NEW OBSERVATIONS ON ADULT BEHAVIOR OF THE WHITE PINE WEEVIL AND IMPLICATIONS ON CONTROL WITH DIFLUBENZURON

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Summary

Studies on the biology and activity of the white pine weevil, *Pissodes strobi* (Peck) (Coleoptera: Curculionidae), a severe, deforming pest of several conifers, revealed that it was active in temperatures as low as 0.5° and emerged very early in spring and shortly thereafter mated and oviposited in the terminal leaders. We found the weevils emerging had turgid abdomens even before they had a chance to feed on the leaders suggesting that they might have fed on the roots underground. Such feeding would facilitate rapid mating and oviposition. If the terminal leaders are sprayed, early in spring, prior to weevil emergence with diflubenzuron, an insect growth regulator that inhibits chitin synthesis, near perfect control of the weevil can be achieved. The eggs laid by the female get coated with diflubenzuron either directly or indirectly, which is then absorbed into the developing embryo where it inhibits the synthesis of chitin resulting in a malformed integument. Such an embryo is unable to eclose and dies within the egg. We recommend applying diflubenzuron at the rate of ≥ 30 g/ha very early in spring when the snow is still on the ground making sure that the terminal leader is completely covered by the spray for preventing weevil damage.

Introduction

The white pine weevil, *Pissodes strobi* (Peck), is a tenacious pest on pines and spruces, severely deforming the growing tip and degrading the value of the lumber (Belyea and Sullivan 1956, Hopkins 1907, 1911, MacAloney 1930). Weevil damage adversely affects the first-log quality of merchantable timber and control of this insect could substantially raise the value of a species such as white pine, *Pinus strobus* L. (Brace 1972, Stiell 1979). Serious questions have been raised regarding the economic utility of planting white pine because of the persistence of weevil attack and the lack of an effective control measure (Dixon and Houseweart 1982).

Although many types of preventative and control measures have been tried, as yet a reliable method is unavailable. In this paper, we report for the first time, some new observations on adult behavior during post-diapause emergence and its implications on the development of an effective method of controlling the white pine weevil with diflubenzuron and at the same time preventing damage to the shoots.

Materials and Methods

Biology

A 15-year-old Scots pine *(Pinus sylvestris L.)* plantation of 4 ha with a white pine weevil infestation of around 45% located in Thessalon Township (latitude 46°30') near Sault Ste. Marie in Ontario was selected as the permanent plot. Samples were taken at bi-weekly intervals for 4 years, 1986 to 89. Ten leaders were clipped each time, beginning in April and ending in August, and were examined for the presence of eggs, larvae, pupae and adults. Weather records for the period was obtained from the Kirkwood Nursery, Ontario Ministry of Natural Resources, located 5 km from the permanent plot. Adult weevils collected both in the spring (post-diapause) and in the fall (pre-diapause) were maintained in the laboratory on white pine twigs. Adult weevils were sexed on the basis of the 8th abdominal tergite in the male being round and the 7th and 8th tergite in the female being fused to form a triangular shaped pygidium. The weevil was held in place in a male-male Luer adapter in a vacuum manifold using minimal suction (sufficient to pick up a 6-cm Whatman No. 1 filter paper) and examined under a binocular microscope (Fig. 1). Weevils maintained in cold storage were allowed to feed on white pine twigs for a least 8 h to enable the abdomen to become turgid which was a prerequisite to sexing.

Diflubenzuron or Dimilin tests

Mated females and virgin male and female pairs were treated with a 1% AI suspension of Dimilin-WP25 in water for 30 s and maintained on white pine twigs. Mortality, oviposition and egg viability were observed 20 days after treatment to determine contact effects. Treated white pine twigs were used for determining feeding effects. Field trials were generally conducted with a back-pack sprayer using Dimilin-WP25 in water or Dimilin-ODC45 in 7N oil. In Madoc Township near Belleville, the spraying was conducted with a tractor-mounted power sprayer.

Activity assay

A rectangular box containing 8 cylindrical plexiglas tubes, 50 cm long x 5 cm diameter, lined with window screening was used (Fig. 2). Ten weevils, pre-cooled to total inactivity by being held for 2 h at 0° over ice, were placed at the bottom of each tube and the entire box placed in a lighted incubator maintained at a particular temperature, 0.5° to 5°. The light shining at the top provided the phototactic stimulus for the weevil to climb up and the distance climbed was periodically measured and used as the measure of activity.

