

Wing wear of adult *Choristoneura fumiferana* (Lepidoptera: Tortricidae) in relation to age, sex, sex ratio, and presence of host plant

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Abstract Wing wear of adult butterflies has been used to record age-related demographic parameters in hundreds of studies, but this technique has surprisingly been rarely used in moths and never in the context of pest management. A method for scoring wing wear of eastern spruce budworm, *Choristoneura fumiferana* (Clemens), the most severe pest in eastern North American boreal forests, is proposed based on the proportion of forewings covered with scales. Studies conducted in the laboratory reveal a higher level of wing damage for males than females, for 4-day-old individuals than 2-day-old individuals, and for adults that are in contact with host plant material. Males provided with mating opportunities had a lower incidence of wing damage than males deprived of mating opportunity, whereas wing wear of females was independent of the presence or absence of males. In combination with other variables, wing wear of adult spruce budworms may help to identify and forecast migration events.

Keywords *Choristoneura fumiferana* · Migration · Source sink population dynamics · Wing wear

Introduction

Quantitative measurements of wing wear are commonly used in field populations of insects to unravel processes related to age, sex ratio, longevity, dispersal movements, and mating success (Watt et al. 1977; Cartar 1992; Rudd

and McEvoy 1996; Baguette et al. 1998; Fischer et al. 2008). The main advantage of this technique is the ease with which large numbers of adults can be processed (e.g., >8,000; Ehrlich et al. 1984). A literature review conducted with Google Scholar on 21 April 2012 (using as keywords “wing wear Lepidoptera”) yielded several hundreds of studies for butterflies but surprisingly few on moth species, and none of them in the context of pest management. For example, individual variation in wing wear has never been investigated in a group as diverse and economically important as the Tortricidae. The fundamental reasons underlying the neglect of wing wear studies in moths remain unclear, at least to the authors. In this note, we develop a method for scoring the wing wear of eastern spruce budworm, *Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae), and report some factors that affect wing damage.

Materials and methods

The experiments were conducted at the Atlantic Forestry Centre in Fredericton, New Brunswick, Canada. Spruce budworm pupae reared on artificial diet (McMorran 1965) at the Insect Production facility of the Great Lakes Forestry Centre in Sault Ste Marie, Ontario, were shipped to Fredericton where they were maintained in a laboratory at 20 °C under a constant photoperiod (L15:D9). Pupae were confined individually in translucent plastic cups (37 cm³: 3.5 cm diameter × 3 cm high) and monitored every 2–8 h to determine the timing of emergence; all adults were <12 h old at the onset of experiments. The adults were frozen at –20 °C at the end of experiments, mounted on insect pins, and labeled according to treatment for subsequent assessment of wing wear. Preliminary observations

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revealed a high (>99 %) level of survival during the first four days of adult life, followed by a sharp increase in mortality affecting >50 % of individuals 1 day thereafter; hence all experiments were completed in 4 days. In experiment 1, variation in wing wear as a function of age was estimated by confining adults individually in plastic cups for 2 and 4 days (± 8 h) after emergence; no assessment was conducted for individuals <1 day old because, once frozen, the wings of these specimens became distorted and discolored, possibly due to incomplete sclerotization.

In experiment 2, the effects of host tree and mating opportunity on wing wear were evaluated by releasing 24 adults in $45 \times 60 \times 60$ -cm-high acrylic glass cages that were either empty or contained a 3-year-old potted balsam fir with current-year foliage. The following treatments were tested: for cages without a tree, 24 females ($N = 3$), 24 males ($N = 3$), 12 females + 12 males ($N = 4$); for cages with a tree, 24 females ($N = 3$), 24 males ($N = 7$), 12 females + 12 males ($N = 7$).

In experiment 3, the effect of mating opportunity on wing wear was evaluated by confining 12 adults inside a fine-mesh cloth-sleeve cage (100×75 cm) that covered

the upper canopy of a 3-year-old balsam fir. Treatments consisted of 12 females ($N = 7$), 12 males ($N = 5$), and 6 females + 6 males ($N = 7$).

After completing experiments, wing wear of 954 specimens (416 females and 538 males) was scored by recording the proportion of forewings covered with scales using increments of 10 % (score of 1: <10 % of the wing surface covered by scales; score of 10: wings entirely covered with scales) (Fig. 1). Factorial analysis of variance (ANOVA) was used to compare scores of wing wear as a function of sex, age, mating opportunity, and presence/absence of host tree; two- and three-way interactions were included in the different statistical models.

