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Temperature and Development of Cinnabar Moth, *Tyria jacobaeae* (Lepidoptera: Arctiidae), in New Zealand

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Abstract

The effect of temperature on the larval development and mortality of cinnabar moth, *Tyria jacobaeae*, was investigated. At constant temperatures of 12, 15, 20, 25 and 30°C the times taken from egg to pupa were 106, 71, 34, 24 and 19 days respectively. Corresponding mortalities were 95, 70, 41, 51 and 56%. The lower threshold temperature for development was 11°C. Viabilities of pupae reared as larvae at 15, 20, 25 and 30°C were 91, 78, 76 and 53% respectively. These results, in relation to field data on life stages of *T. jacobaeae* from one site in the southern North Island of New Zealand, and meteorological data for years when populations were observed to be high in the region, indicate a possible correlation of high populations with high spring temperatures.

Introduction

The cinnabar moth, *Tyria jacobaeae* (L.) (Lepidoptera: Arctiidae), was first introduced into New Zealand in 1929 for control of ragwort, *Senecio jacobaea* L. (Compositae). Although released at many sites throughout the country, it has persisted only in the southern part of the North Island (Syrett *et al.* 1984). Redistribution from this surviving population to other areas has been undertaken since 1982, and indications are that at some sites the insects are establishing well (Syrett and Harman unpubl. data). Some factors which adversely affect establishment (parasitism and disease, unfavourable climatic conditions and the moth's limited powers of dispersal) have been identified by workers in other countries (Syrett 1983), but the reason for much higher populations building up in some years than others (Anonymous 1979), although attributed to climate, has not been clearly identified in New Zealand.

The climatic factor which has been most studied is rainfall. It has been shown at sites in the United Kingdom and North America caterpillars can reach sufficiently high populations to deplete their food resource causing violent fluctuations in numbers. The availability of ragwort is affected by rainfall, which in turn has a controlling influence on caterpillar numbers (Dempster and Lakhani 1979). At sites with wetter summers there is no relationship of plant numbers and hence caterpillar numbers with rainfall (Lakhani and Dempster 1981). Dempster (1971) noted that pupal mortality could be very high in waterlogged soils indicating that soil type and winter rainfall could have a significant effect on populations.

Areas in New Zealand where *T. jacobaeae* is established have rainfall comparable to the wetter areas overseas and observations indicate that caterpillars are rarely if ever resource-limited. It is concluded that other factors must be contributing to population control. The aim of this study was therefore to investigate the possible effects of temperature on populations of *T. jacobaeae* in New Zealand. There is little published information on the effects of temperature on *T. jacobaeae* elsewhere, apart from a laboratory study by Philogène (1975). Larvae were reared at two constant temperatures (21 and 28°C) and adverse effects were noted at the higher temperature. Philogène concluded that hot weather in spring and early summer could be detrimental to the insect.

Methods and Materials

Laboratory Studies

Ragwort leaves bearing egg batches aged 0 to 24 hr were removed from plants caged with adult moths. Each leaf with its batch of approximately 30 eggs was held in a vial of water plugged with plastazote and the vial placed in a transparent ventilated container (100 x 100 x 120 mm) with a lid and with a piece of filter paper in the bottom. Three of these containers were placed at each of seven temperatures (10, 12, 15, 20, 25, 30, 35 ± 1°C) under a 16:8 LD photoperiod in Contherm® temperature controlled cabinets. Humidity was maintained between 50 and 80% RH by moistening the filter paper in each container. As the insects hatched they were transferred into labelled transparent plastic containers (80 x 80 x 110 mm) with filter paper and holding a bouquet of fresh ragwort leaves wrapped in moist cotton wool. Larvae were transferred daily as a group to fresh food. When larvae within a group moulted they were separated from those still at the previous instar. In this way the insects could be followed from egg to pupa with the duration of each instar known for each individual. The mortality at each instar was noted also. When the larvae pupated they were transferred to room temperature in plastic containers (100 x 100 x 120 mm) filled with strips of tissue paper and lined with cardboard to exclude light. These were kept over winter under ambient conditions and checked the following spring for the percentage of pupae emerging as adults.

Threshold temperatures for the development of each stage were determined by the regression of the rates of development against temperature in the zone where development is a linear function of temperature, extrapolation through the x-axis providing the lower threshold temperature (Campbell *et al.* 1974).

Although this model has limitations in accurate prediction of field behaviour, particularly at temperatures close to the threshold (Logan *et al.* 1976, Wagner *et al.* 1984) it was considered adequate here since we had insufficient field data to require a more sophisticated model. Thermal requirements (physiological time) of the eggs and larvae to complete development were determined from the reciprocal of the slope of the straight line taken from the regression equations obtained earlier.

