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Influence of reforestation technique, slash, competing vegetation, and duff depth on the overwintering mortality of *Pissodes strobi* (Coleoptera: Curculionidae), the white pine weevil

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Abstract

We quantify the effects of reforestation technique (planted vs. seeded stands), distance from slash (beside slash vs. 100 m from slash), presence of competing vegetation (weed vs. weed-free patches), and depth of the duff on the overwintering mortality of the white pine weevil (*Pissodes strobi* Peck) in jack pine (*Pinus banksiana*) plantations in northern Ontario, Canada. Open (control) and screened (exclusion) cages were used to separate mammalian predation from other overwintering mortality factors. Over 3 years, winter mortality of adult weevils ranged from 83 to 88% with mammalian predation significantly increasing adult mortality by 5–13%. More weevils died over winter in a planted stand (92%) than in a seeded stand (76%), although subsequent damage was similar in both stands. The distance from slash and the presence of competing vegetation had no effect on the overwintering mortality of weevils. More small mammals were found in patches with competing vegetation than without, which was associated with higher levels of weevil predation. The total number of weevils dying was inversely related to the depth of the duff. However, this difference was not significant because of a high variation within treatments. The implications of these results for forest management and the reduction of white pine weevil populations are discussed.

Keywords: Pest management; Jack pine; Small mammals; Predation; Silviculture

1. Introduction

Several species of pines and spruce are infested by white pine weevils, *Pissodes strobi* Peck, throughout North America. White pine weevil damage causes loss of the central shoot (leader) of young, vigorous trees. Although weevil infestations rarely result in tree mortality, they reduce timber volume and quality (Brace, 1971; Davidson, 1991).

The main management options to control white pine weevil include the provision of shade with nurse crops, underplanting, shelterwood or the establishment of high density plantations; the removal of infested leaders; and the destruction of overwintering sites through controlled burns or raking (Dixon et al., 1979; Hodge et al., 1989).

Overwintering mortality of the white pine weevil has been shown to significantly reduce populations (Dixon and Houseweart, 1982). Aspects of the biology and behavior of the white pine weevil have been documented in white pine (*Pinus strobus*) (Wallace

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and Sullivan, 1985), sitka spruce (*Picea sitchensis*) (McMullen et al., 1987), and jack pine (*Pinus banksiana*) (Applejohn, 1993), but few studies have examined the factors affecting overwintering mortality. The white pine weevil overwinters as an adult between the upper zone of dry needles and the lower zone of moist organic debris, about 20 cm from the bole of the host tree (Dixon et al., 1979). Abiotic factors acting against overwintering weevils have been described as key mortality factors (Dixon and Houseweart, 1982). Thus, increasing the already high overwintering mortality of weevils (15–50% of the adult population in white pine plantations) might lead to significant reductions in damage the following year.

Silvicultural treatments of stands create different environmental conditions for weevil development and survival. The type of reforestation (hand-planted or aerially seeded) may result in differences in the spatial pattern of host trees. This, in turn, can lead to differences in temperature and humidity between shaded and exposed stands or patches that can affect weevil development (Sullivan, 1960). The high moisture content of some overwintering sites is thought to cause insect mortality through the formation of ice crystals (Danks, 1978). Bellocq and Smith (1994b) suggested that moisture content could be related to the depth of the duff, where a shallower duff may increase overwintering mortality of weevils. Deeper duffs are associated with the presence of deciduous trees (competing vegetation) in young plantations. Additionally, stand conditions influence the abundance of mammalian predators of weevils. For example, some rodent species are more abundant when slash is left at a site following harvest (Larson et al., 1986) while herbicide applications may reduce the abundance of insectivorous mammals through changes in vegetation coverage and structure (Santillo et al., 1989).

