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YPONOMEUTA MALINELLUS ZELLER (LEPIDOPTERA: YPONOMEUTIDAE), A NEW IMMIGRANT PEST OF APPLES IN THE NORTHWEST: PHENOLOGY AND DISTRIBUTION EXPANSION, WITH NOTES ON EFFICACY OF NATURAL ENEMIES

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Abstract. — *Yponomeuta malinellus* Zeller is a recent invader of the Pacific Northwest. Its southern and eastern spread from northwestern Washington was determined with pheromone trapping surveys. Given the broad distribution of *Y. malinellus* in Europe and its spread east through the Cascade Mountains and south into Oregon, we perceive there will be no barrier to its movement through Oregon into California. Low rates of parasitism in Washington contrast with high parasitism throughout its native home of temperate Eurasia. Sleeve-cage exclusion of predators showed that generalist predators caused 40–60% and 20–50% mortality of young larvae and cocooned larvae or pupae, respectively. Egg mass predation through August of 1989 varied between 10% and 60% at two localities. Maximum daily pheromone trap catch and egg mass densities monitored from 1988–1992 indicated populations were relatively stable in the original infestation area of northwestern Washington.

Key Words. — Insecta, Lepidoptera, *Yponomeuta,* introduced species, apple pest, predation

Yponomeuta malinellus Zeller (Yponomeutidae), a univoltine defoliator of apples found throughout the temperate regions of the Palaearctic, was recently discovered in Washington and British Columbia. The first reports of the introduction were two interceptions on nursery trees in 1981 and 1982 on Vancouver Island, British Columbia (Anonymous 1985); by the summer of 1985, the species was found to be broadly established in the Fraser River Valley, east of Vancouver, and in Whatcom Co., Washington, especially in and around Bellingham (LaGasa, unpublished data). *Yponomeuta malinellus* first colonized North America 80 years ago in New York, but these populations were eradicated (Parrott 1913). Recently, Hoebeke (1987) outlined the status of three Palaearctic congeners of *Y. malinellus* that are presumed to be established in the eastern United States: *Yponomeuta cagnagellus* (Hubner), *Y. padellus* (L.) and *Y. plumbellus* (Denis and Schiffermueller).

Yponomeuta malinellus is a member of the "padellus complex" of small ermine moths, a group of five morphologically similar species that have been extensively studied as a model of host-plant associated sympatric speciation (Thorpe 1928, Menken et al. 1992). Like most species in this group, *Y. malinellus* is narrowly oligophagous, using *Malus* and occasionally *Pyrus* as hosts (Menken et al. 1992). Historically, *Y. malinellus* occurred at low, subeconomic levels punctuated by sporadic, localized outbreaks that would cause significant damage to apple or-

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chards throughout Europe (Affolter & Carl 1986). Such damage to commercial orchards is now largely precluded by synthetic insecticides used to control codling moth, *Cydia pomonella* (L.) (Tortricidae) and leaf rollers in western Europe. However, in areas where modern synthetic chemicals are used less regularly, *Y. malinellus* remains the second most important pest to apples behind the codling moth (e.g., former U.S.S.R., Nosyreva 1981). In the absence of control by natural enemies, *Y. malinellus* represents a significant threat to the development of a pheromone-based pest management program for apple pests (particularly codling moth) in North America.

Yponomeuta malinellus has been the target of a biological control program from 1988–1991, the complete details of which will be reported at another time. Herein we summarize the status of the recent introduction, provide measures of the impact of natural enemies endemic to northwestern Washington on this exotic species, and discuss the prospects for its control by endemic and introduced natural enemies. Parasitism by one introduced species, *Ageniaspis fuscicollis* Dalman (Encyrtidae), is reported.

Materials and Methods

Seasonal Biology.—*Yponomeuta malinellus* larvae were collected weekly from May to June 1988 and on selected dates in 1989. Specimens were collected from 10 unsprayed *Malus* trees in a suburban setting (two larval aggregations/tree) on each date and killed in 70% EtOH. Head capsule widths were measured under a binocular microscope equipped with an ocular micrometer. Head capsule widths were used to infer larval instar and, together with field observations of other life stages and collections in 1989–1991, to outline seasonal phenology.

Pheromone Survey Trapping.—Since 1985, *Y. malinellus* distribution in Washington state has been monitored by the Washington Department of Agriculture (WSDA), in cooperation with USDA-APHIS, to determine counties to be quarantined for nursery tree export restrictions. Originally, surveys were visual (1986–1988), but recent identification of the *Y. malinellus* sex pheromone (McDonough et al. 1990) has enabled monitoring with synthetic pheromone lures. Pherocon 1-C traps (Trece Incorporated, Salinas, California), baited with rubber septa impregnated with a two component lure (200 micrograms of Z11-14:OH and Z9-12:Ac in a ratio of 200:3; McDonough et al. 1990) were used in most cases in 1989 and exclusively in 1990. In 1989, some traps placed by USDA-ARS were baited with a three component lure (100 micrograms of Z11-14:OH, E11-14:OH, Z9-12:Ac, in a ratio of 100:30:1); both formulations had similar attractiveness (McDonough et al. 1990; Unruh, unpublished data). Traps were placed in residential or feral *Malus* trees from early to mid-July and removed from mid-August to early September. Some trap transects, such as those south and east of Puget Sound in 1989, were monitored semimonthly and, if several traps caught *Y. malinellus,* the transect was moved farther south to discern the southern edge of the distribution. For these transects, intertrap distances were from 1.6–16 km (1–10 mi). Other transects were examined at the end of the flight season. Results of similar surveys in British Columbia (1990) and in Oregon (1991) have been supplied to us and are also reported (D. J. Hilburn, personal communication).