Results

For adults enclosed in small plastic cups, wing wear was more severe for males than females ($F = 16.68$, $df = 1$, 241, $P < 0.0001$) and increased with age ($F = 17.90$, $df = 1$, 241, $P < 0.0001$). The effect of age was independent of sex, as indicated by the nonsignificant interaction between these terms ($F = 0.39$, $df = 1$, 241, $P = 0.531$). Wing wear of adults confined in acrylic glass cages over a 4-day period was higher for males than females ($F = 15.57$, $df = 1$, 481, $P < 0.0001$), especially in the presence of a tree ($F = 29.45$, $df = 1$, 481, $P < 0.0001$). Separate comparisons of wing wear of males and females in the presence or absence of the opposite sex, as justified by the significant three-way interaction $\text{sex} \times \text{plant} \times \text{mating}$ ($F = 5.31$, $df = 1$, 481, $P = 0.022$), revealed that males enclosed with a tree in the absence of females exhibited the most severe wing damage (Table 1).

For adults confined in sleeve cages with a tree, the most significant term of the factorial ANOVA was the two-way interaction between sex and sex ratio ($F = 9.02$, $df = 1$, 216, $P = 0.003$). Wing wear was more pronounced for males in the absence of females (Table 1).

Discussion

The activity level of moths can be quantified with photo-electric probes to detect the movement of adults, e.g., actographs (Saito 2000), and this approach has demonstrated that male spruce budworms are more active than females (Edwards 1962), a pattern that likely explains why males exhibited more wing wear than females in this study (Table 1). Emergent female spruce budworms are quiescent and release sex pheromones to attract mates, whereas males actively forage for receptive females (Silk and Kuenen 1983). The distinct sexual roles of male and female budworms likely account for sex-specific variation in wing

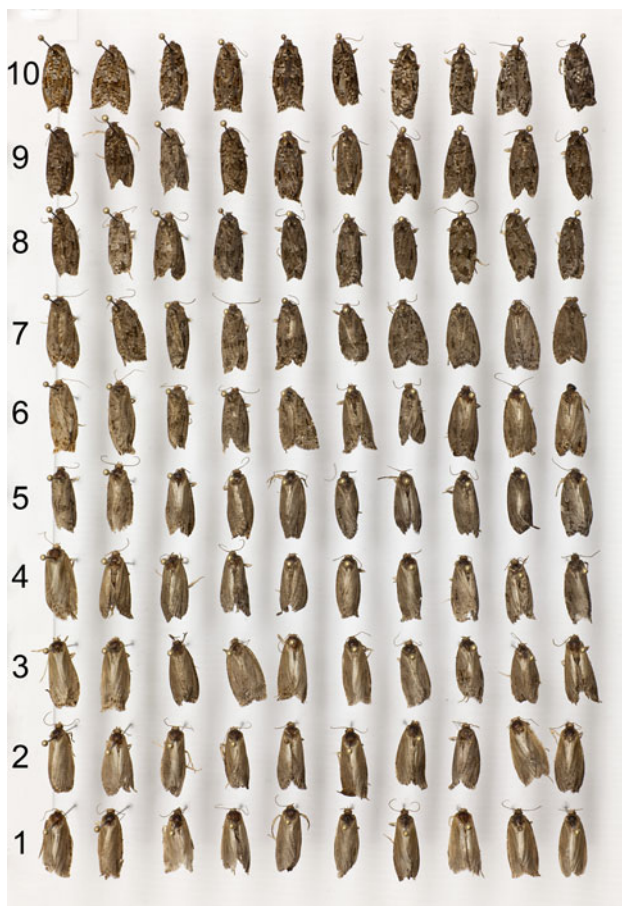


Fig. 1 Wing wear of male spruce budworms as rated by the percentage of forewings covered by scales

Table 1 Wing wear of adult spruce budworm assessed using the proportion of forewing covered with scales (Fig. 1) in different experiments

Exp	Age (days)	Plant	Mating	Wing wear (proportion of individuals)							
				Males				Females			
				1–4	5–7	8–10	Mean \pm SD (N)	1–4	5–7	8–10	Mean \pm SD (N)
1	2	No	No	0	0.197	0.803	8.5 \pm 0.1 (66)	0	0.051	0.949	9.0 \pm 0.1 (39)
	4	No	No	0	0.356	0.644	7.8 \pm 0.1 (90)	0	0.120	0.880	8.5 \pm 0.1 (50)
2	4	No	No	0.018	0.273	0.709	8.1 \pm 1.5 (55)	0.063	0.172	0.766	8.2 \pm 1.6 (64)
	4	No	Yes	0.028	0.306	0.667	8.0 \pm 1.6 (36)	0	0.182	0.818	8.5 \pm 0.9 (33)
	4	Yes	No	0.095	0.701	0.204	6.4 \pm 1.4 (147)	0.046	0.354	0.600	7.7 \pm 1.6 (65)
	4	Yes	Yes	0.047	0.349	0.605	7.6 \pm 1.4 (43)	0	0.283	0.717	8.0 \pm 1.1 (46)
3	4	Yes	No	0.579	0.386	0.036	4.2 \pm 1.7 (57)	0.325	0.413	0.263	5.7 \pm 2.1 (80)
	4	Yes	Yes	0.250	0.659	0.111	5.3 \pm 1.7 (44)	0.436	0.333	0.231	5.2 \pm 2.2 (39)

