

Matacil insecticide spraying, pollinator mortality, and plant fecundity in New Brunswick forests

JAMES D. THOMSON¹ AND R. C. PLOWRIGHT

Department of Zoology, University of Toronto, Toronto, Ont., Canada M5S 1A1

AND

G. R. THALER

Department of Botany, University of Toronto, Toronto, Ont., Canada M5S 1A1

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Exposure-cage trials in spruce–fir forest near Doaktown, N.B., Canada, showed that Matacil aminocarb insecticide, applied for control of spruce budworm, increased mortality rates of several types of solitary bees and syrphid flies, although previous studies had found no effect on bumblebees. Of two plant species predominantly pollinated by the sensitive pollinator taxa, one (*Maianthemum canadense* Desf.) showed significantly reduced fecundity in sprayed areas. The other (*Cornus stolonifera* Michx.) tended toward reduced fecundity in sprayed areas, although this trend was obscured by great within-treatment variability. *Cornus canadensis* L., which is visited by bumblebees as well as by the smaller, Matacil-susceptible insects, showed no reduction of fecundity in sprayed areas. This study generally supports the practicality of assessing plant risk *a priori* by considering (i) the breeding system, (ii) the flowering phenology, (iii) the effective pollinators, and (iv) the known susceptibility of the pollinators to the spray agent in use.

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Des essais en cages, effectués près de Doaktown au Nouveau-Brunswick (Canada), montrent que le Matacil (aminocarb), lorsqu'il est utilisé pour la lutte contre la tordeuse des bougeons de l'épinette, augmente le taux de mortalité de plusieurs types d'abeilles solitaires et de syrphides; cependant, des études antérieures n'ont révélé aucun effet de cet insecticide sur les bourdons. Sur deux espèces de plantes principalement pollinisées par les insectes sensibles à l'insecticide, l'une (*Maianthemum canadense* Desf.) a une fécondité significativement plus basse dans les sites qui ont subi des pulvérisations de Matacil. L'autre (*Cornus stolonifera* Michx.) a tendance à présenter une fécondité moindre dans ces sites, mais cette tendance est obscurcie par une grande variabilité inter-traitement. Le *Cornus canadensis* L., qui est visité aussi bien par des bourdons que par des insectes plus petits sensibles au Matacil, ne présente aucune réduction de fécondité dans les sites soumis aux pulvérisations. Cette étude montre que les risques courus par les plantes peuvent être évalués *a priori*, de manière pratique, en tenant compte (i) des systèmes de croisements, (ii) de la phénologie de la floraison, (iii) des pollinisateurs effectifs et (iv) de la sensibilité des pollinisateurs à l'insecticide utilisé.

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Introduction

Since 1962, large blocks of coniferous forest in New Brunswick, Canada, have been sprayed with various insecticides to control the spruce budworm, *Choristoneura fumiferana* Clem., a defoliator of commercially important pulpwood species, notably balsam fir (*Abies balsamea* (L.) Mill.). Following reports by blueberry growers of poor yields, Kevan (1975a, 1977), Kevan and Collins (1974), and Kevan and LaBerge (1979) suggested that the spray program was disrupting pollination by killing nontarget insects, especially wild bees. Kevan (1975b) predicted that similar disruption might be affecting the fruit-set of native forest plants as well as blueberries, and his surmise has been supported by studies (Plowright *et al.* 1978, 1980; Plowright and Rodd 1980; Thaler and Plowright 1980) on the effects of fenitrothion (one of the insecticides used in the New Brunswick spray program). This organophosphate became the predominant control compound after the discontinuation of dichlorodiphenyltrichloroethane (DDT) in 1970. Miliczky and Osgood (1979) document similar pollinator reductions due to Sevin® spraying in Maine, U.S.A.

In some years, fenitrothion has been supplemented by Matacil, an aminocarb formulation, and in 1979 Matacil was almost exclusively used as the spruce budworm control agent.

Because Matacil exhibits lower toxicity to bees (Atkins *et al.* 1970), it was uncertain whether Matacil would disrupt pollination systems to the extent reported for fenitrothion. Indeed, Plowright and Rodd (1980) reported that in contrast to fenitrothion, Matacil sprays appeared to be innocuous to bumblebees. Nevertheless, they found that solitary bees did suffer detectable mortality in exposure cages set out under Matacil applications.

