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EXAMINATION OF THE ARTHROPOD COMMUNITY ON A GOLF COURSE FAIRWAY AND ROUGH

By

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ABSTRACT

EXAMINATION OF THE ARTHROPOD COMMUNITY STRUCTURE ON A GOLF COURSE FAIRWAY AND ROUGH

By

Breana Lee Simmons

The arthropod community structure was studied in the fairway and rough on the eighth hole at Groesbeck Golf Course in Lansing, Michigan. Pitfall traps (32ml) were used to study surface arthropod activity. Tullgren-type funnels were used for heat extraction of soil samples in order to determine the abundance and distribution of soil-dwelling arthropods on a golf course fairway and rough. In both 1999 and 2000, Staphylinid adults were 3-fold more active in the rough compared with the fairway. Collembola and Acari were also 2 to 3-fold more abundant in the rough compared with the fairway in both years($P<0.05$). Carabidae were significantly but only slightly more active in the rough in 1999, and significantly but only slightly more active in the fairway in 2000. Activity of Formicidae was greater in the fairway than in the rough, in both 1999 and 2000. The number of all species recovered decreased in 2000 compared with 1999. High levels of Collembola and Acari in the rough compared with the fairway may create a food chain for supporting more generalist predators such as Staphylinidae, in the rough.

For mom, dad, andy and steph, thanks.

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LITERATURE REVIEW

Grasses cover a larger portion of the world's land surface than any other vegetation type (Tscharntke and Greiler 1995). The grasses, *Gramineae,* appeared in the fossil record during the late Cretaceous period, evolving with grazing mammals (Beard 1973). Temperate grasslands are dominated by insect herbivores and tropical grasslands are dominated by large ungulate herbivores (Tscharntke and Greiler 1995). It can be inferred that since grasses are adapted to grazing by herbivores, and compensate for herbivory with rapid regrowth, then they also tolerate being mowed. Young plants are usually more nutritious for herbivores, but may actually deter certain insects due to high concentrations of secondary compounds (Tscharntke 1988). Most grasses, however, are simply structured and do not have toxic defenses; therefore they do not deter herbivory (Bernays 1990, Bernays and Barbehenn 1987).

Lawns and golf course turf is similar in many ways to native grasslands. Turfgrasses are herbaceous plants that can be annual or perennial. There are 40 species of turfgrasses in the Poaceae family that are utilized for various purposes throughout the world (Vittum et al. 1999). While turf is considered mainly ornamental or recreational, it is also of economic importance, not only for control of wind and water erosion of soil, but also for climate control. Turfs reduce glare, noise, air pollution, and heat buildup in urban areas (Beard 1973). For recreational purposes, well maintained turf is not only aesthetically pleasing, but in many cases it is necessary for functional purposes, such as tight, short grass for putting. Turfgrass health and performance is essential to the recreation industry as well as to homeowners and landscapers.

Contrary to popular opinion, grasses harbor the heterogeneity necessary for the evolution of a diverse insect community (Tscharntke and Greiler 1995). While studies have shown that sown seed, such as that found on a golf course, will not sustain the large and diverse populations of insects that are found in natural grasses (Harper 1977), the diversity of insect species found in monoculctures of cereal or fodder grasses is surprisingly high (Altieri 1991). Root feeders and other soil invertebrates are usually more abundant on grazed or mowed grasses than ungrazed or unmowed grasses (Grieler and Tscharntke 1993). Damage caused by root feeders may increase the abundance of foliar feeders due to the increased vulnerability of the plant (Masters et al. 1993). Long grasses support more predacious and saprophagous beetle families than does mowed grass. Mowing reduces seed and foliage feeders, which also reduces predators (Morris and Rispin 1987). As the number of mowings per year increases, permanent turfgrass communities, both plant and animal, become less diverse (Grieler and Tscharntke 1993). Cutting decreases species richness of insects, and cessation of mowing results in changes in insect populations, sometimes resulting in increased species richness (Morris 1981, Morris and Plant 1983). As the cutting height is lowered, turf plants exhibit decreased carbohydrate synthesis and storage, increased shoot growth, and decreased root growth (Beard 1973), which may explain changes in insect diversity as well.

Insect outbreaks in natural grasses are common and many times are not threatening to grass health. When a particularly large outbreak occurs it can cause cycles of damage resulting in substantial loss of biomass (Henderson 1978). However, on well-maintained turf, such as on golf course fairways, greens, and tees, even small outbreaks are almost immediately problematic (Beard 1973). Although grasses show low susceptibility to grazing pressure due to their rapid regrowth, root feeding may be more problematic, as it weakens the plant from the more susceptible underside. According to Stanton (1988) soil organisms are the limiting factor to grassland productivity, as microbial grazers may serve as regulators of plant growth.

Of the herbivores, white grubs (Coleoptera: Scarabaiedae) may be the most damaging to turf because they feed on the more susceptible roots (Potter 1998). *Popillia japonica* (Neuman), for example, is an introduced species that is considered the single most important scarab turf pest in the United States (Vittum et al.1999). The larvae of *P. japonica* cause significant damage to turfgrass in eastern North America by chewing the roots. The adults are also a major pest, feeding on foliage or flowers of nearly 300 species of plants (Tahsiro 1987). *P. japonica* overwinters as larvae below the frost line, moving to the surface to pupate in May and June. Adults are usually present in June and July, and larvae are found again in August and September, feeding on turfgrass roots until cold weather forces them further down into the soil (Potter 1998).

Outbreaks of grubs, especially invasive pest species, are devastating to turf, and we know very little about why outbreaks occur. To understand why outbreaks of many different species of grubs occur in lawns and golf courses, we need to have a better understanding of the arthropod community structure in the soil, where scarabs spend three-quarters or more of their life as eggs and larvae.

In the soil, Stanton (1988) allows for two major trophic levels: herbivory and decomposition. However, in studying insects it becomes clear that predation is also a major component of the grasslands system. Of course, prey availability is the most important factor in determining the diet of any predatory arthropod (Pollet and Desender

1987), and soil fauna are typically found in numbers 2-10 times higher than their aboveground counterparts (Lavigne et al. 1972). If there is an abundance of prey underground, then therefore there may be an abundance of generalist predators that may also feed on scarab eggs and larvae.

In the soil, soil protozoans and nematodes are the most abundant animals, followed by the microarthropods (Leetham and Milchunas 1985). These organisms are important decomposers, but certain microarthropods also may be important predators in the soil. Many mites in the suborder Mesostigmata may be important predators of insect eggs, nematodes, Collembola and other small arthropods (Wallwork 1976). In leaf litter, mites are generally the most important predators of Collembola, followed by psuedoscorpions (Arachnida: Chelonithi), and members of the families staphylinidae and carabidae (Coleoptera) (Christiansen 1964). Larvae of Staphylinidae and Carabidae are important predators of Collembola and mites below the soil surface (Wallwork 1976 based on Luff 1966). Carabid larvae are especially adept at catching Collembola, which are typically trapped in soil cavities where they cannot jump. If Collembola are encountered in a larger arena, the carabid larvae still have the advantage, as their touch is too gentle for the flight stimulus of the Collembola (Bauer 1978). The habitat of the larvae of any carabid species is determined by the position of the egg, and as larvae are not able to move long distances they must survive where the female oviposited (Lovei and Sunderland 1996).

According to Theile (1977) carabid activity in temperate zones is based on their reproductive habits, whether they are summer or autumn breeders, larval or adult hibernators, and if there are dormancy periods in the adults. In a study spanning 10 years in Western Europe den Boer and den Boer-Daajne (1990) reported the reproductive cycles of the 68 most abundant carabid species of Drenthe (The Netherlands) including *Amara aenea* (Degeer) and *Pterostichus melanarius* (Illiger) which are also found in Michigan. *A. aenea* is a spring breeder, reproductive between April and June with larvae present between July and October, and overwintering as adults (den Boer and Den Boer-Daajne 1990, Kegel 1990). *P. melanarius* is an autumn breeder, reproducing between June and September with larvae present between January and May (den Boer and Den Boer 1990).

Collembola are relatively abundant above and below the soil surface, where they feed on a variety of materials such as plant material, fungi, and bacteria (Butcher et al. 1971). The abundance of these food items are of major importance to the distribution of soil Collembola. Collembola are rapid reproducers that may become resistant to pesticides (Christiansen 1964). They are bionomically divided into three major life forms, epigious, hemiedaphic, and euedaphic. Epigeous Collembola are those with well-developed eyes, antennae, pigmentation and have a long furcula. These are the surface Collembola. Hemiedaphic Collembola have moderately long antennae, pigmentation, and well-developed eyes. These are found in ground litter, moss and bark. Euedaphic Collembola are true soil dwellers, with reduced eyes, short antennae and little pigment. They inhabit the deep soil, as well as caves and soil cavities (Butcher et al 1971). Some soil dwelling Collembola, unable to jump within the soil cavities, are capable of secreting noxious fluids as a defense against predators (Villani et al, 1999).

After six years of studying 2 species of small grubs (*Ataenius spretulus* and *Aphodius granarius*) and generalist predators on golf course fairways and roughs, it is still not understood why Staphylinids (a generalist predator) are much more abundant in the roughs, while scarab larvae are much more abundant in the fairway (Smitley et al 1998, Rothwell and Smitley 1999).

I believe that a broader examination of the entire arthropod community in pesticide-free fairways and roughs may reveal a relationship within the food chain that will help explain outbreaks of *A. spretulus* and A. *granarius* on golf course fairways. If we examine these scarabs as part of a larger system, rather than as an isolated pest of turfgrass, it may be possible to predict, treat, and possibly prevent outbreaks more effectively than our current knowledge of them allows.

