Evaluation of Degree-Day and Julian-Day Logistic Models in Predicting Cabbage Maggot (Diptera: Anthomyiidae) Emergence and Flight in Upstate New York[1]

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Abstract A 2 yr (1999-2000) study using water-pan traps in the field indicated four generations, including the spring generation, of cabbage maggot adults, *Delia radicum* (L.), in upstate New York. On average over the 2 yrs, an accumulation of 160.7 ± 8.1 degree-days and 120 ± 3 Julian-days was required for the first adult emergence of flies from overwintered puparia (spring generation). The emergence of 10% of the population required a mean accumulation of 176.6 ± 3.8 degree days and 122.0 + 1.0 Julian days, 25% emergence required 204.2 ± 2.3 degree days and 125.0 ± 1.0 Julian days, 50% emergence required 251.3 ± 3.5 degree-days and 129.3 ± 1.5 Julian days, 75% emergence required 297.6 ± 30.4 degree-days and 132.0 ± 0.0 Julian days, and 95% emergence required 390.9 ± 10.1 degree days and 141.0 ± 3.0 Julian days. From the emergence of the first adult flies, the population required a mean accumulation of 449.2 ± 1.4 degree days to complete the spring emergence. For complete emergence of flies, the F_1 generation required a mean accumulation of 508.4 ± 32.9 degree days, the F_2 generation required 465.3 ± 21.5 degree days and the F_3 generation required 399.1 ± 3.1 degree days. With the help of a degree-days model, it is possible to predict fly emergence in the spring and succeeding generations. This model can help growers minimize insecticide use through better timing of treatments or adjustment of planting dates. In addition, this model will be useful in developing sampling plans and control strategies for immature stages of cabbage maggot.

Key Words Cabbage maggot, *Delia radicum*, cabbage, degree days, logistic model

The emergence pattern of individuals in an insect population has ecological significance and pest management implications. Knowledge of the emergence pattern of an insect species allows one to forecast seasonal cycles of insect populations and provides insights into ovipositional patterns and potential infestation levels by the immature stages.

The cabbage maggot, *Delia radicum* (L.), is a chronic pest of cruciferous vegetable crops in the Northern Hemisphere (Bomford et al. 2000) because maggots can kill young plants, reduce yields, or render the crop unmarketable. The only information available for this species in upstate New York is a report predicting adult flights using the blooming period of wild plants as an indicator (Pederson and Eckenrode 1981).

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However, because the blooming periods of wild plants varies considerably within locations (e.g., shade or sun) and environmental conditions, we believe a forecast based on degree days will help growers predict adult emergence from overwintered puparia and subsequent generations more accurately than the blooming period of wild plants. The accumulation of degree days has become a useful tool in monitoring the emergence and development of insect populations (Eckenrode and Chapman 1972, AliNiazee 1976, Riedl et al. 1976).

Although degree-days model to predict *D. radicum* adult emergence patterns and seasonal cycles have been developed in Great Britain (Collier and Finch 1985) and in Wisconsin (Eckenrode and Chapman 1971, Eckenrode and Chapman 1972, Wyman et al. 1976), there is little information available on degree days requirements for this species in upstate New York, where the cabbage crop is valued at approximately $80 million (NYASS 2003). The objective of this study was to develop a degree-days model for the adult flight from the overwintered population during the spring and for subsequent generations of flights of *D. radicum* in upstate New York.

Materials and Methods

Location, traps and insects. This study was conducted at the Cornell Univ. New York State Agricultural Experiment Station Fruit and Vegetable Research Farm near Geneva, NY, from spring to fall of 1999 and 2000. A total of 30 pan traps was placed on the surface of the ground and spaced 10 m apart along the border of the farm's roads to monitor cabbage maggot adult populations daily from the beginning of April through October of each year. The pan traps were rectangular plastic containers (22 × 15 cm) sprayed with fluorescent "Saturn" yellow, and filled 8 cm deep with water and a few drops of liquid soap. The pan traps were refilled with water and liquid soap as needed throughout the experiment. The adults were collected from these pan traps in vials (5 mls) filled with 75% ethyl alcohol and transported to the laboratory. The adult flies were identified under a microscope based on the presence of prealar bristles using keys of Brooks (1951), and their numbers were recorded on a daily basis for each pan trap.