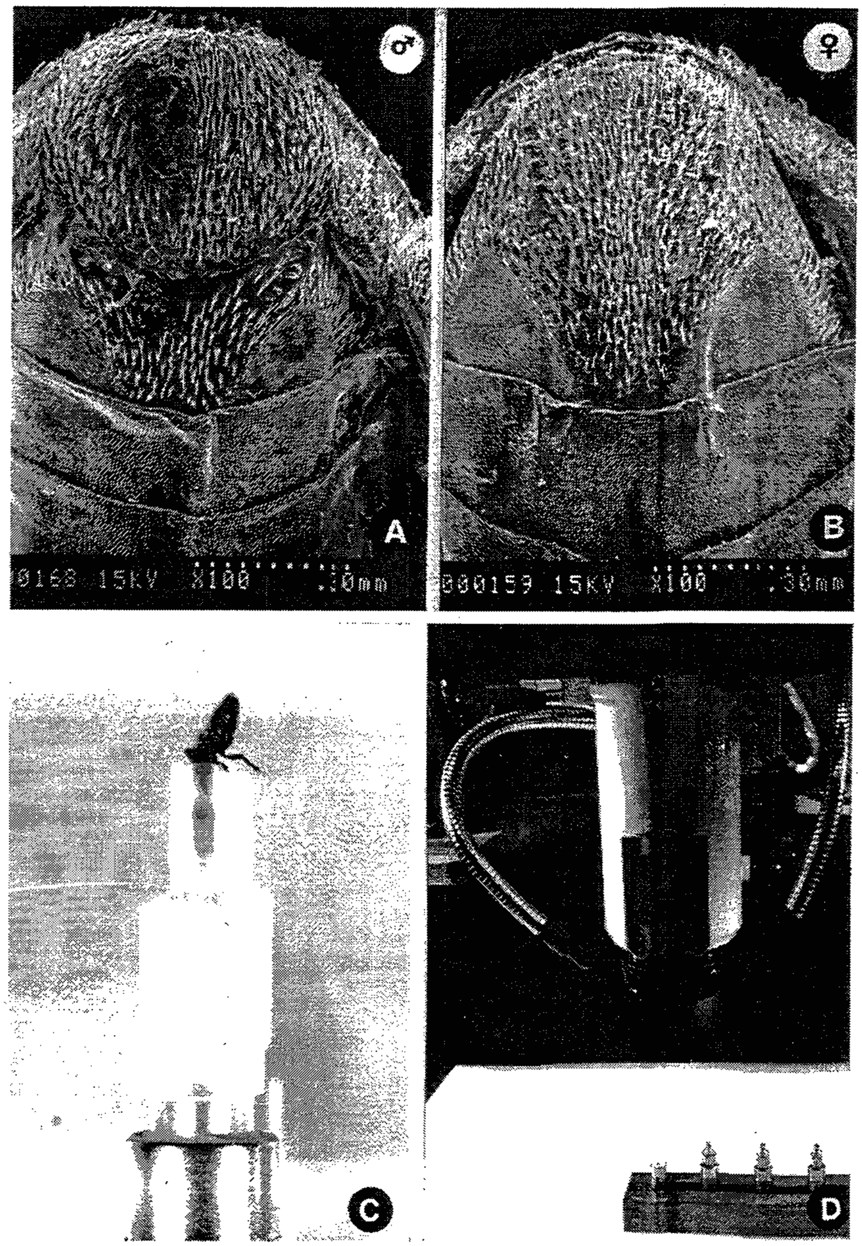

Fig. 1. A method for sexing the white pine weevil using the dimorphium of the last two abdominal tergites. A) Scanning electron micrograph (SEM) of the last three abdominal tergites (6, 7 and 8) in the male after removal of the elytra showing the characteristic, rounded 8th abdominal tergite. B) SEM of the same in the female showing the characteristic, triangular, fused 7th and 8th abdominal tergites (pygidium). C) Weevil held in place in a male-male Luer adapter by mild suction. D) Viewing the flexed abdominal end of the weevil under a binocular microscope.

