BIONOMICS OF STRAWBERRY ROOT WEEVIL ADULTS, *OTIORHYNCHUS OVATUS* (L.)(COLEOPTERA: CURCULIONIDAE), ON YOUNG ORNAMENTAL CONIFER TREES IN SOUTHERN ONTARIO

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Abstract

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Field and laboratory studies were undertaken in southern Ontario to gain bionomical information on the adult strawberry root weevil (*Otiorhynchus ovatus*), a pest of ornamental conifer trees in nurseries. Emergence of overwintering adults began on 3 June 1991 and lasted 56 days, with 50% emerging within 18 days. Adults dispersed less than 5 m in 48 days from a single release point. About 50% of females were fecund. The laboratory temperatures at which adults were reared (15, 20, and 25°C) had no significant effect on fecundity (62.3 eggs per female) but influenced longevity; adults at 15°C lived longer than at 20 or 25°C. The mean preovipositional and ovipositional periods were 31.5 and 49.0 days, respectively. Less than 1% of adult weevils released in the field survived the winter; overwintering adults lived 10 months. Egg eclosion occurred 16 days after oviposition with 78% of the eggs viable. The significance of these biological observations in the development of management strategies for this pest is discussed.

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Résumé

Des recherches en nature et en laboratoire ont été entreprises dans le sud de l'Ontario dans le but d'étudier la biologie du Charançon de la racine du fraisier (*Otiorhynchus ovatus*), un insecte qui infeste les conifères ornementaux dans les pépinières. L'émergence des adultes qui ont survécu à l'hiver a commencé le 3 juin 1991 et a duré 56 jours, mais 50% des individus étaient déjà sortis après 18 jours. Les adultes se sont déplacés de moins de 5 m en 48 jours à partir d'un point de libération unique. Environ 50% des femelles étaient fécondes. Les températures utilisées en laboratoire pour l'élevage des adultes (15, 20 et 25°C) n'avaient pas d'influence particulière sur la fécondité (62,3 oeufs par femelle), mais influençaient la longévité; les adultes élevés à 15°C ont vécu plus longtemps que ceux élevés à 20 ou 25°C. La durée moyenne de la période de préponte a été évaluée à 31,5 jours, celle de la ponte à 49,0 jours. Moins de 1% des charançons adultes libérés en nature ont survécu à l'hiver et leur longévité a été estimée à 10 mois. L'éclosion s'est produite 16 jours après la ponte et 78% des oeufs étaient viables. L'importance de ces observations dans l'élaboration de stratégies d'aménagement fait l'objet d'une discussion.

[Traduit par la Rédaction]

Introduction

In the past, the strawberry root weevil, *Otiorhynchus ovatus*, was considered primarily as an agricultural pest. It feeds on a wide range of crops including strawberry, cranberry, currant, alfalfa, and clover (Treherne 1914). *Otiorhynchus ovatus* is now considered a generalist, feeding on whatever plant is available including trees from the genera *Abies*, *Picea*, *Thuja*, and *Tsuga* (United States Department of Agriculture 1985). In Ontario, root weevils represent a serious problem to the production and maintenance of tree quality in nurseries. Root weevils reduce tree value from $30–72 per metre of height (wholesale price range) to almost zero (pers. comm. John Somerville, Somerville Nurseries Inc., Alliston, Ontario). The nursery trade industry generated $196 million to the Ontario economy in 1990 (Ontario Ministry of Agriculture and Food 1992).

Otiorhynchus ovatus belongs to the largest genus of introduced weevils established in North America (Warner and Negley 1976). It is parthenogenetic in North America, whereas in Europe both males and females may occur (Warner and Negley 1976). The elytra of *O. ovatus* are fused so the adult is incapable of flight. Dispersal is by walking or transport on infested plants (Treherne 1914). The adult weevil feeds at night in the host tree and moves to the soil litter or other concealed places during the day (Downes 1922).

Regardless of the host attacked, damage caused by the strawberry root weevil takes two forms. First, larvae girdle large roots or strip small roots, or both (Gambrell 1938). This limits the tree's ability to absorb water and nutrients. Mortality from root feeding can be severe. In one nursery, 60% of the trees died in a heavily infested plantation of Colorado spruce (*Picea pungens* Engelm.) (John Sommerville, pers. comm.). The second type of damage caused by root weevils is needle and twig feeding by the adult (Gambrell 1938). When not laying eggs, adults feed on needles and bark of small twigs. If girdling occurs on twigs, the resulting discoloured branches can become prominent; this ultimately reduces the tree's value because of its poor quality and form.

