitahara *et al.*(1994)、中村ら(1995)、今井ら(1996)などがあり、日本環境動物昆虫学会編(1998)により、解説書が出版されるなど、調査環境が整うとともに、桜谷ら(1991)、清(1996a, b)、氷室ら(1994)、Tashita *et al.*(1996, 1997)、Spitzer *et al.*(1997)、有本(2002)、中村ら(2003)など調査実績が蓄積されてきている。

今回の調査は、チョウ類を通じた環境調査の機会を広く一般市民に広げていくために、チョウに関して特別に詳しい知識を持っていない一般市民の参加により環境モニタリング調査が実施可能であるか検討するために行った。

材料と方法

1. 調査地の概要

調査地は、長野県松本市倭地区、標高約 620 m の信濃川水系犀川の右岸で、温帯落葉広葉樹林帯にあたる。堤外地には、幅約 10 m にわたり、樹高 5 m ~ 7 m 程度のニセアカシア *Robinia pseudoacacia* L. やヤナギ類 *Salix* sp. がまばらに生えている。堤防上は、イネ科の外来種に混じって、アカツメクサ *Trifolium pratense* L., コマツナギ *Indigofera pseudotinctoria* Matsum., ハタザオ *Arabis glabra* Bernh., ムシトリナデシコ *Silene armeria* L. などが生え、比較的多様性に満ちた植生である。堤防は、定期的な草刈りが行われている。天然石のコンクリート練積の護岸には、長野県版レッドデータブックの準絶滅危惧種であるツメレンゲ *Orostachys japonicus* Berger が見られる。堤防天端付近の堤内地の植生は、ノイバラ *Rosa multiflora* Thunb. 等の灌木類が多く、ナンテンハギ *Vicia unijuga* A.Br. 等が減少し、草原植生は単調化してきている。堤内地の主な土地利用は水田である。流水側ルートの主な景観は、砂礫の河原やヤナギの高木、コマツナギの生える草地であり、堤防側ルートの主な景観は、ヤナギの高木とコマツナギの生える草地であった。

2. 調査の方法

調査は、2003 年 6 月 14 日と 9 月 13 日の 2 日間行った。6 月 14 日の調査では、チョウに関して詳しい知識と高い識別能力がある 8 名の調査者が堤防の天端上 500 m 区間を 30 分で往復し、調査者の前方で見かけたチョウの種類と個体数を調査した。

9 月 13 日は、堤外地で、流水側と堤防に近い側の 2 ルートに分かれて 30 分間、チョウの種類と個体数を数えた。流水側ルートでは、チョウに関して詳しい知識と高い識別能力がある調査者 4 名と昆虫に関心はあるが、チョウに関しては特に詳しい知識をもっていない調査者 10 名の計 14 名が、堤防側ルートでは、チョウに関して詳しい知識と高い識別能力がある調査者 3 名が参加して行った。両ルートは、およそ 30 m 程離れて並行している。両ルートの調査は、同時刻に熟練者と非熟練者が混じって全員一斉に実施した。各調査者は、10 m 程度の範囲にできる限り固まって調査を行った。調査の開始前に天候、気温及び照度を記録した。

調査に先立ち、現地で見ることのできる種を記載した簡単な図鑑を参加者に配布し、現地で見ることのできるミヤマシジミ、ヒメシロチョウ *Leptidea amurensis* Menetries 等の貴重種について説明した。

3. 評価手法

チョウ類の群集構造については、種の多様性を示す指標により熟練者と非熟練者の記録を比較し、非熟練者の記録の信頼性を検討した。評価指標として、Shannon の平均多様度 H' (木元ら, 1989)、Simpson の多様度指数 $1-\lambda$ (日本環境動物学会編, 1998)、RI 指数 (中村ら, 1995)、環境階級存在比 ER (田中, 1988)、環境階級度 ER" (田下ら, 1997) および HI 指数 (田下ら, 1997) を用いた。

平均多様度 H' は次式で算出した。

$$H' = -\sum (n_i/N) \log_2 (n_i/N)$$

また、多様度指数 $1-\lambda$ は次式で算出した。

$$\lambda = \sum n_i(n_i-1) / N(N-1)$$

ここで、 N は総個体数、 n_i は i 番目の種の個体数である。

RI 指数は次式により求めた。

$$RI = \sum R_i / S(M-1)$$

ここで、 S は全種数、 M は 4 である。 R_i は、観察されないうとき 0、1~2 個体を観察したとき 1、3~9 個体を観察したとき 2、10 個体以上観察したとき 3 として計算した。

環境階級存在比 ER は次式により求めた。

$$ER(X) = (\sum X_i \cdot T_i \cdot I_i) / (\sum T_i \cdot I_i)$$

また、各階級の指数に重みづけを行うことにより、一次元化した環境階級度 ER" を次式により計算した。

$$ER'' = (((4ER(ps) + 3ER(as) + 2ER(rs) + ER(us)) - 10) / 30) \times 100$$

本指数は、原始段階の環境から都市化した環境へ 100 から 0 の値を示す。

ここで、 X_i は i 番目の種の各環境段階 (α : 原始段階(ps), β : 非定住利用段階(as), γ : 農村・人里段階(rs), δ : 都市段階(us)) の生息分布度、 T_i は i 番目の種の総個体数、 I_i は i 番目の種の指標値である。