The present study was designed to provide additional data on the effects of Matacil on smaller bees and flies and on the fecundity of some plants pollinated by them. There were three phases to the research: (i) discovering which pollinating insects were sensitive to Matacil; (ii) discovering which insects were the major pollen vectors for the plants; and (iii) comparing plant fecundity between sprayed and unsprayed blocks of forest.

Because preliminary data existed for the first two phases, the plant species could be chosen to provide a practical test of the utility of *a priori* assessment of plant risk, an idea previously stressed by Plowright (1977) and Thaler and Plowright (1980). The risk to a plant (in terms of fecundity) should depend on its breeding system (particularly the extent of autogamy), the timing of its anthesis relative to the spray, and the susceptibility of its pollinators to the spray. Of the three plant species investigated here, all require insect visitation for maximum fruit-set. Bagged inflorescences do not set fruit. S. C. H. Barrett and

¹Present address: Ecology and Evolution Department, State University of New York at Stony Brook, Stony Brook, NY, U.S.A. 11794.

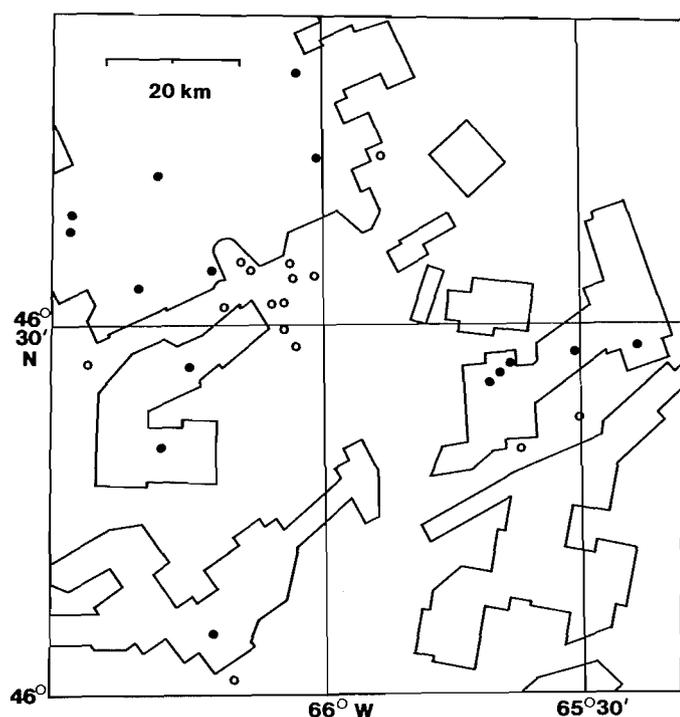


FIG. 1. A map of the study area in central New Brunswick. The outlined areas were aerially sprayed with insecticide in 1979 (information from Forest Protection Limited, Fredericton, N.B.). The circles represent sites at which *Cornus canadensis* and *Maianthemum canadense* fruit-sets were measured. ○, control sites; ●, sprayed sites.

K. Helenurm (to be published) have examined the breeding systems of *Cornus canadensis* L. and *Maianthemum canadense* Desf. in detail and conclude that both show self-incompatibility. All bloom shortly after the spray period, when pollinator depression should be greatest. However, two of the species, *Maianthemum canadense* (Liliaceae) and *Cornus stolonifera* Michx. (Cornaceae), are pollinated almost exclusively by small bees and flies, while the third, *Cornus canadensis*, is visited by bumblebees (*Bombus* Latr.) as well as the smaller insects. Thus, to the extent that exposure trials confirmed a higher susceptibility for the smaller pollinator taxa, we hypothesized that *C. canadensis* should be less affected by Matacil spray than either its congener *C. stolonifera* or its habitat associate *M. canadense*.

Methods

Pollinator collections

Collections were made at various intervals and at various (unsprayed) locations near Doaktown, N.B. (46°30' N, 66° W) during the blooming period of each species. All diurnal insect visitors (to flowers of the three plant species) whose morphology and behaviour suggested an ability to transfer pollen from anthers to stigma were collected by net, with the exception of bumblebees, which could be identified accurately without capture. Observers spent more time collecting from the less-visited plant species.