INTRODUCTION

The black turfgrass ataenius, *Ataenius spretulus* (Haldeman), and a similar looking beetle, *Aphodius granarius* (L.) (Coleoptera: Scarabaeidae), are pests of turfgrass (Potter 1998). Larvae of both species consume turfgrass roots, causing patchy damage to turf. *A. spretulus* is native to North America, and is an important pest of golf course fairways, greens and tees in the eastern and mid-western United States and some provinces of Canada (Niemczyk and Dunbar 1976). The first report of damage caused by *A. spretulus* came from a golf course in Minnesota in 1927. However, *A. spretulus* was not well documented as a turf pest until after 1970, when the amount of reported damage rose sharply (Tashiro 1987). This increase was apparently due to development of resistance to insecticides (Weaver and Hacker 1970, Niemczyk and Wegner 1982). All reports of turf damage by *A. spretulus* have been limited to golf course fairways, greens and tees (Niemczyk and Wegner 1982).

A. spretulus completes two generations a year in regions south of central Ohio and has one generation a year in northern Ohio and Michigan (Wegner and Niemczyk 1981, Smitley 1994). In southern Ohio, overwintering adults deposit eggs in May, larval densities reach their peak in June, and a new generation of adults emerges in July. Eggs are laid again in July developing into larvae in August (Potter 1998). In Michigan, eggs are laid in June and larvae are present in July (Jo 2001).

A. granarius adults are very similar in appearance to *A. spretulus* adults. European in origin, *A. granarius* is a pest of golf courses in Ontario, Michigan, Colorado, and Ohio, where it was originally mistaken for *A. spretulus* (Tashiro 1987). Adults of *A. granarius* are distinguished from *A. spretulus* adults by the presence of transverse carinae on the hind tibia, while the larvae of each can be identified by the rastal pattern (Tashiro 1987). *A. granarius* larvae damage turf in the fairway in a pattern similar to that of *A. spretulus*. *A. granarius* was originally believed to complete 2 generations in Ontario and Ohio due to the presence of adults in May and then again in August (Tashiro 1987). However only one generation of *A. granarius* larvae apparently occurs in New Jersey (Wilson 1932) and Michigan (Smitley 1994). In Michigan, *A. granarius* adults overwinter and become active again in May. The larvae are present in June, about four weeks earlier than those of *A. spretulus* (Smitley et al. 1998).

In a recent study, *A. spretulus* and *A. granarius* larvae were found to be most abundant in the short turf of the fairway (1-2 cm); while surface predators (Carabidae and Staphylinidae) were uncommon in short turf, but abundant in the adjacent rough (5-7 cm) (Smitley et al. 1998). The activity of *A. spretulus* and *A. granarius* may be inversely proportional to the number of insect predators on the ground surface. When mowing practices were changed, *A. spretulus* and *A. granarius* numbers increased in the shorter fairway while surface predator numbers increased in the longer rough (Rothwell and Smitley 1998). These differences existed in the absence of pesticides, although differences may be even greater when pesticides are used (Smitley et al. 1998). The differential distribution of these predator and prey species in different habitats suggests predation affects the abundance of *A. spretulus* and *A. granarius* in turfgrass.

The activity of Carabids and Staphylinids was shown to be lower in the fairway compared with the rough (Rothwell 1998) and we suspected their primary source of food is also different in the fairway and rough. One potential source of prey for Staphylinid and Carabid adults and larvae are several species of Collembola and mites (Pollet and

Desender 1987). The microarthropod fauna in the soil may be especially important to larvae of Carabids and Staphylinids because these carabid and staphylinid larvae reside entirely in the soil. Both the Collembola and mites can be found in all layers of soil, including the thatch layer of turfgrass. If populations of generalist predators are dependant on small arthropods in the soil, as well as surface prey, then outbreaks of pest species in the fairway may occur because the bottom of the food chain is too small to support enough generalist predators to control invasions of turf pests.

The objectives of this research were to determine the abundance of Collembola and mites in the soil of a golf course fairway and in the rough, and to determine the relationships between the soil fauna, the activity of insect predators and the presence of scarab larvae.

MATERIALS AND METHODS

Study Site. This study was done on a single hole at Groesbeck Golf Course in Lansing, Michigan. A sprinkler head in the center of the fairway provided irrigation coverage for both the fairway and the rough. The soil is generally loamy, and the turf is at least 25 years old, and is a mixture of bentgrass (*Agrotis spp.* L.) and annual bluegrass (*Poa annua* L.), with Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) moving in. In 2000, fine fescue (*Festuca capillata* Lam.) was found to have invaded the inner circle of the fairway in large patches. On this particular hole, the grass has not been reseeded or disturbed since 1927 (John Johnson, Superintendent, Groesbeck Golf Course, personal communication). Currently, the rough seems to be in transition back to *P. pratensis*, having been predominantly *L. perenne*. Pesticides are sparingly used on this course, for economic reasons. The greens are treated regularly with herbicides, and the fairways and roughs are spot treated for fungal outbreaks if necessary. No insecticides were used on this area of the golf course in the two years prior to this study.

Arthropod communities in the fairway and rough were compared with a randomized complete block split-plot design. Six blocks were set up around the outside of an oval shaped fairway (Fig 1A). Each block (5m x 2m) was centered on the border between the fairway and rough (Fig 1A). Blocks were divided length-wise for taking soil samples and for pitfall trapping.

Sampling for subsurface arthropods. Once a week between 25 May and 20 July in 1999, 4 standard golf course cup-cutter samples 12 cm in diameter and 12-13 cm deep were pulled from each block and placed in sealed plastic bags. They were replaced by pre-cut soil cores from the same turf type so as not to disturb the turf environment. Soil cores were always taken at 1m and 2m away from the border but at different distances (0-1.0m) away from the medial line to minimize disturbance to the area, and to avoid collecting from the same spot twice.

The plastic bags containing the soil cores were placed in a large cooler for transportation to the field station at Michigan State University. The sampling took approximately 1-2 hours between the hours of 9 am and 11am. The samples were gently crumbled by hand inside plastic bags and searched for visible arthropods at the field station. The turf at the top of the soil core was also separated into large pieces to allow arthropods to more easily escape from the samples during heat extraction. Any arthropods found at this time were placed in 70% ethanol and transported to the Landscape Entomology lab at Michigan State University for identification.

After visual inspection, the contents of the plastic bag were poured onto a screen in Tullgren-type funnels to collect arthropods too small to observe without magnification. Before the study began, the 24 Tullgren-type funnels were set up in 2 large racks. The lips of the funnels were sprayed with Teflon ® to keep contaminating species out. During the experiment, the funnels were heated with 40-watt bulbs connected to a rheostat. Each day the heat was slowly increased over a period of 7 d, or until the sample was dry. Specimens extracted from the soil cores were collected for counting and identification by Dr. R.J. Snider (MSU), Breana Simmons (MSU), Brian McCornack (MSU), Gary Parsons (MSU) and Dr. Roy Norton (Syracuse, NY). Those that were unidentified were categorized by morphotype and placed in an "other" category. This experiment was repeated exactly between 22 May and 20 July 2000.

Pitfall trapping. Small glass vials (32 ml) filled with ethylene glycol were used to sample surface insects. Eight pitfall traps were placed 0.5 m apart in a line perpendicular to the border between fairway and rough in each block. Pitfall traps were collected and the insects were sorted weekly (Fig 1b). The pitfall traps remained at the same location throughout the study. In 1999 the traps were set between 25 May and 20 July, coinciding with the soil sampling. In 2000, the traps were set earlier, on 10 April, to detect adult activity of *Aphodius granarius*. Specimens of the families Carabidae were identified by Brian McCornack (MSU), Staphylinidae by Breana Simmons (MSU) and Curculionidae by Gary Parsons, (MSU). As in the soil sampling, those that were unidentified were placed in the "other" category.

Arthropod identification. From each pitfall trap, the first individuals counted (up to five) in each family were kept for identification to the species level. From each heat extraction sample, the first five mites and collembola counted were collected for further identification. Also collected were any unknown individuals, so that they could be identified and categorized by family if necessary.

Sampling for *A. spretulus, A. granarius, and P. japonica.* To determine the distribution of *A. spretulus* and *A. granarius* larvae, soil cores were collected during the peak incidence of third instars, when grub visibility is highest. For *A. granarius*, this is usually in the first 2 weeks in June and *A. spretulus* larval densities peak 4-6 weeks later. Eight cup-cutter samples were taken from the fairway and rough of each of the 6 blocks and dissected for grubs on site. The grubs were collected for species identification and the soil cores placed back into the ground. On 19 June 2000, we also sampled for *P.japonica* larvae in this manner. *P. japonica* was sampled because the population at

Groesbeck was predicted to rise to pest proportions, much like *A. granarius* had in previous years. For analysis, these were added to any larvae recovered from the soil cores that were subjected to heat extraction.

Soil tests. The Aquaterr ® soil moisture/ temperature probe (Aquaterr Instruments Inc. 1990) was used to measure soil moisture in each block to ensure that the blocks were homogeneous. The probe was calibrated in a bucket of water before each use to ensure accuracy. Ten soil probes per block in both the fairway and the rough were recorded for 3 consecutive weeks between July 17 and July 31, 2000. The equipment was not available before this time period, and was not used past 31 July because the time period of the study had already past. Temperatures and moisture readings were averaged by fairway and rough and analyzed for statistical significance. Also, weather data was obtained from the Michigan Automated Weather Network Interactive Data Access website (2000) for East Lansing Michigan, which was as close to the research site as possible.

