Impact of Predation on the Skewed Distribution of *Ataenius spretulus* (Coleoptera: Scarabaeidae) on Golf Course Fairways and Roughs

ABSTRACT

Ataenius spretulus (Haldeman) is more abundant and causes more damage to golf course fairways than to the roughs. This study focuses on how predation by carabids and staphylinids affects the distribution of *A. spretulus* grubs in the fairway and rough. In initial tests, adults of 6 of the most abundant species of carabids and staphylinids found in turfgrass in Michigan were individually placed into petri dishes with *A. spretulus* eggs or larvae. Consumption of eggs varied from 64 to 100% and consumption of larvae from 14 to 100% depending on the species being tested. Predation of *A. spretulus* larvae was investigated in field plots by introducing *A. spretulus* grubs and recovering them 1 wk later. In 4 separate trials more grubs were recovered from the fairway (65%) than the rough (49%). In a different field study, carabid and staphylinid adults were enhanced or suppressed through the use of directional barriers. *A. spretulus* adults were added to all of the plots at a time when females are expected to deposit eggs. About 8 wk later a similar number of *A. spretulus* larvae was found in both treatments despite a 6-fold difference in the activity of carabid and staphylinid adults. Most carabid and staphylinid adults are capable of consuming *A. spretulus* eggs and larvae. However, field conditions they may not be the most important predators, perhaps because most of their activity is near the turf surface. Although our experiments support that predation is important, more work is needed to determine the relative importance of carabid and staphylinid adults and larvae as predators of *A. spretulus* and other white grubs.

Key words: *Ataenius spretulus*, predators, golf courses.

Introduction

As a native species in North America, *Ataenius spretulus* (Haldeman) is found throughout the continental United States. It is most prevalent in the midwestern and northeastern states. The first damage to turfgrass by *A. spretulus* was reported in Minnesota in 1932 (Hoffman 1935). By 1980, turf damage was reported from at least 12 states (Cartwright 1974, Kawanishi et al. 1974, Weaver and Hacker 1978, Wegner and Niemczyk 1979, Wegner and Niemczyk 1981). Most of the damage caused by *A. spretulus* occurs on golf course fairways (Niemczyk and Dunbar 1976, Vittum 1995, Smitley et al. 1998, Vittum et al. 1999). Damage to home lawns or golf course roughs is very rare.

The importance of generalist predators for regulating populations of insect pests has been investigated in some agricultural systems. Carabid beetles in particular are the most studied predators because of their abundance and obvious predation. Carabids are known to be important predators of aphids in cereal crops (Scheller 1984, Winder 1990), Caterpillars in soybean (Fuller 1988), and fly maggots in onion (Grafius and Warner 1989). Staphylinid beetles are considered the most important predators of dung-inhabiting flies (Roth 1983, Hu and Frank 1997), but little work has been done with staphylinids in turfgrass.

Research on how to alter conditions to support the conservation of natural enemy communities has been conducted in field crop systems. Common agricultural practices such as pesticide applications (Los and Allen 1983, Frampton and Cilgi 1992) and tillage (Andersen 1999, Kromp 1999) reduce carabid beetle abundance. Organic farming (Pfiffner and Niggli 1996, Clark 1999), low-input production systems (Fan et al. 1993) and dense vegetation (Armstrong and McKinlay 1997, Thomas and Marshall 1999) help sustain a high density of beetle predators.

Previous studies about natural enemies in the turfgrass ecosystems provide some evidence for pest regulation by indigenous natural enemies (Cockfield and Potter 1985, Potter 1992). Disruption of natural enemies by insecticides incurs outbreaks of some turf pest insects that have been under control by predators (Cockfield and Potter 1983, Cockfield and Potter 1984, Potter 1993, Terry et al. 1993).

Smitley et al. (1998) in Michigan studied the spatial distribution of natural predators and *A. spretulus* in golf course fairways and roughs. Predacious insects are relatively more active in roughs than in fairways but conversely *A. spretulus* adults are less active in roughs. They suggested that the low density of *A. spretulus* in roughs may be caused by predation and a high incidence of milky disease caused by a *Bacillus* sp. (Smitley et al. 1998, Rothwell and Smitley 1999).

More data are needed to define the relationship between natural predators and *A. spretulus* grubs in golf course fairways and roughs. The objective of this research was to evaluate predation of A. spretulus by carabids and staphylinids in turfgrass. As part of this work we tested individuals of different carabid and staphylinid species to determine their capacity to consume *A. spretulus* eggs and larvae under laboratory conditions.

Materials and Methods

Laboratory Feeding Experiments. The most abundant turf-dwelling staphylinids and carabids were tested as potential predators of *A. spretulus* eggs and grubs. In July 2000, we tested the most frequently captured staphylinids, *Apocellus sphaericollis* (Say), *Philonthus carbonarius* (Grabvenhorst), *Philonthus cognatus* Stephens and immature *Philonthus* sp., and the most abundant carabids, *Amara* *impuncticollis* (Say), *Harpalus affinus* (Schrank) and *Stenolophus ochropezus* (Say). We collected staphylinids and carabids in empty pitfall traps (1.5 cm diameter, 10 cm deep and 32 ml) in turfgrass. The traps were checked every morning and healthy predators were collected for testing. Individual predators were held in separate petri dishes (90 mm diameter, 15 mm height) lined with moist filter paper. They were starved in a growth chamber (dark, 25°C, and 60 % relative humidity) for 24 h.

We used third instars of *A. spretulus* collected at Royal Scot Golf Course, Lansing, MI in July. Six *A. spretulus* grubs were put in each petri dish containing a single predator. The predation on grubs was determined after 24 h in a growth chamber. The experiment was repeated 4-9 times, depending on the number of live predators obtained from pitfall traps.

In the egg predation experiment, corn rootworm eggs (*Diabrotica virgifera virgifera* LeConte) were substituted for *A. spretulus* eggs because *A. spretulus* eggs were difficult to obtain. Corn rootworms eggs were supplied by the Northern Grain Insects Lab, Brookings, SD. A corn rootworm egg is a little smaller than an *A. spretulus* egg (0.7 mm by 0.5 mm). Ten corn rootworm eggs were introduced into each petri dish containing a single predator. Dishes were held in a growth chamber (dark, 25°C, and 60 % relative humidity) and the number of consumed eggs was determined after 24 h.

We also evaluated the efficiency of corn rootworm eggs as a substitute for *A. spretulus* eggs. We conducted a choice test where each predator was exposed to corn rootworm and *A. spretulus* eggs at the same time. On moist filter paper in a petri dish, three corn rootworm eggs and three *A. spretulus* eggs were alternated with each other and equally spaced in a circular pattern. A single predator was released into this petri dish with eggs. After 24 h in a growth chamber, the remaining eggs were counted.

Proportions of consumed eggs were arcsine square root transformed. All statistical analyses were performed using SAS software (SAS Institute 1990). We tested for differences in predation rates between *A. spretulus* eggs and corn rootworm eggs by all carabid species combined, and all staphylinid species combinded using PROC MIXED.

Predation of *A. spretulus* Grubs in the Fairway and Rough. Third instars of *A. spretulus* were used as a prey item to evaluate the activity of predacious insects. *A. spretulus* larvae were collected from Royal Scot Golf Course in July 1999 and 2000. We visually located adult beetles on the surface of greens and picked them by hand. This experiment was conducted in an annual bluegrass (*Poa annua reptans* L.*)* fairway and its adjacent rough at the Hancock Turfgrass Research Center of Michigan State University, East Lansing, MI. The fairway and rough were established in 1995 and have been maintained on a standard program of fertilizer, herbicide and fungicide treatments (Table 1). There was no history of damage by insects or insecticide application.

