The Influence of Pruning on Wasp Inhabitants of Galls Induced by *Hemadas nubilipennis* Ashmead (Hymenoptera: Pteromalidae) on Lowbush Blueberry

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ABSTRACT The efficacy of pruning methods for managing blueberry stem galls caused by the chalcid wasp, *Hemadas nubilipennis* (Ashmead), was studied in five commercial lowbush blueberry (*Vaccinium angustifolium* Aiton) fields in Nova Scotia, Canada, between October 1999 and May 2000. Blueberry fields were mowed in the fall, and burning treatments were subsequently applied either in the fall or the spring. Three treatments were compared: mowing only, mowing plus fall burning, and mowing plus spring burning. Galls collected from the mow plus spring-burn treatment had the least wasp emergence of the three treatments, while the total number of galls was not affected by treatment. Wasp mortality, not gall destruction, is why wasp emergence is reduced in burn treatments. More galls were located and, for the burn treatments, higher wasp emergence was seen from galls found within the leaf litter than those above it. Five co-inhabitants emerged from blueberry stem galls in this study. Three, *Eurytoma solenozopheriae* (Ashmead), *Sycophila vacciniicola* (Balduf), and *Orymus vacciniicola* (Ashmead) are commonly found associates. The other two, *Eupelmus vesicularis* (Ritzius) and *Pteromalus spp.*, are new records for Nova Scotia. *O. vacciniicola* is likely an inquiline because it is the largest wasp emerging from galls, and there was a positive relationship between its emergence and that of *H. nubilipennis*. Larger gall size improved *H. nubilipennis* emergence from mow and spring-burn galls. After a field has been mowed in the fall, we recommend a spring burn to reduce gall populations and the threat of product contamination.

KEY WORDS gall, *Hemadas nubilipennis*, lowbush blueberry, *Vaccinium angustifolium*

The native North American lowbush blueberry, *Vaccinium angustifolium* Aiton (Ericaceae), is an important cash crop in Maine, Atlantic Canada, and Quebec, and is sold as fresh and as frozen fruit mainly for the processed food market (Hall et al. 1972, Blatt et al. 1989). Lowbush blueberry grows perennially on well-drained acidic soils (pH 3–5) in clones (genets) connected by rhizomes (Vander Kloet 1988). Developing from dormant buds on rhizomes, new adventitious shoots grow until midsummer, when maximum height is reached and terminal buds die (Vander Kloet 1985). Commercial production uses a 2-yr cycle consisting of a vegetative growth year (commonly called "sprout" year), followed by the crop year. In the autumn or early spring following the harvest, pruning by mowing and/or burning the dormant plants is required to stimulate new vegetative shoot growth and fruit buds (Blatt et al. 1989). Biennial pruning maintains high fruit yields because floral buds develop only on first-year tissue, and the ratio of branch-to-fruit increases with plant age (Eaton and McIssac 1997). Mature commercial lowbush blueberry fields look much like pasture or hay fields, consisting of even, dense plant cover throughout the entire area.

Studies of pruning methods of blueberry have largely focused on the aspects of plant development and productivity (Chandler and Mason 1943, Black 1963, Kender et al. 1964, Smith and Hilton 1971, Ismail et al. 1981, Ismail and Hanson 1982, McLeod and Misener 1988, Vander Kloet and Pither 2000). Burn pruning destroys leaf litter and many overwintering insects that dwell near the soil surface, and contributes to low economic injury level (EIL) from insect pests on lowbush blueberry (Kinsman 1993). In recent years, many growers have switched from burn to mow pruning, to reduce costs and environmental concerns. Although there has been little interest in the influence of pruning method on pest control, this may change if the switch to mow pruning results in increasing pest abundance.

The gall-inducing chalcid, *Hemadas nubilipennis* Ashmead (Hymenoptera: Pteromalidae), forms large, multichambered galls on shoots of lowbush blueberry when female *H. nubilipennis* deposit eggs into tender vegetative shoots (Goulet and Huber 1993). During the 60–90-d period of gall growth and maturation, chambers enlarge and separate. The larvae and gall are

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Table 1. Characteristics of the lowbush blueberry fields used for examining the effects of pruning treatments for control of blueberry stem gall