Heat extraction efficiency test. According to Snider et al. (1997) a heat extraction efficiency test must be run on field samples at least once to determine the actual percentage of individuals recovered from the extraction process. Heat does not extract all individuals from a soil sample. Some individuals are dead before placement in the funnels, and some die before they make it all the way through the sample and into the alcohol. Therefore, in order to determine the actual number of individuals in the sample, it is necessary to float out any remaining specimens after the heat extraction has been completed. Floatation is more accurate then heat extraction, but is time consuming and labor intensive. Heat extraction is a standard method for sampling soil invertebrates, and is an acceptable means of collection, as long as an efficiency is determined (Snider et al. 1997). In 1999, 24 soil samples were taken in August and placed in the Tullgren funnels for 7days. Each sample was retrieved from the funnel and placed in a 0.946 liter jar. The jar was filled with a saturated sugar solution and shaken. The contents of the jar were allowed to settle for 2 hours to allow the organic matter to rise to the surface. The solution was decanted through a 200-mesh sieve into a plastic container. Care was taken to ensure that none of the silt that had settled to the bottom was poured onto the screen. Any organic material on the mesh screen was placed in a 0.473 liter jar and preserved with 95% ethanol. The sugar solution was poured from the bowl back into the jar containing the sediment, shaken again, and allowed to sit for 2 hours. This process was repeated twice more (Snider and Snider 1997). Invertebrates collected from the original heat extraction were counted and compared with the number of invertebrates found in the sugar floatation experiment.

Statistics. Due to the initial design of the project, a split plot analysis was run using SAS ® (SAS Institute,1990). The whole plot factor was the treatment (fairway v rough), and the sub-plot factor was the distance from the fairway/rough border. An ANOVA was created for each individual group of arthropods to determine if the treatment was significant within the group. Due to concerns about the non-parametric nature of the data, another test was run using a log regression model in SAS ®. In this model, a regression was created for each group of arthropods, which could determine significant differences between blocks, treatments (whole plot and sub plot), and weeks. In 2000, only the pitfall trap data that corresponded in time with the 1999 data was used for analysis. Data from April and early May were not included, because sampling at that time was only intended for trapping *A. granarius*. Also not included in the analysis was count data collected from week #6, which was considered to be inaccurate due to exceptionally heavy rains, which, combined with sprinkler irrigation system installed on the eighth hole, flooded the pitfall traps. In addition to these statistical procedures, simple regressions were run using SUPERANOVA ® (Abacus 1991) to show correlations between the distribution of predatory arthropods and potential prey items.

RESULTS

Arthropod identification. Carbidae recovered from pitfall traps in 1999 and 2000 consisted mainly of *Amara anea* (Degeer). Of 135 specimens kept for identification 126 were *A. aenea.* Other species of Carabidae recovered included *Scarites quadriceps* (Chd), *Stenolophus comma* (F.), *Anisodactylus rusticus* (Say), and *Pterostichus melanarus* (Illiger). Most of the mites extracted from soil cores were found to be of the suborders Mesostigmata and Prostigmata (Families: Eupodidae, Tetranychidae, Pygmephoridae). Only 2 individuals were found to be of the family Oribatidae: *Epilohmannia elongata* (Banks) and *Graptoppia italica* (Bernini). Of the suborder Astigmata, members of the genus *Tyrophygus* were identified. All Staphylinidae kept for identification were identified as *Philonthus cognatus* (Stephens) which are known predators of turf pests (Jo 2000). All Curculionidae kept for identification were identified as *Sphenophorus minimas* (Hart) which are pests of turfgrasses (Vittum et al. 1999). The most abundant collembola at Groesbeck Golf Course are *Psuedosinella rolfsi* (Mills), and *Isotoma notabilis* (Folsom). *P. rolfsi* is a common collembola found in grassy areas. *P. rolfsi* has a well-developed furcula for jumping and is found in the top layers of soil. *I. notobilis* is another common species frequently found in lower Michigan (Snider 1967).

Surface and subsurface sampling. In 1999 there were differences in Carabidae activity between the fairway and the rough as determined by both parametric and non-parametric statistical tests (Fig 2). The activity of Carabids in the rough (6.9/10traps/week) was significantly higher (DF 1,7, F=5.75, P=0.02) in the rough than in the fairway (4.8/10traps/week). In 2000, the activity of Carabidae was significantly higher (DF 1,7, F=6.13, P=0.01) in the fairway (8.9/10 traps/week) than in the rough (6.7/10 traps/week), just the opposite of what was observed in 1999 (Fig 4). Total trap catch for Carabidae was similar in both years (208 individuals caught in 1999 and 212 in 2000).

Staphylinid activity was significantly greater (DF1,7, F=65.76,P=0.0001) in the rough than in the fairway (Table 1). In 2000, Staphylinidae were again significantly (DF 1,7,F=52.41,P=0.0001) more active in the rough than in the fairway (Fig 4). Total trap catch for Staphylinidae decreased from 407 individuals caught in 1999 to 213 individuals caught in 2000.

Due to the way the experiment was designed, it was also possible to examine the data for a border effect. A border effect is a phenomenon in which the abundance of an insect changes as you approach the border of a different habitat. If it is beneficial to exploit both the fairway and the rough, then the individuals will remain near the border between both habitats, and there will be a build up of activity nearest the border on both sides. In the rough, the number of Staphylinidae caught in pitfall traps was constant between 1.0m and 2.0m of the border but nearly doubles within 0.5m of the border with the fairway (Fig 3). A slight increase in Staphylinid activity on the fairway side of the border suggests some movement from the rough into the first 1.0m of the fairway, however, this may simply be spillover. There were significantly more Staphylinids caught at 0.5 m from the border in the rough than in any other pitfall trap in 1999. This may indicate that the Staphylinids are not utilizing both habitats, but are stopping before they crossover into the fairway. However, no other significant differences were found between pitfall traps in the same grass length.

In 1999, number of Collembola extracted from soil samples was 2-fold higher (DF1,3,F=43.7,P=0.0001)in the rough than in the fairway (Table 2, Fig 5). Similarly, the number of mites extracted from soil samples was 3-fold higher (DF1,3,F=58.5,P=0.0001) in the rough than in the fairway. In 2000, the total number of Collembola and mites recovered from soil samples was reduced compared with 1999. In 1999, a total of 9234 Collembola and mites were extracted from soil cores, whereas in 2000, only 2722 individuals were extracted. However, despite the reduction in abundance, the numbers of both Collembola (DF1,3,F=19.7,P=0.0001) and mites (DF1,3,F=19.5,P=0.0001) were again 2 to 3-fold higher in the rough than in the fairway (Table 2, Fig 6). No significant border effect was found in either of these groups in either 1999 or 2000.

The unidentified insects included members of the orders Diptera, Coleoptera (Elateridae, Tenebrionidae, Curculionidae), and Homoptera. The total number of unidentified insects found in both surface and subsurface sampling was also higher in the rough than in the fairway in 1999 (Tables 1 and 2). In 2000, a separate category for Curculionidae was added to the pitfall trap data because we began to catch them in high numbers and thought they could be important members of the arthropod community, as many curculionids are pests of turfgrass. For this reason we also added a category for Homoptera (later classified Aphididae) in the soil data. In 2000, Curculionidae and Aphididae were found in higher numbers in the rough (Table 2). In 2000, unidentified insects from subsurface samples were higher in the rough (Fig 6). Data were collected on spiders during both 1999 and 2000, but not presented because only 12 were caught in pitfall traps in 1999 and only 17 were caught in pitfall traps in 2000.

More ants were caught in pitfall traps in the fairway than in the rough (Table 1), while ants found in the soil were slightly more abundant in the rough compared with the fairway in 1999 (Table 2). Because large numbers of ants were collected from soil cores and pitfall traps, and the species composition was the same in the fairway and rough, we could use the soil core data to compare pitfall trap efficacies in the fairway and rough. The ratio of ants in pitfall traps to ants in soil cores was not different between fairway and rough samples in 1999 (P=0.4) or 2000 (P=0.7), suggesting that the efficacy of pitfall traps was similar in the fairway and rough (Table 3).

Sampling for *A. spretulus, A. granarius, and P. japonica.* *A. granarius* was abundant in previous years at Groesbeck Golf Course, causing extensive damage to some greens, but populations appeared to be very low in 1999 and 2000. In 1999 no *A. granarius* larvae were found. In 2000, only 19 larvae were found, not enough to evaluate differences between the fairway and rough. In 1999 only 10 *A. spretulus* larvae were found, and in 2000, only 20 larvae were found. This amount of larvae was not enough to evaluate differences between the fairway and the rough. No differences were discovered for the adults of *A. spretulus* or *A. granarius* in 1999 or 2000 (Figs 2 and 4). While *A. granarius* and *A. spretulus* were found in low numbers, numbers of *P.japonica* adults and larvae were on the increase, allowing us to obtain good data in 2000. More *P. japonica* larvae were found in the fairway than in the rough (Table 4). The adults of *P. japonica* were also found in higher numbers in the fairway than in the rough (Table 1).

Simple regression tests. Positive linear relationships were found for the 1999 data, and for combined 1999 and 2000 data, between the abundance of Staphylinidae and the abundance of both mites and Collembola. In 1999, as the abundance of mites increased, so too did the abundance of Staphylinidae (r^2=0.55) (Fig 7). Also, as the number of Collembola present in the soil cores increased, so did the number of Staphylinidae caught in adjacent traps (r^2= 0.37) (Fig 8). No other significant relationships were found between other major arthropod groups (Table 5).

For *P. japonica*, relationships between grub distribution and predator abundance were varied (Table 6). No significant relationship was found between Carabidae caught in 1999 or 2000 and *P. japonica* larvae found in soil cores in 2000. For Staphylinidae, in both 1999 and 2000, significant negative linear relationships were discovered between adult Staphylinids caught in pitfall traps and *P.japonica* larvae found in adjacent soil cores (r^2=0.29, r^2=0.45). Relationships between the distribution and abundance of ants caught in both 1999 and 2000 and the larvae of *P. japonica* found in adjacent soil cores in 2000 were positive and minimal, although 1999 was significant to the p=0.05 level (r^2=0.2, r^2=0.15)

Soil tests. No significant differences in moisture content or temperature were found between the fairway and rough within blocks, nor were significant differences recorded between blocks. We did not expect any differences in soil temperature or moisture between the fairway and the rough, but we were testing for homogeneity. Readings from the Aquaterr® meter registered different soil temperatures depending on the ambient temperature data, and moisture levels were dependant on the time elapsed since the last irrigation. However, despite these dependencies on surface conditions, the readings were uniform throughout the plots on each sampling date. On a moisture scale of 0-100, the fairway averaged 84.5 over the three sampling dates, while the rough averaged 83.9 (Table 7).