In 1999, four spots were randomly chosen in one fairway block (18 by 18 m) and additional four spots were chosen in its adjacent rough, 0.8 m from the fairway/rough interface. We pulled a soil column with a standard cup-cutter (10 cm diameter and 10 cm deep) from each spot. The column was wrapped around its side with burlap and put back into the ground. Ten grubs were released on the top of each column and observed until they burrowed into the soil. If individuals failed to burrow within 5 min, they were replaced with new ones. The burlap kept released grubs within the soil column. The released grubs were recovered and counted 7 d later. Three trials were conducted on 7 July, 14 July and 21 July 1999, respectively.

In July 2000, we increased the number of replicates to 6. We randomly chose eleven spots in each of 6 fairway blocks and 6 adjacent rough blocks: five in the fairway, five in the rough, and one control in either fairway or rough. At this time we used plastic cups (6 cm diameter and 70 ml) to contain *A. spretulus* grubs. Each cup was punctured with a pin to allow water drainage. A turf/soil column was cut to fit into the shape of the cup with a knife. The cup containing the turf/soil column was put back into the ground. Five *A. spretulus* grubs were released into each cup. The control cups were covered with fine mesh immediately after *A. spretulus* grubs were introduced to prevent access by surface predators. The cups were recovered 7 d later and examined for surviving grubs.

To meet the assumptions of analysis of ANOVA, the proportion of larvae recovered was arcsine square root transformed before analysis. The mowing height effect was tested using a one-way ANOVA with PROC MIXED.

Predacious Insect Manipulation and *A. spretulus* Grub Infestation. This field study was conducted at the Hancock Turfgrass Research Center. Our experimental area consisted of 6 annual bluegrass fairway blocks and their adjacent rough (18 by 18 m). By changing the mowing pattern in each annual bluegrass block in April 2000, we expanded the rough 1 m inward into the fairway (Fig. 1). This new rough, therefore, has the same irrigation coverage, turf species, soil quality and thatch development as its adjacent fairway. The fairway was mowed three times per wk and the rough one time per wk. The entire area received daily irrigation.

We monitored the activity of predacious insects along the fairway/rough interface with pitfall traps. Eight pitfall traps were arranged within each experimental block: 2 traps in the rough and 2 traps in the fairway, 0.8 m from the interface, and 2 in the rough and 2 in the fairway, 0.2 m from the interface (Fig. 1). The pitfall traps were 1.5 cm-diameter, 10 cm-deep and 32 ml empty glass vials. We monitored pitfall trap captures over a 24 h period, 3-5 times per wk. The pitfall traps were capped when we did not monitor traps or inclement weather was forecasted. We did not count captures from pitfall traps that were flooded by rain or irrigation.

At the fairway/rough interface in each experimental block, two rectangular plots (0.6 by 0.45 m) were installed (Fig. 1). In previous studies of predatory arthropods, ingress and egress boundaries were used to change their density in barley (Chiverton 1986, Chiverton 1987), in corn (Menalled et al. 1999) and in vegetable gardens (Snyder and Wise 1999). We assigned predator-enhanced and predator-suppressed boundaries to our rectangular plots (Fig. 2). The predator-enhanced boundary emulated the ingress boundary (Menalled et al. 1999). Each plot was surrounded by a trench with a 10 cm-deep vertical slope on the outside wall and a 30-degree incline on the inside wall. The vertical slope was lined by 2.5 mm-thick epoxy glass (Fig. 2A). Once turf-inhabiting predators fell into the ingress trench, they could move only into the plot but not back out. Our predator-suppressed plot had a v-shaped trench with an epoxy-glass wall in the middle on the trench to prevent predators form crossing (Fig. 2B). Predators that fell into the v-shaped trench could climb back only to their original side of the plot.

We implanted two pitfall traps inside the barriers in each plot: one in the fairway and one in the rough, 0.2 m from the fairway/rough interface (Fig. 1). Captured predatory insects were counted and identified in the field. Data of predators captured in pitfall traps were converted to the number of predators per pitfall trap per wk. Insects caught in the predator-enhanced plots were returned to the plots but those in the predator-suppressed plots were eliminated from the plots. Insect activity was monitored for ten wk from 28 May to 29 July 2000.

For inoculation of *A. spretulus* to our plots, adult beetles were collected at Royal Scot Golf Course. We released a total of 218 beetles into each plot: 20 beetles on 31 May, 37 on 1 June, 30 on 7 June, 26 on 21 June, and 10 on 22 June. On 31 July, approximately, eight wk after releasing adult beetles, the abundance of *A. spretulus* grubs in the plots was determined. We pulled ten soil cores (10 cm diameter, 10 cm deep) from each plot with a standard golf course cup-cutter: five from the fairway and five from the rough. We broke up the soil samples and counted *A. spretulus* larvae, pupae and immature predators.

Our experiment was designed as a split block model with the location of an 18 by 18-m fairway/rough plots as the block effect. To test whether the density of predators was different at 0.2 m and 0.8 m from the interface, the distance was the split effect, assigned into each mowing height. To test whether the density of predators was different in predator-enhanced compared with predator-suppressed plots, mowing height was the split effect, assigned into each boundary plot.

Count data were square root transformed to make the data distribution more appropriate for analysis of variance (ANOVA). The converted count data were used to test effects of time, mowing height, boundary type and distance by PROC MIXED with a REPEATED measure statement. Multiple comparisons between different levels of the effects were made by a least squares means (LSMEANS) statement.

The relationship between the independent variables (carabid densities, staphylinid density and mowing height) and the dependent variable (abundance of *A. spretulus* grubs) was tested with multiple linear regression statistics in PROC GLM.

Results

Laboratory Feeding Experiments. Two of the most abundant carabid species in our experimental areas (*A. impuncticollis* and *S. ochropezus*) consumed all ten corn rootworm eggs within 24 h in all replicates. They also consumed more than 50% of available *A. spretulus* grubs (Table 2).

A. sphaericollis, the predominant staphylinid species, showed relatively less predation, consuming 57% of the eggs and 14% of the grubs in 24 h. Adult *Philonthus* sp. consumed most of the applied eggs and 54% of the grubs. *P. cognatus* consumed 1.7 times more grubs than *P. carbonarius*, which consumed more eggs than *P. cognatus*. Immature *Philonthus* sp. showed a different predation preference from adult *Philonthus* sp. The immature *Philonthus* sp. fed on a few eggs but actively preyed on all the released grubs in 24 h (Table 2).

In the choice test, carabids consumed nearly equal amounts of *A. spretulus* eggs and corn rootworm eggs while staphylinids consumed more *A. spretulus* eggs than corn rootworm eggs (Table 3). Therefore, corn rootworm eggs were a good substitute for *A. spretulus* eggs in feeding studies. If any bias was introduced through this substitution, it would be to underestimate the amount of staphylinid predation of *A. spretulus* eggs.

Predation of *A. spretulus* Grubs in the Fairway and Rough. In 1999, more *A. spretulus* grubs were recovered from the fairway than the rough ($P < 0.001$). The recovery of grubs was different in different trials. The highest recovery of *A. spretulus* grubs was in the first trial (88% in the fairway and 62% in the rough) and the lowest recovery was found at second trial (63% in the fairway and 49% in the rough).

In 2000, the recovery of grubs was not different in the rough and fairway ($P = 0.40$) (Table 4). When recovery rates in the fairway and rough were compared to recovery in the control, less grubs were recovered in the rough than in the control, while recovery of grubs in the fairway was not different from the control (Table 5). About 8% of the grubs missing from screened control plots may be due to predation from carabid or staphylinid larvae already present in the soil columns, or mortality from unknown causes.