Degree-day and Julian-day calculations. Beginning 1 January, the degree days were calculated from the daily minimum and maximum temperatures (National Oceanic and Atmospheric Administration's Station, 30-3184-0, Fruit and Vegetable Research Farm, New York State Agricultural Experiment Station, Geneva, NY). The degree days were computed according to Arnold (1960) as: $(T_{min} + T_{max})/2 - T_b$; where T_{min} is the daily minimum temperature (°C), T_{max} is the daily maximum temperature (°C), and T_b is the base temperature for development (4°C) of the cabbage maggot (Collier and Finch 1985). The accumulation of degree days and Julian days totals beginning 1 January was used to predict the emergence pattern of flies from the overwintered populations (spring generation) of each year and the subsequent generations.

Logistic model. Based on the total number of degree days and Julian days, the logistic model was used to predict the emergence patterns of adult flies for the spring generation of each year and for the combination of 2 yrs. Through linear interpolation of this model, we estimated total Julian days and degree days for the emergence of 10, 25, 50, 75, and 95% of the flies for the spring generation. Parameters of the following logistic equation were estimated for Julian-day and degree-day summations for each year and for the combination of 2 yrs:

$$Y = a + \frac{c}{1 = \exp\{-b(X - m)\}}$$

where Y is the percent emergence, X is either summation of Julian days or degree days, b and m are slope and point of inflexion, respectively, and c and a are asymptote parameters. The logistic model has been used to describe the growth of populations (Pearl and Reed 1920). It also has been shown to fit temperature development of poikilothermic animals (Davidson 1944) and has been used to describe the emergence from overwintering populations (Ruppel and Dimoff 1978).

Means of the adults from all traps per week for each year were calculated using PROC MEANS (SAS Institute 1995). The start of a spring flight was determined by the first fly captured in the spring generation (April-May), and the start of the subsequent flight was determined for subsequent generations (June-October) when flies began to increase following a period of no or few fly captures. The accumulation of degree-days was calculated from the start of first flies for the spring emergence following a period of no fly captures. The accumulation of degree days for F_1, F_2 and F_3 generations of flies was calculated when the flies began to increase following a period of no or few fly captures.

Results and Discussion

First emergence. The first adult flies were trapped in water pan traps on 1 May after a total of 121 Julian days (Fig. 1) and an accumulation of 152.7 degree days (Fig. 2) in 1999, and on 28 April after a total of 119 Julian days (Fig. 1) and an accumulation

