

ABSTRACT

Title of Thesis: EVALUATION OF CONSERVATION STRIPS AS A
CONSERVATION BIOLOGICAL CONTROL TECHNIQUE ON
GOLF COURSES

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Conservation strips combine the conservation biological control tactics of beetle banks and flowering insectary strips. Conservation strips were established on golf course fairways to evaluate their effect on arthropod abundance and distribution. The conservation strips contained two flowering plants, alyssum and coreopsis, and an ornamental grass. In general, the plants species in the conservation strips supported a greater abundance of predators, parasitoids and alternative prey than turf. Conservation strips also resulted in a greater abundance of natural enemies and alternative prey in the fairway adjacent to the conservation strips versus fairways without conservation strips. Predation on cutworm larvae in fairways was significantly more frequent when conservation strips were present. For these reasons conservation strips show great potential as a conservation biological control tactic on golf courses. Installation of conservation strips could result in reduced pest pressure and a reduction in the need for insecticide applications on golf courses.

EVALUATION OF CONSERVATION STRIPS AS A CONSERVATION
BIOLOGICAL CONTROL TECHNIQUE ON GOLF COURSES

by

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INTRODUCTION

Turf grass systems are often intensively managed to maintain high aesthetic standards and low damage thresholds. This is especially true on golf courses. Golf courses are frequently under pressure from clients to maintain flawless fairways, tees and greens. Golf courses are at risk of losing clients or members, and superintendents their jobs, if the highest aesthetic and playability standards are not met. This economic pressure results in the use of insecticides that is often excessive and preventative rather than curative (Racke and Leslie 1993). This pest management strategy is monetarily expensive for golf courses and holds a number of known and unknown risks to the environment and public. The use of pesticides puts many people at risk from the personnel who apply the chemicals to the people living in the vicinity of the golf course (Potter 1998, Vittum et al 1999). Pesticide use can also pollute ground and surface water and have negative effects on non-target organisms including predatory beetles, ants, and spiders (Cockfield and Potter 1983, 1984, 1985; Terry et al 1993; Kunkel et al 2001) and contribute to insect pesticide resistance (Reinart 1982, Tashiro 1982). This reduction in predatory insects may also result in pest resurgence (Cockfield and Potter 1984, Terry et al 1993). However, changes in legislation governing pesticide use and the growing environmental awareness of the general public have put golf course superintendents in a difficult position; trying to please their clientele while working under the scrutiny of the public and government. For this reason, interest in developing successful IPM strategies for golf courses, and turf in general, is on the rise.

Turf grass is an inherently simple system with regards to vegetational and structural diversity. A large body of research suggests that this lack of complexity makes turf grass systems, like those found on golf courses, especially prone to pest insect outbreaks and reduced predator populations. Complex habitats are more favorable to predator communities than simple habitats. This is a key component of the ‘enemies hypothesis’ proposed by Root (1973). The ‘enemies hypothesis’ states that predator numbers, diversity, and efficiency increase with increasing plant heterogeneity. Simple habitats are often unsuitable or unattractive to predatory arthropods. Conversely, these areas of low vegetational complexity can be beneficial for herbivorous pest species. This is partly due to the lack of natural enemies but also has other explanations. The ‘resource concentration hypothesis’ suggests that herbivores flourish in monocultural or simple habitats due to the concentration of food and other resources found there (Root 1973). Resource abundance will reduce the time and energy required to find a host plant, which may result in increased survivorship, developmental rates, and earlier first reproduction (Price et al. 1980). Shrewsbury and Raupp (2000) found greater abundances of herbivores in structurally simple habitats. It is suggested that structurally simple habitats may offer a thermal refuge that could influence oviposition preference, growth rate, or plant quality (Price et al. 1980, Shrewsbury and Raupp 2000).

Studies have shown that even minor changes in the complexity of turf grass systems can alter the composition of the arthropod populations living in those systems (Smitley et al. 1998, Rothwell and Smitley 1999). In all the studies added complexity took the form of tall versus short mowing heights. Comparisons between predator populations in the roughs and fairways of golf courses help to illustrate this point.