Predation by small mammals influences beetle communities and populations (Parmenter and MacMahon, 1988; Churchfield et al., 1991), and may significantly increase the overwintering mortality of weevils (Andersen and Folk, 1993; Bellocq and Smith, 1994b). Insectivorous and omnivorous mammals undoubtedly forage on weevils in the duff during the fall and winter, but little is known about their impact on overwintering adult weevils. Poten-

tial predators in northern Ontario jack pine sites include the masked shrew (*Sorex cinereus*), the short-tailed shrew (*Blarina brevicauda*), and the deer mouse (*Peromyscus maniculatus*) (Bellocq and Smith, 1994b).

This study was designed to quantify the effects of reforestation, distance from slash, presence of competing vegetation, and depth of duff on the overwintering mortality of the white pine weevil. Control (open) and exclusion (screened) cages allowed us to distinguish mammalian predation from other overwintering mortality factors.

2. Materials and methods

2.1. Study area

The study area was located on an extensive sand-flat region in the southern boreal forest, approximately 32 km south of Gogama, Ontario, Canada (47°49'N, 81°44'W). The area is dominated by jack pine (over 70% of the forest community) in extensive monospecific forests created by artificial regeneration (hand-planting or aerially seeding) after clearcutting or wildfire. Mixed deciduous-coniferous forests are also present in the area where the dominant tree species are trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). The study was conducted in 3–10 year-old jack pine plantations during 1991–1994.

2.2. General procedure

Experiments were conducted to quantify overwintering mortality of adult white pine weevils under different situations given by: (1) the type of reforestation (hand-planted vs. aerially seeded stands); (2) the distance from slash (beside slash vs. 100 m from slash); (3) the presence of competing vegetation (weeds vs. weed-free patches); (4) the depth of the duff layer.

Adult weevils used in the experiments were collected from jack pine leaders. Leaders killed by weevils were collected in late July, after weevil pupation, and brought to the laboratory where they were kept in a dark container until adult emergence (in August). The emerging adult weevils were kept

outside in a screened container sheltered from rain and direct sunlight. Weevils were fed weekly with branches of fresh jack pine until utilized in experiments in October.

For the experiments, adult weevils were placed in cages that consisted of an aluminum ring (20 cm diameter, 12 cm deep) inserted flush with the ground. With the exception of the duff experiment, both control and exclusion cages were used to assess mortality due to small mammal predation. Control cages were open rings that allowed access of mammalian predators, whereas exclusion cages had a screen (7 mm × 7 mm) welded on top to prevent access by small mammals. One open cage was placed approximately 1 m from an exclusion cage and 20 cm from the bole of the same tree. A fine-mesh screen (1 mm × 1 mm) was glued to the top of all cages to ensure that the weevils remained inside the cages to establish their own overwintering sites in the duff. This screen was removed from all cages in late fall, and the cages remained throughout the winter under natural snow cover and field conditions. In early spring, a black inverted funnel was placed over the top of each cage. The surviving weevils were collected inside inverted, clear vials which were glued over the top spouts of each funnel (for more details see Bellocq and Smith, 1994b).

Because the number of surviving weevils per cage was not normally distributed, non-parametric Kruskal–Wallis, Mann–Whitney, and *G*-square tests (with Williams' correction) were used to compare the treatments.

2.3. Reforestation technique

To quantify the effect of the reforestation technique on the overwintering mortality of weevils, a line of 15 pairs (15 m apart) of control and exclusion cages (eight weevils per cage) was set in both a planted and seeded stand (total 30 cages and 240 weevils per stand) in the fall of 1991. In both stands, the density of jack pine was estimated using *T*-square sampling (Krebs, 1989) on 50 points randomly selected along a transect. The height of the jack pine was measured, and the percentage of trees damaged by weevils was estimated.

To estimate the abundance of mammalian predators, four parallel lines (50 m apart) of snap traps

were set in each stand. Trap lines consisted of ten stations with 15 m between stations and two traps per station, that operated during five nights between 31 July and 4 August 1991. This produced a sampling effort of 400 trap nights in each stand. Captured mammals were frozen for later identification, and relative abundance was estimated as the number captured per 100 trap nights. Predator removal was considered to have no effect on weevil mortality because small mammals could disperse readily into the trapping area.