Parasitism Surveys.—Collections and rearing of *Y. malinellus* larvae and pupae

showed that parasitism rates could be accurately assessed from cocooned larvae and pupae because no parasitoids emerged from earlier life stages. In 1988, cocoons were collected from unsprayed *Malus* trees in suburban and rural settings of Whatcom County, Washington on 28 Jun to 2 Jul. These were individually placed into 4 dram glass vials with a cork stopper and were allowed to develop at 22° (± 2°) C and 50 (± 10) %RH with 16:8 photophase : scotophase. In 1989, cocoon collections were made from unsprayed *Malus* in San Juan and Whatcom Counties on 16 Jun to 14 Jul and were either individually isolated or pupal clusters were placed in resealable sandwich bags. In 1990, cocoons were collected from Whatcom County on 28 Jun to 17 Jul and cocoon clusters were placed in either plastic vials (40 dram) or sandwich bags. After parasitoid emergence ceased, the remaining host cocoons were dissected under a binocular microscope. Percentage parasitism for all 3 years was based on the number of cocoons from which a parasitoid emerged, divided by the total number of cocoons from which insects emerged, or which died, as pupae. Adult *Y. malinellus* found dead within the pupal cases were considered emerged adults. A few fly puparia dissected from *Y. malinellus* pupae that did not eclose are reported as Tachinidae. All other unemerged host cocoons, whether due to predation or unknown causes, are reported as unknown mortality.

Predator Exclusion Studies.—Two forms of exclusion cages were used to determine the impact of endemic predators on the second through fifth larval stadia in 1989. Complete exclusion cages, designed to exclude both insect and bird predators, consisted of a 30 cm diameter by 1–1.5 m long cylinder of white, nylon, organdy screen (300 Denier Nylon, 39 strands/cm [100/inch]) secured at each end with tightened wire bands over a branch containing a larval colony. Bird exclusion cages consisted of two or more layers of plastic bird netting (0.64 cm [0.25 inch] mesh) wrapped around a branch containing larvae and held in place with staples. Marked, uncaged branches containing a single larval brood were used as experimental controls (= natural mortality).

Unsprayed, residential *Malus* trees were inoculated with larvae to artificially establish colonies for predator exclusion studies; thus, the number of larvae present at the beginning of the experiment was known. The day before inoculating, the trees were pruned to minimize larval movement and to accommodate exclusion cages. Within 8 hours of collection, larvae of each colony were counted and moved to clean, excised apple leaves in 15 cm diameter plastic petri plates that were covered and left overnight at room temperature. The following morning all colonies had established tents on the excised leaves. These artificial colonies (ACs) were returned to their collection sites and randomly assigned to prepared branches and covered with an exclusion cage or, for the controls, left uncovered. ACs were attached to a vigorous cluster of leaves by stapling a thin (2–3 cm) strip of paper around the cluster and the infested leaf.

ACs were visually inspected each week after inoculation and those that failed to establish or were contaminated from naturally occurring colonies (as evinced by the copious webbing left by larval colonies and the increased number of larvae in the AC) were excluded from the study. ACs were established at two sites in Bellingham, Washington on 12, 17, 24 and 31 May and removed on 6 to 7 Jun. The ACs setup on the first two dates consisted of small larvae (second, third and small fourth instar) and were pooled for statistical analyses. Those on the third

and fourth dates were relatively larger (large fourth and fifth instar) and were also pooled.

A similar experiment was done with pupal clusters, except that leaves to which clusters adhered were carefully removed, cocoons enumerated, and then stapled through extra webbing directly to undamaged leaves. Cocoon clusters were then covered with one of the two exclusion cages used for larvae or left exposed. Forty pupal clusters were set up on 6 Jun (20 exposed, 10 with bird exclusion and 10 with complete exclusion; half of each type in each study site) and removed on 28 Jun. Intact pupae and those from which moths successfully emerged were counted as survivors; missing larvae or pupae and dead ones with feeding damage (yellow hemolymph stains, etc.) were scored as dead.

Finally, two exclusion treatments were used to measure egg mass predation: (1) all predators were excluded with close-fitting organdy sleeves, and (2) walking predators were excluded with a 1 cm wide band of Stickem®, 2–5 cm proximal and distal to the egg mass. Eighty naturally occurring egg masses were monitored (40 exposed and 20 for each exclusion treatment) at each of two sites on 6 and 7 Aug 1989. A census of egg masses was taken on 12 Sep 1989. A census of a subset of surviving hibernacula (= egg case with diapausing/quiescent larvae) was taken again on 15 Mar and 9 May 1990.

Differences among exclusion treatments for the two larval size classes and cocoons were analyzed separately using factorial analysis of variance (ANOVA) of untransformed survival proportions, with exclusion treatment and site as crossed factors. (Arcsine transformation gave qualitatively similar results, but because a few cases had more larvae at the end of exposure than counted at the onset and because the arcsine transform is undefined for values greater than one, it was not used.) The initial number of larvae or pupae in each AC was treated as a covariate. Comparisons between means employed Tukey's Studentized (HSD) range test (Proc GLM: SAS 1988). Differences in the frequency of intact egg masses versus those empty or missing at the census intervals were analyzed using Chi square.

Population Density Estimates.—In 1989–1992, samples consisting of 30 vigorous branches (with developed terminal bud) were taken from five trees at each of four sites early each year prior to bud burst and larval exit from hibernacula. All hibernacula on the terminal two seasons of wood growth were counted under a binocular microscope. The same five trees were sampled at each site each year, minimizing year to year variance.

