CLEOPUS JAPONICUS, A POTENTIAL BIOCONTROL AGENT FOR *BUDDLEJA DAVIDII* IN NEW ZEALAND

X. ZHANG, Y. XI, W. ZHOU

Department of Plant Protection, Nanjing Agricultural University,
Nanjing 210014, People's Republic of China

and M. KAY

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 13 January 1992; revision 29 June 1993)

ABSTRACT

Laboratory populations of *Cleopus japonicus* Wingelmüller (Coleoptera : Curculionidae) were studied in controlled conditions. A constant temperature of about 20°C and a photoperiod of up to 14 hours appeared to optimise survival and oviposition of *C. japonicus* and indicated that this weevil should readily acclimatise to conditions in New Zealand.

Keywords: ecology; photoperiod; temperature; *Cleopus japonicus*; *Buddleja davidii.*

INTRODUCTION

Since 1989 a research programme at the Nanjing Agricultural University in People's Republic of China, has investigated the feasibility of classical biological control for *Buddleja davidii* Franchet. This ornamental shrub from central China occurs throughout New Zealand and has become an invasive weed of exotic and indigenous forests of the Bay of Plenty (Kay & Smale 1990). Through field surveys and laboratory studies, the defoliator *Cleopus japonicus* assumed importance as a potential agent for control of *B. davidii* because of its ubiquity and apparent host specificity. Both adults and larvae "graze" the upper leaf surface, leaving the lower trichomatous epidermis intact. Heavily attacked leaves wither and small plants may be killed.

Cleopus japonicus is multivoltine, and adults and larvae are common in spring and autumn. Pupation takes place in the leaf litter beneath the host plant. After a 5-day teneral period the female begins mating and 15 days later oviposits single eggs (occasionally two to three eggs) into the leaf at numerous sites during the night. Mating and oviposition occur readily in the laboratory. Maximum recorded egg production is 250 and the average is 130 eggs/female (Zhang unpubl. data).

Field observations over two seasons showed that the growth and abundance of natural populations of *C. japonicus* in central China (latitude 30°N) were high in spring and autumn, but during summer, when temperatures may exceed 30°C, there appeared to be an ovipositional aestivation, as population densities were extremely low and females were never found laying eggs.

To most biological control practitioners, climate-matching of targets and agents is a basic prerequisite during selection of potential biological control agents (Lawton 1990). In the study reported here laboratory populations of the weevil were subjected to different conditions of temperature and photoperiod in order to determine the relationship between these environmental factors and survival, fecundity, and rates of development.

MATERIAL AND METHODS

Overwintering adults were collected from Zhang Jia Jie National Forest, Hunan province P.R.C., in May 1991. The first generation, from newly deposited eggs, was reared on sprigs of the host plant *B. davidii* at combinations of five different temperatures (16°, 20°, 24°, 28°, 32°C) and four photoperiods (L:D 8:16 h, L:D 12:12 h, L:D 14:10 h, L:D 16:8 h. The stems of the host plant material were held in water-filled vials. The test insects were transferred to new material, which was introduced as required to maintain plant turgor and/or an adequate food supply. All experiments were carried out in cabinets where fluctuations in temperature were controlled within ± 1°C. Light in the cabinets was provided by two 8-W fluorescent tubes. Photoperiod was controlled automatically by electronic clocks. The development, survival, and oviposition were observed and recorded at 12-h intervals. Results were subjected to analysis of variance.

RESULTS

Effect of Temperature on Survival

The survival of each developmental stage at given temperatures is shown in Table 1. Survival to eclosion was low for eggs at 16°C or above 24°C; larval survival from 16°C to 28°C was adequate. Successful pupation declined with increasing temperatures and adults failed to emerge from pupae above 24°C.

Effects of Temperature and Photoperiod on Growth and Development

The duration of each stage of weevil development at different temperatures is listed in Table 2. The development rate at each stage accelerated as the temperature rose from 16° to 28°C, but at 28° and 32°C the weevil could not complete its life cycle and died in the pupal stage. Development rate over one whole generation was most rapid at 24°C, for which the average time from egg to pre-ovipositional adult was 50.5 days.

Photoperiod had little effect on development. For example, the effects on the development of different stages under four different photophases at 20° and 24°C, where egg to adult survival was greatest, are compared in Table 3. Variance analysis of data from 20° and 24°C

TABLE 1–Survival (%) of various stages of *Cleopus japonicus* at different temperatures. Number per treatment is given in parentheses.