Predacious Insect Manipulation and *A. spretulus* Grub Infestation. Among arthropods caught in our pitfall traps, we counted only potential predators. We collected 1101 predacious insects, representing 4 families: Carabidae, Staphylinidae, Formicidae and Histeridae (Table 6). Formicidae and Histeridae were not captured frequently, comprising 1% and 0.5% of total insects, respectively. The most abundant predators caught by pitfall trap were Carabidae (44%) and Staphylinidae (38%). Two species of carabids, *A. impuncticollis* and *S. ochropezus*, accounted for 75% of all carabids captured. *A. sphaericollis* and *Philonthus* sp. were the most abundant staphylinid species, comprising 96% of all staphylinids captured.

Adult carabids and staphylinids were active at different times of the season (Table 7). When their captures in May, June, and July were compared using an ESTIMATE statement of SAS MIXED, carabids were most active in May and June, while staphylinids were most active in May and July (Figs. 3,4,5 and 6).

In control plots, the numbers of adult predators caught in the fairway and rough were not different between 0.2 m and 0.8 m from the fairway/rough interface ($P = 0.62$). The density of staphylinid adults was different in the fairway and rough. More adult staphylinids were caught in the rough than in the fairway, while carabids did not show any difference between the fairway and rough (Table 7).

In predator-enhanced and predator-suppressed plots, captures of adult predators were different depending on the different types of boundaries (Tables 7 and 8). Predators did not increase in the plots having predator-enhanced boundaries compared with control plots. Predator-suppressed boundaries decreased the captures of predators by 4-fold compared with control plots. No difference was found in the densities of carabids adults ($P = 0.57$) and staphylinid adults ($P = 0.33$) in the fairway and rough within predator-enhanced and predator-suppressed plots. The interaction between the boundary and mowing height effect on the carabid density was significant ($P < 0.01$). Because of this, the interaction effect was analyzed depending on the boundary types, using a SLICE option of PROC MIXED of SAS. The interaction was significant in predator-enhanced plots ($P < 0.05$) but was not significant in predator-suppressed plots ($P = 0.14$). This suggested that the carabid density was greater in the fairway than in the rough of predator-enhanced plots. An average of 6 immature predators was isolated per 0.1 m^2. Their abundance was not different in the fairway and rough ($P = 0.32$) or in predator-enhanced and predator-suppressed plots ($P = 0.62$) (Tables 7 and 8).

Releasing *A. spretulus* adult beetles was a successful way to infest plots with *A. spretulus* grubs. At the end of experiment we found the average of 85 *A. spretulus* grubs per 0.1 m^2. There was no difference in the numbers of grubs found in predator-enhanced compared with predator-suppressed plots ($P = 0.85$) and a marginal difference in the fairway and rough ($P = 0.06$). In predator-suppressed plots, more grubs were found in the fairway than in the rough (Tables 7 and 8).

With multiple linear regression analysis, we determined how the numbers of adult carabids and staphylinids, and mowing height were related to the number of *A. spretulus* grubs in predator-enhanced and predator-suppressed plots (Table 9). The density of staphylinid adults was positively related with grub density while the adult carabid density was negatively correlated to the grub density.

Discussion

Laboratory Feeding Tests. Little is known of the feeding habits of staphylinids and carabids inhabiting turfgrass because actual observation of predation on grubs or eggs under field conditions is difficult. Staphylinids and carabids were shown to be beneficial predators of pest insects in previous laboratory feeding tests. Adults and larvae of dung-inhabiting *Philonthus* sp. contribute to the control of horn fly eggs and larvae in northern Florida (Roth 1983, Hu and Frank 1997). Some *Philonthus* sp. collected in turfgrass in KY also prey on 24% of 10 Japanese beetle (*Popillia japonica* Newman) eggs and 47% of 10 first instars of Japanese beetle in 48 h. In the same experiment, an *Amara* sp. ate up to 77% of 10 Japanese beetle eggs in 48h (Terry et al. 1993).

The most abundant staphylinid species at our research site in MI, *A. sphaericollis*, is reported to be a scavenger, feeding on humus and decaying vegetation (Chittenden 1915). Thus, it did not feed *A. spretulus* grubs in our laboratory tests. However, it consumed up to 50% of the available *A. spretulus* eggs in 24 h. *P. carbonarius* and *P. cognatus*, our second and third most abundant staphylinid species, both consumed *A. spretulus* eggs and grubs. In petri dishes, *Philonthus* larvae were voracious predators of *A. spretulus* grubs. They preyed on all the available grubs in our tests. More field research is needed to determine their role in grub predation.

Our feeding tests clearly demonstrated that adults of the most abundant carabids and *Philonthus* sp. found in turfgrass are capable of feeding on *A. spretulus* eggs and grubs. Furthermore, *Philonthus* sp. larvae were more efficient predators of *A. spretulus* grubs than any other predator except adult *H. affinus*. However, adult *A. sphaericollis*, the most abundant staphylinids species, was only a moderate egg-feeder and did not feed on *A. spretulus* grubs.

Predation of *A. spretulus* Grubs in the Fairway and Rough. Grub predation in turfgrass has received little attention so far. Most of the previous experiments have focused on surface predation. In these tests, predators consumed up to 75% of 5 sod webworm (*Crambus* and *Pediasia* sp.) eggs, 73% of 10 Japanese beetle eggs and 27-53% of 10 fall armyworm (*Spodoptera frugiperda* (J. E. Smith)) pupae in 48 h of exposure on the soil surface in Kentucky bluegrass (*Poa pratensis* L.) (Cockfield and Potter 1984) (Terry et al. 1993).

In our experiments, the actual missing rate of *A. spretulus* grubs in the fairway and rough was 16-26% in 7 d if missing rates in the fairway and rough were subtracted by missing rates in controls. Compared to the immobile eggs or pupae used in previous tests, relatively less predation of grubs in our experiment may be due to the habitation of grubs in the soil and the fact that they were healthy and unrestrained.

Overall, more *A. spretulus* grubs disappeared in the rough than in the fairway. The density of staphylinid adults was much higher in the rough compared with the fairway in our experimental areas, but we only assume that the density of staphylinid larvae were also greater in the rough because we could not sample them effectively. The difference in predation rates may have been caused by the distribution of predators in the rough and fairway (Smitley et al. 1998, Rothwell and Smitley 1999).

Predacious Insect Manipulation and *A. spretulus* Grub Infestation. In Kentucky bluegrass lawns in KY, centipedegrass turf in GA and golf courses in MI, ants are the most abundant surface insects. Staphylinids and carabids account for over 90% of the total number of predacious insects other than Formicidae (Cockfield and Potter 1985, Braman and Pendley 1993, Smitley et al. 1998). Most of the staphylinids in Kentucky bluegrass in KY are less than 5 mm long(Arnold and Potter 1987). *A. sphaericollis* is the most abundant staphylinid in centipedegrass (*Eremochloa ophuiroides* (Munro.) Hack) in GA (Braman and Pendley 1993). Most of the staphylinids found in perennial ryegrass (*Lolium perenne* L.) fairways and roughs in MI are *Philonthus* sp. and the most common carabids are species of *Bembidion, Amara* and *Stenolophus* (Rothwell and Smitley 1999). The community of predacious insects in our experimental areas at the Hancock Turfgrass Research Center, MI was similar to that described in previous studies, with the exception that ants were not abundant. Ants comprised only 1% of total collected predacious insects in our experimental areas while 46% of all predacious insects were ants on golf courses in MI (Smitley et al. 1998).

Coincidence in time with *A. spretulus* is important for potential predators to become efficient control agents. In MI, *A. spretulus* adult beetles appear on turfgrass in early May and lay eggs in the thatch and soil from late May to early July. Eggs hatch and grubs grow under turfgrass until late July or early August (Smitley et al. 1998, Vittum et al. 1999). The most vulnerable period of *A. spretulus* for predation may be from late May to late July when it is in the egg or the immature life stages.

