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EASTERN PINE SEEDWORM, *CYDIA TOREUTA* (LEPIDOPTERA: TORTRICIDAE) IN RED PINE CONES IN WISCONSIN

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ABSTRACT

Cydia toreuta population densities, prolonged diapause behavior, parasitism and adult emergence patterns were examined over four years at two red pine locations in Wisconsin. Last-instar densities ranged from 0.54 to 3.18 per cone. This was considered a wide range for this species in red pine. Population clumping was evident at last-instar densities below 2.90, however no consistent pattern was evident between years. Clumping disappeared at populations greater than 2.90 last-instars. Prolonged diapause varied from 7.8 to 38.9 %. Parasitism rates varied from 10.9 to 46.6 %. *Phanerotoma toreuta* (Hymenoptera: Braconidae) was the most abundant parasite at both sites and emerged in unison with male *C. toreuta*. Estimation of percent of last-instars undergoing prolonged diapause prior to spring emergence can be accomplished using forced emergence though cones should be collected after 31 January. Estimation of percent parasitism can be made as early as November. Resident moth populations could be estimated prior to spring flight utilizing this information. Emergence occurred over an approximately 2 week period between mid-May and early June. The majority of male moths emerged prior to females.

The eastern pine seedworm, *Cydia toreuta* (Grote) feeds on the seeds of red pine (*Pinus resinosa*) and other North American conifers including jack pine (*P. banksiana*), loblolly pine (*P. contorta*), shortleaf pine (*P. echinata*), and Virginia pine (*P. virginiana*) (Hedlin et al. 1981). Infested cones have no external indicators of attack. One to three larvae may inhabit red pine cones (Lyons 1957a), with each larva consuming 4–10 seeds (Mattson 1978). Red pine cones contain 30–50 seeds (Lyons 1965). In red pine, last-instars overwinter within the cone axis. Pupation occurs the following spring. A proportion of the overwintering larvae may not pupate, but remain in prolonged diapause until the spring of the following year (Lyons 1957a). One major parasite, *Phanerotoma toreuta* Caltagirone (Hymenoptera: Braconidae) has been reported (Lyons 1957a, Harbo and Kraft 1969).

Previous studies on red pine seed production indicated that this species was a minor seed damaging agent (Lyons 1957b, Mattson 1978); however recent studies found it to be a major seed consumer in certain years (Katovich et al. 1989a).

This study investigated *C. toreuta* at two red pine sites in Wisconsin over a four year period. The objective was to provide information on life history, parasitism,

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and prolonged diapause; and how each of these may be incorporated into potential sampling and control efforts.

MATERIALS AND METHODS

Site 1 was a Wisconsin Department of Natural Resources red pine seed orchard in Grant County (southwestern Wisconsin). It was planted in 1970 and produced cones since 1984. Site 2 was a widely spaced red pine planting in St. Croix County, Wisconsin (westcentral Wisconsin). It was planted in 1972 and produced cones since 1984. At both sites, trees were growing on an approximately 6.1 by 6.1 m grid.

Last-instar density, prolonged diapause, parasitism and adult emergence were investigated at site 1 in 1985 and 1986, and at site 2 in 1985–88. Since *C. toreuta* spend 11 months of their 12 month life cycle within cones, the sample unit chosen was a cone which had matured the previous fall. Cones were collected in mid-April, approximately 5 weeks before field emergence. At site 1, cones were collected from 15 randomly selected trees. Each tree was divided into 4 cells: North- and south-facing crown aspects, and upper- and middle- crown levels. No lower-crown level was used because few cones were located in this level. Five cones per cell were collected from each sample tree. All cones were picked if five were not present.

At site 2 in 1985, 20 trees were randomly selected and divided into two cells: North- and south-facing aspects. In 1986, 1987 and 1988, 24, 18 and 15 trees, respectively, were randomly selected and divided into 6 cells: North- and south-facing crown aspects and upper-, middle- and lower-crown levels. Five cones were collected from each cell. All cones were picked if five were not present.