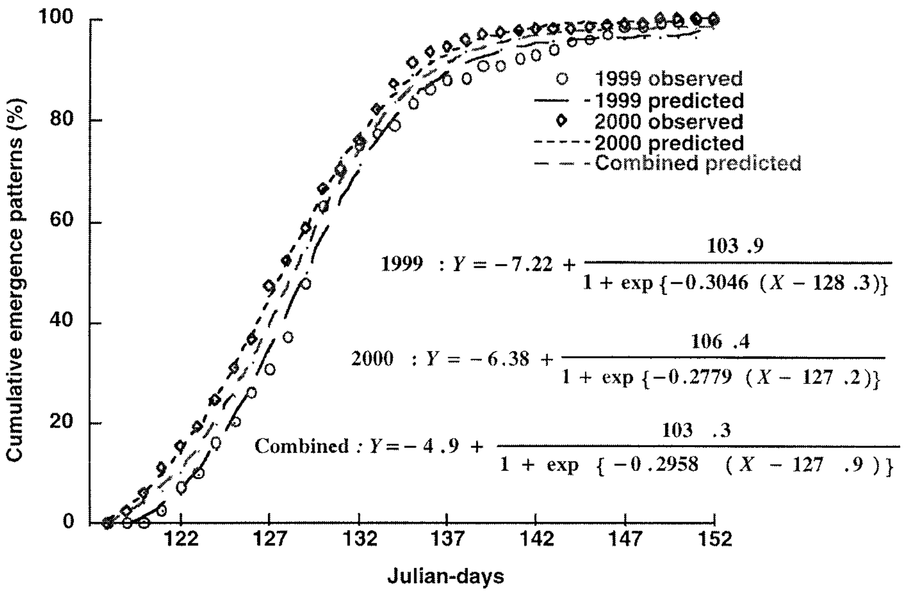

Fig. 1. Spring emergence of cabbage maggot flies in relation to Julian-days above a base temperature of 4°C beginning 1 January 1999 and 1 January 2000.

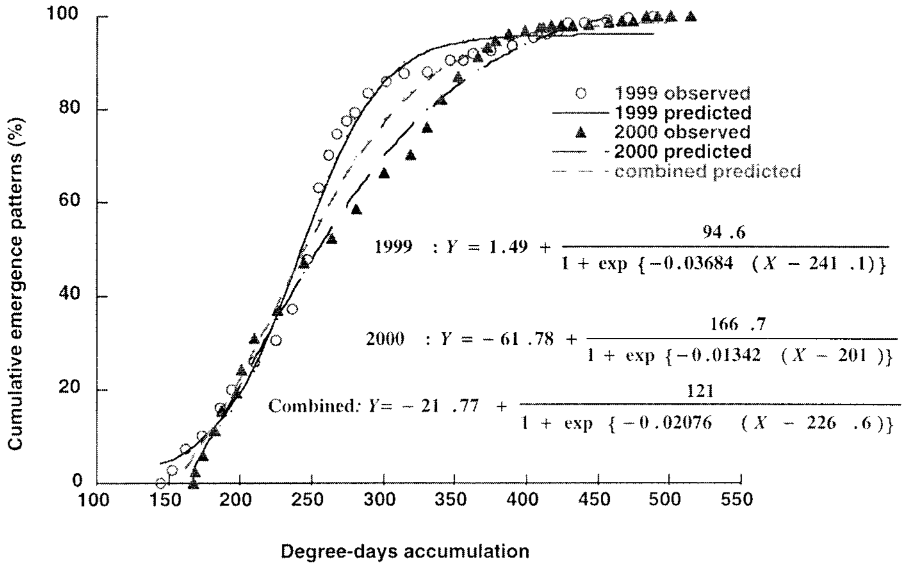

Fig. 2. Spring emergence of cabbage maggot flies in relation to degree-days above a base temperature of 4°C beginning 1 January 1999 and 1 January 2000.

of 168.8 degree days (Fig. 2) in 2000. On the average of these 2 yrs, the first flies appeared on 30 April after a total of 120 ± 3 Julian days (Fig. 1) and an accumulation of 160.7 ± 8.1 degree days (Fig. 2). Our results are in agreement with previous studies that indicated an accumulation of 150 to 170 degree days is needed for the first emergence of flies (Coaker and Wright 1963, Collier and Finch 1983). The small variability in Julian days or degree days accumulation for the first emergence of flies in our study may have been due to differences in microclimatic conditions such as soil temperature or soil moisture. Once the first emergence of flies had been established, succeeding emergence patterns of adult flies from overwintering puparia for the spring generation could be predicted with the logistic model.

Spring emergence pattern. The logistic mode using Julian days (Fig. 1) and degree days accumulation (Fig. 2) indicated that the spring emergence of flies was well synchronized for 1999 and 2000. The emergence patterns of flies followed a more sigmoid (S-shaped) curve in 1999 than in 2000. The logistic models using combined data from both years provided an average prediction of overwintering emergence patterns of adult flies. From these logistic regression lines, we could also estimate percentage emergence of flies in relation to accumulation of Julian days and degree days. Several authors have used the logistic models to describe the emergence patterns from the overwintering populations of pink bollworm (Sevacherian et al. 1977), sorghum midge (Baxendale and Teetes 1983), European red mite (Broufas and Koveos 2000), and tobacco budworm (Potter et al. 1981).