Pollinator susceptibility to Matacil

The vulnerability of selected taxa of insect pollinators to Matacil spray was assessed by direct exposure in the field, using modifications of the cage method described by Plowright *et al.* (1978). Insects were captured while foraging on blueberry (*Vaccinium* spp.) and rhodora (*Rhododendron canadense* (L.) Torr.) (both Ericaceae) during the afternoon of May 22, 1979, near Doaktown. They were placed in individual compartments of wooden cages covered by aluminum

TABLE 1. Insect visitors to the three plant species under study

Order and family	<i>Cornus canadensis</i>	<i>Cornus stolonifera</i>	<i>Maianthemum canadense</i>
Hymenoptera			
Apidae (Bombini)	15.2		1.2
Halictidae	17.0	8.0	23.2
Andrenidae	10.3	48.6	2.4
Other families	4.8	0.6	1.2
Diptera			
Bombyliidae	3.0	1.7	4.9
Syrphidae	33.9	5.1	61.0
Other families	2.4	8.0	2.4
Coleoptera			
All families	13.3	28.1	3.6
<i>N</i>	165	175	82

NOTE: Entries in the body of the table are percentages. *N* indicates the total numbers of insects on which these percentages are based.

screen. The cages were returned to the laboratory and the insects fed with small droplets of honey-water (1:1 v/v) applied to the screen mesh, and a small amount of honey-moistened pollen, also smeared on the screening. After being held in a cool dark basement overnight, the insects were exposed to the spray the next morning. The sprayed cages were set out in a spray block northeast of Bettsburg, N.B., while the control cages were set out for the same time period at an unsprayed location (the intersection of the Bettsburg road and N.B. Highway 123).

The temperature was low (0°C) when the insects were set out at sunrise, and some were still torpid at the time of spraying (0828). The flight path of the closest spray plane was about 10 m from the exposed cages, and although no spray droplets were perceptible at ground level, the air held a definite odour of the oil carrier of the spray.

Both sets of cages were exposed to open sky but kept shaded from direct sun. One hour after the spray, all cages were returned to the basement for 1 day before transfer to a heated room with a normal residential light cycle, where they remained for the duration of the experiment. Insects were fed with honey-water ad lib. Initially, the insects were inspected at 4-h intervals, but these intervals were gradually increased over succeeding days. An insect was declared dead when it could no longer be stimulated to activity by gentle prodding. Dead insects were removed from their compartments and pinned for subsequent identification.

It should be pointed out that this spray (0.9 g/acre (1 acre = 0.404 685 6 ha)) was intended to be the first of two applications. Instead, because of poor weather, most sprayed areas of this part of New Brunswick in 1979 received a higher dose (1.23 g/acre) in a single application. Thus, our insects received a lighter dose than was typical in 1979.

Fecundity survey

For *Cornus canadensis* and *Maianthemum canadense*, the following sampling technique was used to measure fruit-set. Roadside sites with predominantly coniferous trees were inspected, with the proviso that they lay well within or well outside (>2.5 km) blocks of forest sprayed earlier with Matacil. If both plant species occurred at any site, a random-number table was used to locate an initial point well inside the edge of the forest, from which a 50 × 1 m belt transect was laid out perpendicular to the road. In cases where a transect ran into an area devoid of *C. canadensis* and *M. canadense*, it was broken and continued in the same direction from another randomly chosen point until 50 m had been sampled.

Fifteen sprayed and 15 control sites (Fig. 1) were chosen and for each transect all infructescences of both plant species were collected. Sampling was done just prior to fruit ripening. Except where barren infructescences had wilted to the point where the number of pedicels could no longer be determined reliably, both pedicel and fruit counts