Samples taken in the fairway (short grass) contain more pest insects and fewer predators as distance from the rough (tall grass) increases. Likewise, sampling yields fewer pest insects in the rough further from the fairway (Smitley et al. 1998). Other research has shown that by increasing the mowing height of turf on golf courses or residential turf systems can also result in an increase in predators and decrease in pests (Rothwell and Smitley 1999). This research confirms the belief that greater complexity can reduce the risk of pest outbreaks. Golf courses already contain areas of grass mowed to different heights: fairways and roughs. However, even the roughs are structurally very simple monocultures. While they may be more stable and balanced systems than the fairways, they are not supporting a great enough population and diversity of predators to enrich the fairways to a point of effective pest control. Furthermore, the roughs on golf courses may not be suitable habitat for over-wintering by predator populations forcing the predators to migrate into the course each year from any surrounding wooded or weedy areas that could serve as an over-wintering refuge.

A variety of arthropod taxa have been shown to be effective predators of turf grass pests. These include spiders, carabid beetles, staphylinid beetles, and ants. Sod webworm (Lepidoptera: Pyralidae) eggs are preyed upon by all of the previously mentioned groups (Cockfield and Potter 1984). These predators have also been shown to prey on Japanese beetle, *Popillia japonica* (Coleoptera: Scarabidae), eggs and on the larvae and pupae of fall armyworms, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (Terry et al 1993). The capture of black turf grass ataenius, *Ataenius spretulus* (Coleoptera: Scarabidae), in pitfall traps was inversely correlated to the capture of carabid beetles, staphylinid beetles, and histereid beetles in golf course fairways and

roughs (Smitley et al, 1998). Other predatory groups that are known to feed on armyworm (stages egg through 6th instar larvae) are the coccinellid *Coleomegilla maculata* DeGeer, big-eyed bug *Geocoris punctipes* Say, and several earwig species (Dermaptera) (Gross and Pair 1986).

Research on parasitism of insect pests in turf systems is almost nonexistent. There has been work done to identify parasitoids of turf pests that are also agricultural pests such as cutworms and armyworm (Lepidoptera: Noctuidae). Braconids, Ichneumonids, and Tachinids were found to be the dominant parasitoids of fall armyworms in the southeast United States (Gross and Pair 1986). One study reared 53 species from 10 families of parasitoids from fall armyworms (Ashley 1979). The highest level of parasitism found on armyworms in grass was 54% (Ashley 1986). Cutworms share many of the same parasitoids as armyworms. This was demonstrated by research in peppermint (Coop et al. 1986) and in corn (Turnock et al. 1993).

Recent work has demonstrated that large numbers of predatory beetles and spiders can be attracted to, and maintained in beetle banks (Thomas et al. 1991, 1992). Beetle banks are strips of bunch grass 1.5m wide that are installed within agricultural fields. Beetle banks provide shelter to predators from the routine disturbance agricultural fields incur, protection from extreme temperature variations, and over wintering sites. Predator densities in beetle banks reached over 1500m⁻² in the second year the bank is established (Thomas et al. 1991, 1992). The advantage of beetle banks over traditional hedgerows and field boundaries is that the beetle banks are ‘islands’ of habitat within the crop. Therefore, predators are living and over wintering in the middle of the field as well as in the field margins. This reduces the amount of time required for predator populations to

colonize a field in the spring or recolonize after a disturbance. When carabid beetles emerge in the spring in can take up to 50 days for some species to disperse 50 to 100m into a field (Coombes et al. 1986). By this time pest populations in the center of fields may have already exceeded threshold levels because they have increased unchecked for several weeks. There are limits to the distance predatory beetles travel from field margins. As such, there are limits to the distance from those margins that predator populations are high enough to have an impact on pests populations. The distance carabids emigrate, in high densities, from beetle banks has been shown to be at least 60m in cereal crops (Thomas et al. 1991). By constructing beetle banks at 120m intervals within the field predator populations can be maximized while minimizing the amount of field taken out of production.