Characteristic	Blueberry field				
	Gore	Dean	Newton Mills	Kirkhill	Farmington
Field location	45° 07.227′ N 063° 42.236′ W	45° 11.558′ N 062° 52.204′ W	45° 13.134′ N 062° 51.845′ W	45° 25.651′ N 064° 22.710′ W	45° 34′ N 063° 54′ W
Field size (ha)	10.1	10.5	10.1	3.5	18.6
Years in production	40	30	25	50	40–50
Prune history	Burning with straw (mowed past 2 cycles)	Mowing and burning (burned in spring and fall)	Mowing (only 2 recorded burns—fall 1997 and 1999)	Mowing	Mowing (spot burned in 1998)

mature by mid August (West and Shorthouse 1989). *H. nubilipennis* overwinters inside chambers of galls as prepupae and exits as adults between mid May and June the following spring (Shorthouse et al. 1986). Galls may form on shoots above or within the leaf litter. A number of chalcid wasps have been reared from mature stem galls found on *V. angustifolium* on several occasions (Driggers 1927, McAlister and Anderson 1932, Shorthouse et al. 1990, Brooks 1993, Hayman 1998). *Orymus vacciniicola* (Ashmead), *Eurytoma solenozopheriae* (Ashmead), and *Sycophila vacciniicola* (Balduf) have only been found in *H. nubilipennis*-induced galls, but their effects on *H. nubilipennis* are unknown. *Eupelmus vesicularis* (Ritzius) has been associated with *H. nubilipennis*-induced galls as well as other galls (Krombein et al. 1979).

Although the economic consequences associated with the blueberry stem gall have long been considered to be minor by the commercial lowbush blueberry industry, their populations in Nova Scotia appear to be increasing (KE.M., unpublished data), causing growers concern about their negative impact on yield. In a study of the economic impact of blueberry stem gall, Hayman (2001) found that galls reduced shoot yield in some fields. When galls formed on a shoot tip, berry production was significantly less than when galls formed below the shoot tip. In addition, galls can be similar in size and shape to berries, making them difficult to separate during processing. Consequently, galls have been contaminating fresh and processed products.

Although strategies to control the stem gall have not been tested, Crozier (1997) suggested that increasing parasitoid levels in the gall and the use of burn pruning might reduce their populations. Our objectives were to investigate the blueberry stem gall wasp community, examine field characteristics that influence *H. nubilipennis* and co-inhabitant emergence, and assess the effectiveness of pruning methods (i.e., mowing, burning) and burn season for control of blueberry stem gall wasp inhabitants.

Materials and Methods

Study Sites

The study was conducted between October 1999 and May 2000 in five commercial Nova Scotia lowbush blueberry fields that fruit in odd numbered years (Table 1). Fields were selected because of high stem gall densities, as determined in a 1996 gall survey of 26 fields in Nova Scotia (K.E.M., unpublished data) and because field owners granted access.

Field Design

Following commercial pruning by mowing in October 1999, an area ≈115 m × 60 m was selected, based on growers preference and ease of access in each field. Within this area, six parallel 100 m × 1.5-m plots were spaced 7 m apart and staked off with surveyor flags in each field. The pruning treatments, mowing only and mowing followed by either fall-burn or spring-burn, were duplicated in each field and assigned to each plot using a completely randomized block design (two reps × three treatments × five fields). Using a diesel-fuelled plot burner, the appropriate plots were burned in the fall and spring. Fall burning was done on 26 November for Kirkhill, 6 December for Dean, 6 and 9 December for Newton Mills, 14 December for Gore, and 20 December for Farmington. Spring burning was done on 19 April for Gore, Dean, and Newton Mills, and 26 April for Kirkhill and Farmington.

Gall Collection, Classification, and Measurement of Leaf Litter

Collections of galls were made on 10 May (Gore), 12 May (Newton Mills), 17 and 20 May (Dean), 18 and 19 May (Kirkhill), and 24 May (Farmington). All galls in a 0.5-m^2 quadrat area were systematically collected at 5-m intervals along each plot (i.e., 20 quadrats/plot × 6 plots/field × 5 fields). Galls above and within the leaf litter layer were kept separate for each quadrat and later classified by age. Old galls were soft, dark brown or gray, had emergence holes, and were unattached or easily removed from a stem. New galls were firm, red, green, or light brown in color, had few or no emergence holes, and were firmly connected to a stem. When gall age was not obvious, the gall was cut in half with a scalpel blade. A gall was considered new if living immature wasps were present. The number and type of galls collected differed among quadrats, plots, and fields. Once the galls were collected, leaf litter depths in mm were recorded at 10-m intervals along each plot on 1 June 2000 in Dean, Newton Mills, and Gore; and on 7 June 2000 in Farmington and Kirkhill.