In some replicates, the number of individuals released in cages was lower than the number of observations because some adults could not be found at the end of the experiment

Experiment 1 was conducted in Solo cups, experiment 2 in Plexiglas cages with or without a balsam fir, and experiment 3 in sleeve cages surrounding a balsam fir. Adults either had the opportunity to mate (both sexes present in a cage) or not (one sex alone enclosed in the cage) *SD* standard deviation

wear. In cage experiments 2 and 3, males consistently lost wing scales at a greater rate when they were deprived of mating opportunities. The low level of wing damage of males in the presence of females (Table 1) suggests that sexual encounters and copulations reduce the level of activity of males. In contrast, the presence or absence of males did not significantly affect wing wear of females.

Wing wear of adult budworms increases with age, but the effect is small relative to the variation associated with the presence or absence of a tree. The proportion of individuals (both sexes confounded) with a low level of wing wear (index >8 ; Fig. 1) in experimental treatments where males and females were kept separately in small plastic cups decreased from 85.7 % (90 of 105) to 72.9 % (102 of 140) between age 2 and 4 days. The value was similar for individuals enclosed 4 days in a acrylic glass cage without a plant (73.9 %, or 88 of 119) but severely declined when a tree was present in the cage (31.9 %, or 69 of 216) or surrounded by a sleeve cage (19.7 %, or 23 of 137). Wing wear thus appears to be caused by mechanical damage when a plant is physically touched by spruce budworm. The extent of mechanical damage reported here must be interpreted cautiously because it is likely magnified by artificial containment of moths in laboratory cages.

Populations of moths are most commonly monitored using traps baited with female sex pheromones that attract males and light traps that attract both males and females. A strip of insecticide (usually VaponaTM) is placed at the bottom of traps to ensure that trapped individuals do not escape. The advantages of insecticide strips are their low mammalian toxicity and long residual activity, i.e., the strips do not need to be replaced for several weeks. Because insecticide strips kill trapped adults very slowly

and induce frenzied wing fanning (MR, personal observation), a rapid-killing agent such as ethyl acetate is needed to determine the conditions of wings of adults at (or near) the time of capture. This procedure is not viable in pest management programs because volatile ethyl acetate needs to be replaced daily, but it might provide a useful tool to investigate variation in wing wear among moths sampled at different time periods, spatial locations, or experimental treatments. For example, it has been reported that female spruce budworms autodetect their conspecific pheromone and exhibit an increased level of activity in its presence (Rhainds et al. 2012); high concentrations of pheromone in mating disruption plots may thus be associated with a loss of wing scales, the rating of which could potentially be used to evaluate the efficacy of and mechanisms underlying mating disruption programs.

Mark-recapture studies in butterflies use wing wear scores to estimate rates of adult displacement within and between spatially isolated patches during a determined period of time (Rudd and McEvoy 1996; Baguette et al. 1998). In spruce budworm, long-range migrations by adult spruce budworms are common events in epidemic populations and contribute to the spread of outbreak conditions (Dobesberger et al. 1983), but the role of dispersal on population dynamics remains unclear (Rhainds et al. 2012). As documented in other insects (Burkhard et al. 2002), wing wear of spruce budworm may not be primarily a predictor of age but rather reflect the level of activity of individuals seeking mates or resources for reproduction. It is thus possible that the wings of migrant budworms exhibit more wear and tear than those of resident females that reproduce locally, under the assumption that migrations are associated with increased activity levels. If this hypothesis

is true, the method developed herein for scoring wing wear of adult spruce budworms may help to segregate migrant from resident adults sampled in the field, but wing wear in itself cannot be used as the sole indicator of migration events. Rather, this new tool may, when used in combination with other environmental variables (e.g., time of capture relative to weather patterns conducive to migrations, statistical distribution of moth captures over time in relation to expected flight activity at a given site, landscape variation in body mass, mating success, residual fecundity, or disease rate), provide strong circumstantial evidence that migration events took place and even suggest hypothetical trajectories of the migrants (timing, point of origin, destination).

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