2.4. Distance from slash

To examine the effect of slash (woody debris and stumps and logs piled into rows after clear cutting and site preparation) on the overwintering mortality of adult weevils, a line of 15 pairs (10 m apart) of control and exclusion cages (ten weevils per cage) was established beside a slash pile and another identical line was set 100 m apart from the same slash pile (total 30 cages and 300 weevils per line) in the fall of 1992. The experiment was conducted in a 3-year-old seeded stand that had an estimated 9.3% of the jack pines damaged by weevils.

To estimate the abundance of mice, voles, and short-tailed shrews, a line of 40 Longworth traps (10 m apart) was set in each of the sites. Traps operated every second day from 30 July to 15 August 1992 for a total effort of 320 trap nights in each site. Pitfall traps were also used because they are more efficient than Longworth traps in capturing masked shrews (Innes and Bendell, 1988). Pitfall traps (30 cm deep, 20 cm diameter), containing 5 cm of pine needles, were set in parallel lines about 10 m away from the Longworth traps. In this case, the lines consisted of ten traps, 10 m apart, that operated continuously for 14 days for a total of 140 trap nights per line. Captured animals were identified, ear-tagged and released at the place of capture. Abundance was estimated as the number captured per 100 trap nights.

2.5. Depth of the duff

To analyze the effect of varying depths of duff, a total of 30 cages (ten weevils per cage) was set 1–3 m apart in the fall of 1992. Only exclusion cages

were used in this experiment. Each cage was filled with 0, 2.5, 5, 7.5, or 10 cm of pine needles; this resulted in six replications for each depth. The experiment was conducted in the same stand described above using the same procedure for weevil establishment.

2.6. Presence of competing vegetation

To study the effects of weeds (vegetation other than jack pine) on the overwintering mortality of weevils, a line of 15 pairs (10 m apart) of control and exclusion cages (ten weevils per cage) was placed in each of a weed and a weed-free patch in the fall of 1993, within the same stand as that used during 1992. In this stand, weeds were essentially absent from the high stratum (50–100 cm) with the exception of one area (about 200 m × 100 m) where they were naturally present (the weed patch). After overwintering emergence had finished in early June, the soil inside the cages was examined for the presence of dead weevils.

Small mammals were live-trapped in both the

weed and the weed-free patch during June–September 1993. In each patch, a rectangular grid of 44 Sherman traps (baited with peanut butter) was set in a 4 × 11 pattern, one trap every 12.9 m covering 0.5 ha. Pitfall traps baited with whitefish (Yunger et al., 1992) were also set at every second station of the same grids for a total of 22 pitfall traps per grid. Both types of traps operated for two consecutive nights every 2–3 weeks. Captured mammals were identified, ear-tagged (shrews were toe-clipped) and released at the place of capture. Their abundance was estimated as the number captured per 100 trap nights.

Samples of vegetation were taken to estimate biomass per stratum in the same patches as the overwintering experiment and mammal trapping were conducted. Duff and vegetation from low (0–5 cm), mid (5–50 cm), and high (50–100 cm) strata were collected using a 100 × 20 × 20 cm quadrat. The collections followed a regular pattern (four taken 9 m from each corner and one in the center) in each grid during late August 1993. The samples were dried at 40°C and weighed as soon as their dry weight was constant.