Table 2. Numbers of new blueberry stem galls incubated in June 2000 to assess wasp emergence based on field, leaf litter position and prune treatment

Field	Mow only		Mow + fall-burn		Mow + spring-burn		Total galls reared
	Above litter	Within litter	Above litter	Within litter	Above litter	Within litter	
Gore	17	3	7	4	2	1	34
Dean	8	9	3	113	3	8	44
Newton Mills	16	9	8	9	3	4	49
Kirkhill	19	18	10	14	4	7	72
Farmington	22	16	18	13	13	14	96

Gall Selection and Incubation

The classified galls were stored in a Bally refrigeration unit (Brockville, Ontario) at 5°C, 45%–55 RH. On 22 and 23 June 2000, one new gall from above and within the leaf litter was randomly selected from each quadrat that had one or more new galls. The number of new galls available for rearing varied by pruning treatment, leaf litter position, and field (Table 2). Each gall was individually placed on filter paper moistened with distilled water in the bottom of a 28-ml plastic cup (Solo, Urbana, IL) and labeled by field, plot, quadrat number, gall position regarding leaf litter, and date of collection. Holes were punched in the snap-on lids with insect pins to allow gas exchange and to ventilate the cups. Each cup was then placed in a plastic tray designed to hold the rearing cups, set in an environmental cabinet (Econaire Systems, Winnipeg, Manitoba, Canada) and incubated at 21°C, 50% RH under constant light with an average photosynthetic photon flux of 72.3 ± 3.6 μmoles m^{-2}s^{-1} at the bottom of the cabinet. To fit all plastic trays in one cabinet, the trays were stacked one on top of another and assigned a position on the inside floor of the cabinet. All living and dead emerged wasps were removed from the cups once a week and placed in labeled gel caps. After wasps were removed, the filter paper in each cup was remoistened with distilled water. Each week, the bottom tray was placed on top of the stack, and the stacks were reorganized so that the galls would receive similar environmental conditions during the experiment. The study was concluded when no more wasps emerged from the galls for a 2-wk period.

Community Composition of *H. nubilipennis*-Induced Galls

Emerged adults were identified to species, sex, and then counted. Sex identifications were made for each species because morphologic variations between males and females were originally suspected to be different species. Sex ratios ([number of females]/[number of females + number of males]) were calculated for each species in all fields. Pointed voucher specimens of *H. nubilipennis* and the gall inhabitants are deposited in the Canadian National Collection of Insects and Arachnids, Ottawa, Ontario, and at the Atlantic Food and Horticulture Research Centre, Kentville, Nova Scotia.

Gall Dissection

Once the wasp emergence period was over, the galls were removed from the environmental cabinet for processing. Each gall was viewed under a dissecting microscope to count emergence holes, and then dissected with a scalpel to count the number of wasp chambers, dead wasps, and their stages of development (i.e., larvae, pupae, and adult). Species identifications were not possible because of decay, fungal infection, and the lack of descriptions for the immature wasps.

Data Analyses

Factors Affecting *H. nubilipennis* Emergence. Numbers of *H. nubilipennis* emerging from a gall [transformed by log 10 (Y+1)] failed the test for normality using univariate statistics (PROC UNIVARIATE, SAS Institute 1996). The influence of numbers of chambers, total dead, *E. solenozopheriae*, *S. vacciniicola*, and *O. vacciniicola* per gall on *H. nubilipennis* emergence (yes or no) was tested separately by pruning treatment (i.e., mow only, mow plus fall-burn, mow plus spring-burn) using logistic regression analysis (PROC CATMOD with maximum likelihood tests, SAS Institute 1996).

Leaf Litter Depth

The influence of field and pruning treatment on postpruning leaf litter depth was tested using an analysis of variance (ANOVA): Randomized complete block with fixed effects (PROC GLM, SAS Institute 1996).

Gall Populations

Log transformations of the numbers of old, new, and total galls per quadrat were used as three, separate dependant variables to test the influence of field, treatment, and gall location (above or within the leaf litter) using a split plot ANOVA (PROC GLM, SAS Institute 1996). Field was fixed in the model because they were chosen for high gall density. The pdiff option in SAS was used to compare lsmeans, which produced P values for all combinations of gall location and field.