Seasonal activities of adult staphylinids and adult carabids were monitored in this experiment. The greater activity of adult carabids was concurrent with the eggs and grubs of *A. spretulus*, allowing the potential for predation. Also, the most abundant carabids, *A. impucticollis* and *S. ochropezus*, consumed *A. spretulus* eggs and grubs in petri dish tests. According to the fluctuation of adult staphylinid activity in our experiment over time, they may have less impact on the survival of *A. spretulus* eggs and grubs in May and July. However, we do not know when carabid and staphylinid larvae are the most active.

In previous research, mowing practices are suggested as a potential factor affecting the spatial distribution of adult predacious insects in golf course fairways and roughs. When crossing from rough into fairway, the numbers of staphylinids and in some case the numbers of carabids dropped 3-fold within a distance of 1 m from the fairway/rough border (Smitley et al. 1998). In our control plots, we found 1.5-fold more adult staphylinids were trapped in the rough than in the fairway, but the activity of adult carabids remained similar throughout.

The v-shaped boundary in predator-suppressed plots decreased predator activity as we proposed. Compared to the control plots, 4-fold less carabid adults and 10-fold less staphylinid adults occurred in the predator-suppressed plots. In predator-enhanced plots, the numbers of carabids and staphylinids were not different from those in control plots. In predator-enhanced plots, carabid catches were 65% greater in the fairway than in the rough. This indicates that carabids are either more active or denser in the fairway.

Our experiment was conducted using new roughs that have the same soil conditions as the adjacent fairways. Only mowing practices from April to August 2000 were altered to create the rough from the fairway. We, thus, eliminated all soil conditions, except perhaps soil moisture, which varies depending on the extent of root and mowing height. Two-fold more *A. spretulus* grubs were found in the fairway than in the rough of predator-suppressed plots, while similar numbers of grubs were found in the fairway and rough of predator-enhanced plots. Female ovipositional preference and different predation rates in the fairway and rough may explain this distribution of *A. spretulus* grubs in predator-enhanced and predator-suppressed plots. *A. spretulus* females may have preferred the fairway for their oviposition. Site suitability for scarab beetles is influenced by soil moisture (Potter 1983, Allsopp et al. 1992). Although we did not collect soil moisture data, it is possible that moisture levels were higher in the fairway because fairway turf has a much reduced root system compared with rough turf (Madison and Hagan 1962, Morhard and Schulz 1998). The fairway may be attractive to female *A. spretulus* for other unknown reasons.

Predator activity may explain the similar numbers of grubs found in the fairway and rough of predator-enhanced plots. If *A. spretulus* females prefer the fairway to oviposit, it is expected that grub density would be greater in the fairway of predator-suppressed plots. In the predator-enhanced plots, carabids were more active on the fairway side, which may cover-up the effect of *A. spretulus* ovipositional preference. Thus, their predation may prevent the overpopulation of *A. spretulus* grubs in the fairway of predator-enhanced plots.

With the multiple linear regression analysis, the number of grubs is adversely affected by adult carabid density, according to the negative slope of its parameter. However, the positive parameter of adult staphylinid density implies that adult staphylinids may not be effective predators of *A. spretulus*. The predominant staphylinid species in our experimental areas, *A. sphaericollis,* is a scavenger, feeding on plant materials (Chittenden 1915), and it was the least likely to feed on *A. spretulus* grubs. We used this multiple linear regression model only to evaluate the positive or negative relationship to grub density because this was a weak model. Additional factors may be needed to supplement this model.

The density of carabid and staphylinid larvae may be more important for explaining the density of grubs than adult predators, because we saw little difference in *A. spretulus* grubs between predator-enhanced and predator-suppressed plots. In our experimental plots, we did not detect any difference in the density of immature predators between predator-enhanced and predator-suppressed plots or between fairway and rough sides. This may be caused from the density of carabid and staphylinid larvae, which depends on the density of adults in the previous year. Turf conditions in our plots were uniform in the year previous to our experiment. The density of predator larvae in predator-suppressed plots may be less than in predator-enhanced plots in 2001, according to the density of adult predators in 2000. Sampling from our plots in 2001 will test this hypothesis. Similar results were observed in previous research. *A. spretulus* grub infestation levels were not different in the new fairway and rough in the first year after altering the fairway/rough border of a golf course in MI, but changed significantly in the second year after alteration (Rothwell and Smitley 1999).

Our research raised a question about the damage threshold for *A. spretulus* grubs. An economic threshold for *A. spretulus* grubs has not been determined but levels as low as 30 grubs per 0.1 m^2 have been suggested (Vittum et al. 1999). In annual bluegrass roughs of our plots we found from 3 to 178 *A. spretulus* grubs per 0.1 m^2 but none of the roughs had turf damage. Five of our annual bluegrass fairways of our plots contained more than 100 grubs per 0.1 m^2. Two of them showed slight discoloration and dead spots. Damage to turf is determined by the vigor of the turf and by the population density of *A. spretulus* grubs. Our data suggest that turfgrass in the rough may be more tolerant of grub injury than fairway turf and that more than 100 *A. spretulus* grubs per 0.1 m^2 are necessary to cause significant turf damage in healthy annual bluegrass fairways. Our observations agree with the previous study by Vittum(1995), where heat-stressed and closely mowed bentgrass (*Agrostis* sp.) did not support 20 *A. spretulus* grubs per 0.1 m^2 while up to 250 grubs per 0.1 m^2 thrived in the same species of grass under moderate conditions without visible symptoms.

In previous studies, *A. spretulus* grubs were found to be 3 to 10-fold more abundant in golf course fairways than roughs. At the same time, staphylinids and carabids were much more abundant in the rough, suggesting that predation was greater in the rough. Our study showed that adults of the most abundant species of carabids and staphylinids found in turfgrass are capable of consuming *A. spretulus* eggs and gurbs. We also discovered that staphylinid larvae collected from turfgrass prey on *A. spretulus* grubs. When *A. spretulus* grubs were released into the fairway and rough, more grubs survived in the fairway than in the rough. These experiments provide additional evidence that predation is important for keeping *A. spretulus* grubs under control in golf course fairways and that lack of predation contributes to outbreaks of *A. spretulus* grubs in fairways.

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Figure Captions

Fig. 1. Experimental block (18 by 18 m) of annual bluegrass fairway and its adjacent rough at the Hancock Turfgrass Research Center, MI.

Fig. 2. Vertical cross-section of two types of boundaries around our plots. The 30°-boundary for a predator-enhanced plot (A) allowed predators to immigrate. The v-shape boundary for a predator-suppressed plot (B) interfered with the movement of predators.

Fig. 3. Seasonal captures of Carabidae per pitfall trap per wk in the fairway and rough of control plots at the Hancock Turfgrass Research Center, MI, 2000.

Fig. 4. Seasonal captures of Staphylinidae per pitfall trap per wk in the fairway and rough of control plots at the Hancock Turfgrass Research Center, MI, 2000.

Fig. 5. Seasonal captures of Carabidae per pitfall trap per wk in the fairway and rough of predator-enhanced and predator-suppressed plots at the Hancock Turfgrass Research Center, MI, 2000.

Fig. 6. Seasonal captures of Staphylinidae per pitfall trap per wk in the fairway and rough of predator-enhanced and predator-suppressed plots at the Hancock Turfgrass Research Center, MI, 2000.

Table 1. Schedule of fertilizer, herbicide and fungicide treatments applied to the annual bluegrass fairway and adjacent rough at the Hancock Turfgrass Research Center, 2000.

Application date	Treatment	Rate (kg/ha)	Targets
11 May	fluazifop-P-butyl	1.8	annual grasses
17 May	nitrogen	48.8	
31 May	fluazifop-P-butyl	1.8	annual grasses
1 June	chlorothalonil	4.6	dollar spot
14 June	chlorothalonil	4.6	dollar spot
26 June	nitrogen	48.8	
27 June	chlorothalonil	4.6	dollar spot
6 July	chlorothalonil	4.6	dollar spot
20 July	iprodion	9.2	dollar spot
27 July	nitrogen	48.8	
2 Aug	iprodion	9.2	dollar spot

Table 2. Consumption of corn rootworm eggs and third instar *A. spretulus* by staphylinids and carabids found in turfgrass at the Hancock Turfgrass Research Center.