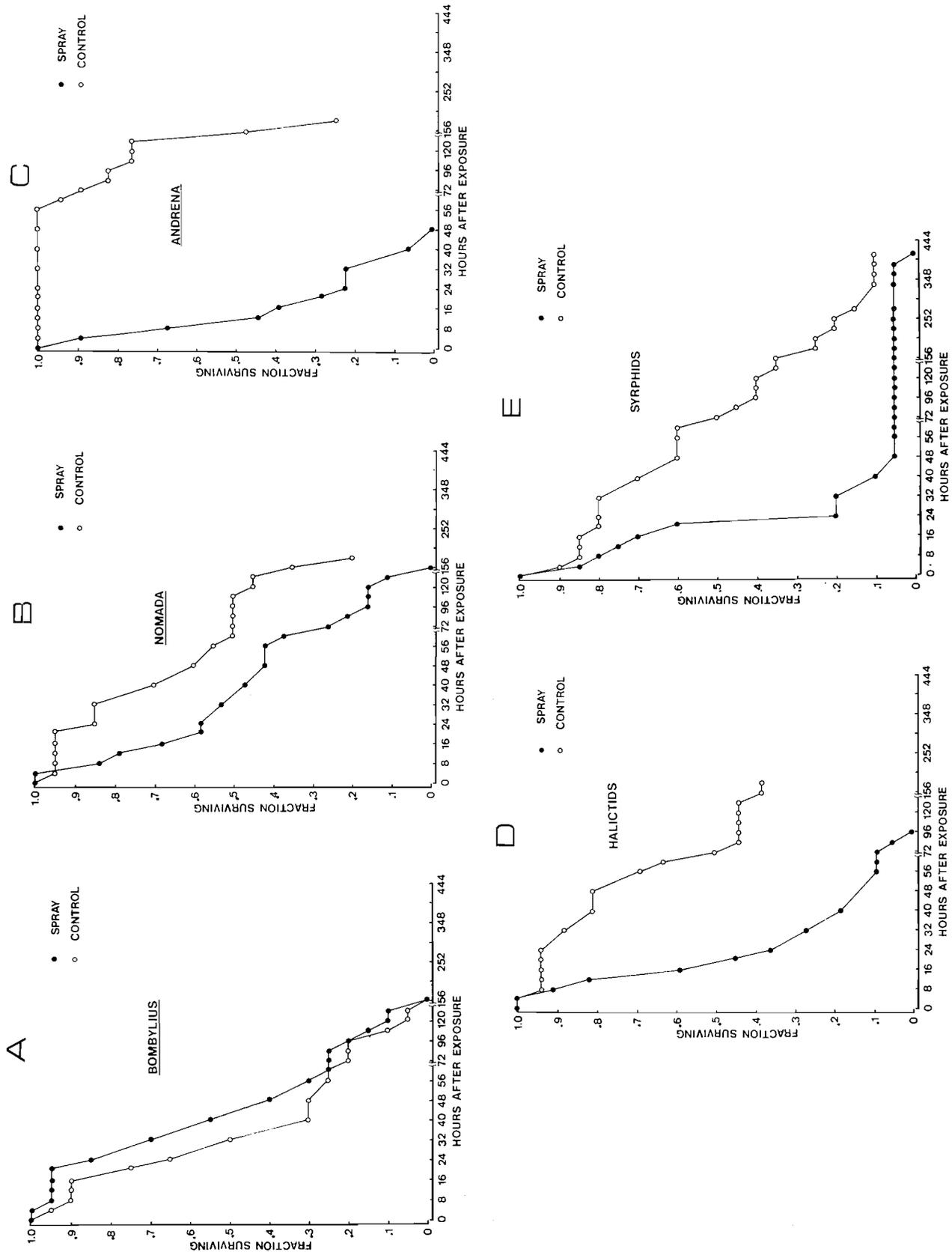


FIG. 2. Survivorship curves for insects exposed to Matacil spray (●), vs. control insects (○). Methodological details in text. Mann-Whitney *U*-tests were used to test the null hypothesis of equal median survivorship between spray and control groups. For bombyliid flies (A), there was no significant difference; for the other four taxa (B-E), control insects lived significantly longer than spray-exposed insects (for *Nomada* (Anthophoridae), $p < 0.01$; for *Andrena* (Andrenidae), for Halictidae (mostly *Halictus*, *Evyllaes*, and *Dialictus*), and for Syrphidae (mostly *Parasyrphus* spp.), $p < 0.001$).

were made, using the method reported by Thaler and Plowright (1980). In a few high-density stands, these counts were taken only on a randomly chosen sample, although in all cases the total number of infructescences was recorded to permit estimates of density. Fruit loss to herbivores was very low at this time, but some cases were noted and these infructescences eliminated from fecundity analysis.