Table 3. Community structure of galls formed in 1999 on *Vaccinium angustifolium* collected from commercial lowbush blueberry fields at Gore, Newton Mills, Kirkhill, Dean and Farmington, Nova Scotia

Field	Parameter	*Hemadas nubilipennis*	*Eurytoma solenozopheriae*	*Sycophila vacciniicola*	*Orymus vacciniicola*	*Eupelmus vesicularis*	*Pteromalus* spp.
Gore	No.[a] (%)[b]	130 (50.8)	60 (23.4)	8 (3.1)	57 (22.3)	1 (0.4)	0 (0)
	Sex Ratio	1.00	0.75	0.33	0.58	1.00	N/A
Dean	No. (%)	202 (70.1)	5 (1.7)	26 (9.0)	29 (10.1)	10 (3.5)	16 (5.6)
	Sex Ratio	0.93	0.58	0.62	0.25	1.00	0.90
Newton Mills	No. (%)	84 (23.9)	142 (40.3)	41 (11.6)	70 (19.9)	13 (3.7)	2 (0.6)
	Sex Ratio	1.00	0.59	0.44	0.36	1.00	1.00
Kirkhill	No. (%)	133 (27.8)	112 (23.4)	59 (12.3)	119 (24.9)	21 (4.4)	34 (7.1)
	Sex Ratio	1.00	0.52	0.51	0.49	1.00	0.58
Farmington	No. (%)	141 (26.3)	87 (16.2)	94 (17.6)	186 (34.7)	7 (1.3)	21 (3.9)
	Sex Ratio	1.00	0.46	0.53	0.49	1.00	0.68

[a] Number of emerged wasps from reared galls. Reared gall totals are reported in Table 2.
[b] Percentage of total wasp emergence.

Wasp Emergence Success

Using the number of all species of emerged wasps and total wasps per gall (alive and dead), a dependant variable, called "emergence success," was created examining live relative to dead wasps per gall [emergence success = log ((emerged + 0.5)/(total − emerged + 0.5))]. The influence of field (which was fixed), pruning treatment, position of galls, field x pruning treatment, and pruning treatment x position of galls on emergence success was analyzed with a split plot ANOVA (PROC GLM, SAS Institute 1996). The pdiff option in SAS was again used to compare lsmeans, which produced P values for all pair-wise comparisons.

Results

Community Composition of *H. nubilipennis*-Induced Galls

The populations of *H. nubilipennis* and the five species of co-inhabitants associated with blueberry stem gall, including *E. solenozopheriae, S. vacciniicola, O. vacciniicola, E. vesicularis,* and an unidentified species of *Pteromalus* are presented in Table 3. The co-inhabitant communities were dominated by *E. solenozopheriae* in Newton Mills, *O. vacciniicola* in Farmington and jointly by *S. vacciniicola* and *O. vacciniicola* in Dean. Gore and Kirkhill had similar numbers of *E. solenozopheriae* and *O. vacciniicola. Pteromalus spp.* was not present in Gore. *H. nubilipennis* was the most abundant wasp in the Dean, Gore, and Kirkhill communities, and the second most abundant wasp in Farmington and Newton Mills. Co-inhabitant levels were highest in Newton Mills, followed closely by Farmington and Kirkhill. Almost 50% of the wasps at Gore and 30% at Dean were co-inhabitants. Wasp sex ratios among fields were relatively consistent, except for *Pteromalus spp.* Only females emerged for *H. nubilipennis* and *E. vesicularis,* except for a small proportion (0.07) of male *H. nubilipennis* at Dean. The other three species tended toward even sex ratios, except the *E. solenozopheriae* population was 75% female at Gore, and females made up less of the populations for *S. vacciniicola* in Gore (33%), and *O. vacciniicola* in Dean (25%) and Newton Mills (36%).

Factors Affecting *H. nubilipennis* Emergence

There were significant, positive associations between *O. vacciniicola* and *H. nubilipennis* emergence from mow only ($\chi^2 = 6.42$, $P = 0.0113$), mow plus fall-burned ($\chi^2 = 12.02$, $P = 0.0005$), and mow plus spring-burned galls ($\chi^2 = 7.04$, $P = 0.008$) (Table 4). Significant positive associations also occurred between *H. nubilipennis* emergence and the number of chambers in mowed ($\chi^2 = 10.67$, $P = 0.0011$), and spring-burned galls ($\chi^2 = 4.07$, $P = 0.0436$) (Table 4).