Student's t-test comparisons for independent samples were used to test equality of means when comparing north- versus south-facing aspects or when comparing upper- versus middle-crown levels at site 1. Analysis of variance (ANOVA) was used when comparing all cells at either site or when comparing upper-, middle- and lower-crown levels at site 2. Duncan's (1955) multiple range test was used to separate significantly different means ($P = 0.05$).

Cones were placed in uncovered shallow pans and held at 24°C and a 15:9 light:dark cycle until day 20 when individual cones were isolated in a 0.47 l (1 pint) cardboard carton with lid. Larvae in infested cones kept at this regime required approximately 25 days to break diapause, pupate and begin emergence (Harbo and Kraft 1969). Each container was checked daily to note number of male and female moths and parasites that emerged from each cone. After emergence, cones were dissected to record numbers of (1) *C. toreuta* larvae in prolonged diapause, which was defined as living larvae which had not pupated; (2) dead *C. toreuta* larvae; (3) dead *C. toreuta* pupae and/or adults which failed to emerge; and (4) dead parasites that failed to emerge. Larval counts per individual cone at the time of cone collection were then reconstructed by adding emerged moths to numbers 1, 2 and 3, and by substituting one *C. toreuta* larva for each parasite. Harbo and Kraft (1969) have shown that the parasite *Phanerotoma toreuta* is solitary. Since other parasites were rare in this study, and when they were present, only single specimens emerged, it was assumed that they were also solitary.

In addition, at site 2, cone collections were made on 5 November and 5 December, 1986 and 5 January and 25 April, 1987. Collected cones were held at 24°C and a 15:9 light:dark cycle. Comparisons were made between percent parasitism and percent prolonged diapause among the four collection dates. Percent data obtained for each cone was transformed using arc sine $\sqrt{\text{percent}}$ (Gomez and Gomez 1984), ignoring uninfested cones. Data was analyzed using ANOVA and individual means were separated using Duncan's (1955) multiple range test ($P = 0.05$).

In order to observe actual field emergence at site 2 in 1986 and 1987, 450 cones were randomly collected 15 days after pupation was initially observed. Cones were

Table 1.—Number of last-instars and emerging adults per cone of *Cydia toreuta* at site 1, Grant Co., 1985 and 1986, and site 2, St. Croix Co., Wisconsin, 1985, 1986, 1987 and 1988.

Site	Year	No. of Cones Sampled	Larvae/Cone ± SE	Adults/Cone ± SE
1	1985	300	1.12 ± 0.05	0.21 ± 0.03
1	1986	323	0.54 ± 0.10	0.15 ± 0.02
2	1985	184	2.17 ± 0.10	1.07 ± 0.10
2	1986	712	1.02 ± 0.05	0.63 ± 0.04
2	1987	330	2.94 ± 0.04	1.60 ± 0.06
2	1988	450	3.18 ± 0.06	1.42 ± 0.05

Table 2.—Number of last-instars ± standard error by crown aspect and crown level for *Cydia toreuta* at site 1, Grant Co., and site 2, St. Croix Co., Wisconsin. Dashed lines indicate no samples were taken.

Site and Year	Crown Aspect		Crown Level		
	North	South	Upper	Middle	Lower
Site 1 1985, n = 300	1.1 ± 0.1a	1.2 ± 0.1a	1.3 ± 0.1a	0.9 ± 0.1b	--
Site 1 1986, n = 323	0.5 ± 0.1a	0.6 ± 0.1a	0.4 ± 0.1b	0.7 ± 0.1a	--
Site 2 1985, n = 184	2.1 ± 0.1a	2.1 ± 0.1a	--	--	--
Site 2 1986, n = 712	1.1 ± 0.1a	1.0 ± 0.1a	1.1 ± 0.1a	1.4 ± 0.1a	0.5 ± 0.1b
Site 2 1987, n = 330	3.0 ± 0.1a	3.2 ± 0.1a	3.0 ± 0.1a	3.2 ± 0.1a	2.9 ± 0.1a
Site 2 1988, n = 450	3.1 ± 0.1a	3.2 ± 0.1a	3.2 ± 0.1a	3.2 ± 0.1a	3.2 ± 0.1a

Means within the same row followed by the same letter are not significantly different (P = 0.05).
Multiple camparisons made by Duncan's multiple range test.
Two-sample comparisons made by Student's t-test.

placed into 1 pint cardboard containers with lids which were kept in the field under a 2 m tall plywood roofed structure. Absence of sides on the structure allowed free air flow. Containers were checked daily for emerged insects. All emerged moths were sexed.