Management of the strawberry root weevil is difficult because adult weevils are nocturnal and immature stages are found in the soil. Control strategies aimed at active adult weevils need to be implemented at night. An application of a pesticide aimed against larvae requires that the treatment penetrate several centimetres into the soil.

Although bionomic information does exist on this root weevil, most of it is not readily applicable to management of *O. ovatus* in tree nurseries of eastern Canada. First, the biological information must be translated from agricultural crops to ornamental trees. Second, all information gathered to date is primarily from warmer climates in western North America. Our study was designed to provide information on the behaviour, dispersal, and reproduction of adult strawberry root weevils on ornamental conifer trees in southern Ontario. This information will aid pest managers in developing effective management strategies for this pest in eastern Canada.

Materials and Methods

Field studies were carried out in 1990 and 1991 at Somerville Nurseries Inc. near Hockley, Ontario (44°01′N, 79°58′W), in a Colorado spruce plantation. The trees were planted in 1984 as 2½–1½ seedling stock (seedbed – transplant bed) at a spacing of 1.8 m by 1.8 m. Laboratory studies at the University of Toronto examined fecundity, adult longevity, egg viability, and egg eclosion. Voucher specimens were identified by R.S. Anderson at the Canadian Museum of Nature, Ottawa, Ontario.

Adult Emergence. Adult emergence was monitored in May 1991. An emergence cage was placed on the east side beneath the lower branches of 16 randomly selected trees at the study site where *O. ovatus* was known to occur at a population level causing tree mortality. The cages were constructed of 1.5-cm spruce plywood (25 cm wide by 25 cm long by 13 cm high). The top was covered with a metal wire mesh that was stapled to the plywood and sealed with silicone. Cages were buried about 2 cm to prevent emerging weevils from escaping. The cages were monitored daily from 21 May to 9 August 1991.

The diurnal pattern of adult emergence was determined by monitoring cages continuously every 3 h between 10 and 14 June 1991 when peak adult emergence occurred. Cages were monitored by lifting each from the soil surface and then counting and removing the adults.

Nocturnal Behaviour. Behavioural observations of the nocturnal activities of *O. ovatus* were made in an attempt to locate oviposition sites. Three trees were examined on three consecutive evenings from 1 h before sunset until 1 h after sunrise. Each tree was monitored by one observer. Notes were taken on adult activities such as walking, feeding, burrowing, and oviposition on or beneath each tree. Observation lights were covered with Kodak^R Wratten No. 14 red filters so that the adult weevils could be seen but not disturbed. Observations were made on 24–26 July 1991.

Adult Dispersal. Adult dispersal within a plantation of Colorado spruce trees was studied by marking adult weevils with Testor's^R fluorescent yellow paint and releasing them from a single tree. During 11–14 June 1991, 4000 active adult weevils were collected in an adjacent spruce plantation and were released on 18 June 1991. To estimate adult dispersal, the trees were examined at 2-m intervals in concentric circles up to 14 m from the release tree on 19, 20, 24 June, 3, 8, 23 July, and 6 August 1991. On each date, the number of marked adults found on or beneath trees at various distances from the release point was recorded, and the weevils were left where they were found.

Mean distance travelled by dispersing adult weevils was determined using the formula

$$d = \Sigma F_i \frac{1}{2}(x_{i+1} + x_i)$$

where d is the mean distance travelled in m, F_i is the mean proportion of adults in annulus i, x_i is the inner radius of the ith annulus centred on the release point, and x_{i+1} is the outer radius of the same annulus (Southwood 1978).

Adult Fecundity and Longevity. Reproduction was examined by determining the percentage of fecund females, mean daily and total fecundity, and timing of oviposition. Seventy-five newly emerged teneral adults (adults collected from emergence cages that contained no adults on the previous day) were collected on 20 June 1990 and 72 newly emerged adults on 7 June 1991. The adults were placed individually in plastic containers (25 mL) with a small amount of sandy loam soil and a freshly cut spruce shoot to serve as food. The adults were then separated into three groups containing 25 weevils each. The three groups were placed in growth chambers at 15, 20, or 25°C (16:8 = L:D photoperiod, RH = 50%). Individual containers were examined at least once a week in 1990 and at least three times a week in 1991, until adults died, to determine the number of eggs laid per adult and adult longevity. After each examination, a freshly cut spruce shoot was placed in each vial.