Adult population trends were also monitored using pheromone traps baited with the two component lure as described for survey trapping. Four sites were monitored in 1988 and nine were monitored during 1989–1991 flight seasons. Traps (Pherocon 1-C, Trece) were changed approximately every two weeks (range 10–20 days) and traps at all sites were replaced on the same day. Only the second half of the flight season for 1988 was trapped because that is when the pheromone became available. The numbers of traps deployed at each site were two in 1988, three to 14 in 1989, and three in 1990 and 1991. *Yponomeuta malinellus* males are typically caught within 10 m of their release site in mark recapture studies (Menken et al. 1992; Unruh, unpublished data) and intertrap distances exceeded 10 m at all sites. Data were expressed as the number of males/trap/day for each trapping interval. Mean trap catch for the trapping interval with highest capture rate in each year at each site is reported.

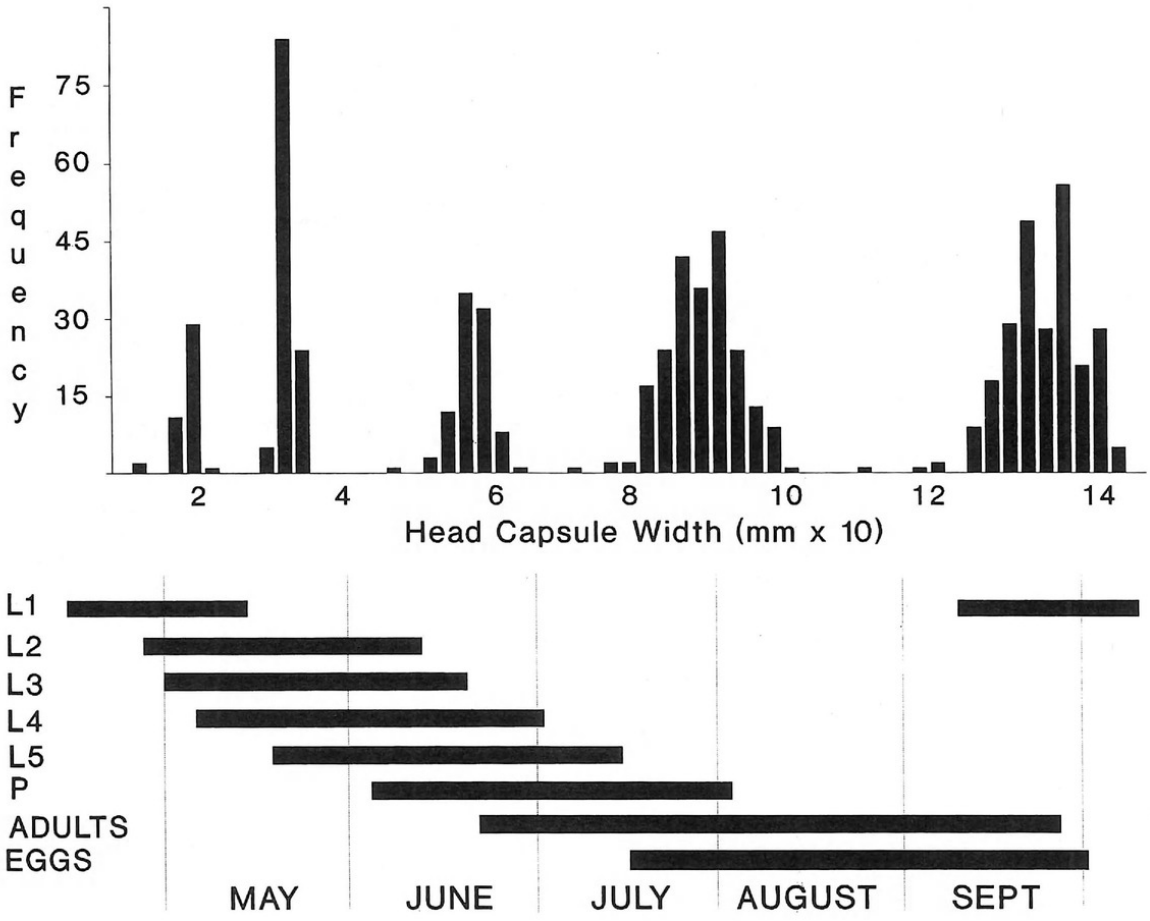

Figure 1. Head capsule widths for five larval instars of *Y. malinellus* and approximate duration of all life stages in the field in Whatcom County, Washington. Based on 20 tents collected weekly from early May to late Jun 1988 and on selected dates in 1989.

Results and Discussion

Life History.—The frequency distribution of head capsule widths of *Y. malinellus* larvae fell in five discrete groups (Fig. 1); based on inspection of the distributions we chose 0.25, 0.4, 0.7 and 1.15 mm as head capsule growth intervals between instars. Given these intervals, head capsule widths averaged [SEM] 0.1891 mm [.0023], 0.3317 mm [.0011], 0.5828 mm [.0028], 0.8998 mm [.0035] and 1.373 mm [.0033] for first through fifth instars, respectively.

The seasonal biology of *Y. malinellus* in northwestern Washington is also diagrammed in Fig. 1 and is similar to that reported for the Palaearctic (e.g., Beirne 1943, Junnikkala 1960). Eggs were laid in an overlapping pattern in an irregular mass about 5 mm in diameter; egg laying commenced in mid-summer (earliest observed 6 Jun 1987). In Washington, egg masses consisted of about 50 eggs ($\bar{x}$ = 45.7, S.D. = 14.2, range 16–82, n = 58; 1988). From cage studies in Sweden, Junnikkala (1960) found that females lay an average of 1.37 egg masses. Egg masses were typically found on one to three year old wood, rarely on the growth of the current season. The eggs hatched about three weeks after oviposition and first instar larvae remained under the hibernaculum, which consists of upper surface of the egg mass, through winter until early spring.