Leaf Litter Depth

Postpruning leaf litter depth was significantly affected by field ($F = 41.89$; df = 4, 15; $P < 0.0001$) and

Table 4. Logistic regression of the likelihood that blueberry stem gall attributes effect the emergence of *Hemadas nubilipennis* from galls collected from three pruning treatments in Nova Scotia blueberry fields

Gall Attribute	Mow only				Mow + fall-burn				Mow + spring-burn			
	Estimate	SE	Chi-Square	P	Estimate	SE	Chi-Square	P	Estimate	SE	Chi-Square	P
Intercept	−1.9077	0.3174	36.12	0.0000	−1.7841	0.3412	27.34	0.0000	−3.3877	0.4680	52.41	0.0000
Chambers/Gall	0.0867	0.0266	10.67	0.0011	0.00404	0.0306	0.02	0.8951	0.0736	0.0365	4.07	0.0436
Total dead/Gall	−0.0490	0.0513	0.91	0.3396	0.0297	0.0446	0.44	0.5052	0.0126	0.0480	0.07	0.7920
Eurytoma solenozopheriae	0.0595	0.0682	0.76	0.3831	0.0663	0.0986	0.45	0.5014	0.2346	0.22	1.14	0.2863
Sycophila vacciniicola	−0.1389	0.0972	2.04	0.1533	0.1388	0.1703	0.66	0.4150	−0.1884	0.2133	0.78	0.3773
Orymus vacciniicola	0.1941	0.0766	6.42	0.0113	0.6307	0.1819	12.02	0.0005	0.4598	0.1733	7.04	0.0080

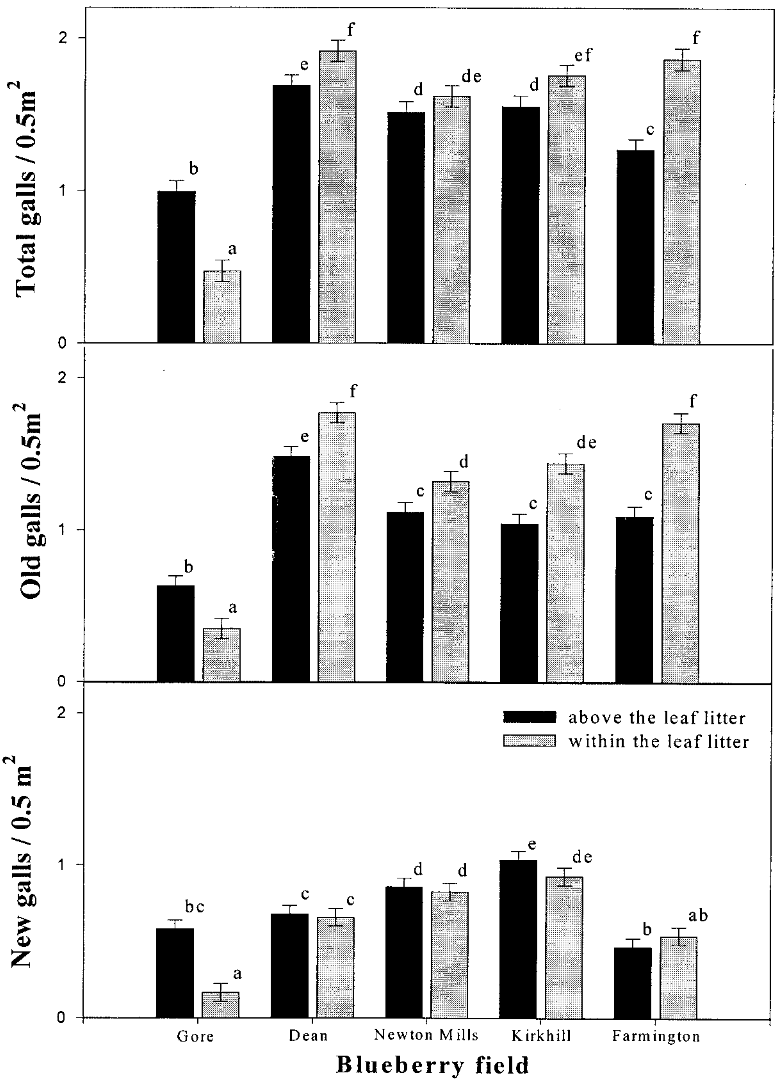

Fig. 1. Total, old, and new stem gall populations (least square mean ± SE) collected from above and within the leaf litter of five Nova Scotia blueberry fields in spring 2000. Mean with the same letter is not significantly different.