Predacious insects	Predation of eggs[a]		Predation of grubs[b]	
	n	Mean ± SE (%)	n	Mean ± SE (%)
Carabidae				
Amara impucticollis (Say)	18	100 ± 0.0	8	50.0 ± 11.4
Harpalus affinus (Schrank)	7	64.3 ± 18.0	4	100 ± 0.0
Stenolophus ochropezus (Say)	14	100 ± 0.0	6	55.6 ± 11.1
Staphylinidae				
Apocellus sphaericollis (Say)	15	56.7 ± 5.7	6	13.9 ± 8.0
Philonthus carbonarius (Gravenhorst)	15	98.7 ± 1.3	6	38.9 ± 10.2
Philonthus cognatus Stephens	18	77.8 ± 7.3	9	66.7 ± 7.3
Immature *Philonthus* sp.	2	15.0 ± 5.0	4	100 ± 0.0
Control	15	0.0 ± 0.0	6	8.0 ± 5.5

[a]Proportions consumed out of 10 corn rootworm eggs.

[b]Proportions consumed out of 6 *A. spretulus* grubs.

Table 3. Suitability of corn rootworm eggs compared with *A. spretulus* eggs for consumption by staphylinids and carabids found in turfgrass at the Hancock Turfgrass Research Center.

Predacious insect	n	*A. spretulus* eggs	Corn rootworm eggs	*P*[a]
		Mean ± SE (%)	Mean ± SE (%)	
Carabidae				
Amara impucticollis (Say)	2	100 ± 0.0	100 ± 0.0	—
Harpalus affinus (Schrank)	1	100	33.3	—
Stenolophus ochropezus (Say)	2	100 ± 0.0	100 ± 0.0	—
All Carabidae	5	100 ± 0.0	86.7 ± 13.3	0.35
Staphylinidae				
Apocellus sphaericollis (Say)	4	83.3 ± 16.7	58.3 ± 8.3	—
Philonthus carbonarius (Gravenhorst)	2	100 ± 0.0	66.7 ± 33.3	—
Philonthus cognatus Stephens	1	100.0	33.3	—
All Staphylinidae	7	90.5 ± 9.5	61.9 ± 8.7	0.02*
Control	2	0.0 ± 0.0	0.0 ± 0.0	—

[a]*P*-value followed by one asterisk means the predation rate is significantly different between *A. spretulus* eggs and corn rootworm eggs at the 5% level.

Table 4. Recovery of *A. spretulus* grubs in fairway and rough soil columns one wk after grubs were released at the Hancock Turfgrass Research Center.

Date	n	Grubs recovered (%)		P^a
		Fairway	Rough	
7-14 July 1999[b]	4	87.5 ± 7.5	62.5 ± 7.5	0.0022**
14-21July 1999[b]	4	63.2 ± 4.4	49.2 ± 4.4	0.21
21-28 July 1999[b]	4	77.7 ± 4.1	58.6 ± 1.8	0.07
20-27 July 2000[c]	6	71.3 ± 11.7	54.3 ± 9.7	0.40

[a]*P*-value followed by two asterisks means the grub recovery is significantly different between the fairway and rough at the 1% level.

[b]Conducted in one 18 by 18 m annual bluegrass fairway and its adjacent rough. A soil column was 10 cm diameter and 10 cm deep.

[c]Conducted in six 18 by 18 m annual bluegrass fairways and their adjacent roughs. A soil column was 6 cm diameter and 3 cm deep.

Table 5. Proportion of *A. spretulus* grubs recovered 7 d after grubs were released at the Hancock Turfgrass Research Center, 2000.

Treatment	n	*A. spretulus* grubs recovered (%)
Fairway	6	71.3 $\pm$ 11.7ab
Rough	6	54.3 $\pm$ 9.7a
[a]Control	6	91.9 $\pm$ 8.1b

Means $\pm$ SE within a column followed by the same letter are not significantly different (P = 0.05; LSMEANS statement in SAS MIXED).

[a]Control plots which prevented surface predators from accessing *A. spretulus* grubs.

Table 6. Predacious insects in our experimental plots.

Taxa	n[a]	Relative abundance (%)
Carabidae		
Amara impuncticollis (Say)	304	27.6
Stenolophus ochropezus (Say)	140	12.7
Harpalus affinus (Schrank)	37	3.4
Stenolophus comma (Fabricius)	23	2.1
Anisodactylus sanctaecrucis (Fabricius)	10	0.9
Acupalpus partiarius Say	7	0.6
Other species	77	6.7
Staphylinidae		
Apocellus sphaericollis (Say)	255	23.2
Philonthus cognatus Stephens	69	6.3
Philonthus carbonarius (Gravenhorst)	55	5.0
Immature *Philonthus* sp.	36	3.3
Other species	19	1.7
Formicidae	61	1.0
Histeridae	11	0.5

[a] Total captures in pitfall traps at the Hancock Turfgrass Research Center from 21 May to 29 July 2000.

Table 7. Statistics (*P*-value) testing the effects of block, time, boundary type and mowing height on the density of insects in predator-enhanced and predator-suppressed plots at the Hancock Turfgrass Research Center, 2000.

Source of variation	Adult carabids	Adult staphylinids	Immature predators[a]	*A. spretulus* grubs[a]
Block	0.75	0.48	0.22	0.31
Time	0.0004**	0.0001**	—	—
Boundary	0.0006**	0.0043**	0.62	0.85
Mowing height	0.57	0.33	0.32	0.06
Time X Boundary	0.03*	0.0001**	—	—
Time X Mowing height	0.21	0.06	—	—
Boundary X Mowing height	0.008**	0.35	0.28	0.14
Time X Boundary X Mowing height	0.17	0.32	—	—

P-values followed by one or two asterisks are significant at the 5% or 1% level, respectively.

[a]No time effect because of only one observational data on 31 July 2000.

Table 8. Predators and *A. spretulus* grubs recovered from our research areas where the number of adult staphylinids and carabids were manipulated with different boundary types in the fairway and rough at the Hancock Turfgrass Research Center, 2000.

Insects	Predator-enhanced plot		No-boundary control plot		Predator-suppressed plot	
	Fairway	Rough	Fairway	Rough	Fairway	Rough
Adult carabids[a]	4.1 ± 0.6a	2.5 ± 0.3b	2.5 ± 0.3b	2.2 ± 0.3b	0.3 ± 0.1c	0.9 ± 0.2c
Adult staphylinids[a]	1.5 ± 0.3a	1.7 ± 0.2a	1.6 ± 0.3a	2.4 ± 0.3b	0.2 ± 0.1c	0.2 ± 0.1c
Immature predators[b]	0.4 ± 0.1a	0.6 ± 0.2a	—	—	0.5 ± 0.3a	0.5 ± 0.3a
A. spretulus grubs[b]	6.7 ± 2.0ab	6.4 ± 2.2ab	—	—	9.8 ± 3.0a	3.7 ± 0.8b