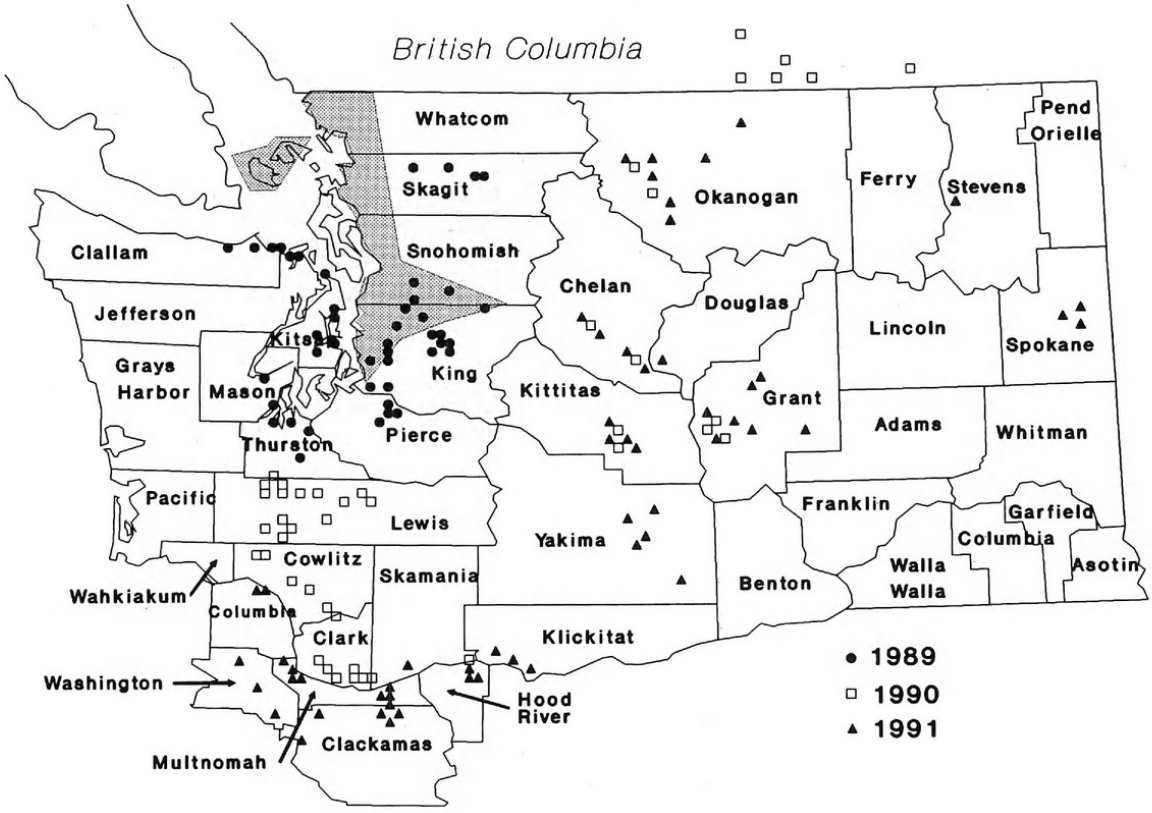

Figure 2. Geographic pattern of pheromone trap catch for 1989–1991 in Washington, five Oregon counties and the area bordering Washington in southern British Columbia. Infestation boundaries based on visual surveys in 1988 are also depicted as a shaded area.

Larvae abandoned hibernacula and began leaf mining in early April with the first sign of leaf tissue on apple. Newly established mines, always on young leaves, were observed until late May. The second through fifth instars fed externally on leaves and spun loose white-grey webbing (tents) around and near attacked leaves. All larval stages formed aggregations, presumably of the siblings from the same egg-mass. High population densities and disturbance by predators appeared to cause confluence of aggregations or their partial dissolution into smaller groups, respectively.

Cocoon spinning and pupation also occurred gregariously, beginning as early as late May but normally in mid June in western Washington. In high density infestations, where trees were largely or entirely defoliated, cocooning occurred in irregularly shaped super aggregations (composed of multiple sibships) in the crotches of tree branches, below branches, under large bark flakes, in holes in the trunk, etc., and large masses reached 10 cm in diameter. In moderate to light infestations, cocoons were typically found as isolated clusters on the underside of undamaged leaves.

Adult eclosion was first observed about 2 weeks after cocooning; emergence of adults in the laboratory was spanandrous with the bulk of the males emerging about 3 days before the females. First male trap catch followed first observed eclosion by 1–2 weeks and first observations of oviposition or of egg masses were 2–3 weeks after the onset of eclosion. This timing is consistent with observation in Europe—that adults are not sexually mature at eclosion, that mating occurs

about one week later, and oviposition commences 2 weeks after eclosion (Junikkala 1960, Menken et al. 1992).

Distribution.—Figure 2 shows the geographic distribution of *Y. malinellus* in Washington based on pheromone trap catches from mid Jul through mid Sep 1989 to 1991. Also displayed are the distributions as determined by visual surveys in 1988, representative positive sites for southern British Columbia east of the Cascade Mountains, and positive traps for northern Oregon in 1991.

For Washington, we refer to two regions, east and west, separated by the crest of the Cascade Mountains and seen in Fig. 2 as the eastern borders of Whatcom, Skagit, King, Pierce, Lewis, and Skamania Counties. In 1989, 312 traps placed in nine western counties produced 81 positive trap sites and 500 moths. In contrast, no moths were captured in 58 traps arrayed in four eastern counties (Chelan, Douglas, Kittitas, Yakima). In 1990, 480 traps placed in four southwestern counties produced 53 positives and 117 moths, demonstrating the moth had reached the Columbia River in western Washington. Fourteen counties in eastern Washington were added to the survey in 1990 (Asotin, Benton, Columbia, Ferry, Franklin, Garfield, Grant, Kickittat, Okanogan, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman). Of 825 traps placed in 18 eastern counties, 21 were positives with 34 moths in four counties. These four counties included two (Chelan and Kittitas) that were trapped with no captures in 1989, with traps placed in the same areas, if not the same trees, in both years. In 1991, survey trapping was restricted to eastern Washington and two counties along the Columbia River Gorge (Skamania and Klickitat). Columbia, Pend Oreille, and Whitman Counties were not trapped in 1991. Of 1130 traps in the remaining 15 counties, 62 caught 145 moths with new records in Douglas, Klickitat, Spokane, Stevens and Yakima Counties. Because these areas were trapped the previous year, the results suggest trap catch was contemporaneous with colonization of these counties.