Heat extraction efficiency test. As expected, the floatation experiment (Table 8) resulted in more Collembola and mites than the previous heat extraction methods. Collembola were heat extracted at a 40% efficiency level in the rough and a 45% efficiency level in the fairway. Using both the floatation efficiency percentages and heat extraction data (volume of soil core/mean number individuals found per core/percent effiency) we can estimate that there were approximately 30,000 Collembola per m^3 in the fairway and 80,000 Collembola per m^3 in the rough. Mites were extracted at a 52% efficiency in the rough and a 44% efficiency in the fairway. As with the Collembola, this means that there were approximately 29,000 mites per m^3 in the fairway and 70,000 mites per m^3 in the rough.

Other insects collected included several types of unidentified Dipteran larvae and Homoptera nymphs, which were categorized as "others" for statistical analysis in the heat extraction experiments, thus they were classified in the same way for this test. No other arthropods were found in the experiment. This does not mean that heat extraction of other arthropods was 100% efficient, but that at that time, in those soil cores, no other individuals were present.

DISCUSSION

Arthropod identification. The identification of the mites and Carabidae put a new spin on the interpretation of the research results. First, *Amara aenea* are generally phytophagous carabids, and are not considered predatory. As they made up the bulk of the trap catch, this may explain the weak relationship between Carabids and prey items. However, Pollet and Desender (1987) found Collembola in the gut contents of adult *A. aenea*, suggesting that the species is not entirely phytophagous, and may be a predator of Collembola, but probably not of larger arthropods. In the same study mites were identified as a minor food source for Carabidae, due mainly to their subterranean lifestyle, although the authors speculated that mites may be an important source of food for carabid larvae. Although feeding data on this particular genus of carabids is not available, some carabid larvae are known predators of Collembola, which they trap in soil cavities (Bauer 1979). In laboratory studies, *A. aenea* was found to consume small arthropods, but was presumed too small to consume scarabaeid grubs (Hagley et al 1982). In feeding tests involving adult *A. aenea* and larval *A. spretulus*, in petri dishes, *A. aenea* did consume this small third instar grub (Jo 2000). It is not known if the larvae of this species are predators, but if they are, *A. spretulus* and other small scarab larvae as well as insect eggs may be impacted.

In laboratory feeding studies, *Philonthus* adults were found to readily consume corn rootworm (substituted for *A. spretulus*) eggs but were not as likely to eat *A. spretulus* larvae (Jo 2000). Because adult Staphylinidae are surface insects, they may not come into contact with the eggs or larvae of scarab beetles very often. *Philonthus* larvae should be investigated as potential predators of scarab larvae because of their high

density in home lawns and golf course roughs (Potter 1998). In laboratory studies *Philonthus* larvae were the best predators of *A. spretulus* larvae (100% consumption) of any potential predator tested, which included adult carabids *A. aenea, Harpalus affinis* (Schrank), *Stenopholus ochropezus* (Say) and adult staphylinids *Apocellus sphaericollis* (Say) *Philonthus carbonarius* (Gravenhorst) and *Philonthus cognatus* (Stephens). (Jo 2000).

The mites recovered form the heat extraction samples consisted of high numbers of mites in the group Mesostigmata. A large portion of this group are considered predatory on nematodes and other mites, while others feed exclusively on Collembola (Wallwork 1976). This does not mean that they cannot be considered prey items, but that they may also be important predators in the turf system.

In 2000 we added a category for Curculionidae, as they are widely studied as pests of turfgrasses and we were finding them at our course in large numbers. The curculionid was identified by Gary Parsons (MSU) as *Sphenophorus minimas* (Hart). *S. minimas* is a small weevil closely related to the bluegrass billbug, *S. parvalus* (Gyllenhal) (Vittum et al 1999). Discovery of *S. minimus* at a high enough density to cause turf injury in this study indicates a need to study billbug pests of turf more carefully in Michigan, where *S. parvalus* was the only species of *Sphenophorous* previously believed to be a pest.

However, it is not possible for us to extrapolate species diversity and richness from this data, as not all individuals form the samples were identified. Because only five individuals per family were kept for identification from each sample, information on the total number of species inhabiting Groesbeck Golf Course can not be ascertained. For example, although *A. aenea* made up the bulk of our samples, without more precise data on how many of this particular species were caught, it is not clear whether *A. aenea* are actually more abundant than other carabids, or if they simply are more likely to fall in the pitfall traps.

Surface and subsurface sampling. In 1999, the insect distribution data collected from one hole on Groesbeck golf course seemed consistent with the data from previous studies of predatory arthropods on four other golf courses in Michigan (Smitley et al 1998), which reported a sharp difference in predator abundance in the rough compared with the adjacent fairway. In previous studies, samples were taken from 0.75 m to 10 m from the turf border, whereas in this study, all sampling was done within 2.0 m of the border, due to the desire to study a potential border effect. In 2000, staphylinids were again more abundant in the rough, but carabids were slightly more abundant in the fairway, differing from the distribution reported in the previous studies (Smitley et al. 1998). In both years, ants were more abundant in the fairway, which is the opposite of the results from previous studies done at Franklin Hills Golf Course in Oakland County, MI and Oakland Hills in Oakland County, MI in 1994 (Smitley et al. 1998).

Staphylinid activity was highly correlated with mite and Collembola abundance for both years. The greater abundance of Collembola and mites in the rough compared with the fairway supports our hypothesis that Staphylinids residing in the rough did not need to travel to find food. If Collembola and mites are found in 3-fold more abundance in the rough, and staphylinids are preying on them, then this might explain the high correlation between them. A larger prey base may keep the predators from moving out of the rough, even when high prey populations (such as outbreaks of pest species) are present in the fairway. This is the first account of how the specific abundance of soil Collembola and mites relates to the abundance of Staphylinids in the turf. Adult female Staphylinids may select the rough for ovipostion over the fairway due to the larger amount of potential prey for their larvae.

However, other environmental factors, such as soil compaction, mowing frequency, soil nutrition and heat build-up may also play a role in the distribution of both soil animals and surface predators. At Groesbeck, the fairway was mowed three times as often as the rough, but was less likely to be driven on by golfers. Also, the fairway experiences high temperatures during the day, and the risk of desiccation may be greater in the fairway than the rough. There could be differences in evapotranspiration rates between the fairway and rough. Evapotraspiration rates in turf are dependent on solar radiation (Beard 1973) which may be higher in the fairway. Most likely, it is a combination of factors which contributes to the high numbers of predators caught in the rough compared to the fairway. More research is needed to establish this food chain connection between staphylinids (*Philonthus*) found in turf and Collembola and mites.

Another concern of this study was the ability of the pitfall trapping to accurately portray the abundance of surface predators in relation to the abundance of soil animals. Pitfall traps are not a measure of abundance, but rather an indication of activity (Snider and Snider 1986). And while most insects will fall into a pitfall trap, it is not known if certain species are capable of avoiding this sampling method. Also, the vials used in this study may not have been effective for all arthropods, especially large ones, such as the carabid *Scarites quadriceps,* which is almost too large to fit in the mouth of the vial.

In 2000, Carabidae and Staphylinidae were found in much lower numbers. In fact, abundance of all arthropod groups, surface and subsurface, was dramatically reduced in 2000. Collembola and mites were found at about 1/4 of the numbers recovered in the previous year. This may be due to unusually heavy precipitation levels in May and June of 2000 (Fig 9) as well as a cooler spring, between May and June of 2000 (Fig 10). However, accumulated degree-day totals (Fig 11) reveal that there were actually more degree-days accumulated between May and June of 2000 than in the previous year, therefore it is unlikely that the cool weather had an effect on the insect activity.

Despite the higher number of degree-days, it is still possible that wet weather played a major role in arthropod activity. During several sampling trips, the turf was soggy, and during sampling week number six, the plots were under water for 48 hours, causing the pitfall traps to overflow. The vials measure 8.5cm deep, and were already filled with over 4 cm of ethylene glycol. More than 4.0 cm rain in one week caused them to overflow, and the trapped arthropods are washed away.

High levels of precipitation also affect soil samples. Mold can form on the samples while in the heat extraction units, hindering the drying process and possibly causing death. Also, arthropods from wet soils may not be as affected by the heat, and therefore, do not move into the alcohol as quickly as those found in drier soils. Soil arthropods such as Collembola and mites do not tolerate high moisture content very well (Wallwork 1976). A study by Weis-Fogh (1948) showed a preference of 20 -30% water content/dried soil (g) for most soil microfauna, with the exception of certain species of Cryptostigmata. This is true for Carabidae as well, which decrease in abundance as soil moisture increases from moist to saturated (Wallwork 1976). Thus, the wet weather may have played a role in the low abundance of soil arthropods at Groesbeck in 2000.

Relatively few *A. spretulus* or *A. granarius* were found during the course of this study. The adults were present in moderate levels in pitfall traps, but the larvae were scarce. Groesbeck did not have turf damage from *A. spretulus* or *A. granarius* in 1999 or 2000. They have had damage from *A. granarius* in previous years. However, larvae of Japanese beetle and European chafer caused turf damage in 1999 and 2000, mostly in the roughs. Therefore, no clear information can be ascertained from Groesbeck regarding *A. spretulus* and *A. granarius*, except that perhaps they are heavily preyed upon, and therefore do not cause problematic turf damage.