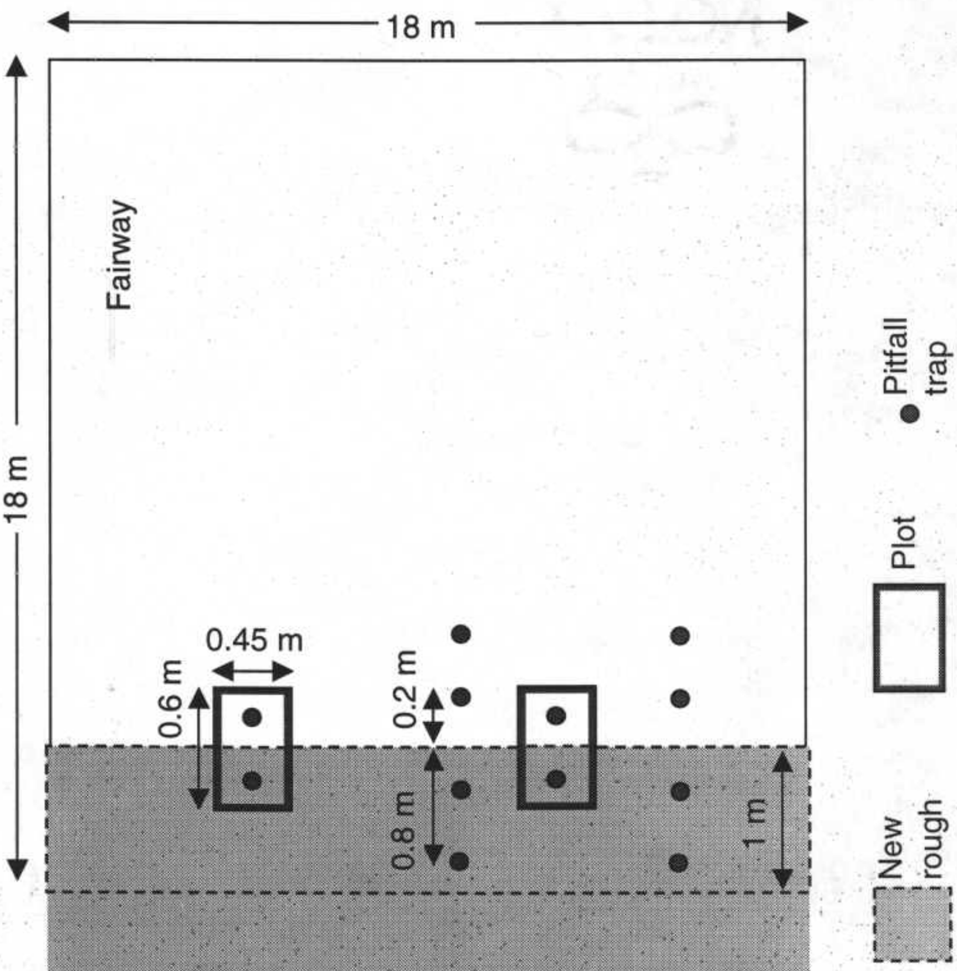
Means ± SE within a row followed by the same letter are not significantly different (P = 0.05; LSMEANS statement in SAS MIXED).

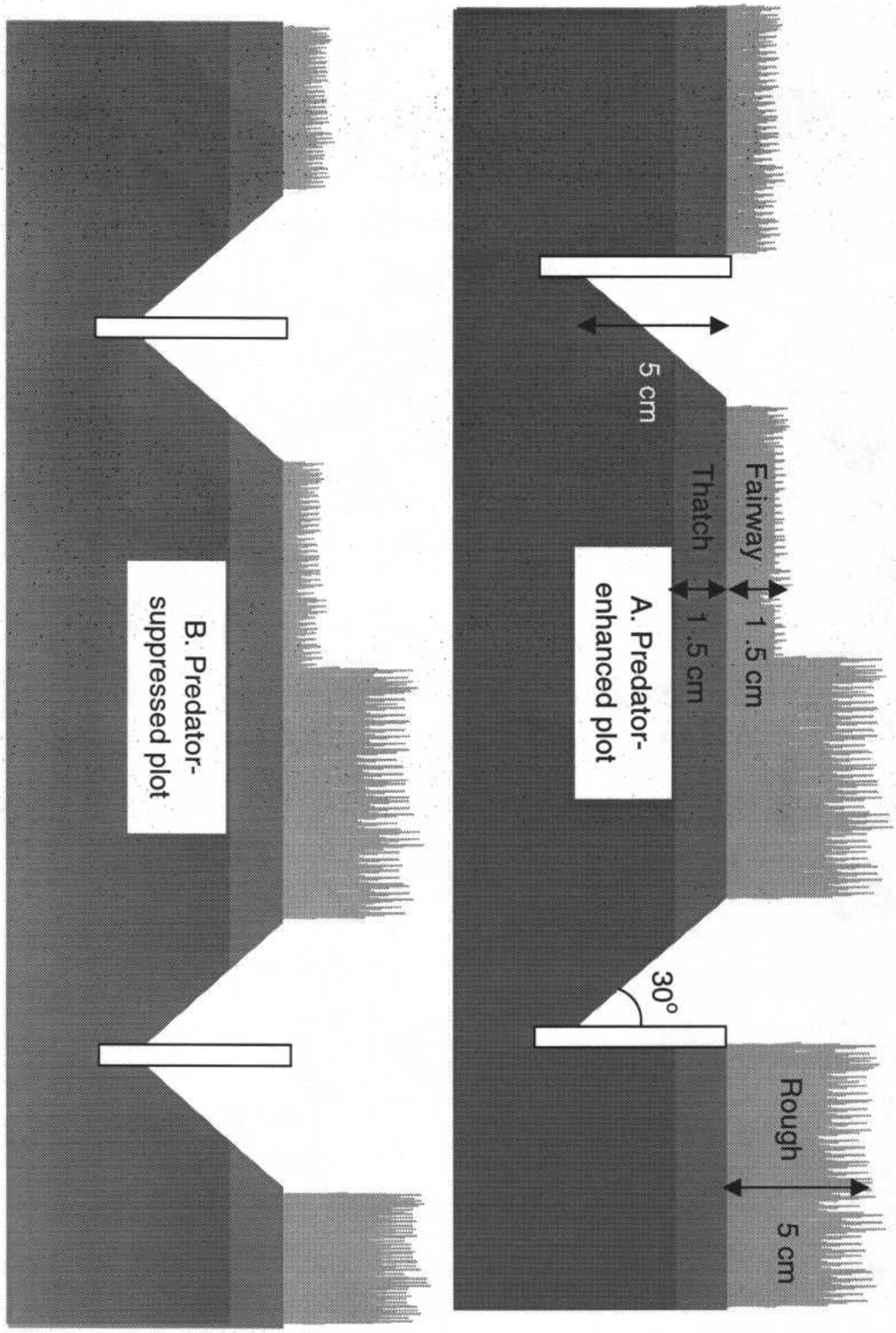
[a] Captures per pitfall trap per wk.