また、人為による土地への攪乱の状況を判別するため

に、HI 指数を下記により算出した。

$$HI = \sum niDiFi / (\sum 3niDi) \times 100$$

当指数は、ER”と同様に原始段階の環境から都市化した環境へ 100 から 0 の値を示す。

ここで、ni は i 番目の種の個体数、Di は分布の広さの指数で、①都市（住宅地）②耕作地③浅い山地・里山④深い山地の植栽林・二次林⑤極相的環境の 5 つのうち、すべての環境に生息する種、4 つの環境に生息する種、3 つの環境に生息する種、1~2 の環境に生息する種に、それぞれ、0, 1, 2, 3 の値を与えた。Fi は幼虫期の食性の指数で、食草の大部分が帰化植物・栽培種や攪乱地への先駆植物である種には 0, どちらかという帰化植物・栽培種・攪乱地への先駆植物を多く食する種には 1, どちらかという上記の植物種以外を多く食する種には 2, 食草の大部分が上記植物種以外の種には 3 の値を与える。

結 果

1. モニタリング調査全般について

調査日における天候、調査時刻、調査ルートおよび参加者を表1に示す。9月13日は堤防上を強風が吹いていたが、調査ルートを設定した堤外地は風が弱く、チョウは普通に飛翔していた。各調査日ごとにそれぞれの調査者が確認したチョウの種類と個体数を表2-1、表2-2に示す。

6月14日には、8名の熟練者(a~h)が調査し、それぞれの調査者が8~11種、41~80個体を確認した。全体では、13種が見つかり、うちヒメウラナミジャノメ、モンキチョウ、アサマイチモンジが個体数で上位3位を占めた。

9月13日には、流水側を熟練者4名(a,f,h,i)、非熟練者10名(A~J)が、堤防側を熟練者3名(b,d,e)が調査した。各調査者ごとの確認種数と個体数は、表2-2のとおりで17名の合計で21種が確認された。うちミヤマシジミ、キチョウ、イチモンジセセリが個体数で上位3位を占めた。

2. ルート別の調査結果

9月13日に行ったルート別の調査について、熟練者が行った流水側ルートと堤防側ルートを比較した。どちらのルートもミヤマシジミ、キチョウ、イチモンジセセリが優占

種であった。しかし、ミヤマシジミの個体数は、堤防側ルートで著しく高い値を示した。種数は、調査者の平均値と比較すると流水側ルートで4種多く確認された。H'とRI指数は流水側ルートの方が高く(表3)、ER(図1-1、図1-2)は、堤防側ルートの方が原始段階の数値が高く、HI指数(表3)も堤防側ルートの方が高かった。

3. 熟練者と非熟練者の調査結果のちがいが

6月14日(8名)、9月13日(堤防側3名、流水側4名)に行った熟練者による確認個体数および種数は、有意な個人差を示さなかった(Freedman 検定、有意確率 0.2343-6月14日、0.0821-9月13日堤防側、0.7384-9月13日流水側)。しかし、9月13日に行った非熟練者10名の調査では、確認個体数および種数に有意な差が生じた(Freedman 検定、有意確率 0.0218)。9月13日に行った熟練者4名および非熟練者10名の確認種数および個体数について、C.V.を表4に示す。熟練者、非熟練者ともに種類よりも個体数でC.V.が大ききな値を示し観察者による誤差がより大きくなることがわかった。9月13日の調査の熟練者と非熟練者との間では、種数、個体数ともに有意の差が出ている。

9月13日の確認個体数上位3種を調査者別に表5に示す。優占種の確認個体数は、熟練者と非熟練者の間で大きく異なるものの、上位3種のキチョウ、ミヤマシジミ、イチモンジセセリは、調査者による若干の相違はあるものの、ほぼ似た傾向で確認できている。表5を基に熟練者4名から種の順位と個体数の95%信頼幅を算出し、非熟練者10人の正解率を調べると、種の順位では53.3%と比較的高く、個体数では、13.3%と低かった。

熟練者と非熟練者それぞれによる種ごとに確認できた調査者の割合を表2に示す。長野県の希少種であるミヤマシジミは、非熟練者の9割が確認できている。また、熟練者と非熟練者それぞれによる種ごとの確認個体数を表3に示す。熟練者の方が明らかに多くの個体を確認できる結果となった。

図4には、各調査者ごとに確認できた種と見落としした種の割合を示した。6月14日には、8名で13種が、9月13日には、14名で種名が不詳な種を除き18種が確認されているが、非熟練者では、およそ60%の種を見落とししており、

表1 各調査日の天候、調査時刻、調査ルートおよび参加者

調査日	天候	気温 ¹⁾ ℃	照度 ¹⁾ lux	調査時刻	調査ルート	参加者					
						識別能力	小学生	中高生	社会人	計	
2003.6.14	曇り	27.5	52,700	11:10 ~ 11:40	堤防 天端	熟練者		1	7	8	
						熟練者		1	3	4	
2003.9.13	曇~晴 (強風)	28.5	28,900 ~ 93,800	10:30 ~ 11:00	堤外地 流水側	熟練者		7	1	2	10
						非熟練者					
					堤外地 堤防側	熟練者			3		3

1) 気温、照度は、調査開始前に測定。