Formicidae presented a particular problem for analysis, as they were highly abundant in some samples, and absent in others. The resulting trend for ants in the fairway may be misleading. Ants are highly aggregated, and using the soil sampling methods employed in this study, it was possible to sample an entire colony of ants at a single time, or miss them entirely. If the ant colony itself was missed, ants would be absent from the sample after heat extraction. We did not intentionally choose sites that contained high numbers of colonies. In fact, the colonies were not visible in the turf, therefore, we didn't know that we had sampled one until the soil was placed in the plastic bag. In samples containing an entire ant colony, other types of arthropods were scarce. Ants are notoriously protective of their colonies, and may actively prey on or remove other arthropods residing near their colonies. Also, when using pitfall traps to capture surface dwelling ants, their habit of laying down a scent trail causes the ants to be captured in clumps, creating more variability. However, our efficacy test shows that, while these methods of monitoring ants are highly variable, ants have an equal chance of falling in a pitfall trap in the fairway or the rough.

Sampling for *A. spretulus, A granarius, and P. japonica.* Groesbeck Golf Course does not currently have a problem with infestations of *A. spretulus* or *A. granarius* larvae, on new #8 or any other fairway on the course (John Johnson, Groesbeck Golf Course Superintendent, personal communication). In 2000, the presence of *P. japonica* allowed us to examine the relationships between potential predators and *P. japonica* larvae. *P. japonica* was found to be more abundant in the fairway, consistent with the observations made by Rothwell and Smitley (1998) on *A. spretulus* larvae. More *P. japonica* adults were caught in pitfall traps in the fairway than in the rough, either because more adults emerged in the fairway, or adults are attracted to the fairway (Table 1). From our data we cannot tell if more *P. japonica* larvae were found in the fairway because more eggs were deposited there or because more larvae survived there compared with the rough.

Heat Extraction Efficiency. The results of the heat extraction efficiency test show that the number of individuals obtained by heat extraction during this study were significantly lower than the actual total number of animals present in the soil core. Thus, it appears that the numbers of Collembola and Acari found per soil core during this study were approximately only 50% of the true number of individuals in the soil (Table 8). While the floatation method is more accurate, it is labor intensive and time consuming. Heat extraction is a simpler and acceptable method for providing data on soil animals, provided that a true estimate of the efficiency of the method is obtained (Snider and

Snider 1997). The efficiency of heat extraction of samples taken from the fairway compared with those taken from the rough was not significantly different.

Mowing height regimes. The fairway at Groesbeck Golf Course was mowed to a height of 15 mm 3 times per week. Previous research at Spring Lake Country Club in Ottawa County, MI and the Cattails Golf Course in Oakland County, MI by Smitley et al. (1998) was conducted on fairways mowed to heights between 10 and 16mm, and mowed between 2 and 4 times per week. Populations of *A. spretulus* and *A. granarius* larvae were higher at those courses than at Groesbeck. However, Staphylinids were slightly more abundant at Groesbeck than at Cattails, and less abundant than at Spring Lake, which were sampled in 1995 and 1996. This may indicate a slightly higher level of potential predation by Staphylinids at Groesbeck, than at the Cattails. The abundance of insects found at Groesbeck fell between the previous studies. There was not as large a difference between the number of Staphylinids caught in pitfall traps in the fairway and rough at Groesbeck as there was at Spring Lake. Groesbeck had larger differences between fairway and rough than did the Cattails, although the Cattails had a similar mowing regime. This suggests that the distribution of insects on golf course fairways and roughs is affected by factors other than mowing height. This should be expected, as frequent mowing translates into higher disturbance of the turf. A large mower could also lead to increased soil compaction in the fairway, but golf cart activity in the rough may be equally disturbing and have similar effects on soil compaction.

A limitation of this study is that the experiment was not replicated at other sites. Because only one fairway and one surrounding rough were studied, it is not appropriate to make generalizations about the distribution and abundance of soil animals on all golf courses. Replicating this study at other field sites will reveal more information about the dynamics of the arthropod food chain in turfgrass. This information will be helpful in understanding the role of generalist insect predators as biocontrol agents for invasive pest species, such as *A. spretulus* and *A. granarius.*

Most previous research done on turf arthropods focused on bionomics, control, and treatment of arthropod pests (Potter 1998, Tashiro 1987, Vittum et al.1999). This research, with a focus on examining and understanding the turf arthropods as an ecological community, will hopefully prove helpful for further studies on the ecology turf and the biocontrol of turf pests. However, further research into this system must also include investigation of the micro site variability of the turf, and environmental conditions such as heat, plant density, soil compaction and disturbance as other factors in the distribution of predators in turfgrass, and consequently, the outbreaks of pest species on golf course fairway.

Table 1. Activity of adult *A. spretulus, A. granarius,* Carabidae, Staphylinidae, Formicidae, and others at Groesbeck Golf Course in Lansing, Michigan.

Year	Insect	*n*	Fairway	Rough	F	P
1999	*A. spretulus*	48	1.5 ± 0.5	3.5 ± 0.8	3.49	0.07
1999	*A. granarius*	48	1.3 ± 0.3	4.5 ± 2.3	4.22	0.06
1999	Carabidae	48	4.8 ± 1.7*	6.9± 2.1	5.75	0.02
1999	Staphylinidae	48	5.1 ± 1.7*	16.4 ±1.6	65.76	0.0001
1999	Formicidae	48	23.1 ± 6.0*	17.0 ± 4.8	10.72	0.001
1999	Others	48	11.4± 5.5*	14.4 ± 8.2	9.3	0.03
2000	*A. spretulus*	48	1.9 ± 0.4	1.5 ± 0.4	1.02	0.31
2000	*A. granarius*	48	3.9 ± 0.5	3.6 ± 0.7	0.13	0.72
2000	Carabidae	48	8.9 ± 1.0*	6.7 ± 1.2	6.13	0.01
2000	Staphylinidae	48	1.7 ± 0.7*	6.4 ± 1.0	52.4	0.0001
2000	Formicidae	48	16.6 ± 3.9*	10.8 ± 2.5	31.7	0.0001
2000	Curculionidae	48	3.4 ± 0.6*	6.7 ± 1.1	17.11	0.0001
2000	*P. japonica*	48	4.3 ± 0.8	2.2 ± 0.6	1.7	0.19
2000	Others	48	2.5 ± 0.8	1.5± 0.6	3.18	0.07

Data are the mean number of insects caught per 10 traps per week ± SD.

Fairway means ± SD followed by an asterisk are different from corresponding rough means at the P = 0.05 level.

Table 2. Numbers of Mites, Collembola, Formicidae, and others extracted from soil cores taken from Groesbeck Golf Course in Lansing, Michigan.

Year	Arthropod	*n*	Fairway	Rough	F	P
1999	Mites	24	12.2 ± 2.2*	37.7 ± 6.8	58.5	0.0001
1999	Collembola	24	14.2 ± 1.6*	32.8 ± 5.4	43.7	0.0001
1999	Formicidae	24	6.9 + 12	8.6 ± 15	2.35	0.135
1999	Others	24	1.8 ± 4.4	4.6 ± 13.3	0.26	0.61
2000	Mites	24	3.5 ± 5.2*	8.1 ± 8.9	19.5	0.0001
2000	Collembola	24	3.8 ± 4.0*	8.4 ± 8.0	19.7	0.0001
2000	Formicidae	24	7.1 ± 8.8*	4.9 ± 6.8	12.1	0.0005
2000	Aphididae	24	0.67 ± 2.1	0.96 ± 4.3	0.33	0.56
2000	Others	24	0.5 ± 1.4	0.67± 1.3	1.79	0.18

Data are the mean number of individuals found per soil core ± SD.
Fairway means ± SD followed by an asterisk are different from corresponding rough means at the P = 0.05 level.

Table 3. Efficiency of pitfall traps for capturing Formicidae. Data are the ratios of ants caught in pitfall traps to ants found in soil cores, grouped by block.

Block	Fairway 1999	Rough 1999	Fairway 2000	Rough 2000
1	0.14	0.12	0.19	0.49
2	0.29	0.09	0.15	0.22
3	0.96	1.26	0.16	0.36
4	0.46	0.15	0.54	0.24
5	0.31	0.17	0.15	0.05
6	0.33	0.25	0.53	0.15

Paired t-test results

Hypothesized difference = 0

	Mean Diff.	DF	t-Value	P-value
1999 Fairway v Rough	0.072	5	0.851	0.4337
2000 Fairway v Rough	0.038	5	0.345	0.7444

Table 4. Larvae recovered from soil cores taken from 25 May to 20 July 2000 at Groesbeck Golf Course in Lansing, Michigan

Insect	*n*	Fairway	Rough
A. spretulus	24	2.5 ± 1.0	3.0 ± 0.8
A. granarius	24	1.2 ± 0.4	1.4 ± 0.5
P. japonica	24	9.7 ± 1.0*	4.2 ± 1.0

Data are the mean number of individuals found per 10 soil cores (0.1m^2)± SD. Fairway means ± SD followed by an asterisk are different from corresponding rough means at the P = 0.05 level.

Zero *A. granarius* grubs were found in 1999, *P. japonica* were not sampled in 1999.

Table 5. Relationship among the major groups of arthropods found within 2m of the border between fairway and rough on a single hole at Groesbeck Golf Course in Lansing, Michigan. Data are the seasonal distributions after $\log_{10}$ tranformations.