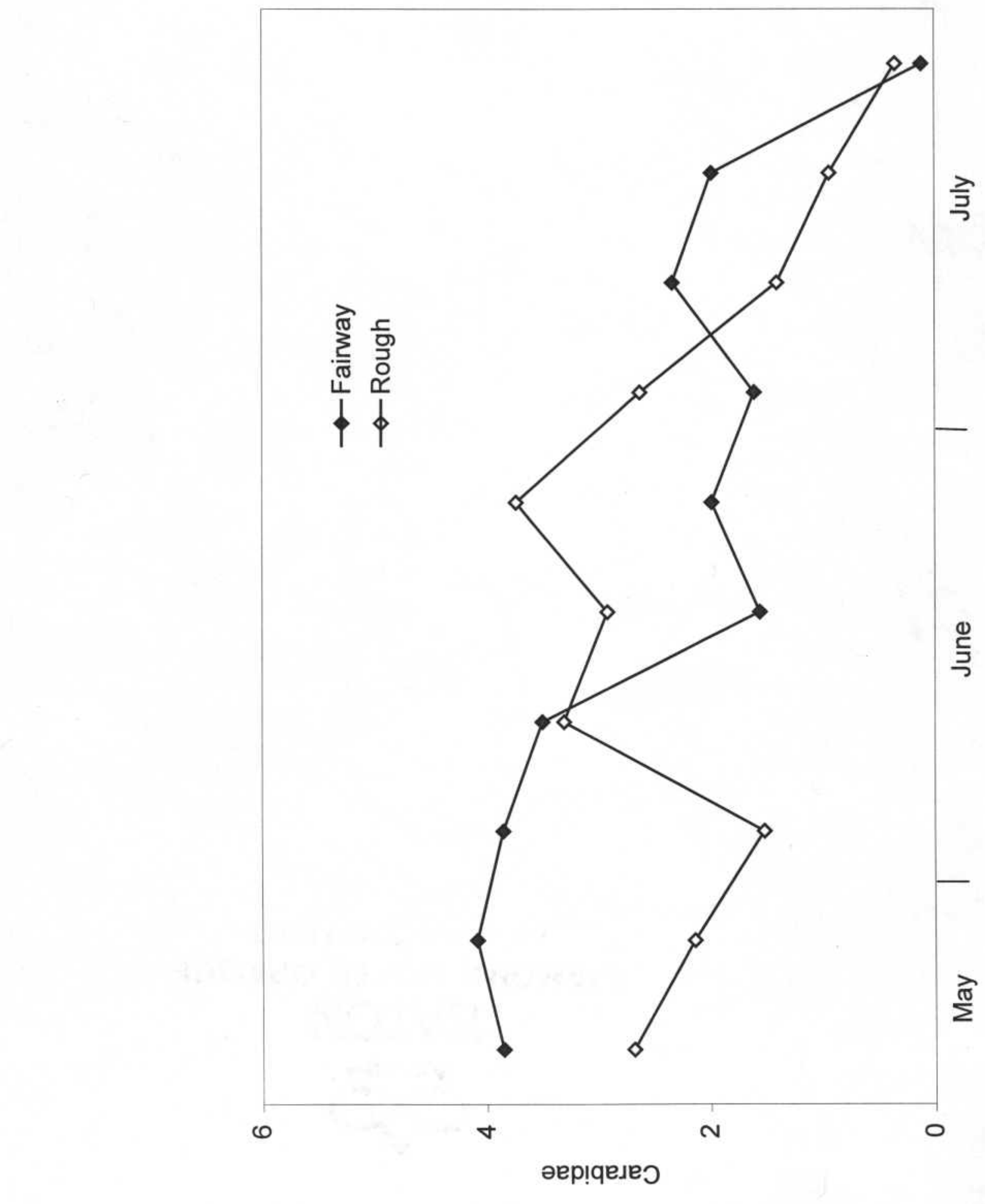
[b] Numbers per 10 cm-diameter and 10 cm-deep soil column.

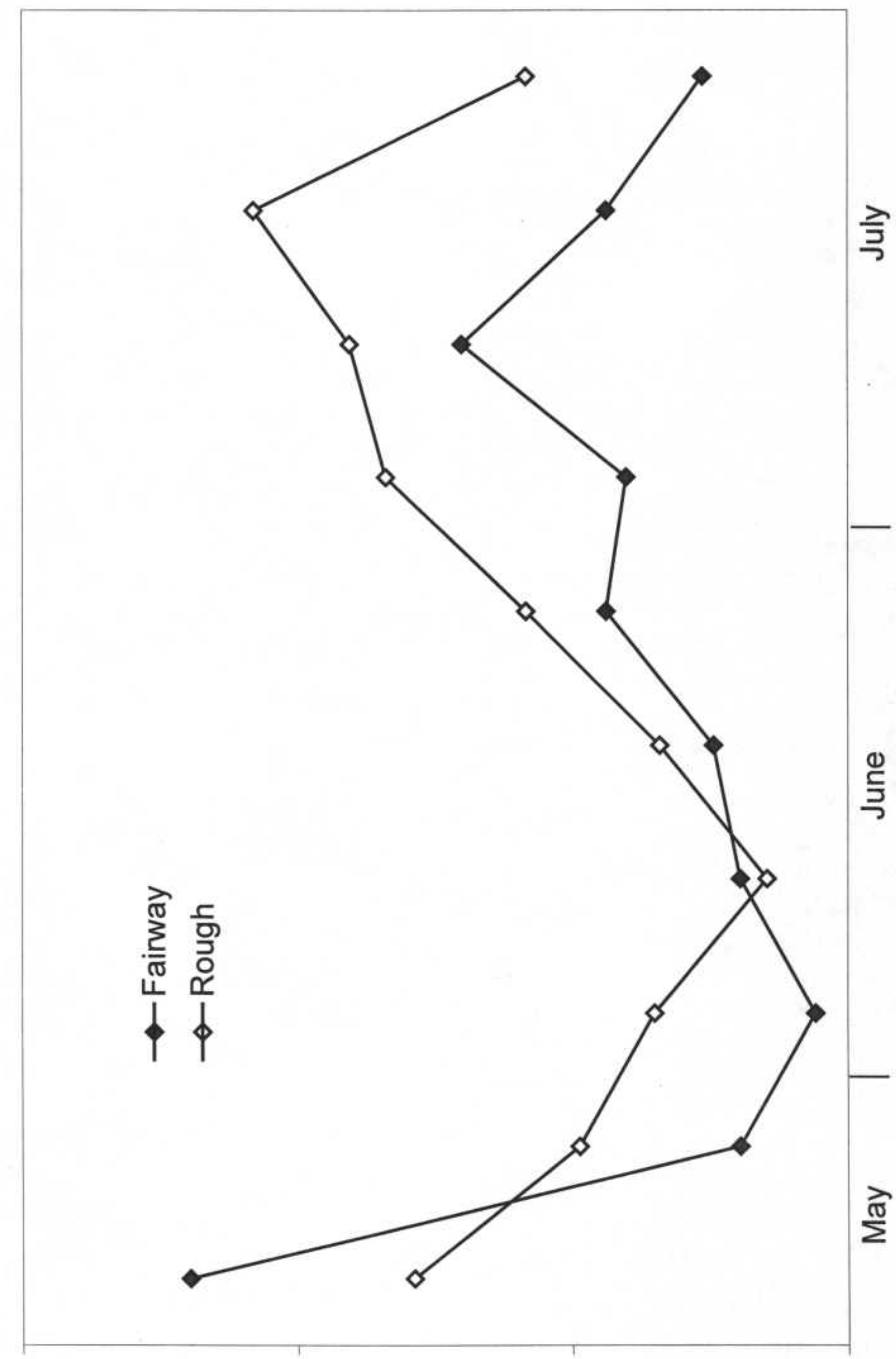
Table 9. Parameters of a multiple linear regression model with the independent variables (mowing height, adult carabid and adult staphylinid) and the dependant variable (*A. spretulus* grub). For this linear model, r^2 = 0.32, n = 24, F = 3.14 and P = 0.048.