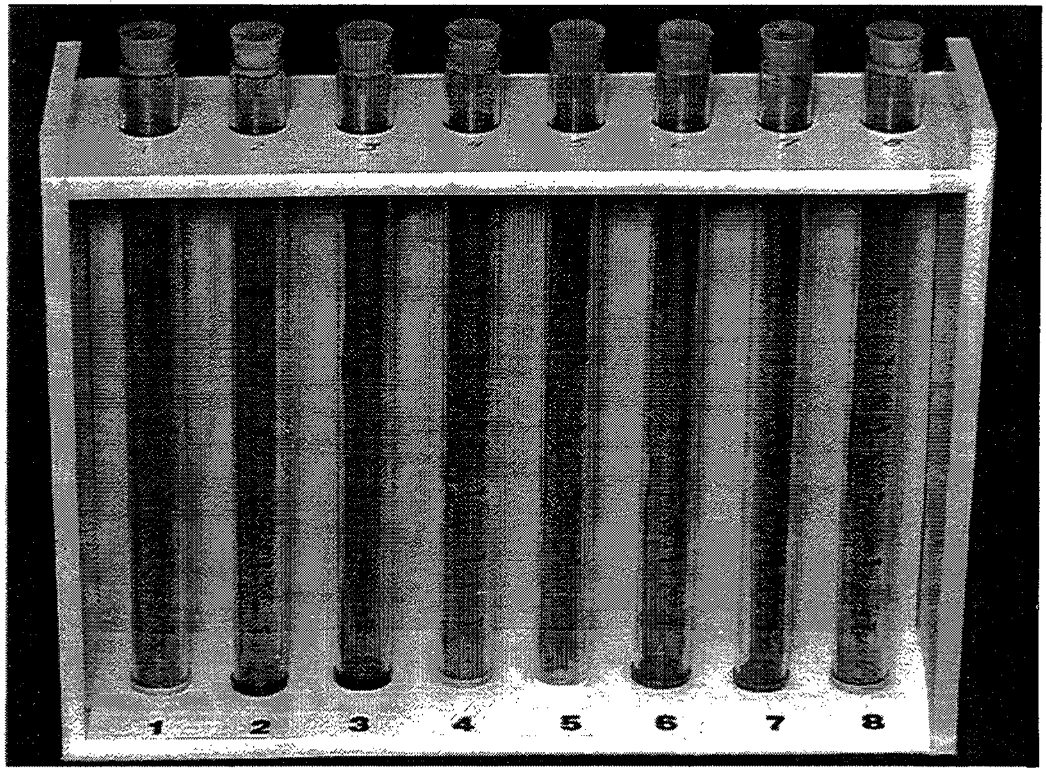

Fig. 2. Climbing chamber assay to measure white pine weevil activity at different temperatures.

Results

Biology

The weevil overwinters as an adult, about 30 cm from the bole of the host tree, underneath the dry pine needles at a depth of 5 cm and our observations confirmed that of Dixon *et al.* (1979). In northern Ontario, where our plot is located, we found the adults emerged in April when the daylength was around 13 h and the ground temperature in the overwintering area was above freezing, and moved up to the terminal leader where they fed, mated and laid eggs. Resin oozing from feeding punctures was indicative of the presence of the weevil. It is univoltine and each female lays close to 100 eggs in the feeding punctures which is then plugged. The weevils generally prefer trees that are 2-6 m tall having terminal leaders that are >4 mm thick for oviposition. The larvae hatch in about 2 weeks and go through 4 or occasionally 5 larval instars. As the larvae start growing they feed in the cambium, girdling the terminal leader and killing the shoot. The dead leader takes on the characteristic shape of a "shepherd's crook" that is usually noticeable in mid July and counting the number of dead shoots is used as a measure of weevil damage. Pupation occurs in the pith region of the dead leader in late July. Adults emerge in early August and start feeding on the lateral leaders. The results of the 4-year study (1986-89) of weevil biology conducted near Thessalon Township is summarized in Fig. 3. The hours of daylight (photoperiod) for the latitude of 46°30' was taken from Beck (1980). It extends from a short day of 8 h 30 min to a long day of 15 h 30 mln. In April at the time of weevil emergence the daylength was 13 h. The mean temperature was above 0° only after mid-April. Adult emergence extended from