Year	*y*	*x*	*n*	Model	r^2	F	P
1999	Carabidae adults	Mites	24	$y = 0.17x+.925$	0.04	0.902	0.3527
1999	Carabidae adults	Collembola	24	$y = .171x+.936$	0.03	0.649	0.4292
1999	Carabidae adults	Formicidae adults	24	$y = -0.19x+1.85$	0.41	0.929	0.3456
1999	Staphylinidae adults	Mites	24	$y = .904x-.850$	0.55	27.36	0.0001
1999	Staphylinidae adults	Collembola	24	$y = .850x-.705$	0.37	13.16	0.0015
1999	Staphylinidae adults	Formicidae adults	24	$y = .002x+1.57$	none		
1999	Staphylinidae adults	Carabidae adults	24	$y = .192x+1.31$	0.02	0.437	0.5156
1999	Collembola	Formicidae adults	24	$y = .110x+2.43$	0.01	0.3	0.5893
2000	Carabidae adults	Mites	24	$y = -.197x+152$	0.14	3.555	0.0727
2000	Carabidae adults	Collembola	24	$y = -.239x+1.59$	0.14	3.423	0.0778
2000	Carabidae adults	Formicidae adults	24	$y = .152x+1.00$	0.07	1.663	0.2106
2000	Staphylinidae adults	Mites	24	$y = .253x+.389$	0.03	0.628	0.4366
2000	Staphylinidae adults	Collembola	24	$y = .310x+.279$	0.03	0.623	0.4384
2000	Staphylinidae adults	Formicidae adults	24	$y = -.251x+1.13$	0.02	0.521	0.478
2000	Staphylinidae adults	Carabidae adults	24	$y = -1.32x+2.39$	0.21	5.961	0.0231
2000	Collembola	Formicidae adults	24	$y = -.212x+1.91$	0.06	1.356	0.2567
1999+2000	Carabidae adults	Mites	48	$y = -.049x+2.81$	0.01	0.138	0.7135
1999+2000	Carabidae adults	Collembola	48	$y = -.192x+3.43$	0.07	1.648	0.2125
1999+2000	Carabidae adults	Formicidae adults	48	$y = -.010x+2.65$	none		
1999+2000	Staphylinidae adults	Mites	48	$y = 1.04x-2.04$	0.42	15.997	0.0006
1999+2000	Staphylinidae adults	Collembola	48	$y = 1.13x-2.48$	0.36	12.447	0.0019
1999+2000	Staphylinidae adults	Formicidae adults	48	$y = -.287x+3.44$	0.03	0.777	0.3876
1999+2000	Staphylinidae adults	Carabidae adults	48	$y = -.305x+3.15$	0.01	0.312	0.582
1999+2000	Collembola	Formicidae adults	48	$= -.135x+4.80$	0.03	0.602	0.4462

Table 6. Relationship of potential adult predators caught in pitfall traps to the distribution of Japanese beetle larvae (y) collected in May and early June 2000. Regression statistics are the seasonal distributions after $\log_{10}$ transformations of the data.

Year	x	n	model	R2	F	P
1999	Carabidae	24	$y = .071x + 0.34$	0.002	0.042	0.8396
2000	Carabidae	24	$y = 1.02x-.797$	0.158	4.127	0.0545
1999	Staphylinidae	24	$y = -0.62x + 1.43$	0.281	8.608	0.0077
2000	Staphylinidae	24	$y = -.600x+.909$	0.449	17.922	0.0003
1999	Formicidae	24	$y = 0.69x - 1.18$	0.197	5.383	0.03
2000	Formicidae	24	$y = .570x-.348$	0.149	3.854	0.0624

Table 7. Data from soil moisture tests using the Aquaterr ® soil moisture meter. Data are the means per ten probes per block per treatment over 3 sampling dates in 2000.

Date	Fair	Rough
17-Jul	84.9 ± 1.2	82.8 ± 1.9
24-Jul	86.7 ± 2.3	87.4 ± 1.6
31-Jul	81.9 ± 1.7	81.5 ± 2.0
	84.5*	83.9*

* Cumulative means data for all 3 sampling dates

Table 8. Results of the heat extraction efficiency for selected arthropods based on the total number of specimens obtained per treatment. %Efficiency = [(N individuals obtained by heat extraction)/ (N total obtained by heat plus floatation)] x 100; F and R = Fairway and Rough.

Species	n	Treatment	Heat extraction*	Floatation**	% Efficiency
Collembolla	12	F	241	291	45.30
	12	R	566	856	39.80
Mites	12	F	125	153	44.96
	12	R	762	694	52.34
Others	12	F	72	49	59.50
	12	R	104	55	65.41

* Number of individuals extracted by heat

**Number of individuals obtained from sugar floatation, after heat extraction.

n is the number of soil cores used in this experiment, data were pooled for each turf type.

Figure 1A. Experimental design on new #8 at Groesbeck Golf Course in Lansing, MI.

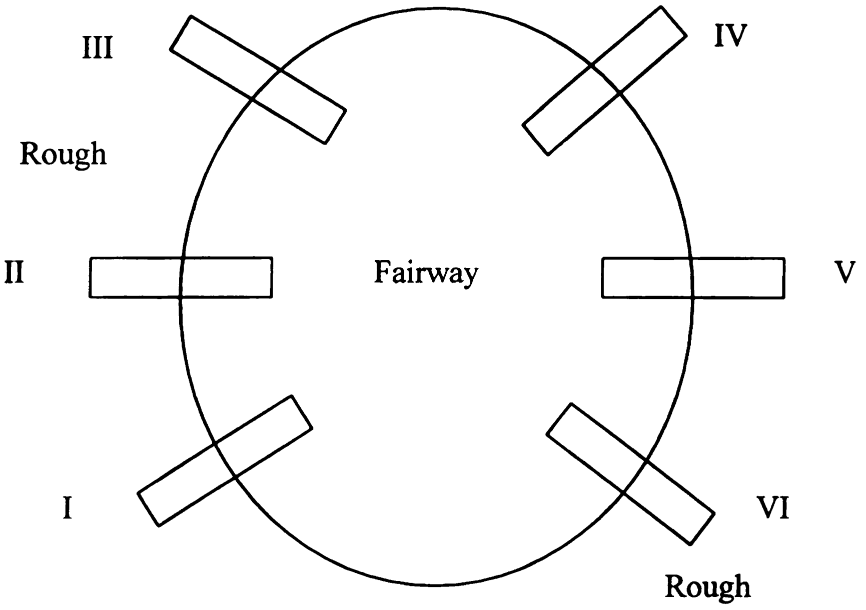


Figure 1B. Example of a single block of the experiment at Groesbeck Golf Course.

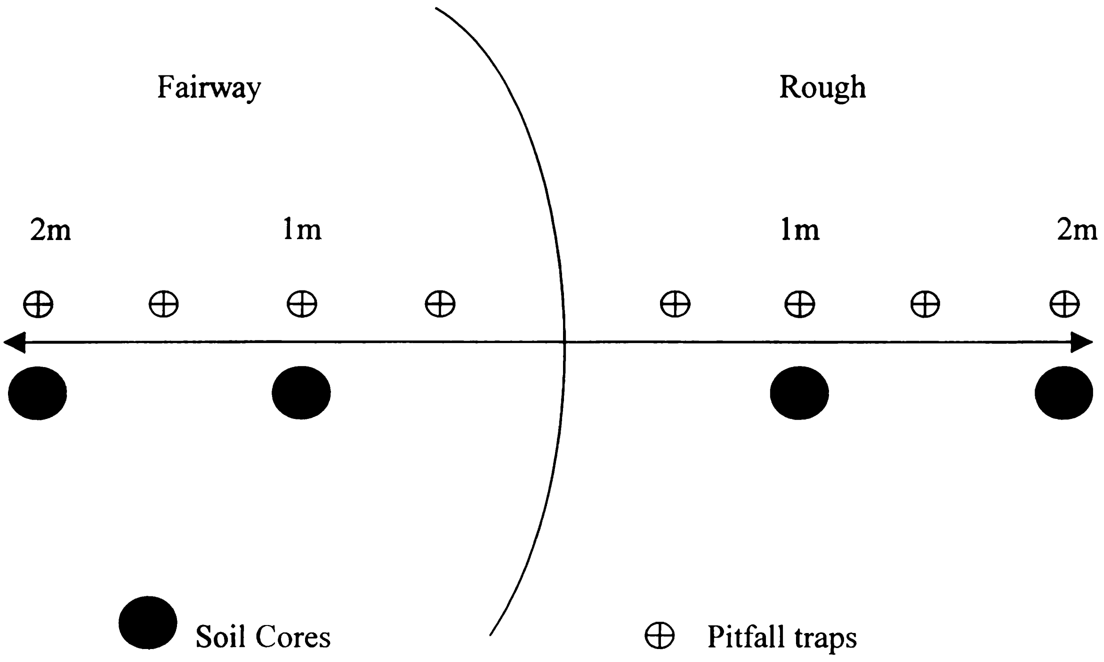


Figure 2. Results of surface sampling for arthropods on Groesbeck Golf Course. Bars represent seasonal distributions of arthropods caught in pitfall traps between May and July 1999.

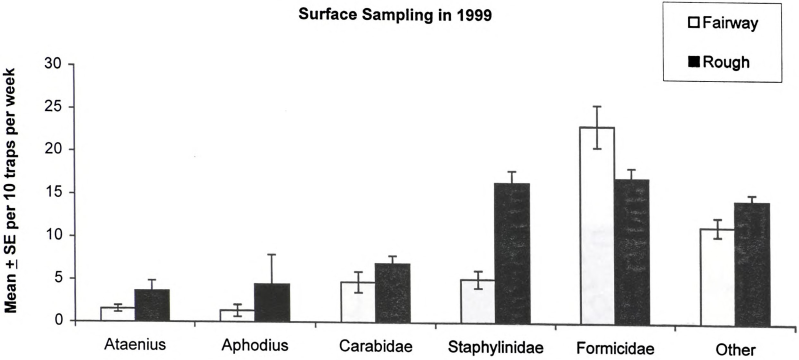


Figure 3. Border effect shown in Staphylinids caught in pitfall traps between 25 May and 20 July 1999 at Groesbeck Golf Course in Lansing, Michigan. Data are the total trap catch for each pitfall trap. Grey columns are pitfall trap, at 0.5m to 2.0 m from the turf border in the fairway, while black columns represent pitfall traps, at 0.5m to 2.0m from the turf border in the rough.