Field Studies

A site with a good population of *T. jacobaeae* was selected 3 km along Kaiporora Road off State Highway 2 between Eketahuna and Masterton. The ragwort area, on a river bank and bounded by forestry plantation was lightly grazed by cattle. Two-weekly samples of life stages of *T. jacobaeae* were taken during summer 1982-3 from 8-11-82 until 16-3-83. Fifty ragwort stems were randomly selected and hand-searched in the field for eggs and larvae. All egg batches were noted and the total numbers of eggs counted. The five larval instars could be separated visually and the numbers of each instar found on the stems were recorded. All adults encountered during the sampling time were collected.

Meteorological Data Study

Rainfall and mean daily temperature records for four climate stations in the area where *T. jacobaeae* is well established (southern North Island) were examined (N.Z. Met. Service 1969-81). Years when high populations of caterpillars were reported (1969-74 and 1978-9) were compared with years when numbers were reported to have declined (1975-77 and 1980-81). Although this information is anecdotal (Anonymous 1979, R.S. Morgan and J.B. Pearson pers. comm.) we consider observations from professional noxious plants officers to be reasonably reliable since they are based on regular observation over a wide geographical area. One-way ANOVA was used to test differences in total spring (October to December), summer (January to March) and winter (April to September) rainfall, as well as maximum daily rain in winter. Differences between spring and summer temperatures were also tested for significance.

Results and Discussion

Laboratory Studies

The duration of each developmental stage at different temperatures is shown in Table 1. Data from those individuals that failed to complete development through to pupation was not included. The relationship between developmental time and temperature for all stages is presented in Figure 1. Lower threshold temperatures were 11, 11, 11, 12, 11 and 6°C for eggs, 1st, 2nd, 3rd, 4th and 5th instar larvae respectively.

Physiological time for development is also shown in Table 1. Approximately 380 day-degrees are required for eggs of *T. jacobaeae* to develop through to pupae. No eggs hatched at either 10 or 35°C. However first instar larvae hatched at room temperature and then transferred to 35°C survived into the 3rd or 4th instar. Mortalities at each temperature are shown in Figure 2. Mortality from egg to pupa at temperatures of 12, 15, 20, 25 and 30°C was 95, 70, 41 ± 29, 51 ± 20 and 56 ± 14%, respectively.

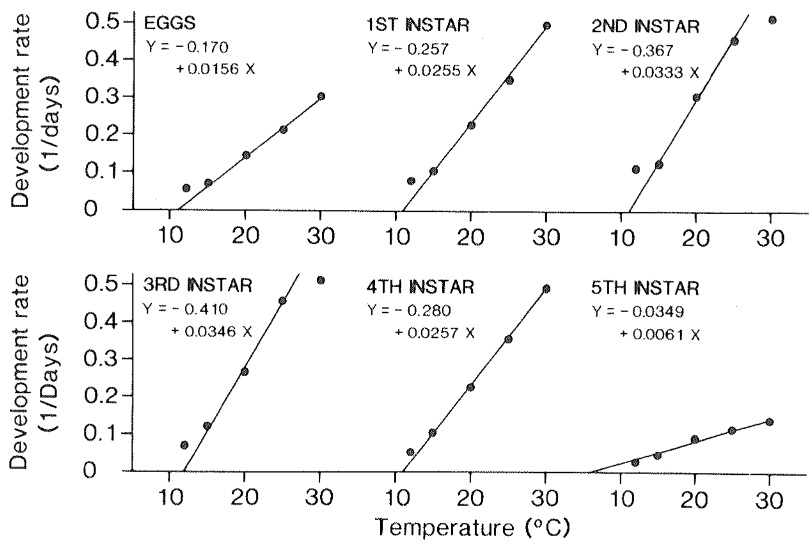

Figure 1. Development rates of egg and larval stages for *Tyria jacobaeae* (L.) under a series of constant temperature regimes.

Table 2 shows the viability of pupae from individuals reared at different temperatures.

Field Studies

Numbers of male and female moths sampled are shown in Figure 3. Figure 4 shows the numbers of eggs and larvae recorded. No first instar larvae were noted. First instars are relatively inconspicuous and may have been overlooked. Second and 3rd instars also may be under-represented.

Meteorological Data Study

No significant differences were recorded between high and low caterpillar years for rainfall or for summer temperatures. Differences in mean spring temperatures (October to December) were highly significant at three stations and significant at one (Table 3).

Table 1. Number of days (±S.E.) taken by each stage of *Tyria jacobaeae* (L.) under a range of constant temperature conditions. Results include only those larvae that pupated (except for those at 35°C). Physiological time (D°) has been calculated from the slope of the regression line.