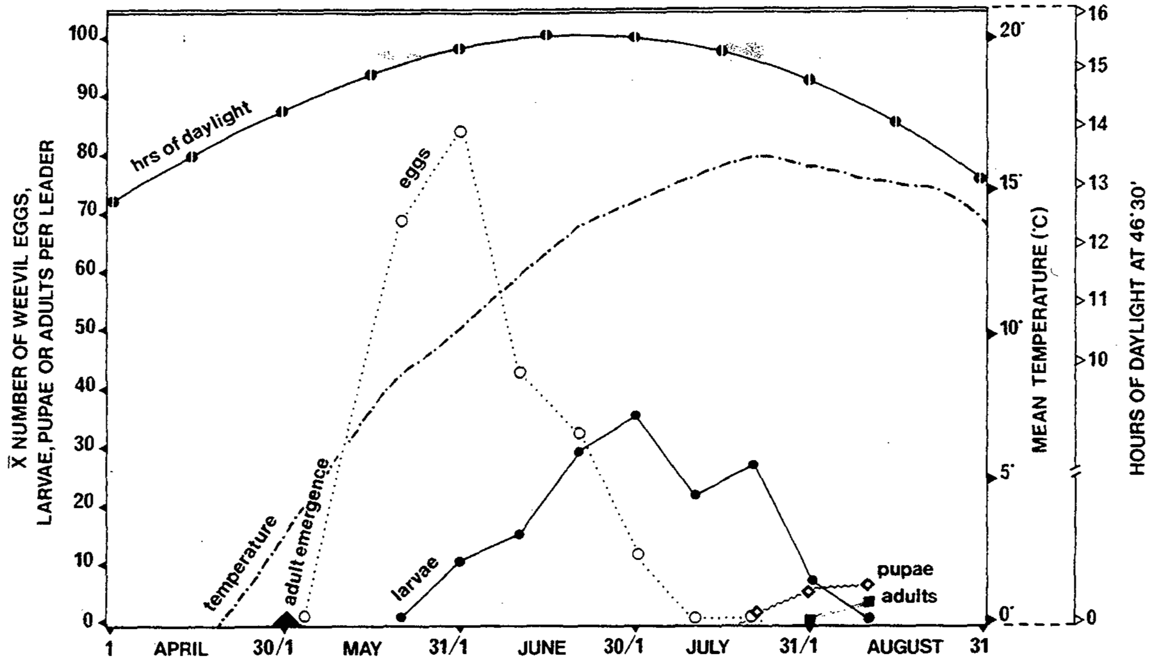

Fig. 3. Development of the white pine weevil in the Scots pine plantation in Thessalon Township (latitude 46°30') during 1986 to 1989 in relation to photoperiod and temperature. The average values for the 4 years are shown.

mid-April to the end of June and coincided with the distribution of eggs. Larvae started appearing in mid-May and extended into August. Pupae appeared at the end of July and fall adults emerged in August. The various phases of weevil life history, the different stages and the damage caused is shown in Fig. 4 a and b.

Sexing of adults

Two hundred field-collected adults were sexed on the basis of the rounded 8th tergite in the male and the triangular, fused 7th and 8th tergite in the female. None of the weevils showed any sign of injury and the diagnosis was confirmed in every instance by dissection of the reproductive organs.

For conducting tests with diflubenzuron, weevils were individually maintained prior to sexing and treatment.

Diflubenzuron effects

Topical treatment had no effect on mated females as well as pairs of virgin males and females. Ingestion on the other hand resulted in total inhibition of egg hatch (Table 1). Field trials with Dimilin WP-25 and ODC-45 formulations were both effective. When Norway spruce (*Picea abies* [L.] Karst.) was sprayed with Dimilin WP-25, it was ineffective on tall trees but provided protection on the shorter trees (Table 2). The percentage of current year's terminal leaders that were damaged ("shepherd's crooks"), was 0 in the treated plot in St. Narcisse where the average height was 3 m. In Madoc, near Belleville, the use of water or oil formulation did not appear to have too much difference (Table 3). A comparison between fall