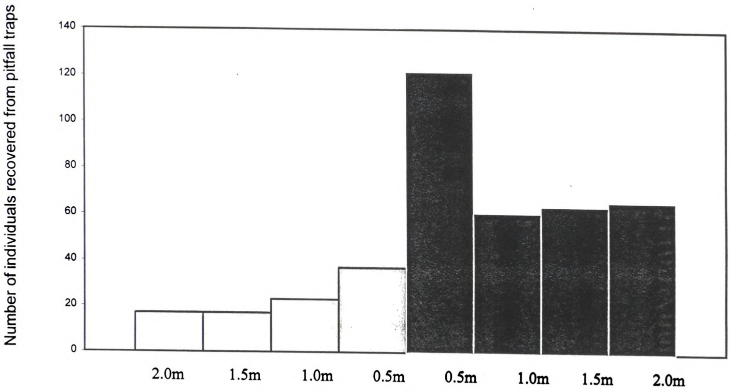


Figure 4. Results of surface sampling for arthropods on Groesbeck Golf Course. Bars represent seasonal distributions of arthropods caught on pitfall traps between May and July 2000.

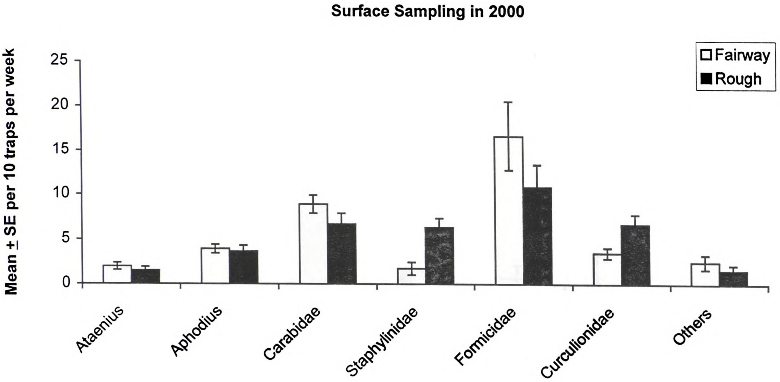


Figure 5. Results of subsurface sampling for arthropods at Groesbeck Golf Course. Bars represent seasonal distribution of arthropods heat extracted from soil cores between May and July 1999

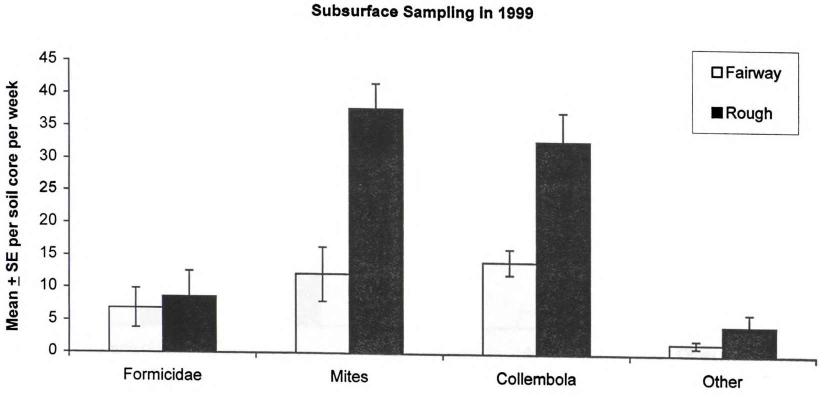


Figure 6. Results of subsurface sampling for arthropods at Groesbeck Golf Course. Bars represent seasonal distribution of arthropods heat extracted from soil cores between May and July 2000

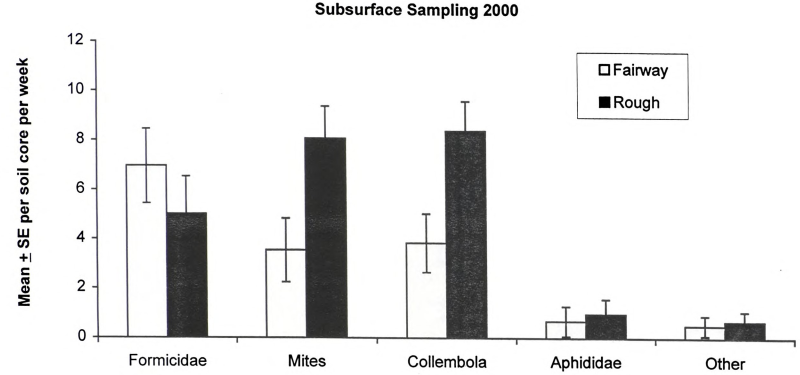


Figure 7. Relationship between Collembola extracted from a soil core and the staphylinid adults caught in the 2 adjacent pitfall traps at Groesbeck Golf Course in 1999. Equation for regression and regression statistics can be found in Table 5.

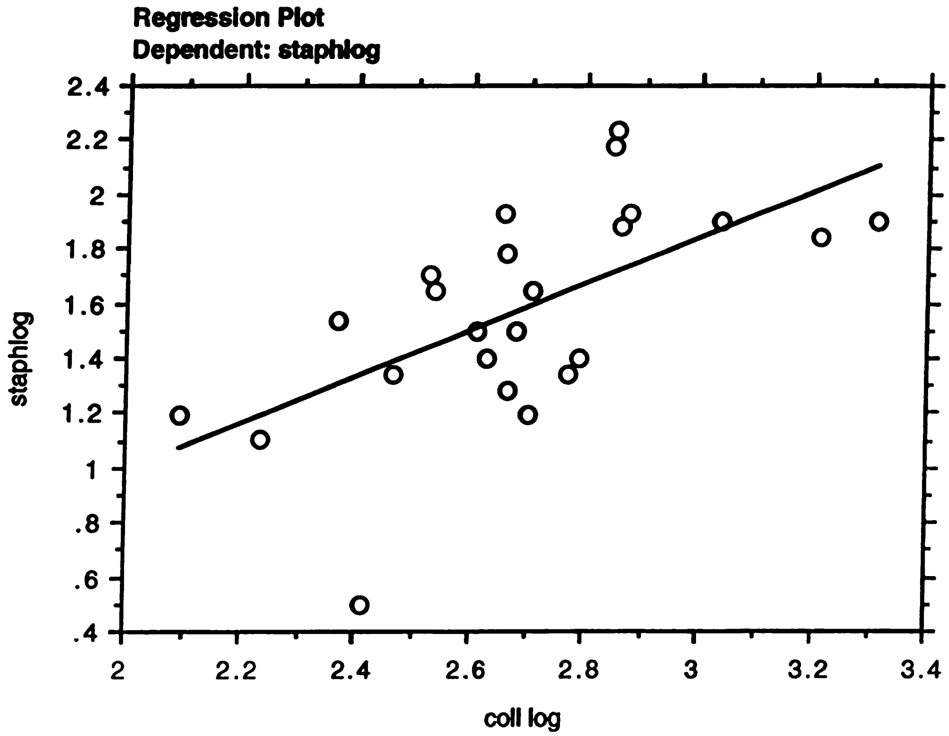


Figure 8. Relationship between mites extracted from a soil core and the staphylinid adults caught in the 2 adjacent pitfall traps at Groesbeck Golf Course in 1999. Equation for regression and regression statistics can be found in Table 5.

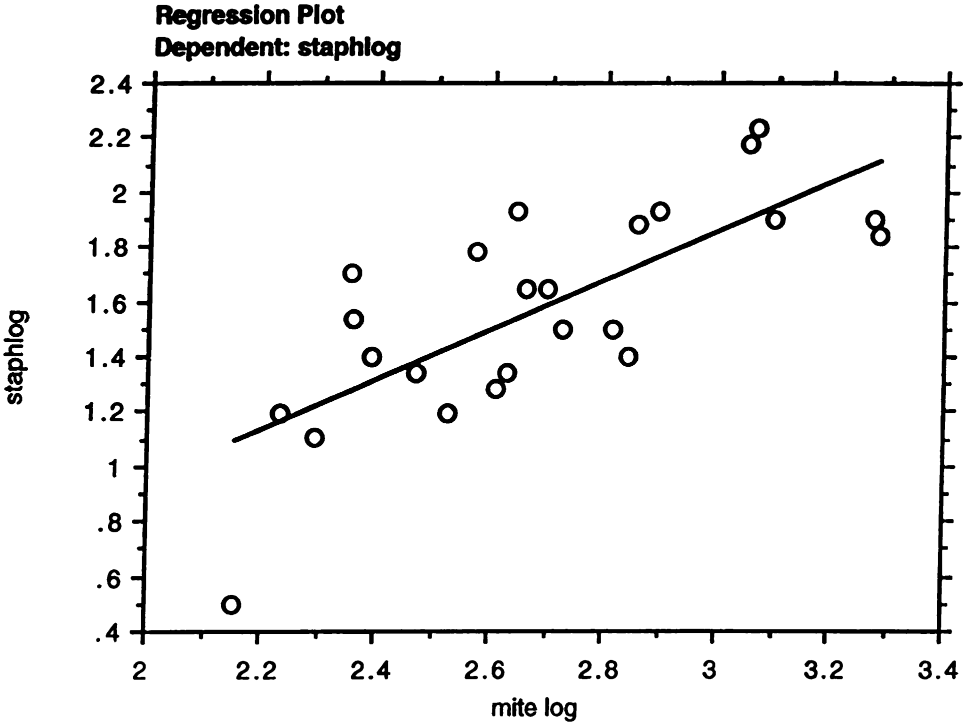


Figure 9. Precipitation data from East Lansing, Michigan for April to July in 1999 and 2000.