A chi-square test was used to analyse the dependence of fecund versus sterile females on temperature in 1990 and 1991 (SYSTAT^R 5.0, Tables; Wilkinson 1990). The proportion of fecund versus sterile females has a binomial distribution.

Histograms of total fecundity of fecund females at the three experimental temperatures were examined to determine if these data were normally distributed and of common variance. The distributions suggested that a logarithm transformation was required. Data were transformed to natural logarithm ($x + 1$). A two-way ANOVA was performed with temperature and years as sources of variation (SAS Institute Inc. 1989). The fixed-effect model used in the analysis of variance was

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$$

where y_{ijk} is the total fecundity of the kth adult weevil in ith year and the jth temperature; μ is a constant; α_i is a constant representing the effect of year; β_j is a constant representing the effect of temperature; γ_{ij} is a constant representing the interaction effect between year and temperature; and ε_{ijk} is an error term. A similar procedure was used for longevity of fecund females. Longevity data did not require transformation.

Egg Viability and Eclosion. To determine egg viability and eclosion, 86 eggs were collected from four adults. Adults were randomly selected from seventy-five numbered adults reared in the laboratory. The eggs of each adult were placed on moistened filter paper in four petri

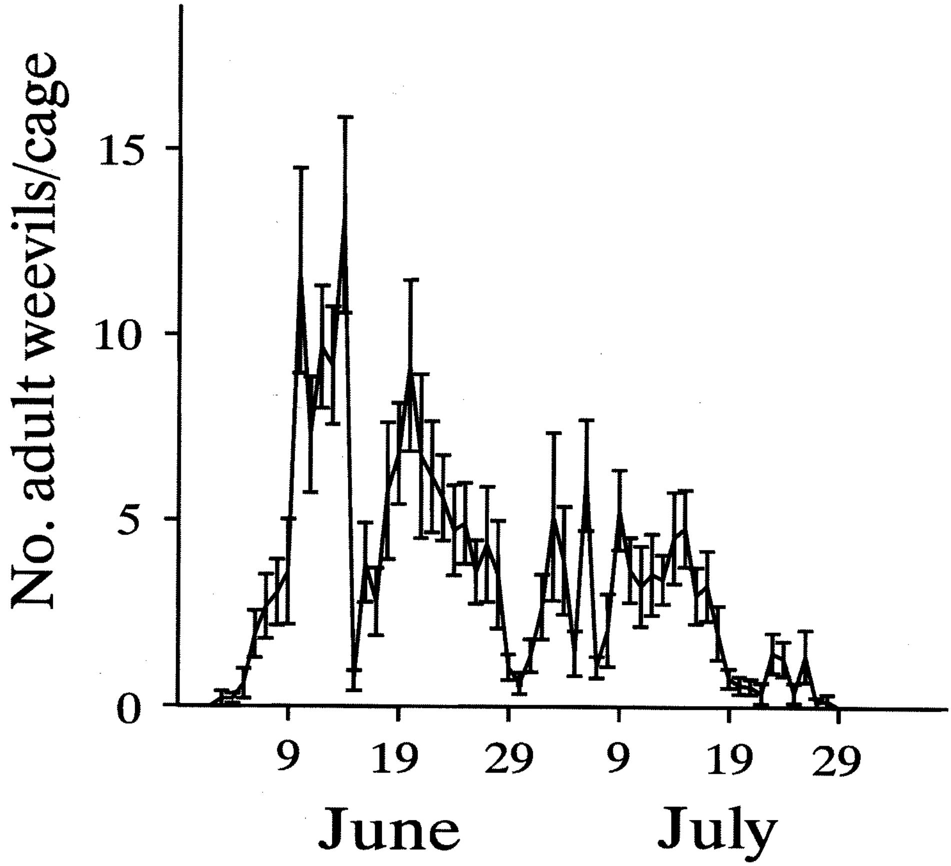

FIG. 1. Mean daily emergence of adult *Otiorhynchus ovatus* from 16 emergence cages placed beneath individual Colorado spruce trees (*Picea pungens* Engelm.) near Hockley, Ontario, in 1991. Bars around each mean indicate standard errors.

dishes, and maintained at 15°C (16:8 = L:D photoperiod, RH = 50%). The dishes were examined daily to record the number of hatched eggs.