pruning treatment ($F = 17.20$; df = 2, 15; $P < 0.0001$). The order of largest to smallest litter layers (SE = 0.97) was Farmington (31 mm), Kirkhill (23 mm), Newton Mills (21 mm), Dean (18 mm), and Gore (14 mm). The least squares mean (SE = 0.75) of leaf litter depth (i.e., mm) was similar for mow plus burn pruning in the fall (19.54) and spring (19.78) but was highly reduced, compared with mow only (25.05).

Gall Populations

Gall populations differed by field, leaf litter location, and gall category (Fig. 1). The least squares mean (SE = 0.04) of total gall populations among mow only (1.41), mow plus fall-burned (1.45), and mow plus spring-burned (1.52) plots were not significantly different ($F = 2.4$; df = 2,15; $P < 0.1181$). The different fields varied in the numbers of galls within and above the leaf litter (Fig. 1). Dean, Kirkhill, and Farmington had significantly more old and total galls overall within the leaf litter than above. The total gall populations above and within the leaf litter were similar at Newton Mills, while Gore had significantly more old and total galls above than within the leaf litter. Although there were also more new galls above than within the leaf litter at Gore, similar numbers of new galls were found in the leaf litter depths at the other four fields.

Total gall numbers were highest within the leaf litter at Dean, Farmington, and Kirkhill (1.76–1.92 galls/0.5m^2), followed by Newton Mills (1.61 galls/0.5m^2) and Gore (0.47 galls/0.5m^2). The numbers of old galls above the leaf litter did not differ among Newton Mills, Kirkhill, and Farmington, but all had significantly fewer old galls than at Dean (1.48 galls/

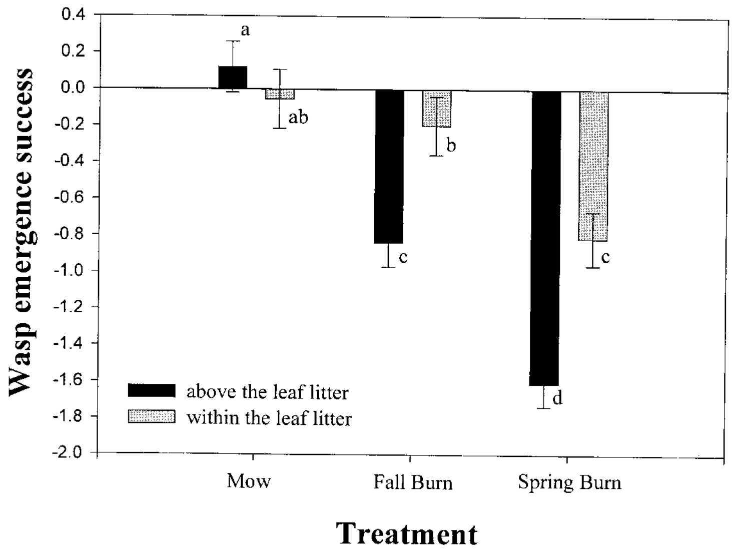

Fig. 2. Least square mean (±SE) of wasp emergence from galls formed in 1999 on lowbush blueberry stems in Nova Scotia relative to total gall inhabitants per gall [wasp emergence success = log ((emerge + 0.5) / (total – (emerge + 0.5))] for each treatment and gall position. Mean with the same letter is not significantly different.

$0.5m^2$) and significantly higher numbers than at Gore (0.63 galls/$0.5m^2$). Dean and Farmington (1.71–1.77 galls/$0.5m^2$) had more old galls within the leaf litter than Newton Mills and Kirkhill (1.32–1.44 galls/$0.5m^2$). Kirkhill had more new galls, above (1.04 galls/$0.5m^2$) and within (0.93 galls/$0.5m^2$) the leaf litter than Gore, Dean, and Farmington. Numbers of new galls above and within the leaf litter at Newton Mills were similar to within the litter at Kirkhill. Within the leaf litter, Gore (0.16 galls/$0.5m^2$) had the fewest new galls. Intermediate levels of new galls were collected above the leaf litter from Gore, and above and within the litter from Dean and Farmington (Fig. 1).