In 1999, the emergence of 10% of the flies for the spring generation required an accumulation of 172.8 degree days and 123 Julian days, 25% emergence required 206.6 degree days and 125.8 Julian days, 50% emergence required 247.8 degree days and 129.1 Julian days, 75% emergence required 267.2 degree days and 132.1 Julian days, and 95% emergence required 401.0 degree days and 143.8 Julian days. In 2000, the emergence of 10% of the flies for the spring generation required an accumulation of 180.5 degree days and 120.8 Julian days, 25% emergence required 201.9 degree days and 124.1 Julian days, 50% emergence required 254.9 degree days and 127.6 Julian days, 75% emergence required 328.1 degree days and 131.8 Julian days and 95% emergence required 380.8 degree days, and 137.3 Julian days. Between years, the differences in degree days varied from 4.7 (25% emergence) to 60.9 (75% emergence) and the differences in Julian days varied from 0.3 (75% emergence) to 6.5 (95% emergence). For use in control practices, these differences appear to be small, so a 2-yr average should be appropriate to use. The 2-yr average for the emergence of 10% of the flies for the spring generation required an accumulation of 176.6 ± 3.8 degree days and 122.0 ± 1.0 Julian days, 25% emergence required an accumulation of 204.2 ± 2.3 degree days and 125.0 ± 1.0 Julian days, 50% emergence required an accumulation of 251.3 ± 3.5 degree days and 129.0 ± 1.5 Julian days, 75% emergence required an accumulation of 297.6 ± 30.4 degree days and 132.0 ± 0.0 Julian days, and 95% emergence required an accumulation of 390.9 ± 10.1 degree days and 141.0 ± 3.0 Julian days.

The flies from overwintered puparia began emerging in early May in 1999 or late April in 2000, and continued to emerge over a period of approximately 30 days, peaking in mid-May. Although there was variability in the numbers of flies during the spring emergence period, the models provided a strong nonlinear relationship between degree-days accumulations and Julian days with the cumulative percentage emergence of the flies.

Seasonal population trends. Population trends of adult flies over time are shown for 1999 (Fig. 3A) and 2000 (Fig. 3B). In both years, there were 3 generations (F_1, F_2 and F_3) after the spring emergence. In each year, the spring and F, generations had similar captures of adult flies (8 to 15 per week), and their peaks were greater than twice the catches either in the F_2 or F_3 generation. Since their first emergence, the flies required an accumulation of 447.8 degree days in 1999, and an accumulation of 450.6 degree days in 2000 to complete their spring emergence patterns. For both years combined, the flies required an accumulation of 449.2 ± 1.4 degree days to complete the spring emergence. Thereafter, to complete emergence of flies in 1999, the F_1 generation required an accumulation of 476.1 degree days, the F_2 generation required 486.9 degree days and the F_3 generation required 402.2 degree days. In 2000, the F_1 generation required an accumulation of 540.8 degree days, the F_2 generation required 443.8 degree days, and the F_3 generation required 398.1 degree days. Between years, the differences in degree days varied from 4.1 (F_3 generation) to 64.7 (F_1 generation). For use in control practices, these differences appear to be small, so a 2-yr average should be appropriate to use. On an average of the 2 yrs, the F_1 generation required an accumulation of 508.4 ± 32.9 degree days, the F_2 generation required 465.3 ± 21.5 degree days and the F_3 generation required 399.1 ± 3.1 degree days to complete their emergence patterns of flies. Although there was some variability in the numbers of flies and the total degree-days accumulation required for each generation, these differences among generations are common in the literature (Eckenrode and Chapman 1972, Wyman et al. 1976). Under field conditions, generation time could vary with microclimatic factors, population genetics and host quality (Pitcairn et al. 1992). Despite the variations in generation time of field populations for