RESULTS AND DISCUSSION

Mean density of last-instars per cone varied from 0.54 ± 0.04 at site 1 in 1986, to 3.18 ± 0.06 at site 2 in 1988. Number of last-instars in a sample cone ranged from 1 to 7. Mean number of adults emerging per cone varied from 0.15 ± 0.02 at site 1 in 1986, to 1.60 ± 0.06 at site 2 in 1987 (Table 1).

Based on x-ray analysis of seeds from 1988-collected cones at site 2, which indicated that 73 % of seeds in all cones had been consumed and that less than 3 % of cones were uninfested (Katovich et al. 1989a), populations approaching 3 larvae per cone appeared very high for this species. These populations appear to be close to the maximum for this species in red pine cones, since it is unlikley that all of the seeds will be consumed, even at these unusually high population densities because larvae do not leave infested cones and move to others which may not be infested. Also, cannibalism has been reported for this species when larval numbers are high within

Table 3.—Percent prolonged diapause and percent parasitism in *Cydia toreuta* larvae collected in red pine cones at four different dates, site 2, St. Croix County, Wisconsin. Cones subjected to 24°C and a 15:9 light:dark cycle.

Cone Collection Date	Number of Cones	Mean Percent ± SE[1]	
		Prolonged Diapause	Parasitism
November 1986	238	54.0±2.9b	10.3±1.1a
December 1986	309	64.4±2.8a	13.3±1.9a
January 1987	229	37.2±1.9c	12.6±1.2a
April 1987	340	35.8±1.9c	11.0±1.0a

[1]Means within the same column followed by the same letter are not significantly different (P = 0.05), using Duncan's multiple range test.

individual cones (Kraft 1968), making it difficult for several larvae to coexist within cones.

In no cases were significant differences (P = 0.05) found between mean number of larvae per cone from north- or south-aspect cones (Table 2). Significant differences were found when comparing crown level means (Table 2), but differences were not consistent at a given location between years. At site 1 in 1985, more larvae per cone were found in upper- than in middle-level cones (t = -4.02, 298 df, $P < 0.001$), while in 1986 more larvae per cone were found in middle- than in upper-level cones (t = -3.04, 321 df, $P = 0.003$). At site 2 in 1986, fewer larvae per cone were found in lower- than in either middle- or upper-level cones (MSE = 0.48, F = 40.2, 2 df for treatment and 709 df for error, $P < 0.001$). In 1987 and 1988 when larval populations were highest no differences were found between crown levels ($P = 0.05$).

Previous studies have implicated cone distribution within tree crowns as influencing *C. toreuta* distribution (Kraft 1968, Rauf and Benjamin 1983). In both of those studies insect distribution followed cone distribution. That was not necessarily the case in this study. At site 2 in 1985, 86 and 87 south-facing cones did not produce more larvae per cone despite being significantly more abundant than cones on other crown aspects (Katovich 1988).

A clumped distribution pattern has been previously reported in jack pine cones (Kraft 1968). In this study, since differences did exist between mean number of larvae per cone by crown level, clumping appeared to be evident for populations less than 2.90 larvae per cone. However, no consistent discernable pattern was evident from year to year, which makes it difficult to utilize this behavior in designing a sampling plan. Therefore, when sampling populations to obtain mean number of larvae per cone, cone collections need to be made from throughout the tree crown. The exception to this would be at high populations, approaching 3 larvae per cone, where clumping apparently disappears and sampling would no longer need to be evenly distributed throughout tree crowns.

At site 1, prolonged diapause was 7.8 and 38.9 % in 1985 and 1986, respectively. At site 2, prolonged diapause was 10.2, 9.3, 34.1 and 16.2 % in 1985, 1986, 1987 and 1988, respectively. Lyons (1957a) likewise found degree of prolonged diapause varied from year to year and between localities in the same year. Delayed emergence is common among cone and seed insects and is generally considered a survival adaptation in the event of a cone crop failure (Tripp 1954, Hedlin 1964).