	Temperature (°C)						
Stage	12	15	20	25	30	35	D°
Eggs	18.3 ± 0.6*	16.7 ± 0.6	7.0 ± 0.3	4.8 ± 0.7	3.6 ± 0.8	-	64.1 ± 3.4
Instars							
1st	12.7 ± 0.6	9.7 ± 0.7	4.4 ± 0.5	2.9 ± 0.6	2.1 ± 0.4	2.3 ± 0.6	39.2 ± 2.1
2nd	9.3 ± 3.2	8.0 ± 0.5	3.3 ± 0.6	2.3 ± 0.6	2.0 ± 0.2	2.1 ± 0.5	30.0 ± 1.8
3rd	14.0 ± 2.0	8.2 ± 0.7	3.8 ± 0.4	2.2 ± 0.4	2.0 ± 0.2	4	28.9 ± 1.1
4th	18.7 ± 3.1	9.3 ± 0.7	4.4 ± 0.6	2.8 ± 0.4	2.0 ± 0.2	-	38.9 ± 1.0
5th	34.7 ± 4.2	20.2 ± 1.3	10.8 ± 0.8	8.4 ± 0.7	7.0 ± 4.6	-	163.9 ± 4.6
Egg to pupa	106.3 ± 1.6	71.1 ± 1.7	33.8 ± 1.3	23.5 ± 1.4	18.6 ± 1.2	-	383.1 ± 5.9
N	3	21	41	58	36	-	-

* Days ± SE.

Table 2. Viability of pupae of *Tyria jacobaeae* (L.) reared at constant temperatures and overwintered under ambient conditions.

Parameter	Temperature (°C) 15	20	25	30
No. of pupae	21	51	58	36
No. of adults emerged	19	40	44	19
Viability (%)	91	78	76	53

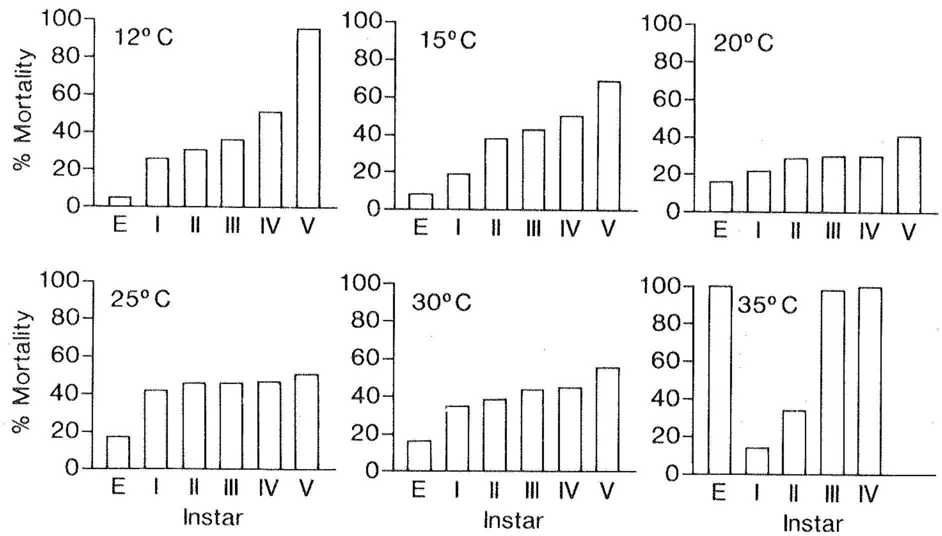

Figure 2. Mortality of life stages of *Tyria jacobaeae* (L.) under a range of constant temperature conditions.

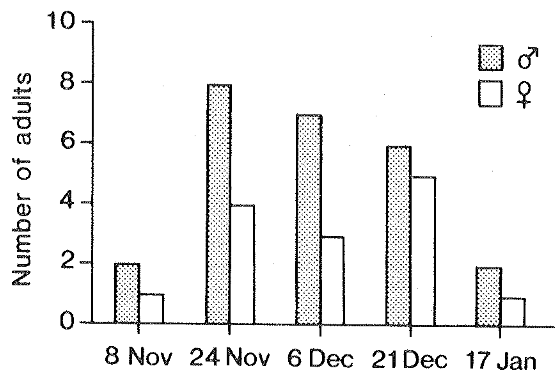

Figure 3. Numbers of adult cinnabar moth, *Tyria jacobaeae* (L.) caught at Kaiporora Road during summer 1982-83.