Table 1

Stand description, overwintering mortality of the white pine weevil, and abundance of small mammals, in a planted and a seeded jack pine stand in northern Ontario, Canada

	Planted	Seeded
Stand description		
Height of jack pines (cm)	173 ± 5 ^a	251 ± 7 [*]
Diameter of jack pines (mm)	15.8 ± 0.2	15.6 ± 0.2 NS
Jack pines ha ⁻¹	3660 (2646–5935) ^b	4649 (3491–6958)
Duff depth (mm)	25.3 ± 1.3	45.2 ± 2.4 [*]
Damage by weevils to the stand (%)	23.9	16.9 NS
Overwintering mortality		
No. surviving weevils in open cages (N = 120)	10	27
No. surviving weevils in screened cages (N = 120)	25	40
% total overwint. mortal. in open cages	92	76 [*]
% mortality due to mammalian predation	13	11
Abundance of small mammals		
No. shrews (insectivores) per 100 trap nights	1.50	0.5
No. mice (omnivores) per 100 trap nights	0	0.75
No. voles (herbivores) per 100 trap nights	1.25	0.75
Total No. small mammals per 100 trap nights	2.75	2.00 NS
Trap effort (trap nights)	400	400

^a Mean ± 1 SE.

^b Values in parentheses are 95% confidence limits.

^{*} P < 0.001; NS, non-significant.

3. Results

3.1. Overall mortality

Over the 3 years of the study, few adult weevils emerged successfully from the cages after the winter. Total overwintering mortality of weevils (based on open cages) was 85% (total number of weevils $N = 240$) in 1992, 88% ($N = 300$) in 1993, and 83% ($N = 300$) in 1994. More weevils survived in the exclusion than in the control cages during the winter of 1992 ($G = 7.75$, $P < 0.01$), 1993 ($G = 3.33$, $0.05 < P < 0.1$), and 1994 ($G = 3.98$, $P < 0.05$) suggesting that mammalian predation significantly increased overwintering mortality of the white pine weevil.

3.2. Reforestation technique

The density of the jack pine was higher in the seeded than in the planted stand (Table 1). The depth of the duff was greater ($t = 4.18$, $P < 0.001$) and the trees were taller in the seeded than in the planted stand ($t = 11.72$, $P < 0.001$). Damage caused by weevils in both stands was similar ($G = 1.21$, $P > 0.25$).

Table 2

Overwintering mortality of the white pine weevil and abundance of small mammals relative to their distance from slash (woody debris and stumps piled into rows after clearcutting and site preparation) in a jack pine plantation in northern Ontario, Canada

	Beside slash	100 m from slash
Overwintering mortality		
No. surviving weevils		
In pen cages ($N = 150$)	19	16
In screened cages ($N = 150$)	29	23
% total overwintering mortality in open cages	87	89 NS
% mortality due to mammalian predation	7	5
Abundance of small mammals		
No. shrews per 100 trap nights	0	1.3
No. mice per 100 trap nights	2.2	0.9
No. voles per 100 trap nights	0.3	0.9
Trap effort for shrews (pitfall nights)	140	140
Trap effort for other mammals (trap nights)	320	320

NS, non-significant.

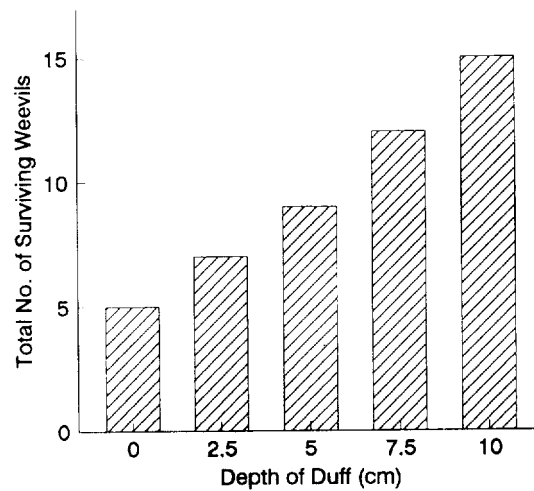


Fig. 1. Total number of white pine weevils surviving the winter in six screened cages (ten weevils per cage) at each depth of duff (totals are presented rather than means because the data were not normally distributed).

Fewer weevils survived the winter in the planted than in the seeded stand ($G = 10.16$, $P < 0.001$) (Table 1). In the planted stand, more weevils survived in the exclusion than in the control cages ($G = 6.64$, $P < 0.01$), showing significant predation by mammals. In the seeded stand, however, the difference was not significant ($G = 2.54$, $P > 0.25$).