In ornamental and agricultural systems, natural enemy populations have been enhanced by installing insectary strips of flowering plants. While these strips increase the structural complexity of an area, they are particularly effective at attracting parasitic Hymenoptera and Diptera. The flowering strips offer natural enemies floral resources and alternative prey. Parasitic hymenoptera have been show repeatedly to be attracted to the nectar resources of flowering plants (Jervis et al. 1993, Idris et al. 1995). Maingay et al. (1991) documented the presence of many parasitic and predatory wasps on the common garden herbs fennel and spearmint. Among these were 12 ichneumonid species that are known to parasitize agricultural pests and three families of predatory wasps. In addition to parasitoids, floral resources have been shown to increase the populations of predators as well. Patt et al. (1997) found a significant increase in coccinellid beetles in fields of eggplant interplanted with dill and coriander. These resources encourage the

natural enemies to remain in the vicinity of the strip and seek prey/hosts in the adjacent ornamental or crop areas. In a mark and release study, marked parasitoids and coccinellids were recovered 75m into adjacent crops from insectary strips (Long et al. 1998). The addition of flowers to the beetle banks will have two benefits on golf courses. It should increase the effectiveness of the beetle banks because several turf pests are susceptible to parasitoid as well as predatory control. Also, adding flowering plants to the beetle banks makes them more visually appealing and look more like traditional ornamental plant beds.

Research on conserving and attracting natural enemies in agricultural and ornamental systems has shown the effectiveness of beetle banks and flowering insectary strips to increase predator abundance and diversity, and the potential of these methods to control pest populations. However, no study has sought to increase predator and reduce pest populations of golf courses or other turf grass systems by installing suitable habitat such as flowering strips or beetle banks. In this study insectary strips and beetle banks were combined to create *conservation strips* in an attempt to attract and conserve natural enemies on golf courses. The overall goal of this research was to evaluate different affects that conservation strips would have on natural enemy, alternative prey, and pest communities and to determine whether conservation strips are an affective strategy for implementing conservation biological control on golf courses.

CHAPTER 1

The Abundance of Arthropods from Different Trophic Groups Found in Alyssum, Coreopsis, Switchgrass, and Turf

Introduction

Research on conserving and attracting natural enemies in agricultural and ornamental systems has shown that the addition of beetle banks (Thomas et al 1991, 1992) and flowering insectary strips (Patt et al. 1997, Chaney 1998) to a habitat can increase predator abundance and diversity. In turn, increased predator activity can reduce insect pest populations. The ability of beetle banks or flowering insectary strips to attract natural enemies can vary with the plant species that are included in these refuges (Thomas et al 1991, Chaney 1998, Al-Doghairi and Cranshaw 1999). Within a beetle bank or flowering insectary strip, one species of plant may attract more natural enemies or different taxa of natural enemies than another plant species. Furthermore, different taxa of natural enemies are attracted to, and live in beetle banks than may be attracted to flowering plants that offer substantial nectar or pollen resources.

There is also the undesirable possibility that the indiscriminate introduction of plants could attract or support pest insects. Baggen and Gurr (1998) used the flowering plants buckwheat (*Fagopyrum esculentum*), and coriander (*Coriandrum sativum*) to attract parasitoids of the potato tuber moth, *Phthorimaea operculella*. Parasitism rates were higher in close proximity to the flowers but the *P. operculella* larvae populations and crop damage were also greater near the flowers. In addition, coriander and buckwheat significantly increased the fecundity of *P. operculella* in the lab relative to

other flowering plants such as borage (*Borago officinalis*) and nasturtium (*Tropaeolum majus*) (Baggen and Gurr 1998). Therefore, it is essential to know the arthropod community that plants attract when selecting plant species to use in natural enemy refuges or conservation strips.

Several different species of grasses have been examined in beetle bank research (Thomas et al. 1991). Among these grasses significant differences were found in the abundance and species of ground beetles (Carabidae), rove beetles (Staphylinidae), and spiders (Araneae) overwintering in them. For example, in the second year of the study, the grass, *Dactylis glomerata*, had significantly more carabid beetles overwintering in it than the grass, *Agrotis stolonifera* (1112.5 and 157.5, respectively). However, these two grass species did not differ in the number of staphylinid beetles overwintering in them (152.5 and 160.3, respectively), nor in the number of spiders (170.0 and 222.5, respectively) (Thomas et al. 1991).