Stage	Temperature (°C)				
	16	20	24	28	32
Egg	19.8 (106)	91.8 (283)	75.1 (273)	19.0 (242)	0 (242)
First instar	57.1 (21)	86.2 (260)	86.3 (205)	91.3 (46)	0 (0)
Second instar	100 (12)	91.5 (224)	90.4 (177)	88.1 (42)	0 (0)
Third instar	66.7 (12)	92.7 (205)	97.5 (160)	97.3 (37)	0 (0)
Larva	38.1 (21)	73.1 (260)	76.1 (203)	78.2 (46)	0 (0)
Pupa	87.5 (8)	82.1 (190)	50.6 (156)	0 (36)	0 (0)
Egg to adult	6.6 (7)	55.1 (156)	28.6 (78)	0 (0)	0 (0)
Adult*	75.0 (7)	75.0 (156)	62.5 (78)	0 (0)	0 (0)

* Survival rate in adult stage means the survival from emergence to oviposition

TABLE 2–Duration (days) of developmental stages of *Cleopus japonicus* at four different temperatures. Number per treatment is given in parentheses.

Stage	16°C		20°C		24°C		28°C		F-value
	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	
Egg	13.57 (106)	0.61	11.99 (283)	0.73	9.00 (273)	0.26	7.06 (242)	0.15	51.45 **
First instar	6.88 (21)	0.17	4.19 (260)	0.41	3.30 (205)	0.09	2.84 (46)	0.14	81.07 **
Second instar	5.75 (12)	0.64	4.25 (224)	0.40	3.68 (177)	0.20	2.59 (42)	0.06	19.54 **
Third instar	5.80 (12)	0.14	3.28 (205)	0.34	2.95 (160)	0.22	2.28 (37)	0.18	53.04 **
Total larva	18.43	0.95	12.18	1.03	9.93	0.42	7.71	0.28	61.27 **
Pupa	21.65 (8)	0.92	14.95 (190)	0.64	12.71 (156)	0.57	died		124.80 **
Pre-ovipositional adult	36.50 (7)	0.71	22.0 (156)	1.56	19.00 (79)	0.82			153.02 **
Total	90.15	3.18	61.61	3.26	50.47	0.97			81.07 **

** significant at $p < 0.01$

$\bar{x}$ mean

Sx standard deviation

showed that there were no significant differences between these photoperiods at the same temperature, whereas there was a significant difference between temperatures. Data for different photoperiods at the same temperature were combined and approximate developmental thresholds and thermal constants for each developmental stage of the weevil were arrived at by extrapolation of the regression of the inverse development time and temperature (Table 4). The developmental threshold temperature (DT) (i.e., the theoretical temperature above which development takes place) and the thermal constant (i.e., the product of temperature (°C) and time (days) above DT) for a generation were calculated as 5.7 ± 1.7°C and 907 degree-days, respectively.

TABLE 3–Duration of various stages of *Cleopus japonicus* under different temperatures and photoperiod. Number per treatment is given in parentheses.

Stage	Temperature (°C)	Photoperiod (h)				F value
		8	12	14	16	
Egg	24	8.95 (58)	8.65 (81)	9.10 (66)	9.28 (68)	0.56
	20	13.02 (54)	11.97 (86)	11.59 (57)	11.38 (86)	
Larva	24	9.84 (52)	9.55 (51)	10.38 (15)	10.07 (42)	0.41
	20	13.51 (35)	12.43 (53)	11.14 (43)	11.63 (74)	
Pupa	24	12.74 (52)	13.00 (49)	11.92 (14)	13.21 (41)	2.49
	20	15.41 (29)	15.58 (51)	14.32 (42)	14.49 (68)	

$F_{0.05} = 9.28$; $F_{0.01} = 29.46$

TABLE 4–Development threshold and thermal constant for various stages of *Cleopus japonicus*

Stage	Development threshold (°C)	Thermal constant (degree-days)
Egg	5.0 ± 2.6	165
First instar	7.1 ± 1.6	57
Second instar	7.0 ± 2.6	56
Third instar	8.1 ± 0.5	45
Larva	7.1 ± 0.9	162
Pupa	4.6 ± 2.5	240
Adult	7.5 ± 3.2	298
Generation	5.7 ± 1.8	907

Effect of Photoperiod and Temperature on Reproduction

Adults were held at three temperatures and four photoperiods in an attempt to determine the interactions between ovipositional aestivation and these environmental conditions. The results from the treatments tested (Table 5) demonstrate that from 8 h to 14 h photoperiod the pre-oviposition period of adults decreased as temperature increased, while at the same temperature, increasing photoperiods appeared to have little influence on pre-oviposition periods until the photoperiod was extended to 16 h. Adults reared at 20° and 24°C and 16 h photoperiod died without laying eggs.