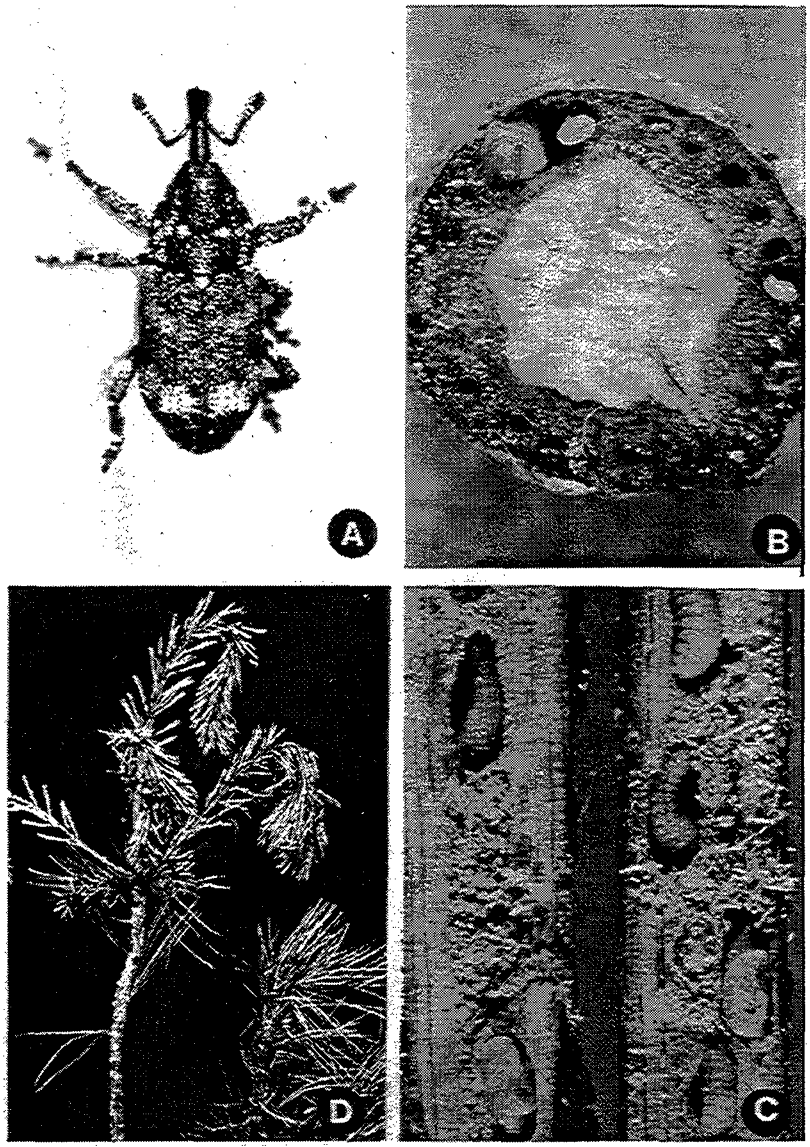

Fig. 4a. Developmental stages of the white pine weevil and its effect on the host. A) Adult white pine weevil. B) Gross section of an infested terminal leader showing eggs, larvae and feeding chambers in the cambium region. C) Longitudinal section of infested leaders showing fully developed larvae and pupae in the pith region. D) "Shepherd's crook", the characteristic appearance of an infested terminal leader.

and spring treatment indicated that spring trial was more effective (Table 4). In 1989, when spraying was done on jack pine trees (*Pinus banksiana* Lamb.) <3 m tall, early in spring when the ground was still snow covered and no feeding punctures with oozing resin flows or weevils were present, the control achieved was >99% even when low dosages of Dimlin were used (Table 5).

The climbing chamber assay showed that the spring weevils were active even at 0.5 (Fig. 5). The activity progressively increased with temperature and at 5°, the weevils were fully active.