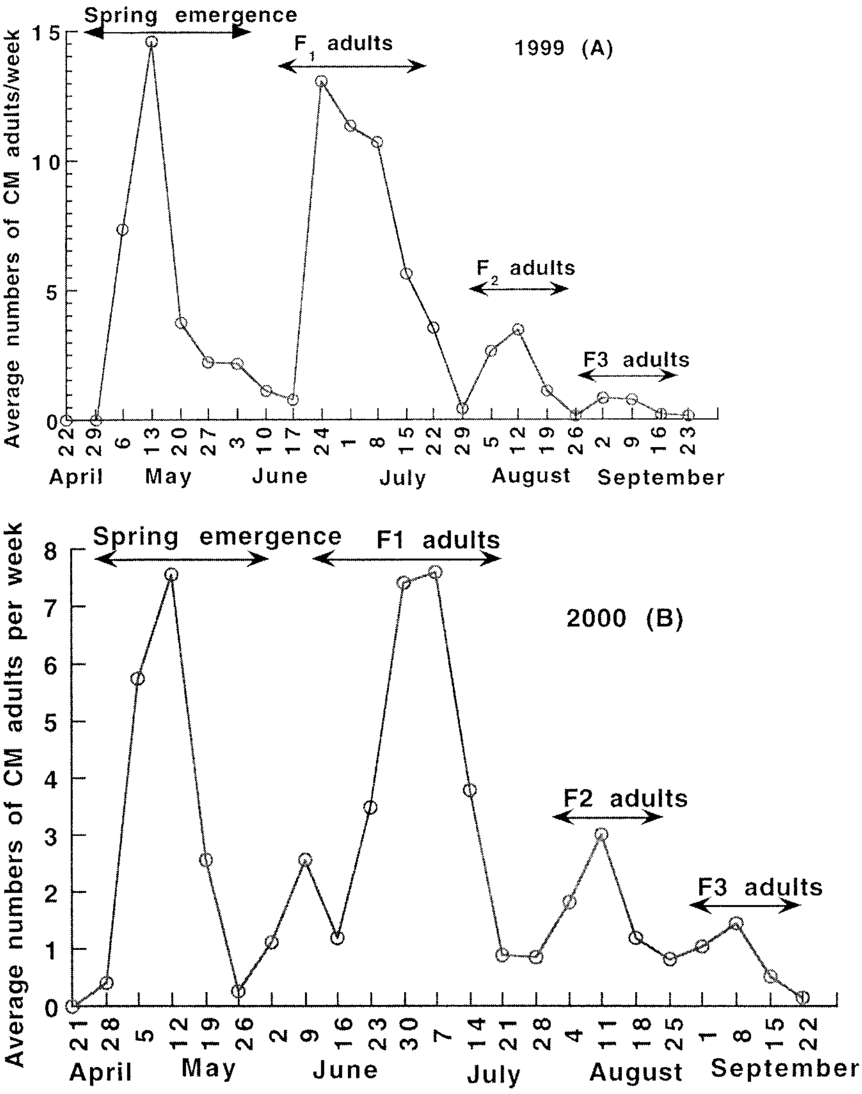

Fig. 3. Mean numbers of cabbage maggot adults in relation to Julian date in 1999 (A) and 2000 (B), Geneva, NY.

the spring, F_1, F_2 and F_3 generations, the deviations about the means of degree-days accumulation for these generations between two years were very small.

The results from this 2-yr study indicate that degree days and Julian days models will help predict the occurrence of the first flight of adult cabbage maggot in the field for spring and subsequent generations in upstate New York. First flight will influence timing of subsequent flights and, therefore, a strategy of control. Knowing the adult activity will provide a prediction for subsequent egg laying and potential damage by larvae. Growers can use information on adult activity to time treatments or to adjust planting dates to minimize damage. This information will be especially valuable for helping growers' cope with the overwintering and F_1 generations, since this is the time when plants are most susceptible to injury. Thus, the accumulation of degree-days totals will be useful for scheduling sampling procedures and to time control measures for cabbage maggots in upstate New York.

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