DISCUSSION

In spite of the limitations of constant temperature observations (Beck 1983), the results reported here indicate that, for the biological control of *B. davidii,* the weevil *C. japonicus* should be able to acclimatise to conditions in New Zealand. For the population tested, the developmental threshold temperature was about 6°C and the weevil exhibited optimal growth, survival, and reproduction at about 20°C, with up to 14 h photoperiod. Meteorological records from the three main forests of the Bay of Plenty (Matahina, Kinleith, and Kaingaroa)

TABLE 5–Pre-oviposition period in days (P) and fecundity* for *Cleopus japonicus* at different temperatures and photoperiods. Number per treatment is given in parentheses.

Temperature (°C)	Photoperiod (h)							
	8		12		14		16	
	P	Fecundity	P	Fecundity	P	Fecundity	P	Fecundity
16			37.0 (3)	34			36.0 (4)	73
20	24.0 (25)	301	20.2 (44)	421	21.8 (33)	438	47.6† (54)	0
24	18.0 (37)	403			20.0 (11)	233	44.5 † (31)	0

* Mean eggs laid per adult/2 till death

† No oviposition in these conditions

show daily mean summer temperatures of 14.7°–19.7°C (mean minimums 9.3°–14°C, mean maximums 20.1°–25.4°C) and day length of 13–14.75 h. A developmental threshold of about 6°C, and a thermal constant for a generation of about 900 degree-days, could result in two generations per season in the coldest forest, Kaingaroa, and three generations per season in warmer coastal forests (New Zealand Meteorological Service 1978). It is possible that temperature extremes of 28°–32°C recorded in Matahina may cause some mortality; however, conditions over-all should be less extreme than those of central China.

The low survival of eggs and first instar larvae recorded at 16°C was possibly due to the extended period these stages spent in the artificial conditions of the trial. As their threshold temperature is about 6°C, the mortality witnessed was unlikely to be the result of low-temperature stress.

The decline in pupal survival at 24°C may indicate that pupation is a critically temperature-sensitive stage in the insects' life-cycle. At 28°C, failure of the pupal stage was absolute.

It appears that a long photoperiod (16 h) is a trigger for ovipositional aestivation but at temperatures lower than 20°C this effect is abated. The negative effect on reproduction of a photoperiod longer than 14 h may have some relevance at higher latitudes, but is unlikely to be responsible for the apparent mid-summer aestivation in China where maximum daylength is 14 h at latitude 30°N (Anon 1991). The mid-summer hiatus in the population of *C. japonicus* in central China is probably a reflection of pupal mortality at high temperatures.

The fecundity recorded from this trial was generally higher than previously recorded averages (Zhang unpubl. data) and suggests that the sex ratio of adults in the trial was biased in favour of females.

ACKNOWLEDGMENTS

The authors thank Dr G. Kuschel for the identification of *Cleopus japonicus*. The funding for the research in China was provided by NZFP Forests Ltd, P.F. Olsen and Co. Ltd and Tasman Forestry.

REFERENCES

ANON. 1991: "Cosmos™". Future Trends Software Inc., Texas.

BECK, S.D. 1983: Insect thermoperiodism. *Annual Review of Entomology 28*: 91–108.

KAY, M.; SMALE, M.C. 1990. The potential for biological control of *Buddleja davidii* Franchet in New Zealand. Pp. 29–33 *in* Bassett, C.; Whitehouse, L.J.; Zabkiewicz, J.A. (Ed.) "Alternatives to the Chemical Control of Weeds". Proceedings of International Conference, Rotorua, July 1989. *Ministry of Forestry, FRI Bulletin No.155.*

LAWTON, I.H. 1990: Biological control of plants: A review of generalisations, rules, and principles using insects as agents. Pp. 3–17 *in* Bassett, C.; Whitehouse, L.J.; Zabkiewicz, J.A. (Ed.) "Alternatives to the Chemical Control of Weeds". Proceedings of International Conference, Rotorua, July 1989. *Ministry of Forestry, FRI Bulletin No.155.*

NEW ZEALAND METEOROLOGICAL SERVICE 1978: Average Degree day Tables, Selected New Zealand Stations. *New Zealand Meteorological Service Miscellaneous Publication 159.* 55 p.