Many species of flowering plants have been evaluated for their value in attracting natural enemies. These surveys frequently show significant variation in the taxa and abundance of natural enemies they attract (Al-Doghairi and Cranshaw 1999, Colley and Luna 2000). Colley and Luna (2000) examined 11 flowering plant species and found significant differences in the number of syrphid flies attracted to plants in their study. For this reason it is important to evaluate the plant species used in any given situation to determine whether they are attracting large numbers of natural enemies and whether they are attracting natural enemies that are important in controlling the pest or pests of interest.

Turfgrass is an inherently simple system with regards to vegetational complexity and plant species diversity. A large body of research suggests that this lack of complexity makes turf grass systems, like those found on golf courses, especially prone to pest insect outbreaks and that even minor changes in the complexity of turf such as increasing mowing height can result in fewer pests and a greater abundance of predators (Smitley et al. 1998, Rothwell and Smitley 1999). Pitfall trap samples taken in the fairway (short grass) contain more pest insects and fewer predators than samples from the rough (tall grass)(Smitley et al. 1998). Other research has shown that by increasing the mowing height of turf on golf courses or residential turf systems can also result in an increase in predators and decrease in pests (Rothwell and Smitley 1999). If minor changes such as mowing height can drastically change arthropod communities then incorporating conservation strips into golf course environments to enhance natural enemy populations may be a feasible approach to reducing insect pest outbreaks.

The objective of this study was to elucidate and compare the arthropod community attracted to two species of flowering plants, alyssum and coreopsis, and one species of ornamental grass, switchgrass, to assess their potential for use in conservation strips. In addition, the arthropod community of these plants was compared to that of turf growing in golf course roughs to determine if plants enhance natural enemy taxa and abundance compared to turf.

Methods

Study sites and experimental design. To evaluate the arthropod community associated with ornamental plants and turf grass in golf course roughs, field studies were conducted at two golf courses in Maryland, Glenn Dale Golf Course (Glenn Dale, MD)

and Timbers of Troy Golf Course (Elkridge, MD). Studies were conducted on six fairways with three fairways located at Glendale Golf Course and three on Timbers at Troy Golf Course (fairways were blocked with 1 replicate / block). Four plants species were surveyed in this experiment: alyssum 'Easter Basket Mix', *Lobularia maritima*; Coreopsis, *Coreopsis verticillata* 'Moonbeam'; switchgrass, *Panicum virgatum* 'Northwind'; and rough mown (10cm) turf grass which was a blend of tall fescue, *Festuca arundinaceae*, and Kentucky bluegrass, *Poa pratensis*. A conservation strip containing the three species of ornamental plants, alyssum, coreopsis, and switchgrass, was installed in each of the six fairways in June of 2002. Each conservation strip was situated in the rough, 4m from the edge of the fairway. Conservation strips varied in size but had the minimum dimensions of 8 x 3m and maximum dimensions of 4 x 16m. Conservation strips were always positioned with the long side parallel to the fairway. Plants were always installed in the conservation strips in the same manner. The conservation strip was longitudinally divided into three sections. Alyssum, being the shortest species, was planted in the section nearest the fairway. Coreopsis was planted in the middle section, and switchgrass, being the tallest, was planted in the section furthest from the fairway. The turf sampled in this experiment was located at least 60m away from the conservation strips in the rough of the same fairway and the same distance from the fairway as the conservation strip to ensure that ornamental plant treatments did not influence arthropod activity in the turf treatment.