Also in 1991, the Oregon Department of Agriculture trapped in 25 counties; including counties bordering the Columbia River, counties surrounding the greater Portland area, and in most areas of high human density; including down the Willamette Valley and in towns along Interstate Highway 5 to the California border. Captures, 51 moths in 34 traps of 1329 deployed, were restricted to the five counties depicted in Fig. 2 (Columbia, Washington, Multnomah, Clackamas and Hood River; D. J. Hilburn, personal communication). These results indicate that the southern edge of the distribution was the northernmost extent of western Oregon in 1991.

In summary, all pheromone trap transects west of the Cascade Mountains caught males in 1989, including those extending up the western slope along the three major trans-Cascadian mountain passes in Washington (Baker, Stevens and Snoqualamie). These were followed by moth catches on the eastern slopes of the Cascades east of the same mountain passes in Chelan, Okanagon and Kittitas Counties in 1990. However, only Chelan and Kittitas were trapped in 1989; hence, only there can we have some confidence that the colonization was recent. A similar expansion eastward up the Columbia Gorge was evident. Because these mountain passes and the foothills on either side are not heavily populated, we infer that the spread of *Y. malinellus* through the Cascade Mountains was unaided by man.

The surveys for *Y. malinellus* in British Columbia (H. Nichols, personal communication) revealed a similar pattern of spread from the original infestation area

Table 1. Parasitism rates of *Yponomeuta malinellus* Zeller for 1988-1990 by parasitoid species.

Year	Number sites	N_1[a]	% *Y.m.*	*C.c.*	Tach	*H.p.*	*I.q.*	*D.c.*	Unk	*A.f.*	N_2
1988	5	857	78.9	0.93	—	0.58	0.70	0	18.9	—	—
1989	35	13,478	96.12	0.13	0.32	0.12	0.49	0.04	2.7	0.35	12,026
1990	16	6430	90.87	1.30	0.40	0.33	1.24	0.02	5.4	0.48	6290

[a] N_1, number of cocoons reared; % *Y.m.*, percent emerged as *Y. malinellus* or died in pupal case as fully formed adults; *C.c.*, percent emerged *Compsilura concinnata* (Meigen); Tach, percent of undetermined tachinids that were probably either *C.c.* or *H.p.* but deteriorated, or remained as puparia; *H.p.*, percent *Hemisturmia parva* (Bigot); *I.q.*, percent *Itoplectis quadricingulata* (Provancher); *D.c.*, percent *Dibrachys cavus* (Walker); Unk, percent unknown mortality of cocooned larvae and pupae; *A.f.*, percent *Ageniaspis fuscicollis* Dalman; N_2, the subset of N_1 taken from sites where *A.f.* was released and used for calculating *A.f.* parasitism rates.

in the Fraser River delta (Anonymous 1985). In 1989, limited trapping surveys showed the Fraser River Canyon to be generally infested up to Lillooet and east of the Cascade crest near Kamloops and Sicamous. The infestation also extended south into the Canadian Okanogan to Kelowna and to the United States border near Grand Forks, British Columbia. Only the southern edge of this distribution is depicted in Fig. 2. It is likely that *Y. malinellus* in eastern British Columbia also arrived by dispersing through the low pass(es) in the Canadian Cascades.

Parasitism and Predation.—Parasitism of *Y. malinellus,* based on cocoon collections from 1988 to 1990, is summarized in Table 1. No parasitoids were discovered emerging from earlier life stages. Combined parasitism by two tachinid species, *Compsilura concinnata* (Meigen) and *Hemisturmia parva* (Bigot), was about equal to that by the ichneumonid *Itoplectis quadricingulata* (Provancher) and was about 2–3% altogether. All three of these parasitoids are polyphagous. *Compsilura concinnata* is of exotic origin and was introduced in large numbers in several biological control programs, notably against the satin moth, *Stilpnotia salicis* (L.) (Lymantriidae), in Washington between 1928 and 1935 (Clausen 1978). *Itoplectis quadricingulata* has a host range that includes many microlepidoptera and sawflies (Carlson 1979) and is common in the forests of the northwest (Ryan 1971). *Hemisturmia parva* has a more narrow host range that includes seven families of Lepidoptera (as *H. tortricis* Coquillett: Arnaud 1978). The gregarious parasitoid *Dibrachys cavus* (Walker) (Pteromalidae) was uncommon and may have acted as either a primary or, more likely, a hyperparasitoid. Total parasitism by these four "endemic" parasitoids was quite low and never exceeded 4% in any year. A trend of increasing parasitism rates, which would suggest adaptation to this exotic host, was not evident.

In 1989, the exotic egg parasitoid, *A. fuscicollis,* was detected at nine of 33 sites at which we had released it in 1988 (release details to be presented elsewhere). Recoveries in 1990 at four sites where *A. fuscicollis* was released in 1988 but not in 1989 showed that this parasitoid is established. Introductions into British Columbia, beginning in 1987 by Agriculture Canada in conjunction with the Commonwealth Institute of Biological Control, CAB, have also resulted in successful establishment of this parasitoid (Frazer 1989). Through 1990, *A. fuscicollis* had not added significantly to parasitism rates of *Y. malinellus* in Washington.