Results of laboratory experiments are close to those of Philogène (1975). He obtained development times of 33.1 and 33.2 days for larval stages at 21°C and 23 and 19.7 days at 28°C and also noted a decrease in pupal viability, a higher proportion of ill-formed pupae and increased failure of adults to emerge properly at the higher temperature. There is a marked difference in threshold temperature for the 5th instar larva. This instar differs from the others in that it is at least twice as long in duration and for much of the latter part of the instar the larva is not feeding. Including this non-feeding time gives an artificially slow rate of development and low threshold temperature. Logan *et. al.* (1985) omitted non-feeding time in the final instar of Colorado potato beetle to give a better estimate of developmental rates. Development was fastest at 30°C and there was no significant difference in mortality between temperatures of 15-30°C. Although this seems to indicate that *T. jacobaeae* in New Zealand is well-adapted to high temperature conditions, viability of overwintering pupae reared as larvae at 30°C was substantially reduced (Table 2). The true optimum temperature is probably between 20 and 25°C.

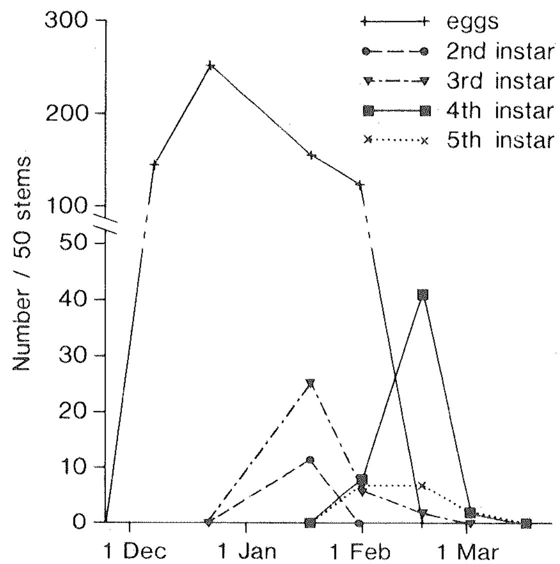

Figure 4. Numbers of egg and larval stages of *Tyria jacobaeae* (L.) collected from Kaiporora Road during summer 1982-83.

The Kaiporora field site is close to Mt Bruce, and thus cooler than other sites where *T. jacobaeae* is established (Table 3). Also in 1982-3 when these observations were made, spring temperatures were lower than average (NZ Met. Service 1982). Therefore it is likely that in other areas where *T. jacobaeae* is established and in other years development may be more advanced. Peak adult numbers were recorded in late November to early December. Miller (1970) noted that moths have been observed in the field as early as August, and although this is probably exceptional, moth numbers may peak earlier at other sites. Eggs were found in the field over a period of two months. They take an average of two weeks to hatch in the field in Europe (Dempster 1982), which corresponds to a mean temperature of 15°C, from our results. Larvae were present from January to March. The duration of the larval stage is said to be about one month in Europe (Miller 1970), which is equivalent to a constant temperature of about 18°C.

It is interesting to speculate why differences in mean temperatures in spring between years with high and low caterpillar numbers are significant while those in summer are not. In spring mean temperatures are all less than 14.5°C while in summer mean temperatures are all above 15.5°C.

Table 3. Mean daily temperature (October to December and January to March) at four climate stations in the southern North Island of New Zealand where *Tyria jacobaeae* (L.) is established.

Site	October to December 1969-74 and 1978-9	October to December 1975-77 and 1980-81	January to March 1969-74 and 1978-9	January to March 1975-77 and 1980-81
Masterton	14.2	13.1 **	17.2	17.4 ns
Mt Bruce	12.9	12.1 *	15.7	15.5 ns
Waiorongomai	14.1	13.2 **	16.9	16.5 ns
Wallaceville	14.1	12.9 **	16.8	16.4 ns

Code: ** = significantly different ($p < 0.01$); * significantly different ($p < 0.05$); and ns not significant.

Optimum survival of *T. jacobaeae* occurred for constant temperatures above 15°C, and mortality was higher at 12°C. It may be that under cooler conditions in spring, warmer than average temperatures are conducive to survival, while under summer conditions average temperatures are always sufficiently high that differences are not critical. Observations on populations transferred to new sites indicate that moths and larvae often appear earlier than at Kaiporora Road (Syrett and Harman, unpubl. data), but even so, at many sites a large proportion of larval development must take place in summer (January to March). Thus it is unlikely that the effect of temperature on larval development alone is causing the differences in population size. It has been noted by one of us (JJD) that adult moths are very inactive in cool conditions. We are planning to investigate the effect of temperature on fecundity to see whether this could be a contributing factor.

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