Wasp Emergence Success

There was a significant interaction between treatment and position of galls ($F = 12.64$; df = 2, 8; $P < 0.0001$), indicating that wasp emergence differed among pruning techniques, depending on position of galls regarding leaf litter. The interaction between field and pruning treatment was not significant. All treatments differed significantly from one another for wasp emergence from galls above the leaf litter (Fig. 2). The least squares mean ± SE of emergence was highest in mow only followed by mow plus fall-burned, and the least in mow plus spring-burned galls. Wasp emergence from galls within the leaf litter was similar for mow only or mow plus fall-burned, and was significantly higher than emergence observed in mow plus spring-burned galls. Position of galls had no influence on wasp emergence in the mowed treatment. However, emergence was significantly higher from galls within the leaf litter than above in both burn treatments.

Discussion

Community Composition of *H. nubilipennis*-Induced Galls

The wasp species associated with mature *H. nubilipennis*-induced stem galls from this study are similar to other studies that have reared wasps from mature stem galls of *V. angustifolium* (Aiton), *V. atrococcum* (Gray), and *V. corymbosum* (L.) (McAlister and Anderson 1932, Judd 1959, Shorthouse et al. 1990, Brooks 1993, Hayman 1998).

In our study, the rarity of male *H. nubilipennis* in Dean is consistent with Shorthouse et al. (1990), who reported a sex ratio (female-to-male) of 0.98. Males were only found in one of the five sites studied, which may be more a reflection of the number of samples needed to detect males when they are present in such small numbers rather than a lack of males in the populations. Sex ratio is a factor that can influence population trends. If sex ratios fluctuate over time, it may indicate whether *H. nubilipennis* and co-inhabitant populations are building or in decline. In fact, Fuester and Taylor (1998) found that the gypsy moth abundance was critically affected by sex ratio, in which low populations were female-biased, and high populations were male-biased.

Although not previously collected in Nova Scotia, the occurrence of *Eupelmus vesicularis* in each field and *Pteromalus sp.* in four fields shows that these species are present in a number of locations in Nova Scotia. The stem gall community shows species composition consistency among the study sites. Within plant galls, rare and common species are usually consistent over time and across wide geographic areas (Askew 1980). For example, *E. vesicularis, Pteromalus* *sp.* and *Tetrastichus sp.* are always rare, while *O. vacciniicola, E. solenozopheriae,* and *S. vacciniicola* occurred commonly in blueberry stem galls, as observed in this study.

Slobodokin and Sanders (1969) argue that community species richness is influenced by the severity, variability, and predictability of the environment in which it develops. In this study, size, years in production, and prune history differ among the commercial blueberry fields. Gall community responses to field-specific factors are largely unknown, making it difficult to tease out the field-related factors that favor the emergence of each gall co-inhabitant.

Factors Affecting *H. nubilipennis* Emergence

As the number of chambers in mow only and mow plus spring-burned galls increase, there is a positive effect on *H. nubilipennis* emergence. Shorthouse et al. (1990) showed that the number of inhabitants is positively correlated with gall diameter. Therefore, more chambers indicates larger galls. Having more chambers may simply signify that with more larvae, there is a better chance that at least one wasp will emerge from a gall.

Orymus vacciniicola, the most common co-inhabitant in this study, was positively associated with *H. nubilipennis.* Thus, as the number of *O. vacciniicola* emerging from a gall increased, so did the number of *H. nubilipennis.* A parasitoid/host relationship should result in fewer hosts emerging as parasitoid wasp numbers increase, the opposite of what was seen. This result, coupled with the fact that *O. vacciniicola* is the largest of the six wasps collected in this study, is strong evidence that *O. vacciniicola* may be an inquiline.

Leaf Litter Depth

Our study showed that postpruning leaf litter layer was significantly deeper in mow only plots than mow plus fall or spring-burned plots. We also found that fields that are only mowed on a regular basis, such as Farmington and Kirkhill, had the highest leaf litter depths of the study sites. Field management history and the number of years of commercial operation are factors that could potentially influence site-to-site variation in postpruning leaf litter depth. The advantages provided by burn-pruning include limiting the spread of leaf spot and red leaf disease, reducing fungi and fruit rotting organisms, and killing insects and weed seeds that overwinter close to the soil surface (DeGomez et al. 1990, Chiasson and Argall 1995).