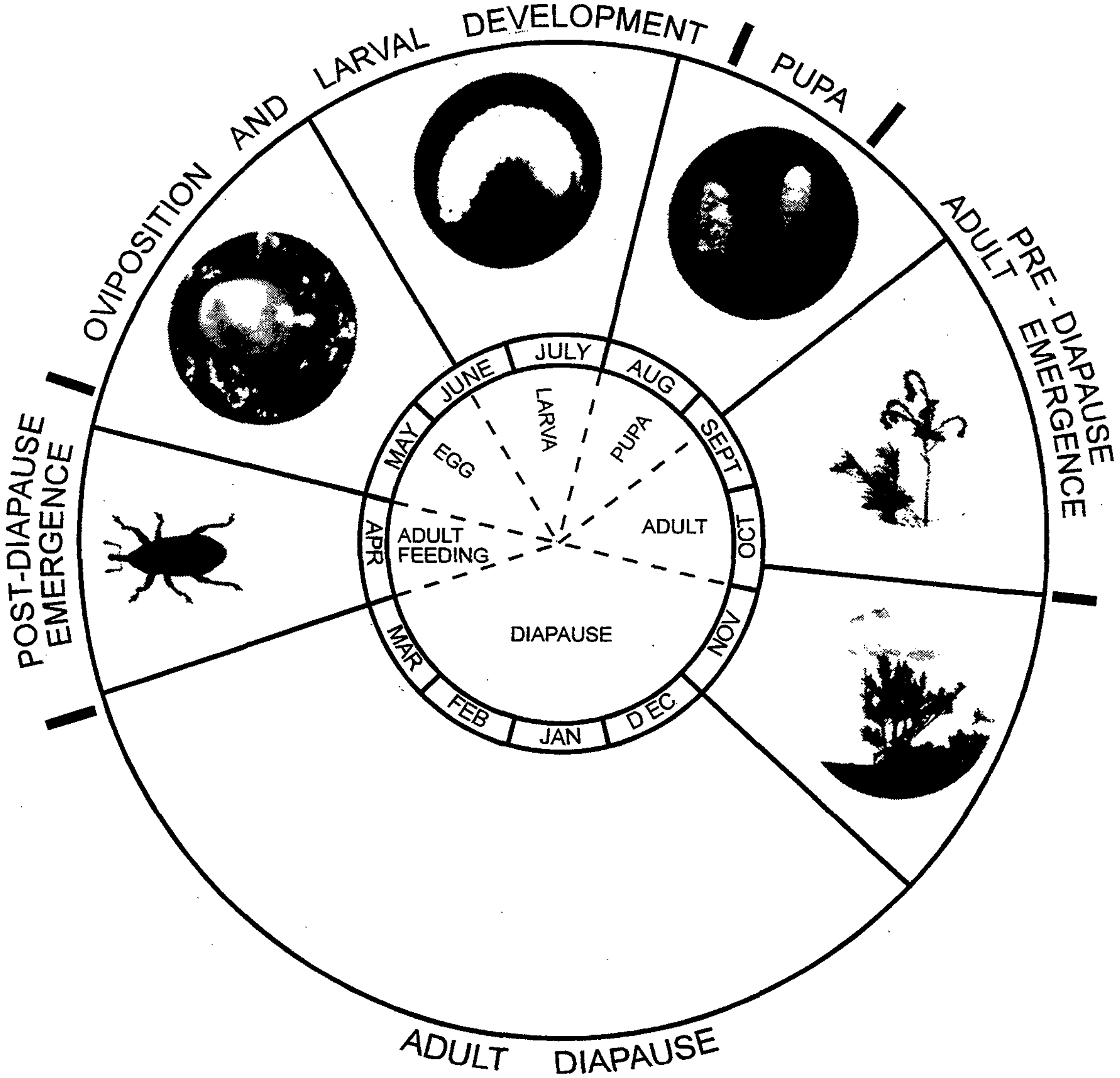

Fig. 4b. Life history of the white pine weevil during the year.

Discussion

Life history

The life history of the white pine weevil has been relatively well studied (Belyea and Sullivan 1956, Dixon and Houseweart 1982, Hopkins 1907, MacAloney 1930, Wallace and Sullivan 1985). Our studies confirmed most of the findings of the others and provided the back-drop for the diflubenzuron tests.

Control methods

The cryptic lifestyle of the damaging larval stage together with the general inefectiveness of

TABLE 1. Topical versus feeding effects of Dimilin on oviposition and egg viability in the white pine weevil.

Treatment	Replicates	Adult mortality	x eggs ± SE	x hatch ± SE	% hatch
1. Untreated,female, single, mated (control)	10	2	20.3±7.54	8.5±4.14	41.9
2. Mated, single, female, topically treated	10	3	10.2±3.61	6.4±2.63	62.8
3. Untreated, virgin pair (control)	10 pairs	6	10.4±2.50	7.0±1.90	67.3
4. Virgin pair, topically treated	10 pairs	4	7.4±2.06	4.8±1.47	64.9
5. Virgin pair, feeding on treated twigs	10 pairs	3	16.4±4.24	0	0

TABLE 2. Effect of tree height on the efficacy of ground spray trials (April 4, 1988) against the white pine weevil on Norway spruce near Quebec City, Quebec using the wettable powder (WP 25) formulation of Dimilin in water.

Plot number and location	Treatment (in 200 L/ha)	Area treated(ha)	Tree height (m ±SE)	Mean % damage
1. Beauceville	Control	0.8	4.5±0.4	40
2. Beauceville	250 g AI	0.4	4.5±0.3	36
3. St. Narcisse	Control	0.4	3±0.2	21
4. St. Narcisse	250 g AI	0.4	3±0.2	0

TABLE 3. Effect of oil versus water formulation of Dimilin on the efficacy of ground spray trials (March 30, 1988) against the white pine weevil on white pine near Belleville, Ontario using a tractor-mounted, power sprayer.

Plot number and location	Treatment (in 200 L/ha)	Formulation	Area Treated(ha)	Mean % damage
1. Madoc	Control	-	5.0	23
2. Madoc	250 g AI	25% wettable powder in water	1.9	7
3. Madoc	250 g AI	45% oil dispersible concentrate in 7N oil	6.0	3

TABLE 4. Effect of fall versus spring treatment on the efficacy of ground spray trials with Dimilin WP-25 in water in 1987-88 against the white pine weevil on Scots pine near Sault Ste. Marie, Ontario.