Results and Discussion

Adult Emergence. In 1991, emergence of adult *O. ovatus* began 3 June and continued until 29 July, a total of 56 days (Fig. 1). Peak emergence occurred on 14 June, 11 days following the onset of emergence. Fifty percent of adults emerged by 21 June. The onset of adult emergence observed in Ontario did not differ from that reported in Michigan (McDaniel 1930) and New York (Gambrell 1938) but the duration of emergence did; emergence in Ontario lasted about twice as long as in Michigan and New York. Adult emergence in Ontario began 2–3 weeks later than in Oregon (Wilcox et al. 1934) and British Columbia (Treherne 1914; Downes 1922) and was also twice as long.

Peak daily emergence of *O. ovatus* occurred shortly after sunrise (Fig. 2). Emergence gradually declined from a peak in the morning to dusk, rising again after sunset. In the hour immediately prior to sunrise, emergence dropped to a point almost as low as that of the late afternoon and early evening hours.

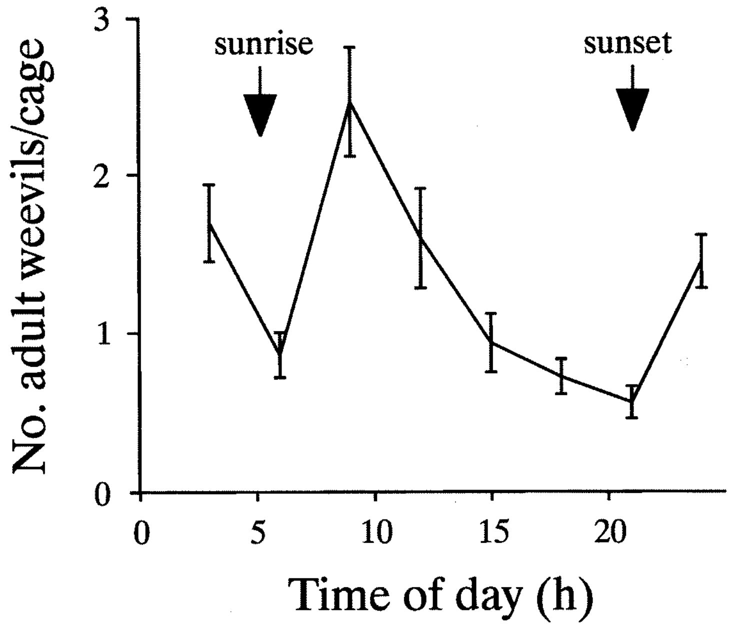

FIG. 2. Diurnal emergence (24 h) of adult *Otiorhynchus ovatus* from 16 emergence cages placed beneath individual Colorado spruce trees (*Picea pungens* Engelm.) near Hockley, Ontario, in 1991. Bars around each mean indicate standard errors.

Diurnal emergence of the strawberry root weevil appears to be affected by both temperature and light. Adult emergence is at its lowest when peak daily temperature (20–24°C) occurs in the late afternoon and early evening (1800–2100 hours). By contrast, adult emergence rises during that time (0300–0900 hours) when daily temperatures are low (ca. 14°C) except when the sun rises around 0600 hours (Fig. 2). Bird feeding is concentrated in the morning hours (Anderson et al. 1979). The decline in root weevil activity may be related to bird feeding at sunrise. Bird droppings found in the plantation where emergence was monitored contained hundreds of exoskeletons of *O. ovatus* (Brandt 1992).

Nocturnal Behaviour. During each evening, adult *O. ovatus* were observed active on the lower branches and on the soil beneath the host tree. Adults were observed feeding on bark and needles of lower branches. Adults walking on the soil beneath the tree crawled into crevices and under clumps of soil. Their activity under the soil clumps was not observed. It is assumed that they crawled to these locations to deposit eggs, although oviposition could not be observed directly. Downes (1920) and Wilcox et al. (1934) observed adults of the strawberry root weevil ovipositing in soil crevices near strawberry plants. Occasionally, adults were observed walking from one tree to the next. When this occurred, adults did not appear to linger in soil crevices but instead walked as quickly and directly as possible to the adjacent tree.