Although pruning costs currently favor the cheaper alternative of mowing, this may result in higher pest control costs in the future. For example, a field that has accumulated a deep leaf litter layer may have to be burned in successive production cycles to kill wasps in galls, or to rid a field of other insects and diseases residing near the soil surface. However, it is likely that this burning strategy could put the population of *S. vacciniicola* at risk, which is a potential candidate for the biological control of *H. nubilipennis* (Hayman 2001).

Gall Populations

Total gall populations were not influenced by the prune treatments. Gore had significantly more galls above the litter, probably because it had the shallowest postpruning leaf litter and most reported burn-prunes. The remaining fields did not differ in the number of new galls regarding leaf litter position. New gall formation below leaf litter may vary according to the timing of oviposition on shoots. As litter accumulates in mowed-only fields, more and more galls will be protected within the leaf litter. In natural lowbush blueberry habitats, Shorthouse et al. (1986) found that 74% of galls were within the leaf litter. Therefore, mowing-only may increase production costs for fuel needed to conduct a slow, deep burn of litter. Field differences in gall density are probably due to differences in pruning practices, number of years of commercial production, and the availability of suitable host shoots. Hayman (1998) reported that the blueberry stem gall showed a patchy distribution in lowbush blueberry fields. Therefore, the rate of new gall formation may also depend on the extent of patch isolation, associations among patches, and trophic relationships among wasps in the gall.

Wasp Emergence Success

There is a higher reduction of wasp emergence from blueberry stem galls when fields are mowed plus burned, compared with fields that are mowed only. The effect of treatments was similar across all fields studied because the interaction of field and pruning treatment was not significant. Ponder and Seabrook (1994) found that mowing followed by burning in the fall provided excellent control for blueberry leaftier (*Croesia curvalana* Kearfott), and DeGomez et al. (1990) reported that there were lower numbers of blueberry spanworm larvae (*Itame argillacearia* Packard) in burned, as opposed to mowed fields. Because the wasp community occupies the gall from early to midsummer, until late May to early June the following spring (Shorthouse et al. 1990), this overwintering location should make stem gall wasps vulnerable to injury from fall and spring burning.

Stem gall wasps were more likely to survive a mow plus fall-burn than a mow plus spring-burn for each position of galls in the leaf litter. Wasp emergence response to burn-prune season may be partially explained by burning intensity, which is influenced by temperature and relative humidity, rainfall, time since prior burning, and the desiccation of surface fuels (e.g., mowed tissue, leaf litter, straw) (Dunwiddie 1991; L.J. Eaton, personal communication). In this experiment, spring burning may have been more effective for gall wasp control than fall burning because of the higher burning intensity as a result of warmer temperatures and less precipitation at the spring burn. This result was partially confirmed by rainfall and monthly mean temperature data obtained for the months of fall and spring burning in Middle Musquodoboit, NS, from the Atlantic Climate Centre in Fredericton, NB. Average temperature in April 2000 (5.7°C) was 6°C warmer than December 1999 (−0.3°C). There was also 44.4 mm less rainfall in April 2000 (111.5 mm) than December 1999 (155.9 mm). In addition to this result, the tissue that was mowed from the plant had four more months to dry out and may have amplified the burn intensity in spring. DeGomez et al. (1990) suggested that fires that are not intense enough would not exert good pest control. This result may explain why mow plus fall-burned galls had higher wasp emergence than mow plus spring-burned galls. The higher emergence success from galls within the leaf litter layer in the fall and spring-burns was probably because the heat intensity of burning was lower within the leaf litter than on the surface. Seastedt and Reddy (1991) have shown that insects dwelling within or near the ground are not as affected by fire as those living in parts of aboveground vegetation. Also, temperature extremes are moderated within the leaf litter, which could increase the likelihood of a wasp surviving winter exposure.

Conclusions and Producer Recommendations

Since new gall numbers above and within leaf litter did not differ in four fields, and because wasp survivorship was higher in the litter of burn treatments, we recommend targeting new galls within the litter, with a deep spring burn after fall mowing as a valuable strategy for control. Once spring burning is used for stem gall control, producers should be mindful of potential future outbreaks. Fay and Samenus (1993) found that prairie gall insect populations are depressed the year after a fire but steadily increase in succeeding years until subsequent fires lower them. This result may also be the case for the blueberry stem gall. Because numerous factors influence treatment effects on insect pests (Dunwiddie 1991), future investigations should examine the effects of different burning fuels and burning equipment on gall wasp survival in various environmental conditions (i.e., temperature and moisture).

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