Exclusion Cage Studies.—Exclusion cage experiments demonstrated significant

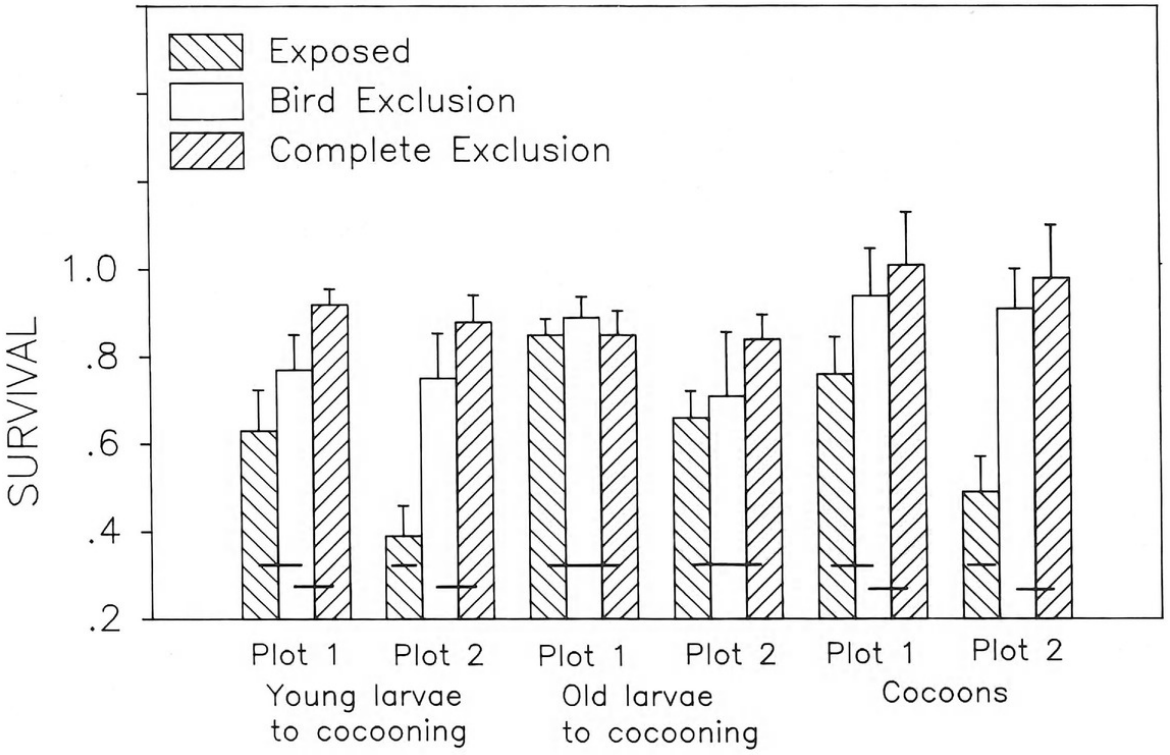

Figure 3. The proportion survival of *Y. malinellus* larvae and cocooned larvae or pupae in exclusion cage experiments of 1989. See text for details of treatments. Within groups, significantly different treatments do not share heavy crossbars (Tukey's HSD, alpha = 0.05).

levels of predation in three life stages of *Y. malinellus*: free living larvae, cocooned larvae and egg masses (Fig. 3). Survivorship from small through large larval stages (early May through early June) was significantly increased by predator exclusion at both study plots. An ANOVA model that included study plot, exclusion treatment, and their interaction as factors, with the number of larvae in each AC at the start of the experiment as a covariate, explained 48% of the variation in survivorship proportions and was highly significant ($P = 0.0001$). Exclusion treatments were significant ($P = 0.0001$) as was the covariate (number of larvae setup, $P = 0.03$); all other effects were insignificant. Bird exclusion gave survivorship intermediate (plot 1) or equal (plot 2) to that provided by complete exclusion (Fig. 3). For the second experiment with large larvae (late May to early June) the ANOVA model explained only 14% of the variation in survival proportions and was not significant ($P = 0.1$). However, plot differences caused a significant effect ($P = 0.03$) and modest, nonsignificant differences in survivorship associated with exclusion treatments were evident at plot 2 (Fig. 3).

In the experimental exclusions with pupae, the ANOVA model explained 44% of the variation in survival and was significant ($P = 0.005$); exclusion treatments were the only significant effect ($P = 0.005$). Exposed pupal clusters had lower survivorship than those under bird exclusion or complete exclusion. The pattern observed for the young larvae to cocooning was again evident for cocoons; bird predation accounted for most mortality, especially at plot 2 (Fig. 3).

Qualitative observations at other study sites showed the diversity of insect predators (e.g., wasps and ants) was abundant and they often fed on both large