Adult Dispersal. Adults of the strawberry root weevil moved less than 5 m during the 48-day period following their release on 18 June 1991 (Table 1). No weevils were found beyond 8–10 m from the release point, with the majority occurring within the first 4–6 m. Between 24 June and 8 July, the distribution of weevils had stabilized with approximately 31, 32, 35, and 2% of marked weevils at 0–2, 2–4, 4–6, and 6–8 m, respectively, from the release point.

TABLE 1. Total number and percentage (in parentheses) of marked adult *Otiorhynchus ovatus* recaptured at each distance from a central point after 4000 adults were released in a young Colorado spruce plantation near Hockley, Ontario, on 14 June 1991

	Distance from release point (m)							
Date	0–2	2–4	4–6	6–8	8–10	10–12	12–14	Mean ± SE*
19 June	450 (100.0)	0	0	—	—	—	—	1.00±0.00
20 June	765 (83.0)	84 (13.7)	18 (3.3)	0	0	—	—	1.41±0.03
24 June	214 (43.0)	80 (24.1)	98 (32.9)	0	0	—	—	2.80±0.09
3 July	24 (19.4)	32 (38.8)	29 (39.0)	2 (2.8)	0	0	—	3.50±0.17
8 July	27 (29.3)	21 (34.3)	19 (34.5)	1 (1.9)	0	0	—	3.18±0.21
23 July	34 (95.2)	0	1 (4.8)	0	0	0	—	1.19±0.12
6 Aug.	4 (53.0)	0	0	1 (23.2)	1 (23.8)	0	0	4.30±1.59

*Mean distance from release point was determined using Southwood's (1978) formula

$$d = \Sigma F_i \frac{1}{2} (x_{i+1} + x_i)$$

where d is the mean distance travelled in m, F_i is the mean proportion of adults in annulus i, x_i is the inner radius of the ith annulus centred on the release point, and x_{i+1} is the outer radius of the same annulus.

Adults of *O. ovatus,* as a pest of peppermint in Oregon, were observed moving less than 6 m over an unspecified period (Emenegger and Berry 1978). The adult black vine weevil, *Otiorhynchus sulcatus* (F.), was reported to walk less than 10 m on average in an urban area; three adult beetles walked more than 70 m (Maier 1978). Even though the distance between host plants is greater in a Colorado spruce plantation than in a field of peppermint, the distance travelled by adult weevils did not differ, possibly because the plants in each system were relatively close together. Based on our findings, the spread of an infestation by adult weevils from one field to adjacent fields should be slow provided infested soil is not transported between fields. In Maier's study (1978) on the black vine weevil in an urban area, the beetles would need to travel farther to get from one food source to the next (i.e. from one garden to the neighbour's garden) and therefore it is not surprising that a greater distance of dispersal was observed.

Adult Fecundity and Longevity. The proportion of fecund females versus sterile females was independent of temperature in both years ($\chi^2 = 3.11$; df = 5; $P = 0.683$). The percentage of fecund females was 50.8 ± 3.3%. This is higher than the 34.4% reported by Treherne (1914). There was no reproductive diapause in the adults examined in the laboratory; all adults were kept until they died. Fecundity studies of *O. sulcatus* reveal that not all adults of this parthenogenetic species lay eggs; this may relate to the host plant that adults feed on (Maier 1981; Nielsen and Dunlap 1981; Shanks 1980).

The preovipositional period, during which adults feed most of the time, was 31–33 days in 1990 and 30–33 days in 1991 at all temperatures (mean ± SE = 31.5 ± 0.56 days) (Fig. 3). On strawberry, the preovipositional period ranged from 8 to 33 days (Treherne 1914; Wilcox et al. 1934). In our study, only newly emerged teneral adults captured in the field were used which was not the case for Treherne (1914) and Wilcox et al. (1934). Cram (1958), working on black vine weevil, noted that the time elapsed to maturity of the reproductive system was