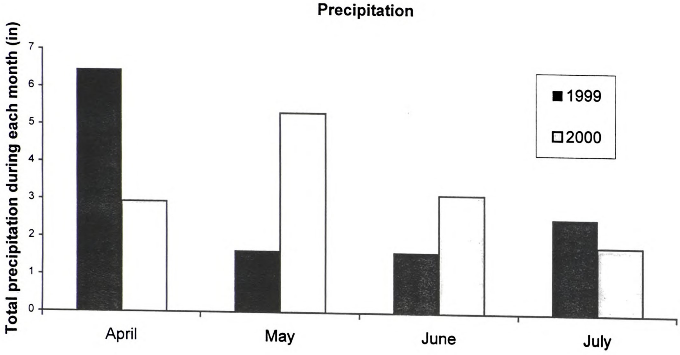


Figure 10. Temperature data in degrees F from East Lansing, Michigan from April to July in 1999 and 2000.

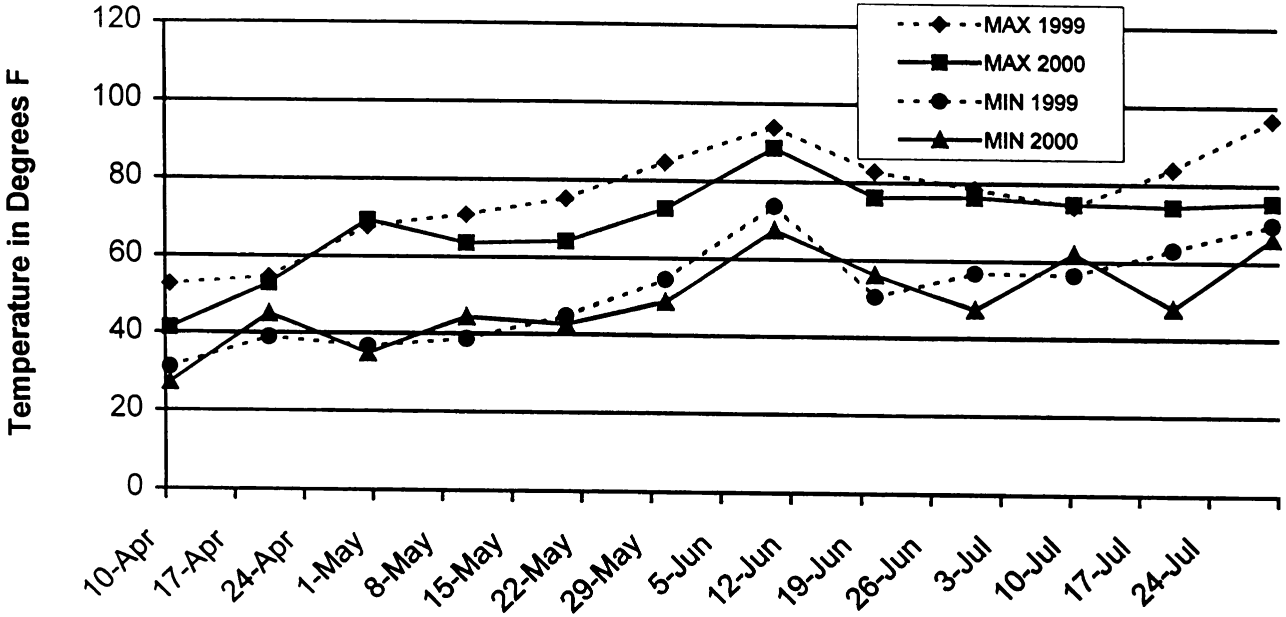
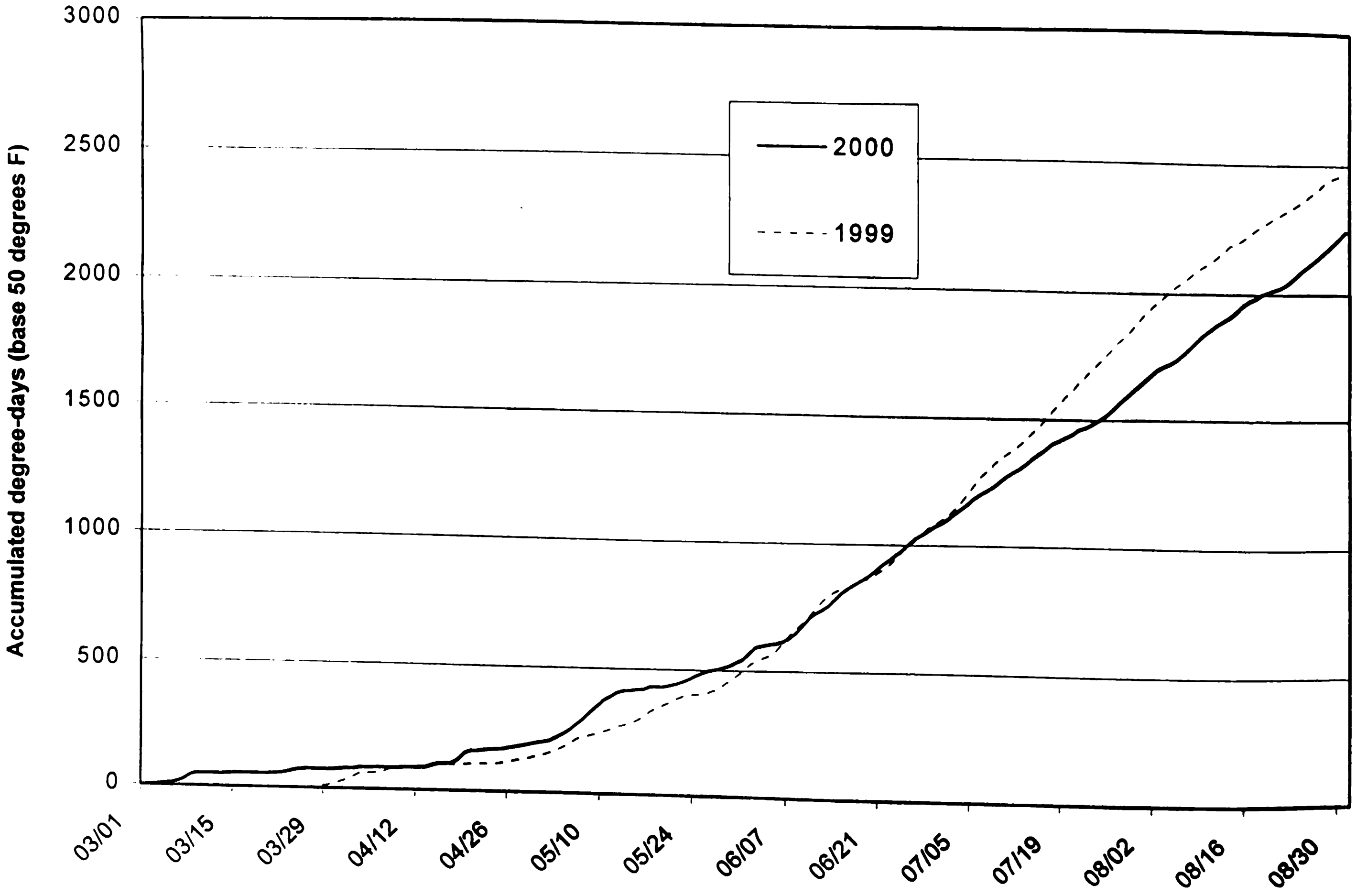


Figure 11. Accumulated degree-days (base 50 degrees F) for East Lansing, Michigan for both field seasons. Data was taken from a weather station at the Horticultural Gardens at Michigan State University.



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Appendix 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2001-02

Title of thesis or dissertation (or other research projects):
EXAMINATION OF THE ARTHROPOD COMMUNITY ON A GOLF COURSE FAIRWAY AND ROUGH

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)
Breana Lee Simmons

Date 02/14/01

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:
Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.1

Voucher Specimen Data

Page 1 of 2 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Ataenius spretulus (Haldeman)	Groesbeck Golf Course, Lansing, MI May-00					5	5		MSU
Aphodius granarius (L.)	Groesbeck Golf Course, Lansing, MI Apr-00					5	5		MSU
Sphenophorus minimus Hart	Groesbeck Golf Course, Lansing, MI Jun-00					5	5		MSU
Amara aenea (DeGeer)	Groesbeck Golf Course, Lansing, MI May-00					5	5		MSU
Stenolophus comma (Fabricius)	Groesbeck Golf Course, Lansing, MI May-00					1			MSU
Philonthus cognatus Stephens	Groesbeck Golf Course, Lansing, MI Apr-00					5	5		MSU
Pterostichus melanarius (Illiger)	Groesbeck Golf Course, Lansing, MI Jun-00					1	1		MSU
Anisodactylus rusticus (Say)	Groesbeck Golf Course, Lansing, MI May-00					1			MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)
Breana Lee Simmons

Date 2/14/01

Voucher No 2001-02
Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date

Appendix 1.1

Voucher Specimen Data

Page 2 of 2 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Scarites sp. (Haldeman)	Groesbeck Golf Course Lansing, MI May-00					1	1		MSU
Psuedosinella rolfsi Mills	Groesbeck Golf Course Lansing, MI Jun-99					10	10		MSU
Isotoma notabilis (Folsom)	Groesbeck Golf Course Lansing, MI Jun-99					10	10		MSU
Graptoppia italica (Bernini)	Groesbeck Golf Course Lansing, MI May-00					3	0		MSU
Epilohmannia elongata (Banks)	Groesbeck Golf Course Lansing, MI Jun-99					1			MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Breana Lee Simmons

Date 2/14/01

Voucher No 2001-02

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date