Percentage of the larval population undergoing prolonged diapause was significantly affected by date of cone collection (Table 3). Cones collected in November and December had a significantly greater percentage of larvae remaining in prolonged diapause when brought indoors than did cones collected in either January or April (MSE = 786, F = 34.0, 3 df for treatment, 1112 df for error, $P < 0.001$). The

Table 4. — Parasites and percent parasitism of *Cydia toreuta* larvae in red pine cones, site 1, Grant Co., WI, and site 2, St. Croix Co., WI. Cones were collected in mid-April each year.

		Percent Parasitism	
Year	Parasite	Site 1	Site 2
1985	*Phanerotoma toreuta*[1]	23.7	31.9
	Exeristes comstockii[2]	1.2	5.4
	Campoplex sp.[2]	0.0	1.2
	Total	24.9	38.5
1986	*P. toreuta*	39.8	20.8
	E. comstockii	6.8	0.6
	Campoplex sp.	0.0	0.5
	Total	46.6	21.9
1987	*P. toreuta*	--	10.5
	E. comstockii	--	0.4
	Campoplex sp.	--	0.0
	Total	--	10.9

[1]Hymenoptera, Braconidae
[2]Hymenoptera, Ichneumonidae

January and April sample means were not significantly different ($P = 0.05$). Bakke (1970) reported the time required for termination of diapause in larvae of *Cydia strobilella* varied considerably in cones collected in the fall, whereas the population was much more homogenous concerning that characteristic in cones collected in early spring.

The percentage of larvae exhibiting prolonged diapause is variable from year-to-year. Consequently, estimating number of emerging adults from larval counts will be inaccurate unless adjusted for numbers of larvae which will extend their life cycle through prolonged diapause. Therefore, a reliable estimation of prolonged diapause would prove valuable. Cone collections after 31 January in Wisconsin and subsequent forced moth emergence should provide reliable estimates for prolonged diapause.

Parasitism was prevalent at both sites in all study years, ranging from 10.9 to 46.6 % (Table 4). *Phanerotoma toreuta* was the major parasite, and has been reported as the most commonly collected parasite of *C. toreuta* in past studies in the Upper-Peninsula of Michigan (Harbo and Kraft 1969) and in Ontario (Lyons 1957a). Two other parasites, *Exeristes comstockii* (Cresson) and Campoplex sp. (Hymenoptera: Ichneumonidae), were collected. *E. comstockii* is a common parasite of lepidopterous larvae attacking conifer foliage, cones and growing tips (Yates 1967, Bradley 1974). It has been reported as a parasite of *C. toreuta* (Ciesla and Bell 1966, Harbo and Kraft 1969). Harbo and Kraft (1969) state that *E. comstockii* parasitize *C. toreuta* larvae in early spring prior to moth emergence. However, in this study adult *E. comstockii* did emerge from winter collected cones, indicating that at least some parasitization was occurring the previous fall or late-summer. *Campoplex* sp. has not previously been reported parasitizing *C. toreuta*, though various *Campoplex* species have been reported as parasites of other *Cydia* seed feeding species in North America (Keen 1958).

At site 2, in 1987, no differences were found in number of *P. toreuta* adults per