A total of five species of small mammals were caught in the stands. Masked shrew and heather vole (*Phenacomys intermedius*) were captured in both stands. Meadow vole (*Microtus pennsylvanicus*) was only caught in the planted stand, while deer mouse and jumping mouse (*Zapus hudsonian*) were only caught in the seeded stand. A similar total number of small mammals was trapped in both stands ($G = 0.52$, $P > 0.5$) although more shrews were caught in the planted than in the seeded stand (Table 1).

3.3. Distance from slash

The number of weevils which survived beside and 100 m from slash piles was similar ($G = 0.93$, $P > 0.5$), showing that the distance from slash had no effect on the overwintering mortality of weevils (Table 2). The number of weevils surviving in exclusion and control cages was similar beside ($G = 2.10$, $P > 0.25$) and 100 m from the slash ($G = 1.26$, $P > 0.05$); but when the data were pooled, the differ-

ence showed a significant mammalian predation at $0.05 < P < 0.1$.

Five species of small mammals were captured, two in the lines set beside the slash and five in the lines set 100 m away from the slash. Deer mouse and meadow vole were caught at both sites, while masked shrew, short-tailed shrew, and red-backed vole (*Clethrionomys gapperi*) were also captured in the line 100 m from the slash. Deer mouse was the dominant species caught in the line near the slash. A total of 17 small mammals was caught, and there was no significant difference in the total number between both sites ($G = 0.057$, $P > 0.5$) (Table 2).

3.4. Depth of the duff

The total number of surviving weevils increased with increasing duff depth (Fig. 1). The difference in survival between depths, however, was not significant because of a high variation within treatments (Kruskal–Wallis, $H = 3.37$, $P > 0.5$).

3.5. Presence of competing vegetation

The jack pine was taller in the weed-free than in the weed patch ($t = 5.31$, $P < 0.001$) whereas the total vegetation biomass was lower in the weed-free than in the weed patch ($t = 3.328$, $P < 0.02$) (Table 3). In addition to the jack pine, trembling aspen and speckled alder (*Alnus rugosa*) dominated the high stratum in the weed patch. Blueberry (*Vaccinium* spp.) and sheep laurel (*Kalmia angustifolia*) dominated the mid-stratum, while mosses dominated the low stratum in both patches. Weevil damage to jack pine, based on the number of dead leaders, was similar in the two patches ($G = 0.50$, $P > 0.5$).

No significant difference was found in the number of weevils surviving in the weed and weed-free patches ($G = 0.131$, $P > 0.5$), suggesting that overwintering mortality of weevils was not affected by the presence of competing vegetation (Table 3). Six pieces of weevils could be identified from the soil inside the cages, but only one was well preserved.

Table 3
Patch description, plant biomass, overwintering mortality of the white pine weevil, and abundance of small mammals in a weed (vegetation other than jack pine) and a weed-free patch of a jack pine plantation in northern Ontario, Canada

	Weed patch	Weed-free patch
Patch description		
Height of jack pine (cm)	151 ± 26 ^a	122 ± 46 ^{**}
Damage by weevils (%)	6.5	9.3 NS
Plant biomass ($N = 5$)		
Duff (g m ²)	1577.7 ± 659.4	410.0 ± 147.8
Low stratum: 0–5 cm (g m ²)	198.7 ± 69.0	76.5 ± 31.2
Mid-stratum: 5–50 cm (g m ²)	639.5 ± 250.0	183.8 ± 52.5
High stratum: 50–100 cm (g m ²)	124.6 ± 50.9	3.0 ± 3.0
Total (g m ²)	672.4 ± 93.2	263.3 ± 80.1 [*]
Overwintering mortality		
No. of surviving weevils		
In open cages ($N = 150$)	22	28
In exclusion cages ($N = 150$)	37	35
Total overwintering mortality in open cages (%)	85	81 NS
Mortality due to mammalian predation (%)	10	5
Abundance of small mammals		
No. shrews per 100 pitfall nights	2.9	1.6 NS
No. mice per 100 trap nights	2.6	0.8 ^{**}
Trap effort for shrews (pitfall nights)	308	308
Trap effort for mice (trap nights)	616	616

^a Mean ± 1 SE.