Plot number and location	Treatment (in 100 L/ha)	Time of application	Area (ha)	Mean % damage
1. Kirkwood	Control	-	1.0	47
2. Kirkwood	375 g AI	Fall (Sept. 15, 1987)	1.0	12
3. Kirkwood	375 g AI	Spring (April 2, 1988)	1.0	2

systemic insecticides on conifers, makes the white pine weevil an extremely difficult insect pest to control. The various control strategies that have been tried are summarized in Table 6. None of the methods, excepting for the diflubenzuron treatment, have proved to be effective. Chitin synthesis inhibitors or benzoylphenyl ureas, upon ingestion, selectively inhibit chitin synthesis in larval insects where there is active chitin biosynthesis during the moulting cycle (Retnakaran *et al.* 1989, Retnakaran and Wright 1987). The Curculionids show a characteristic ovicidal or embryocidal response that was initially discovered in the boll weevil, *Anthonomus grandis* Boheman (Wright and Villavaso 1983). Our initial studies with two such chitin synthesis inhibitors, diflubenzuron and alsystin indicated that the white pine weevilshowed a similar effect (Retnakaran and Smith 1982). Eggs laid by treated insects

TABLE 5. Ground application of Dimilin against white pine weevil in jack pine plantations in Hurlburt and Hynes townships, near Sault Ste. Mar Ontario (April 3, 4, May 1989).

Plot number and location	Treatment: Dosage (g AI/ha) and formulation	Treatment: Diluent and volume (L)	Area treated (ha)	Number of trees	% leader damage: In 1988 prior to treatment	% leader damage: In 1989 after treatment
1. Hurlburt	Control	-	0.1	300	30	18
2. Hurlburt	Control	-	0.1	300	30	16
3. Hurlburt	Control	-	0.1	300	28	22
4. Hurlburt	250 (ODC-45)	Oil (10)	0.2	600	30	0
5. Hurlburt	125 (ODC-45)	Oil (10)	0.16	480	35	2
6. Hurlburt	250 (WP-25)	Oil (0.2) + water (9.8)	0.1	300	36	0
7. Hurlburt	125 (WP-25)	Oil (0.2) + water (9.8)	0.1	300	12	0
8. Hurlburt	125 (WP-25)	Water (10)	0.1	300	28	0
9. Hurlburt	Control	-	0.1	300	22	16
10. Hurlburt	Control	-	0.1	300	30	18
11. Hynes	Control	-	0.1	300	28	18
12. Hynes	Control	-	0.1	300	15	8
13. Hynes	125.00 (WP-25)	Oil (1) + water (9)	0.1	300	20	0
14. Hynes	62.50 (WP-25)	Oil (0.5) + water (4.5)	0.1	300	30	0
15. Hynes	31.25 (WP-25)	Oil (0.5) + water (4.5)	0.05	150	26	0
16. Hynes	125.00 (ODC-45)	Oil (5)	0.1	300	26	0
17. Hynes	62.50 (ODC-45)	Oil (5)	0.1	300	26	0
18. Hynes	31.25 (ODC-45)	Oil (5)	0.1	300	30	0

developed normally but the fully developed embryos failed to hatch because of a poorly formed, fragile integument that lacked chitin. Unlike the boll weevil, the white pine weevil is univoltine and lays only one clutch of eggs making it an attractive candidate for testing this type of control strategy. Also, diflubenzuron remains active for several weeks (longer than the emergence period of weevils in spring) being adsorbed to the waxy surface layer of conifers while at the same time any diflubenzuron reaching the forest floor is rapidly degraded within a week by microorganisms (Retnakaran and Wright 1987).

In order to determine whether or not diflubenzuron had any topical effect, we tested the material on mated females as well as virgin pairs of males and females. As a prerequisite, the weevils had to be sexed. Harman and Kulman's (1966) method of prying open the elytra with a bent minuten pin to observe the last two tergites frequently resulted in injury. We therefore modified the method of observing the dimorphism in the last two abdominal tergites using a vacuum holder similar to the one described by Kinzer and Ridgill (1972). When the weevil was sucked into a male-male Luer adapter, the upside down insect flexes its abdomen exposing the last two tergites which can be observed under a binocular microscope.