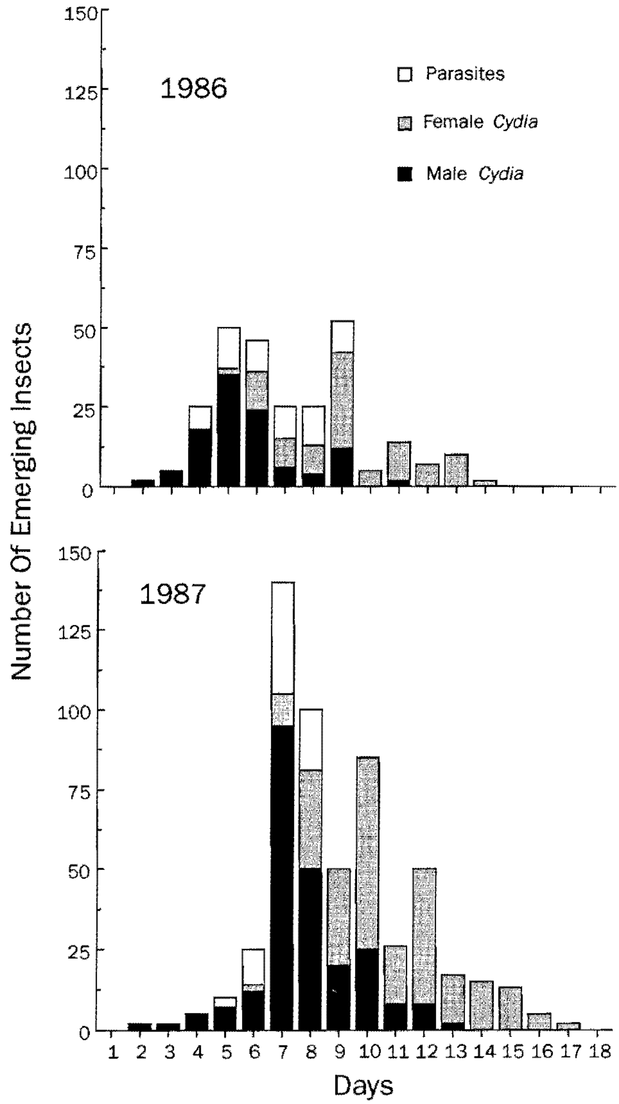

Figure 1. Field emergence of *Cydia toreuta* males and females, and *Phanerotoma toreuta* (Parasites) adults at a red pine site in St. Croix County, Wisconsin (site 2), in 1986 (top) and 1987 (bottom). Emergence occurred between 23 May and 4 June 1986, and between 9 and 24 May 1987.

cone between crown levels (upper = 0.30 ± 0.05, middle = 0.34 ± 0.05, lower 0.35 ± 0.05). Data from 1987 was used because no differences in mean total larvae of *C. toreuta* per cone had been found. Therefore, number of *P. toreuta* per cone was equivalent to percent parasitism by this species.

Percent parasitism by *P. toreuta* was not affected by cone collection date. Percent parasitism rates were not significantly different between cones collected in November, December, January or April (P = 0.05) (Table 3). Therefore, cone samples can be collected as early as November to obtain reliable estimates of percent parasitism.

Field emergence of *C. toreuta* occurred over a 13-day period in 1986, 23 May through 4 June, and a 16-day period in 1987, 9 May through 24 May (Figure 1). In both years, males emerged first with the majority emerging over a two-day period. Female *C. toreuta* emerged after the majority of males. *Phanerotoma toreuta* generally emerged in unison with male *C. toreuta*. Female P. toreuta oviposit in eggs of *C. toreuta*. These results are in general agreement with those reported for Ontario by Lyons (1957a), though he reported emergence approximately one month later.

The initial capture of male moths could be used as a timing technique for application of some control practice applied against adults. Insecticide sprays aimed at the females could be timed for application at a given interval following initial male moth collection. The sex pheromone for *C. toreuta* has been identified (Katovich et al. 1989b), and could be used with traps to capture male moths. Unfortunately, any broad spectrum treatment may also impact *P. toreuta* adults which are present at the same time. Adult *P. toreuta* were not attracted to *C. toreuta* pheromone (unpublished data) and therefore the pheromone could be utilized without directly impacting adult parasite populations.

Though *C. toreuta* has been generally considered an uncommon cone inhabitant and therefore a minor pest of red pine seed production (Lyons 1957b, Mattson 1978), it is shown in this study to be capable of high larval populations of greater than 3 larvae per cone. It appears unlikely that populations much higher would be encountered in red pine cones. This information should provide a reference when comparing future population levels. Further, the collection of cones from November through May and subsequent forced emergence could serve as a valuable indicator of potential moth populations of this species. If an estimate of prolonged diapause is required collections should occur after 31 January, while if predictions of parasitism alone are necessary, then cones could be collected at anytime during that period.

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