^{*} $P < 0.02$; ^{**} $P < 0.001$; NS, non-significant.

The others showed missing parts such as heads or abdomens, which decreased the accuracy of determining the number of dead weevils.

A total of 47 small mammals was captured during the summer (Table 3). More small mammals were trapped in the weed than in the weed-free patch ($G = 11.63$, $P < 0.001$). Deer mouse, masked shrew, short-tailed shrew, and eastern chipmunk (*Tamias minimum*) were caught in both patches. A red-backed vole was also captured in the weed plot. Deer mice were more abundant in the weed patch ($G = 12.320$, $P < 0.001$), whereas the masked shrew was trapped in similar numbers in both the weed and weed-free patch ($G = 0.673$, $P > 0.5$). Mammalian predation was significant in the weed patch ($G = 3.85$, $P < 0.05$) but not in the weed-free patch ($G = 0.77$, $P > 0.5$).

4. Discussion

Over the 3 years of the study, we found that overwintering mortality of adult weevils in young jack pine stands ranged from 76 to 92%. These values are higher than the 15–50% recorded in white pine plantations (Taylor, 1930; Sullivan, 1961; Dixon and Houseweart, 1982). It is possible that our technique overestimated wintering mortality because we were not able to accurately count the number of dead weevils in the cages. Despite precautions, some weevils may have escaped either in the previous fall (before snowfall) or in the spring prior to the funnel being placed over top. The pre-treatment handling of adult weevils (e.g. feeding) or their behavioral response to the metal ring may also have influenced overwintering survival. In contrast, the way in which previous studies were conducted could have led to underestimations. Dixon et al. (1979) placed weevils in outside boxes during the fall, thus preventing them from choosing their own overwintering sites (unlike our study). These authors also returned the boxes to the laboratory in the spring before the snow had melted and weevils could emerge naturally. This would mean that they could not assess spring mortality occurring immediately prior to and during natural emergence. The consistency of our observations on the overwintering mortality of the white pine weevil

over the 3 years of this study, suggests that any bias introduced by the technique we used was similar over the different times and stand conditions. This means that comparisons between the control and exclusion cages (predation) and between treatments are more reliable estimates of weevil mortality than the total overwintering mortality.

Our results showed that factors other than predation were more important in the successful overwintering of adult weevils. Adult mortality appeared inversely related to the depth of the duff (although not statistically significant) and lower adult mortality was observed in the seeded (which also had deeper layers of duff) than in the planted stands. It should be noted however, that abiotic conditions may also influence biotic mortality factors such as predation; e.g. mammalian predation also declines with increasing duff layers (Holling, 1958; Churchfield, 1980). In addition to overwintering mortality, intraspecific competition of weevils and their natural enemies (insect predators and parasitoids) may influence population fluctuations of the white pine weevil (Dixon and Houseweart, 1982). Overwintering populations of adult weevils are unlikely to be affected by intraspecific competition or by insect predators/parasitoids, because the availability of overwintering sites is high and the insects are inactive. This again supports the idea that abiotic factors are the main cause of mortality in overwintering populations of the white pine weevil, although the exact processes are unclear.

The spacing of host trees seems to affect weevil damage in white pine (Wallace and Sullivan, 1985) and sitka spruce (Alfaro and Omule, 1990), where denser plantations sustain lower attack rates than more open plantations. In Norway spruce (*Picea abies*) and jack pine, however, the level of weevil attack seems to be independent of the plantation density (Archambault et al., 1993; Bellocq and Smith, 1994b; respectively). Our results show that the mortality of overwintering weevils was higher in a planted than in a seeded stand. Presumably, low density of trees resulted in a shallow duff layer that favoured a higher weevil mortality in the planted than in the seeded stand (Table 1). Furthermore, mortality from small mammals was significant in the planted stand, where there were more shrews captured than in the seeded stand.