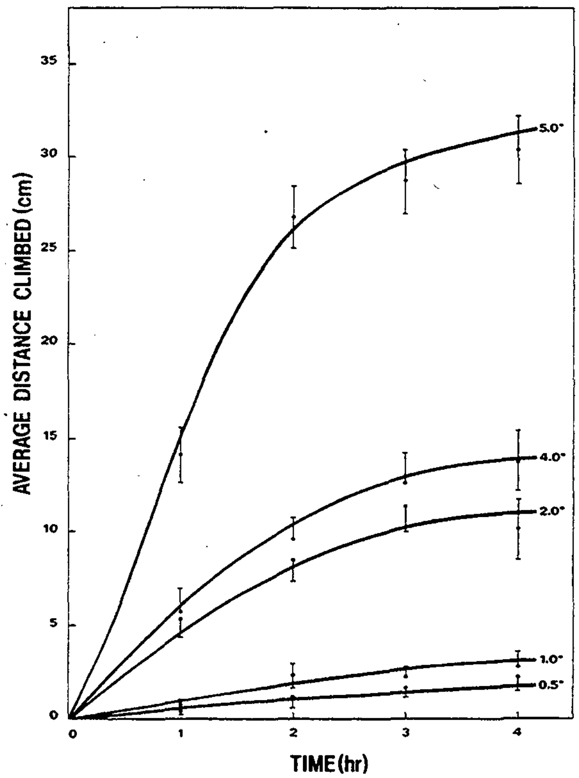

Fig. 5. Activity of post-diapause or spring white pine weevil at temperatures ranging from 0.5 to 5° in the climbing chamber assay (see text for details).

The males show the characteristic rounded 8th tergite whereas the females have a fused 7th and 8th tergite in the form of a triangular pygidium (Fig. 1). Weevils held in diapause under cold temperatures had to be fed for at least 8 h for the abdomen to become turgid prior to sexing by this procedure. Our tests indicated that the ovicidal effect was due to the diflubenzuron being ingested (Table 1). The importance of coverage of terminal leader was evident when we failed to get good control on tall trees where the terminal leader could not be reached with the spray (Table 2). Both oil and water formulations were effective (Table 3). Spring treatment was better than fall treatment probably because much of the sprayed material was lost during the long winter period (Table 4).

While we always had almost 100% control in the laboratory, our field trials were not nearly as effective (Table 2, 3 and 4). We suspected that the weevils were emerging a lot earlier than previously reported, even when there were patches of snow on the ground. This became readily apparent when we found that the weevils were active at temperatures below 5°, even at 0.5°. In early spring, the areas immediately under the pine trees, are the first places to lose their snow cover mainly because of the radiant heat absorbed by the trees (Sullivan 1959). Since the weevils are immediately under the host-trees, once the snow melts and the temperature goes above freezing, they would emerge and climb on the tree. We even

TABLE 6. Overview of control strategies for the white pine weevil.

References	Strategy	Method	Description
I Prophylactic systems (prevention of infestation)	1. Genetic	Resistant trees	Garrett 1972, Gerhold 1966, Heimburger 1967
	2. Ecological	Shading of host trees, moist overwintering sites	Dixon et al. 1979, Stiell and Berry 1985, Sullivan 1961
	3. Sanitation	Clipping and burning of infested leaders	MacAloney 1930
	4. Biochemical	Aggregation, pheromones, host volatiles	Booth et al. 1983, Brooks *et al.* 1987, Wilkinson 1985
	5. Physical	Stickers as barriers	(Retnakaran, unpublished)
II Therapeutic systems (treatment of infestation)	1. Biological	Parasites, predators, nematodes and fungi	Alfaro and Borden 1980, McGugan and Coppel 1962, Schmiege 1963, Turchinskuya and Sherlygina 1974, VanderSar 1978
	2. Broad spectrum insecticides	Methoxychlor, lindane, permethrin, aldicarb, etc.	DeGroot 1985, Kerr 1970, Nigam 1973
	3. Biorational insecticides	Juvenile hormone analogues, chitin, synthesis inhibitors	McMullen and Sahota 1974, Retnakaran 1974, Retnakaran et al. 1985, Retnakaran and Smith 1982, Retnakaran and Wright 1987, Sahota and McMullen 1979

suspect some underground feeding, possibly on the roots, since even the earliest weevils captured in ground traps have turgid abdomens as opposed to the ones maintained in the laboratory. Strangely enough, when lab reared weevils in diapause were placed on white pine twigs inserted in wet sand to prevent dehydration, the weevils tended to burrow and feed on the twig below the surface of the sand. When all these factors were taken into consideration, it became obvious that if we spray very early, prior to the emergence of the weevils, when the snow was still on the ground, in late March or early April, we should be able to get near perfect control. When we followed this prescription, our prediction came true and we obtained >99% control (Table 5). It also became clear that lower dosages were just as effective so long as the terminal leaders were completely covered with the spray.

We feel that an emergence model can be developed for the white pine weevil using photoperiod, thermoperiod and phenology at several latitudes which can then be used to accurately predict the optimal time for spraying (McCann *et al.* 1989, Wickman 1988).

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