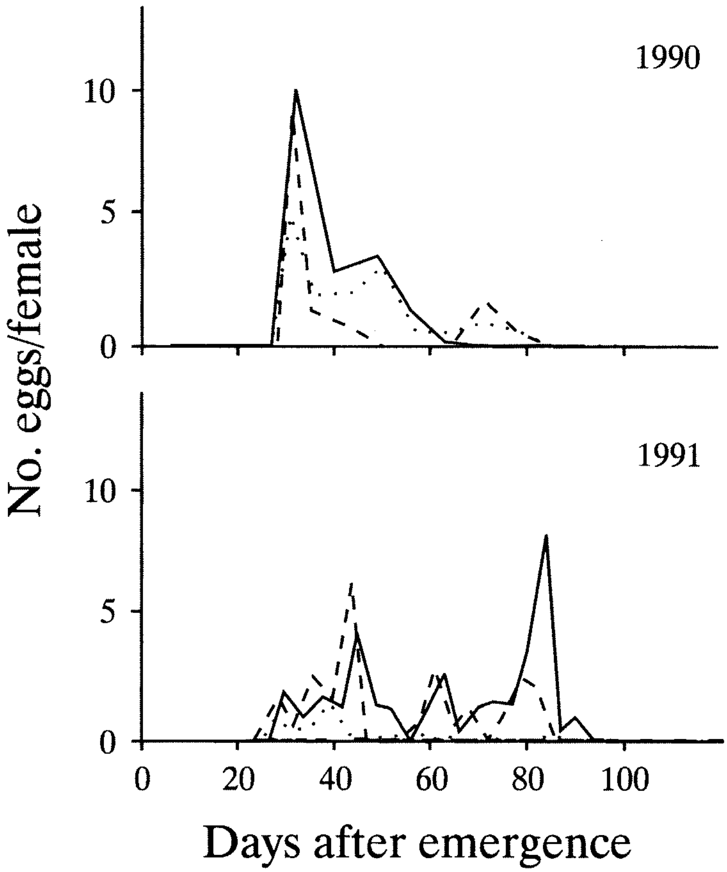

FIG. 3. Daily fecundity of adult *Otiorhynchus ovatus* when reared at three different temperatures in the laboratory (16:8 = L:D photoperiod) during 1990 and 1991. Bars around each mean indicate standard errors. Dotted line represents 15°C, solid line 20°C, and dashed line 25°C.

28 days for adults reared in the laboratory from pupae. If control strategies are targeted at adult weevils, these strategies should be implemented before oviposition starts and continued until adult emergence is complete.

The pattern of daily oviposition of *O. ovatus* in 1990 differed from that observed in 1991 (Fig. 3). In 1990, oviposition lasted 31–47 days depending on temperature, whereas in 1991, it lasted 53–60 days. Differences between years probably relate to variation in soil conditions experienced by larvae and pupae prior to adult emergence. The mean length of the ovipositional period at all three temperatures and both years was 49.0 ± 4.21 days. This is similar to that obtained on strawberry in British Columbia by Downes (1922) and in Oregon by Wilcox et al. (1934).

Significant differences in total fecundity did not exist between years ($F = 0.97$; df = 1; $P = 0.3281$) or temperatures ($F = 2.69$; df = 2; $P = 0.0749$). The interaction between years and temperatures was significant ($F = 4.84$; df = 2; $P = 0.0108$). Mean total fecundity by year and temperature is given in Table 2. On average, *O. ovatus* laid 62.3 ± 8.3 eggs per female. This fecundity is higher than that found by Treherne (1914) (43 eggs per female) working with weevils on strawberry. Treherne (1914) was uncertain as to the activity and

TABLE 2. Total lifetime fecundity of *Otiorhynchus ovatus* when maintained individually at three different temperatures in the laboratory (16:8 = L:D) during 1990 and 1991 (mean ± SE)

Temperature (C°)	Year	Fecundity (no. eggs per female)
15	1990	72.3±17.5a*
	1991	16.5±4.9b
20	1990	100.3±20.6ac
	1991	77.1±29.4abcd
25	1990	40.5±14.2abde
	1991	56.0±15.1acde

*Means followed by the same letter are not significantly different for log-transformed fecundity at $P \leq 0.05$ (two-way ANOVA).

age of the adults prior to his observations. Downes (1922) collected newly emerged adults feeding on strawberry and found fecundity to be between 150 and 200 eggs per female.