The patchy distribution of *Cornus stolonifera* precluded the choice of individuals by random coordinates. Instead, representative shrubs were chosen at various sites along roads that traversed spray blocks. Branches bearing infructescences were clipped from a range of positions on each plant to yield samples of about 20 infructescences per plant. Flower pedicels and fruits were counted. In all three species, "fecundity" was computed as the fraction of flowers setting fruit.

Results

Insect visitors

The insect visitors and their frequency of capture on each plant species are given in Table 1. All three plants attracted a diversity of insect taxa, but many of the same solitary bees and flies were found on all three species. A principal difference among the plants was in the relative proportion of bumblebees: *Maianthemum* and *Cornus stolonifera* were rarely visited by *Bombus* spp., whereas *Cornus canadensis* was visited regularly and frequently. In fact, because we did not capture bumblebees and were probably overly zealous in making sure that no insect was counted twice, the figures in Table 1 may underestimate the extent to which bumblebees visited *C. canadensis*. Certainly, it was unusual to watch a dense stand of this species without seeing a bumblebee, usually a *B. vagans* Sm. queen, working on it. In contrast, many hours of observation yielded only a single *Bombus* sp. on *M. canadense* and none on *C. stolonifera*.

It was apparent to all the insect collectors that *Cornus canadensis* had a much higher overall visitation rate than *M. canadense* when the two occurred together. The lower visitation rate to *M. canadense* probably reflects a lesser nectar reward, which may account for the lack of bumblebee visits.

Pollinator susceptibility to Matacil

Several pollinating taxa showed rapid sensitivity to the spray, as manifested by convulsions, followed by inactivity and death. Figure 2 shows the time course of mortality and gives the results of Mann-Whitney *U*-tests comparing the times of death for sprayed vs. control insects. In all three bee families (Andrenidae, Halictidae, Anthophoridae) and the most important family of fly pollinators (Syrphidae) there were highly significant reductions in median life-span in insects exposed to spray. The spray had no apparent effect on bombyliid flies, but these insects are thought to be relatively ineffective pollinators because they seldom contact flower parts firmly enough to transfer much pollen (Beattie 1971; O'Brien 1980; but see Motten *et al.* 1981). We did not test the vulnerability of bumblebees in this study; Plowright and Rodd (1980) have demonstrated the immunity of caged *Bombus* spp. to field applications of Matacil, using the same methods.

Although exposure-cage trials admittedly simulate field conditions rather imperfectly, previous work on New Brunswick bees (Plowright and Rodd 1980) has shown a positive association between exposure-cage mortality and field densities. The present trials certainly indicate that even at a comparatively low dosage, Matacil can substantially increase the death rate of some important pollinators.

Statistical analysis of plant fecundities

In some stands of *Maianthemum canadense* and *Cornus can-*

TABLE 2. Summary of an analysis of covariance of fecundity (arcsine transformed) for *Maianthemum canadense* and *Cornus canadensis*

Source of variation	Sum of squares	df	Mean square	F
<i>Maianthemum canadense</i>				
Covariates (all)	0.118	3	0.039	3.445*
Density of <i>M. canadense</i>	0.001	1	0.001	0.118NS
Density of <i>C. canadensis</i>	0.043	1	0.043	3.770NS
Mean flowers per inflorescence of <i>M. canadense</i>	0.033	1	0.033	2.910NS
Main effect, spray	0.087	1	0.087	7.641**
Residual	0.286	25	0.011	
Total	0.492	29		
<i>Cornus canadensis</i>				
Covariates (all)	0.018	3	0.006	0.466NS
Density of <i>C. canadensis</i>	0.001	1	0.001	0.041NS
Density of <i>M. canadense</i>	0.006	1	0.006	0.475NS
Mean flowers per inflorescence of <i>C. canadensis</i>	0.005	1	0.005	0.407NS
Main effect, spray	0.013	1	0.013	1.008NS
Residual	0.313	25	0.013	
Total	0.343	29		

NOTE: NS, $p > 0.05$; *, $p < 0.05$; **, $p < 0.01$.