Foliar and flower arthropod community. The arthropod community was surveyed on the foliage and flowers of alyssum, coreopsis, switchgrass, and turf using a D-Vac insect vacuum (Rincon-Vitova Insectaries, Inc, Ventura, CA). The foliar and

flower arthropod samples were taken on two dates, July 15 and 17 2002 and September 12 and 18 2002 (Glen Dale and Timbers respectively). A standardized sampling method was developed and one sample was taken from each of the 4 plant treatments on each fairway on both dates. The D-Vac suction hose had an opening with an area of 0.9m². The hose was placed over the desired plant material approximately 10cm above the ground for five seconds. Then the hose was moved to another place in the same plant type for an additional five seconds. After the plant type was sampled in two locations, the net containing the suctioned arthropods was removed and the end was closed with a rubber band. The closed net was stored in a container with ethyl-acetate fumes to kill the insects. Samples were returned to the laboratory, the contents of each net was emptied into a mason jar containing a 70% ethanol solution. Using a stereo-microscope, specimens were sorted into trophic groups of predator, turf pest, alternative prey, parasitoids. Insects that did not fit into one of these trophic groups were assigned to separate categories (i.e. ants and flies). The most abundant taxa from each trophic group were identified to family.

Ground dwelling arthropod community. Ground dwelling arthropods associated with each plant treatment were sampled with pitfall traps on two dates, July 22 and 25, 2002 and August 12 and 15, 2002 (Glen Dale and Timbers respectively). The pitfall traps were made from glass vials that were inserted in the ground just below the surface of the soil. Each vial was filled one third full with a 20% propylene glycol solution with soap added to reduce surface tension. The diameter of the mouth of the vial was 19mm. Two pitfall traps were installed in each of the 4 plant treatments. On each sampling date the

traps were left out for seven days. Samples were brought back to the laboratory and sorted and identified as described above.

Statistical analysis. To compare the abundance of arthropod trophic groups among the 4 plant treatments, an ANOVA analysis was conducted using the MIXED procedure in SAS (2001). Raw data were $\log_{10}(y+1)$ transformed prior to analysis to meet the assumptions of homogeneity of variance. Foliar and flower arthropods, and ground dwelling arthropods were analyzed separately.

Results

Foliar and flower arthropod community. The taxa and families that make up each trophic group, and the percentage that each contributes to the total number of foliar and flower arthropods caught, are presented in Table 1. In the ANOVA analysis comparing foliar and flower arthropod abundance between plant types, the predator and parasitoid trophic groups had significant treatment (plant type) by date interactions (Table 2). Therefore, comparisons between plant type are discussed separately for each date based.

Predator populations were significantly higher in alyssum than coreopsis (*LSD*, $P=0.0009$, Fig. 1), switchgrass (*LSD*, $P<0.0001$, Fig. 1), or turf (*LSD*, $P=0.0002$, Fig. 1) in July. Predator populations were also significantly higher in alyssum than coreopsis (*LSD*, $P=0.0237$, Fig. 1), switchgrass (*LSD*, $P<0.0001$, Fig. 1), or turf (*LSD*, $P<0.0001$, Fig. 1) in September. In September, predator abundance in coreopsis was significantly higher than either switchgrass (*LSD*, $P=0.0001$, Fig. 1) or turf (*LSD*, $P<0.0001$, Fig. 1).

Parasitoid abundance was significantly higher in alyssum than coreopsis (*LSD*, $P < 0.0001$, Fig. 2), switchgrass (*LSD*, $P < 0.0001$, Fig. 2), or turf (*LSD*, $P = 0.0002$, Fig. 2) in July. In September, alyssum had significantly more parasitoids than switchgrass (*LSD*, $P < 0.0001$, Fig. 2) or turf (*LSD*, $P < 0.0001$, Fig. 2). Coreopsis also had significantly more parasitoids than switchgrass (*LSD*, $P = 0.0206$, Fig. 2) or turf (*LSD*, $P = 0.0052$, Fig. 2).

Alternative prey populations were significantly higher in alyssum than switchgrass (*LSD*, $P = 0.0015$, Fig. 3) or turf (*LSD*, $P = 0.0442$, Fig. 3) in July. In September, alyssum had significantly more alternative prey than switchgrass (*LSD*, $P = 0.0320$, Fig. 3) or turf (*LSD*, $P = 0.0172$, Fig. 3). Coreopsis also had significantly more alternative prey than switchgrass (*LSD*, $P = 0.0030$, Fig. 3) or turf (*LSD*, $P = 0.0016$, Fig. 3). No turf pests were captured during D-Vac sampling of the plant material.