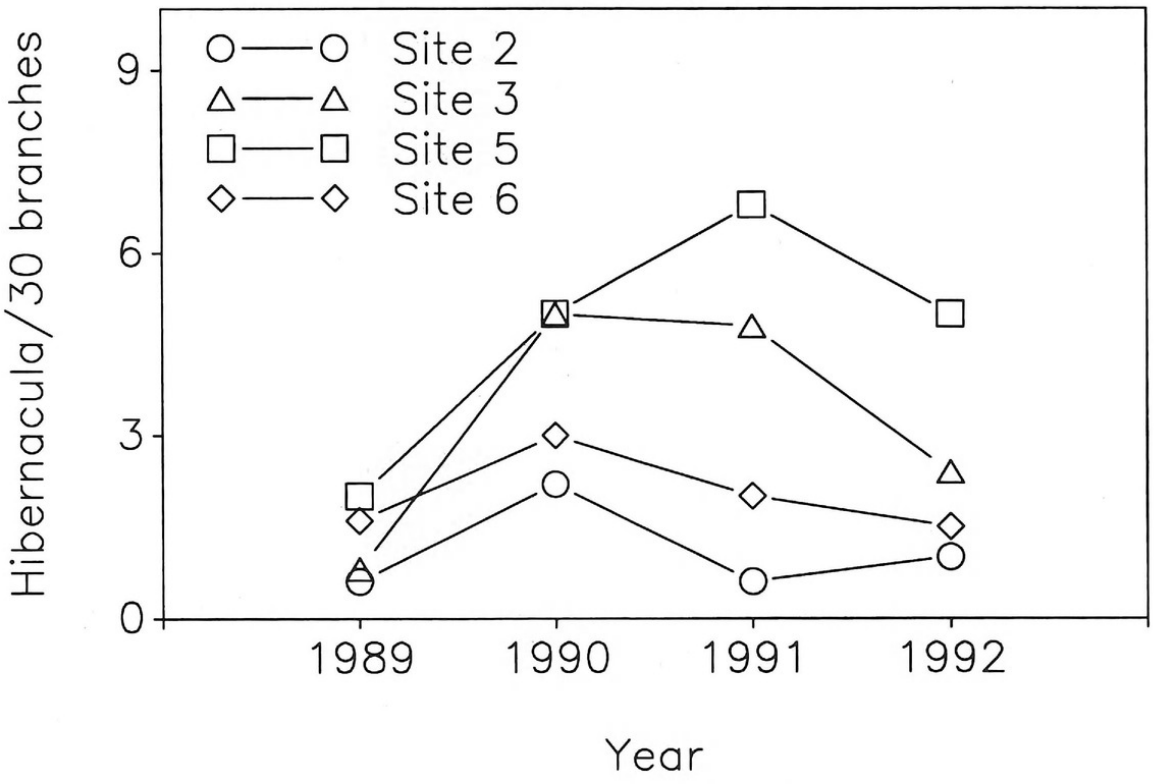

Figure 4. Egg mass (= hibernacula) densities per 30 branch sample (per tree) for *Y. malinellus* at 4 sites in Whatcom County, Washington. Standard errors are not shown but averaged 44% of the mean (range 25% to 66%).

and small *Y. malinellus* larvae. Large numbers of a common hornet, *Vespula* sp., were seen taking larvae at one site. In our exclusion studies, experimental variation was large for bird exclusion treatments because several ACs were excluded from analyses when larval aggregations moved outside of the bird netting enclosures. This suggests that bird netting allowed free access for insect predators. However, this may be true only for predators that forage by walking; flying foragers, such as *Vespula,* would likely be impeded by bird netting. Indirect evidence of bird activity (i.e., droppings) was also commonly observed and starlings (*Sturnus*) were often seen foraging in infested trees. Beirne (1943) claimed birds were significant mortality agents of *Y. malinellus* in Ireland, and Affolter & Carl (1986) reported records of starlings feeding on *Y. malinellus.*

Only 1% of egg masses under exclusion treatments (n = 79) were destroyed from 7 Aug to 12 Sep 1989 at both study sites. However, 36% of exposed egg masses (n = 80) perished over the same interval. Most of this mortality occurred at site 1 (25 of 40 exposed egg masses), producing statistical significance of exclusion treatments (site 1: Chi-Square, df = 2, n = 80, P = 0.0001). Because tanglefoot barriers excluded virtually all mortality one may infer the mortality agents were small and approached egg masses by walking. We made no systematic search for the organism(s) responsible for this mortality but Smith (R. B. Smith, personal communication) found that a mite, *Balaustium* sp. (Erythraeidae), caused similar levels of mortality in nearby British Columbia. Census of a subset of hibernacula (= egg masses with hatched larvae in diapause/quiescence) on 15 Mar 1990 showed mortality was 9% in exposed hibernacula (n = 33) and was not