adensis, the wilting of some nonfruiting inflorescences of both species complicated the determination of total flower numbers. The number of flowers on uncountable infructescences was taken to equal the mean number of flowers per inflorescence for the rest of the inflorescences in the stand. The stand fecundity for each species was calculated as the total number of fruits divided by the estimated total number of flowers. Fecundity in *M. canadense* ranged from 0.06 to 22.7%, with means of 4.58 (SD, 5.32) for the 15 sprayed sites and 9.65% (SD, 6.28) for the 15 controls. Fecundity in *C. canadensis* ranged from 2.19 to 31.12%, with a spray mean of 13.07 (SD, 6.63) and a control mean of 11.56% (SD, 7.39).

There was substantial variation in fecundity within the spray and control treatments, especially in *Maianthemum canadense*, and it seemed likely that some of this variability could be attributed to uncontrolled differences among stands. Inspection of the data suggested that fecundity of *M. canadense* might vary with stand composition and density, and with the mean number of flowers per inflorescence, as well as with spray treatment. These possibilities were examined by means of an analysis of covariance of *Maianthemum* fecundity (arcsine transformed) with one main effect (spray treatment) and three covariates (*Maianthemum* density, *Cornus* density, and the mean number of *Maianthemum* flowers per inflorescence) (Table 2). The mean fecundity of *Maianthemum canadense* populations was significantly lower under aminocarb spray. The covariates taken together also explain a significant portion of the variance in fecundity, although none of them reaches 5% significance individually.

The results of an equivalent analysis of *Cornus canadensis* (Table 2) are quite different. Neither the covariates nor the spray explain significant portions of the observed variation in *C. canadensis* fecundity, which thus seems unaffected by Matacil spray.

Fecundity of *Cornus stolonifera* was considerably higher in the two unsprayed sites than in the three sprayed sites (means of 24.6 to 8.8%; see Table 3). Furthermore, the highest fecun-

TABLE 3. *Cornus stolonifera* fecundity data and a summary of a nested analysis of variance of these data

	Site	Shrubs sampled	Total inflorescences	Flower pedicels	Fruits	% fecundity
Sprayed	1	4	79	3 498	333	9.52
	2	4	81	4 500	668	14.84
	3	4	81	5 042	144	2.86
Sprayed totals		12	241	13 040	1 195	8.78
Unsprayed	1	3	58	3 634	835	22.98
	2	4	79	3 781	931	24.62
Unsprayed totals		7	137	7 415	1 766	23.82

Analysis of variance (arcsine-transformed percent fecundity)

Source of variation	Sum of squares	df	Mean square	F
Between treatments	0.224	1	0.2239	6.89 (0.05 < p < 0.1)
Among sites within treatments	0.099	3	0.0325 ^a	4.35 (p < 0.025)
Residual (within sites)	0.106	14	0.0076	

^aAdjusted following Sokal and Rohlf (1969, p. 274).

dity in the sprayed sites (14.84%) was less than two-thirds of the lower fecundity in the unsprayed sites (22.98%), strongly suggesting a depression of fecundity by the spray. If fecundities of all the shrubs from each treatment are compared without regard to site, a very strong treatment effect appears ($p < 0.001$, Mann-Whitney U -test (Sokal and Rohlf 1969, p. 392)). However, there is considerable variation among sites within the unsprayed treatment. Analysis of variance for arcsine-transformed fecundities, nested by sites, following Sokal and Rohlf (1969, p. 274), shows that the substantial variation among sites within spray treatments ($F = 4.35$, $p < 0.025$) is so large as to render the difference between treatments insignificant ($F = 6.89$, $0.05 < p < 0.1$), even though treatment explains 60.25% of the variance in fecundity. Given the substantial fraction of the variance attributable to the effect of treatment, we feel that the trend toward reduced fecundity in sprayed areas is probably real and that it could readily be statistically demonstrated by sampling more sites. Certainly, *C. stolonifera* showed more tendency toward a treatment effect than its congener *C. canadensis*, where within-treatment variation completely overrode any treatment effects.