Ground dwelling arthropod community. The taxa and families that make up each trophic group, and the percentage that each contributes to the total number of ground dwelling arthropods caught, are presented in Table 3. Predator abundance was significantly different between plant types ($F = 4.85$, $df 3, 29.3$, $P = 0.0074$; Table 4). There was not a significant treatment by date interaction in any of these analyses (Table 4). In July, ground dwelling predators were significantly more abundant in alyssum than in coreopsis (*LSD*, $P = 0.0022$, Fig. 4). Neither of these differed significantly from switchgrass (*LSD*, $P > 0.05$, Fig. 4) or turf (*LSD*, $P > 0.05$, Fig. 4). In August but predators did not differ between plant types (*LSD*, $P > 0.05$, Fig. 4).

Data for specific groups of predators were pooled for both dates. Otherwise numbers for each group were too low to satisfy assumptions of ANOVA. Carabid beetles were significantly more abundant in alyssum than in turf (*LSD*, $P = 0.0275$, Fig. 5)

although the overall treatment effect was not significant ($F=2.05$, $df=3$, 33.2 , $P=0.1256$). Staphylinid abundance was significantly different among plant types ($F=5.49$, $df=3$, 32.2 , $P=0.0037$). Staphylinid beetles were significantly more abundant in alyssum than in coreopsis (LSD , $P=0.0227$, Fig. 5). They were also significantly more abundant in turf than in coreopsis (LSD , $P=0.0009$, Fig. 5), or switchgrass (LSD , $P=0.0074$, Fig. 5). Spiders were similarly abundant in all plant types ($F=0.47$, $df=3$, 32.2 , $P=0.7042$; LSD , $P>0.05$, Fig. 5).

There was a significant effect of plant type on parasitoid abundance ($F=4.98$, $df=3$, 29.1 , $P=0.0066$). In July, parasitoids were significantly more abundant in alyssum than coreopsis (LSD , $P=0.0253$, Fig. 6), switchgrass (LSD , $P=0.0223$, Fig. 6), but not more so than turf (LSD , $P>0.05$, Fig. 6). In August, parasitoids were significantly more abundant in alyssum than switchgrass (LSD , $P=0.007$, Fig. 6).

There was not a significant effect of plant type on alternative prey abundance overall ($F=0.72$, $df=3$, 29.2 , $P=0.5486$). However, alternative prey abundance was significantly higher in alyssum than turf in July (LSD , $P=0.0302$, Fig. 7). In August, alternative prey did not differ significantly between plant types (LSD , $P>0.05$, Fig. 7).

Pests could not be statistically analyzed due to low numbers collected. However, the means for each date and plant type are presented in Fig. 8. Numerically, switchgrass and turf had the most pests present in July and in August.

Discussion

Overall, these field studies on golf courses demonstrated that there were differences in the arthropod communities attracted to each plant species. Moreover, I determined the ornamental plant species, alyssum, coreopsis, and switchgrass, harbored more natural enemies than turf.

Sampling of foliage and flowers yielded significant differences in arthropods between the flowering plants (alyssum and coreopsis) and the two grasses (turf and switchgrass). A variety of predatory arthropods were attracted to the alyssum and coreopsis flowers, of which the most abundant groups included several that are known to be important predators of turf pests. Big-eyed bugs (*Geocoris spp.*, Heteroptera: Lygaeidae), found commonly on flowering plants in this study, have also been found to be important predators in turfgrass systems (Braman et al. 2002). Minute pirate bugs (*Orius spp.*, Heteroptera: Anthocoridae) are predators of eggs and small arthropods in many other ornamental and agricultural systems (Weizierl and Henn 1994) but have not received much, if any, attention in turfgrass systems. Similarly, in my studies minute pirate bugs were sampled from the ornamental plants but none were found in the turf.