Mammal predation significantly increased the mortality of overwintering adult weevils. We observed 5–13% mortality of weevils by mammals consistently over different years and stand conditions. Although our exclusion cages would have excluded birds as well as small mammals, bird predation is unimportant on overwintering weevils because most insectivorous bird species emigrate during the fall, and those that do not are unable to forage through the snow. Previous attempts to quantify mammalian predation on overwintering weevils have failed to provide clear and consistent results (Taylor, 1929; Dixon and Houseweart, 1982). In hardwood forests, short-tailed shrews and white footed mice were shown to reduce the overwintering survival of acorn weevils (Andersen and Folk, 1993). Taylor (1929) considered mammalian predation of adult white pine weevils to be unimportant because overwintering sites were located in the dense needle zone, making them less accessible to small mammals than more readily available larvae and pupae. Dixon et al. (1979) found that the depth of the dry pine needle zone under host trees in young white pine plantations was 2.2 cm, the moist zone 4.6 cm, and that all weevils overwintered no deeper than 3.5 cm in the duff. We found that the depth of the duff (dry and moist zones) in 4–10 year old jack pine (averaging 3.5 ± 1.9 cm) to be shallower than that in white pine. The literature shows that most species of shrews and some species of mice are able to forage efficiently in these first few centimeters of duff. For instance, the short-tailed shrew preys at depths to 15 cm (Semel and Andersen, 1988), the common shrew (*Sorex araneus*) to a depth of 12 cm (Churchfield, 1980), the masked shrew in shallow sand (Holling, 1958), and the white-footed mouse (*Peromyscus leucopus*) to depths of 3 cm (Semel and Andersen, 1988). Food preference trials under conditions of equal food availability also showed that the white pine weevil was palatable to both the masked shrew and the deer mouse, although beetles were not the preferred food items (Bellocq and Smith, 1994a). This suggests that either of these two species could be predators of overwintering weevils in young jack pine plantations.

Of all the small mammal predators we found in these stands, the masked shrew is that most likely to have an impact on overwintering white pine weevils.

Although not statistically significant, more masked shrews were caught in the planted than the seeded stands and in the weed than the non-weed patches; both situations where significantly higher overwintering weevil mortality was observed. Studies on the microhabitat selection of masked shrews introduced into young jack pine plantations have shown that they prefer areas with dense vegetation cover and leaf litter rather than open areas of bare soil, rocks and sand (Bellocq and Smith, 1995). Shrews are noted for both their high predation rate (Buckner, 1964) and their anatomical and behavioral adaptations for foraging on insects on the ground (Pernetta, 1977). In spring, beetles have been shown to be the preferred prey of the masked shrew in a mid-age stand in the same area as the present study (Bellocq et al., 1992), and generally 10–12% of the spring diet of the masked shrew is composed of beetles in mature jack pine stands (Bellocq et al., 1994).

Small mammal predation on overwintering populations of adult weevils has management implications as this is one of the biotic factors which could be used to manipulate population densities. Our results suggest that approximately 7.6% of the weevil population in tree leaders will survive to become overwintering adults in a seeded stand (Bellocq and Smith, 1995). Hypothetically, if we could increase the predation rate by mammals to 21–23% over winter (up by 10%), then the population of adults emerging the following spring should be reduced to 4.1% (given that no density-dependent factors are operating). By promoting heterogeneous habitats (those of high tree density and competing vegetation) in young jack pine stands, the number of small mammals will increase (especially shrews) and this will lead to higher predation rates on white pine weevils. Additional studies are needed to determine the extent to which this would reduce the level of weevil damage and whether these findings are applicable to all forest management situations.

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