Discussion

Our results indicate that plants pollinated mainly by small bees and syrphid flies may suffer reduced fecundity in areas sprayed with Matacil for spruce budworm control. This is clearly true for *Maianthemum canadense* and probably true for *Cornus stolonifera*. However, for *Cornus canadensis*, which is visited by bumblebees as well as the smaller bees and flies, there is no significant reduction in fecundity with spray. The reduced fecundity of the first two species is probably the result of pollinator reductions. The differences among the plant species reflect differential mortality of pollinator classes, since Matacil has been shown to be relatively harmless to bumblebees (Plowright *et al.* 1978; Plowright and Rodd 1980) although toxic to the smaller bees and flies (this paper). The hypothesis of differential mortality from Matacil is consistent with the observation that both *M. canadense* and *C. canadensis*

showed reduced fecundity in areas sprayed with fenitrothion, an insecticide that is highly lethal to bumblebees as well as smaller pollinators (Thaler and Plowright 1980).

There is considerable variation in fecundity among sites within treatments. Although discovering the sources of this variation is far beyond the scope of this report, it is apparent from the analysis of covariance that flower densities may play a role. The past spray history of the sites may also influence plant fecundity; Kevan and LaBerge (1979) have shown that full recovery of the native bee population may take years. Although Plowright and Rodd (1980) suggest that overall *Bombus* densities may return to control levels or beyond in the year of the spray, there are changes in relative abundance of species, favouring those that emerge late in the season.

The variation among sites means that extensive sampling programs are required to identify "treatment effects." It would be prohibitively expensive to screen the entire flora; thus it is best to use more easily available criteria (breeding system, phenology, pollinator type) to identify those plants most at risk and to begin to work on them. Obviously autogamous or non-pseudogamous apomictic species are unlikely to show effects in fruit-set. Some previous efforts at assessing pollination disruption by the budworm spray program have unfortunately involved plants that are likely to be insensitive, by virtue of blooming before the spray (e.g., *Prunus pensylvanica* (Buckner 1975)). If a spray effect cannot be demonstrated on the most sensitive species, it probably cannot be demonstrated at all, although inability to demonstrate an effect should hardly be taken as a demonstration of no effect unless the sampling program has been extremely thorough.

From the standpoint of general pollination ecology, the continued undiminished fecundity of *Cornus canadensis* in sprayed stands indirectly indicates that bumblebees, even if a numerical minority, can contribute considerable pollinator service (see Thomson 1978, Thomson *et al.* 1982). Although fruit-set in *C. canadensis* suffers when bumblebees are killed by fenitrothion spray (Thaler and Plowright 1980), mortality of its abundant smaller pollinators seems to have trivial conse-

quences for fruit-set as long as the bumblebees are spared. Many plants in the boreal forest (S. C. H. Barrett and K. Helenurm, to be published) and elsewhere attract mixed pollinator faunas of bumblebees and other species; the *C. canadensis* example suggests that it may often be legitimate to regard the bumblebees as the main pollinators in such cases.

Because it does spare bumblebees, Matacil would seem to be less disruptive of native pollination systems than fenitrothion. However, Matacil is hardly benign, in that it is quite lethal to smaller bees, especially andrenids. The genus *Andrena* is noted for its many spring-flying specialist species which have co-evolved with specific host plants (Eickwort and Ginsberg 1980). These specialized relationships are probably at risk with Matacil spraying. Reduced fruit-set because of bumblebee reductions is likely to be a temporary phenomenon; these bees can recover quickly if the same area of forest is not sprayed in successive years. However, the chronic reduction of slowly recovering solitary bees may be the most important long-term effect of the spray program on pollination (Kevan and LaBerge 1979; cf. Wood 1979), and Matacil and fenitrothion appear roughly similar in this regard.

It must be pointed out that the effects of reduced fecundity on plant population dynamics are unclear. Most of the forest understory herbs are long-lived perennials with extensive clonal growth. Propagation by seed is rare, episodic, or both. A reduced fruit-set may be more important to the population sizes of fruit- or seed-eating animals than of the plants themselves (see Kevan 1975a, 1975b; Kevan and Collins 1974). Nonetheless, the retention of flowers and the considerable expenditure borne by these plants in developing fruit both argue for an important role of sexual reproduction in evolutionary time, and one should be wary of disrupting such a system simply because its workings in ecological time are poorly understood.

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