A somewhat different array of predators were captured by pitfall trapping. Overall, carabid beetles, staphylinid beetles, and spiders were the most abundant taxa. Interestingly, these taxa each had different distributions among plant types. Carabids seemed to prefer any plant in the conservation strip relative to turf. Spiders appeared to prefer all plants equally, including turf. Staphylinids on the other hand seemed to prefer turf and alyssum over coreopsis and switchgrass. The alyssum was structurally more similar to turf than the other plants in the conservation strips. Alyssum has a ground

cover habit and a low canopy with many stems and leaves within the canopy whereas coreopsis and switchgrass are tall upright plants. It appears staphylinids prefer low growing, ground cover type plants over plants with upright habits. Interestingly, alyssum supported more alternative prey than turf but staphylinid abundance did not differ between the two plant types.

It is not surprising that parasitoid wasps were more abundant in the two flowering species of plants. Many parasitoids feed on nectar and pollen while using other insects strictly as hosts for oviposition. Little work has been done to demonstrate whether an abundance of parasitoids will translate into increased parasitism of turf pests. However, with an eight-fold difference in the mean number of parasitoids between alyssum and turf, combined with a four-fold difference between coreopsis and turf, increased parasitism near conservation strips would not be an unreasonable expectation. The value of parasitoids in turf systems is not well studied. However, fall armyworms, *Spodoptera frugiperda*, are susceptible to parasitoids in agricultural systems. (Ashley 1979, 1986 and Gross et al. 1986). *S. frugiperda* is also a pest in turf systems as are several members of the family Noctuidae (black cutworms, *Agrotis ipsilon*; armyworms, *Pseudaletia unipuncta*). Two species of wasps in the family Tiphidae are ectoparasites of turf infesting scarab beetle grubs. *Tiphia vernalis* parasitizes Japanese beetle, *Popillia japonica* and *Tiphia pygidialis*, are parasites of the masked chaffer, *Cyclocephala* spp. (Coleoptera:Scarabaeidae) grubs (Rogers et al. 2003). Tiphia wasps also feed on nectar from flowers (Potter 1998) and therefore conservation strips may be able to increase tiphia abundance.

In general, alternative prey were more abundant in alyssum and coreopsis than turf or switchgrass when sampled with a D-Vac. When sampled with pitfall traps, alternative prey abundance did not generally differ. Collembola were the most abundant alternative prey item in the conservation strips. Collembola feed on many different things including pollen (Kevan and Kevan 1970, Takeda and Ichimura 1983, Ponge 2000), fungal spores and hyphae, micro-algae, and other organic matter (Takeda and Ichimura 1983, Ponge 2000). These potential food items may be more abundant or diverse in and near the conservation strips than turf. Collembola are also sensitive to moisture levels in the soil and have been found to be more abundant when soil moisture is greater (Frampton et al. 2000). Frampton et al. (2000) inflicted early season drought to winter wheat fields, which resulted in long-term reductions of some species of Collembola, even after irrigation was reinstated. In this sense, conservation strips may be a moister, or at least more stable habitat for collembola to inhabit and find food. Other alternative prey, while not tested statistically, were numerically more abundant in conservation strips than turf. Among these were Heteropterans and Orthopterans.

Overall, very few pests, or potential pests, were caught in the conservation strips. No turf pests were caught in the foliage and flowers of alyssum, coreopsis, or switchgrass. Flea beetles, which are not a turf pest but are a potential pest in some agricultural and ornamental systems, were caught in the alyssum and coreopsis and turf. Ground dwelling pests, the majority of which were curculionids, scarabaeids, were more abundant in the turf than anywhere within the conservation strip. This is an important finding in that the conservation strips do not appear to be providing refuge for pest species.

The plants within conservation strips, especially alyssum and coreopsis, offer resources and habitat that many predators, parasitoids, and alternative prey find attractive. Some of these trophic groups or taxa may be attracted to the pollen and nectar provided by flowers and others by the increased complexity and shelter of these plants. Regardless, conservation strips supported predators, parasitoids, and alternative prey in greater abundance than turf in the rough of golf courses. This study strongly suggests that incorporating alyssum, coreopsis, and switchgrass into golf course habitats may be an effective approach to conserving and enhancing natural enemies. The effect of greater natural enemy abundance on reducing insect pest populations remains unknown.

Table 1. Summary of foliar and flower dwelling arthropod taxa collected with a D-Vac in July and September of 2002.