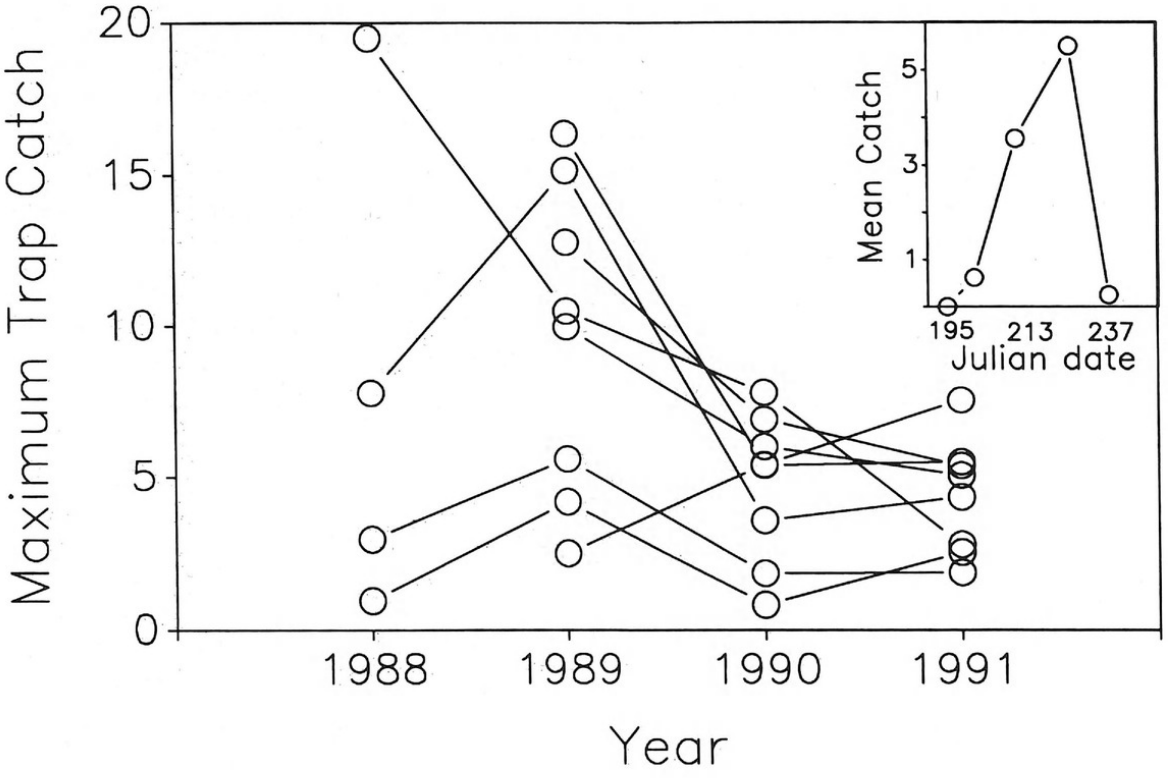

Figure 5. Maximum pheromone trap catch (male moths/trap/day) for 1988–1991 at 4 to 9 sites in Whatcom County, Washington. Traps were changed every 2 weeks from the beginning of flight season (except for 1988; see text). Inset shows a representative flight curve monitored at one study site in 1991. The maximum value, 5.5 males/trap/day, represents a single datum in the body of the figure.

statistically different from cage (0%, $n = 37$) or sticky barrier (6%, $n = 16$) exclusion treatments ($P > 0.3$ at each site). Similarly, census on 9 May showed 100% of exposed ($n = 32$) hibernacula and hibernacula protected by sticky barriers ($n = 15$) survived to larval egress as did 96% of hibernacula in cages ($n = 22$).

Population Trends.—Egg mass samples over 4 years showed similar population trends at four study sites (Fig. 4). The average number of egg masses per 30 branch sample (five trees/site) increased two to five fold from 1989 to 1990 and generally decreased from 1990 through 1992.

The maximum trap catch (mean number of males/trap/day) taken from the seasonal flight curve at each study site (5.5 in inset) was used to summarize flight each year at nine study sites and is depicted in Fig. 5. Generally higher trap catches in 1989 were consistent with the pattern observed for hibernacula densities, although there were exceptions. Maximum daily trap catch varied only 2.5 fold, at most, over years within each site.

Both egg mass densities and pheromone trap catches indicate that *Y. malinellus* populations have been relatively stable over the last 4 years in Whatcom County. High trap catches at sites where infestations were visually obvious (the main infestation areas in Whatcom County) versus low trap catches in newly infested southern counties where densities were too low to be detected visually during pest surveys suggest that pheromone traps will provide some measure of regional population trends across years. Thus, traps should be valuable to assess the long-term effect of introduced biological agents on regional population densities.

However, we do not suggest that pheromone trap catch or egg mass sampling, as employed here, provide resolution adequate to study site-specific population dynamics. We have observed striking year-to-year variation in apparent densities of larvae and cocoons (stages for which we have been unable to develop an objective sampling method). For example, we observed *Y. malinellus* larval populations extirpated in April 1989 at several sites in Whatcom County when trees were completely defoliated by the winter moth, *Operophtera brumata* (L.) (Geometridae), prior to the completion of larval development of *Y. malinellus.* At one of these sites, we monitored male trap catch before and after this event. A decline of only 50% in peak trap catch was evident in the flight following larval extirpation (10 in 1989 versus 20 in 1988), suggesting that a significant percentage of trap catch are males from off site.

Conclusion

Our observations of *Yponomeuta malinellus* in Washington show its phenology is similar with that reported throughout the Palaearctic. From survey trapping, we infer that the moth is capable of colonizing new areas over mountain passes that may provide no suitable hosts for 50 to 100 km. Populations appear to be regionally stable in the original infestation area of Whatcom County and ongoing monitoring will determine how long it will take for newly colonized areas (e.g., Yakima County) to reach the high levels that now are characteristic of northwestern Washington.

In pesticide-free settings in its native range, *Y. malinellus* is host to a large complex of natural enemies that are well known and produce high parasitism rate (20–90%) (e.g., Beirne 1943, Junnikkala 1960, Friese 1963, Dijkerman 1987). These authors and a host of others (reviewed in Affolter & Carl 1986) consider *Y. malinellus* to be regulated by its parasitoid complex, together with generalist predators, throughout the Palaearctic. Prior to use of synthetic insecticides, *Y. malinellus* was a significant pest of apples, second in importance to the codling moth, *C. pomonella,* especially in central and northern Europe (Faes 1928, Jancke 1933, Affolter & Carl 1986). In countries where economic development has lagged and synthetic pesticide use has remained restricted, *Y. malinellus* has continued to show periodic outbreaks that can cause severe, region-wide crop damage (e.g., Vaclav 1958, cited by Affolter & Carl 1986; Nosyreva 1981).

Yponomeuta malinellus does not pose a serious threat to conventional apple producers in North America if an early cover spray of organophosphate insecticide is used for codling moth control. However, if orchardists substitute sex pheromone based mating disruption for codling moth control (Howell et al. 1992) and other pesticide applications are made based on need, then *Y. malinellus* may become one cause for periodic pesticide applications.

The prognosis for control of populations infesting feral and residential *Malus* is uncertain. The constant low levels of parasitism by generalist "endemic" species indicate that they will not control *Y. malinellus.* However, our data suggest that endemic predators do produce significant mortality that may be largely responsible for preventing even more damaging levels of *Y. malinellus* in the western U.S.A. Also, increasing parasitism rates by the introduced parasitoid *A. fuscicollis* in 1991 (Unruh, unpublished data) suggest that this species may eventually contribute to lowering populations to densities more closely approximating those in Europe.

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