Numerous authors have shown that fecundity of *O. sulcatus* is affected by food type (Cram 1980; Shanks 1980; Maier 1981; Nielsen and Dunlap 1981). Shanks (1980) found that *O. sulcatus* laid significantly fewer eggs when fed yew, *Taxus* spp., than when fed strawberries (81 eggs per female as compared with 124 eggs per female, respectively). A comparison between the results of our study and Downes (1922) indicates that *O. ovatus* lays fewer eggs when fed spruce foliage than when fed strawberry foliage.

Longevity was significantly shorter in 1990 than in 1991 ($F = 26.39$; df = 1; $P = 0.0001$). Temperature also had a significant effect on longevity ($F = 5.29$; df = 2; $P = 0.0073$). Longevity was 77.2 ± 4.8 days at 15°C. This was significantly longer than 57.2 ± 4.9 days at 25°C ($P = 0.0018$). Longevity at 20°C (70.5 ± 5.2 days) was not significantly different than longevity at 15°C ($P = 0.1274$) or 25°C ($P = 0.0783$). In general, elevated temperatures decreased adult longevity.

Additional information on longevity under natural conditions was obtained in a corollary study (Brandt 1992). A total of 1320 marked adults was released into cages (15 adults per cage) placed around Colorado spruce trees in a plantation in 1990, from which only two were found the following spring (26 May 1991). One of these overwintering adults laid 23 eggs before dying after 23 days in a growth chamber (20°C, RH = 50%, 16:8 = L:D photoperiod) in the laboratory. It is unknown how many, if any, eggs were laid before capture, because these adult weevils were active around the base of the caged trees. Other researchers have found that adults of the strawberry root weevil live between 40 days and 14–15 months (Treherne 1914; Downes 1922; Gambrell 1938). One factor that affects the length of the adult's life is its ability to survive the winter. Along the west coast of North America, a large proportion of adult *O. ovatus* survive through the winter and continue to oviposit the following spring (Wilcox et al. 1934). Gambrell (1938), working in New York, noted that only a very small proportion of the adults survive through the winter and oviposit the following spring. Our results and those obtained by Gambrell (1938) indicate that winters in Ontario and New York are probably too severe for a large proportion of adult weevils to survive, unlike conditions along the west coast of North America where weevils do survive in large numbers. Less than 1% (0.0015%) of adult *O. ovatus* survive the winter in Ontario. Late-emerging adults are the most likely candidates to survive the winter; managers must assure successful control of these individuals to prevent them from ovipositing in the fall or the following spring.

Egg Viability and Eclosion. Based on 86 eggs produced by four female weevils, 78% of the eggs laid were viable. Other workers studying *O. ovatus* on strawberry and peppermint found similar viability of eggs ranging between 68 and 82% (Treherne 1914; Downes 1922; Emenegger and Berry 1978).

The time required for 67 eggs to hatch at 15°C was 16.1 ± 0.3 days. This is similar to that reported by Treherne (1914) and Downes (1922). Emenegger and Berry (1978) reported that eggs from adults fed peppermint required 13 days at 20°C before eclosion.

Conclusion

New information has been gained on the adult strawberry root weevil as a pest of young ornamental conifer trees and this information can be used to develop a management strategy specific to eastern Canada. Important findings from this study relevant to management include the onset and duration of emergence, the preovipositional period, fecundity, longevity, and dispersal.

Control should be directed at adult weevils before oviposition begins in July and continued until emergence is complete. Some late-emerging adults survive the winter; consequently, managers must successfully control these individuals to prevent oviposition in the fall or the following spring. If adults are able to lay their eggs, then our work shows that larval feeding begins within 2 weeks. The spread of an infestation to adjacent uninfested fields can be managed by preventing the transport of soil containing eggs, larvae, or pupae, or plant material containing adults.

Further research is required to answer questions related to the immature stages of *O. ovatus* and their effect on the root system of host trees. When do larvae feed on the host's roots and at what larval stage does most damage occur? With this information the life cycle and impact of the strawberry root weevil on young ornamental conifer trees would be better understood and improvement of its management would be permitted. Other studies could investigate sampling techniques to monitor immature *O. ovatus* populations and develop damage indices relating immature populations to subsequent host damage and mortality.

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