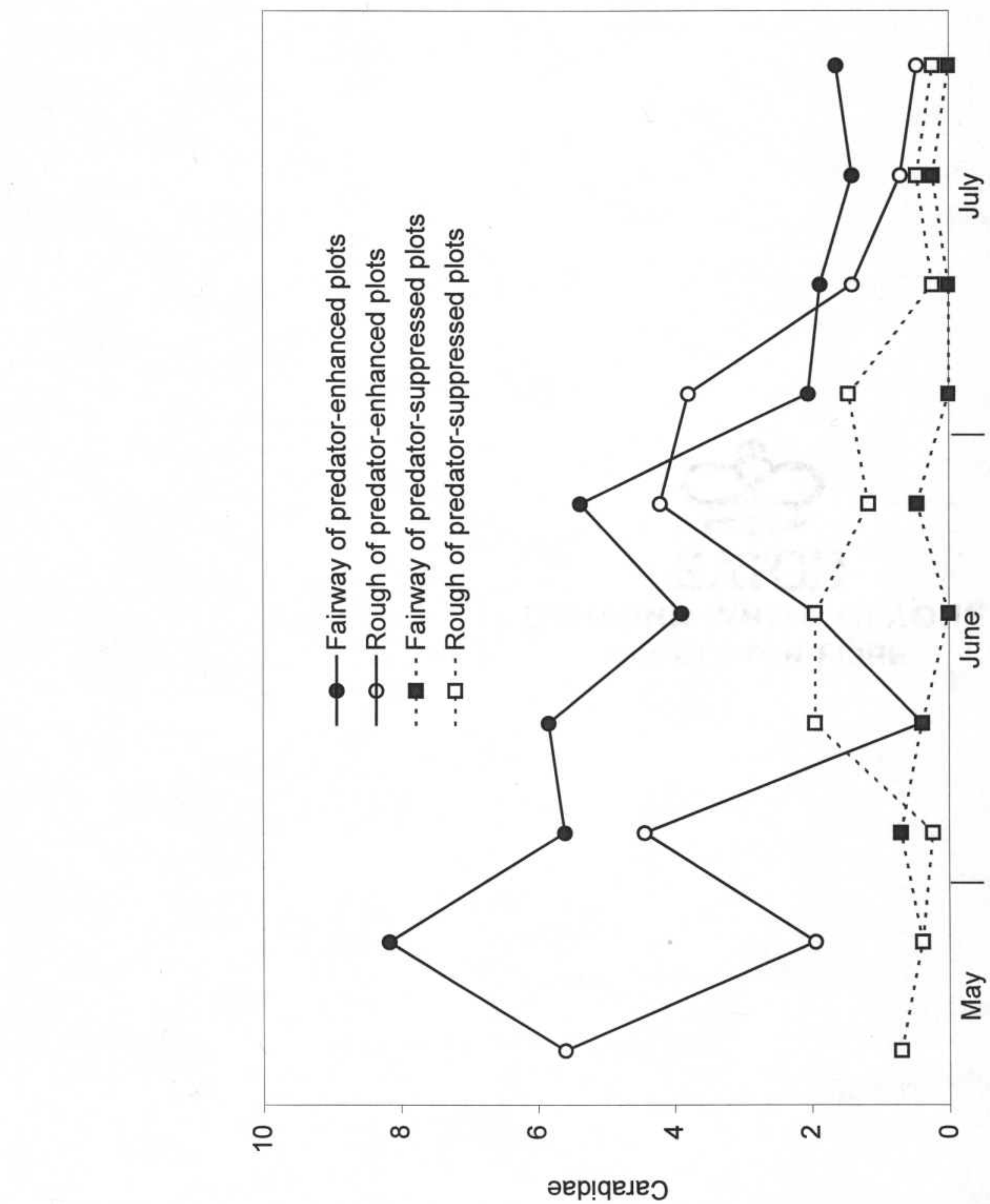
Parameter	Estimate	P for estimates
Intercept	2.00	0.0001
Mowing height	0.77	0.056
Adult carabid	-1.09	0.044
Adult staphylinid	1.68	0.018

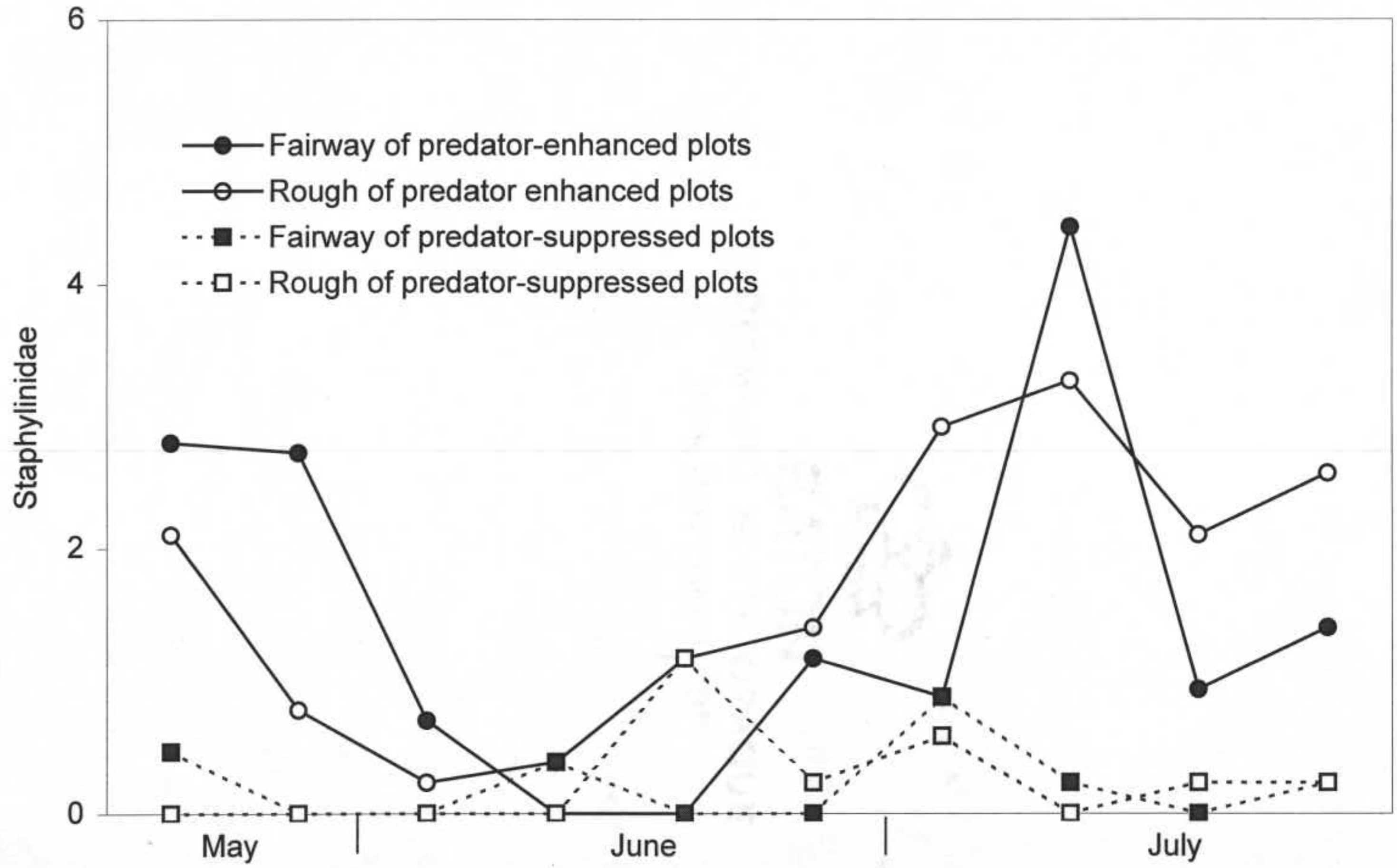

18 m
18 m
Fairway
Rough
0.45 m
0.6 m
0.2 m
0.8 m
1 m
New rough
Plot
Pitfall trap


Fairway
Thatch
1 .5 cm
1 .5 cm
5 cm
A. Predator-
enhanced plot
30°
Rough
5 cm
B. Predator-
suppressed plot


Fairway
Rough
Carabidae
6
4
2
0
May
June
July


Fairway
Rough
May
June
July
Staphylinidae
0
2
4
6


Carabidae
0
2
4
6
8
10
May
June
July
Fairway of predator-enhanced plots
Rough of predator-enhanced plots
Fairway of predator-suppressed plots
Rough of predator-suppressed plots


Fairway of predator-enhanced plots
Rough of predator enhanced plots
Fairway of predator-suppressed plots
Rough of predator-suppressed plots
Staphylinidae
0
2
4
6
May
June
July