Trophic group Taxon	Total no. individuals collected¹	% of total	% of trophic group
Predators	722	10.3	
Spiders	293		40.5
Staphylinidae	42		5.8
Anthocoridae	154		21.3
Lygaeidae	166		23.0
Other predator taxa ²	67		9.4
Parasitoids	1158	16.5	
Alternative prey	623	8.9	
Collembola	88		14.1
Heteropterans	507		81.4
Other alt. prey taxa ³	28		4.5
Pests	0	0.0	
Chrysomelidae	140	0.2	
Diptera	4342	62.3	
Total	6998	100.0	

¹ Totals are the sums of arthropods collected on all dates and all treatments.

² 'Other predators' includes: Carabidae, Coccinellidae, Cantharidae, and Syrphidae

³ 'Other alt. prey' includes: miscellaneous Coleoptera and Orthoptera

Table 2. ANOVA for foliar and flower arthropod abundance alyssum, coreopsis, switchgrass, or rough turf¹. Samples were taken with a D-Vac in July and September 2002

Trophic group	Effect	F	ndf, ddf	Pr>F
Predators	Treatment	28.68	3, 34.2	<.0001
	Date	2.97	1, 34.2	0.0941
	Treatment*Date	3.72	3, 34.2	0.0203
Parasitoids	Treatment	35.66	3, 34.2	<.0001
	Date	4.50	1, 34.2	0.0412
	Treatment*Date	7.65	3, 34.2	0.0005
Alternative prey	Treatment	7.87	3, 35.2	0.0004
	Date	0.07	1, 35.3	0.7979
	Treatment*Date	1.93	3, 35.2	0.1428
Pests²	Treatment	-	-	-
	Date	-	-	-
	Treatment*Date	-	-	-

¹ Data were $\log_{10}(y+1)$ transformed prior to ANOVA. The experiment was a randomized complete block design replicated 6 times on each date.

² No turf pests were caught in the foliar and flower samples

Table 3. Summary of foliar and flower dwelling arthropod taxa collected with pitfall traps in July and August of 2002.

Trophic group Taxon	Total no. individuals collected¹	% of total	% of trophic group
Predators	312	18.4	
Spiders	101		32.4
Staphylinidae	102		32.7
Carabidae	89		28.5
Other predator taxa ²	20		6.4
Parasitoids	76	4.5	
Alternative prey	366	21.5	
Collembola	311		85.0
Other alt. prey taxa ³	55		15.0
Pests	44	2.5	
Curculionidae	14		31.8
Noctuidae	13		29.5
Scarabaeidae	17		38.7
Chrysomelidae	20	1.2	
Diptera	114	6.7	
Formicidae	768	45.2	
Total	1700	100.0	

¹Totals are the sums of arthropods collected on all dates and all treatments.

² 'Other predators' includes: Anthocoridae (minute pirate bugs only), Lygaeidae (big-eyed bugs only), Dermaptera, Chilopoda,

³ 'Other alt. prey' includes: miscellaneous Coleoptera, Diplopoda, Isopoda, Orthoptera, Heteroptera

Table 4. ANOVA for ground dwelling arthropod abundance in alyssum, coreopsis, switchgrass, or rough turf¹. Samples are from pitfall traps in July and August 2002.

Trophic group	Effect	F	ndf, ddf	Pr>F
Predators	Treatment	4.85	3, 29.3	0.0074
	Date	0.30	1, 28.5	0.5866
	Treatment*Date	0.68	3, 28.5	0.5719
Parasitoids	Treatment	4.98	3, 29.1	0.0066
	Date	3.13	1, 28.9	0.0875
	Treatment*Date	0.37	3, 28.8	0.7724
Alternative prey	Treatment	0.72	3, 29.2	0.5486
	Date	0.00	1, 28.9	0.9832
	Treatment*Date	2.25	3, 28.9	0.1037
Pests²	Treatment	-	-	-
	Date	-	-	-
	Treatment*Date	-	-	-

¹ Data were $\log_{10}(y+1)$ transformed prior to ANOVA. The experiment was a randomized complete block design replicated 6 times on each date.

² Turf pests occurred in very low numbers so ANOVA was not performed on these data

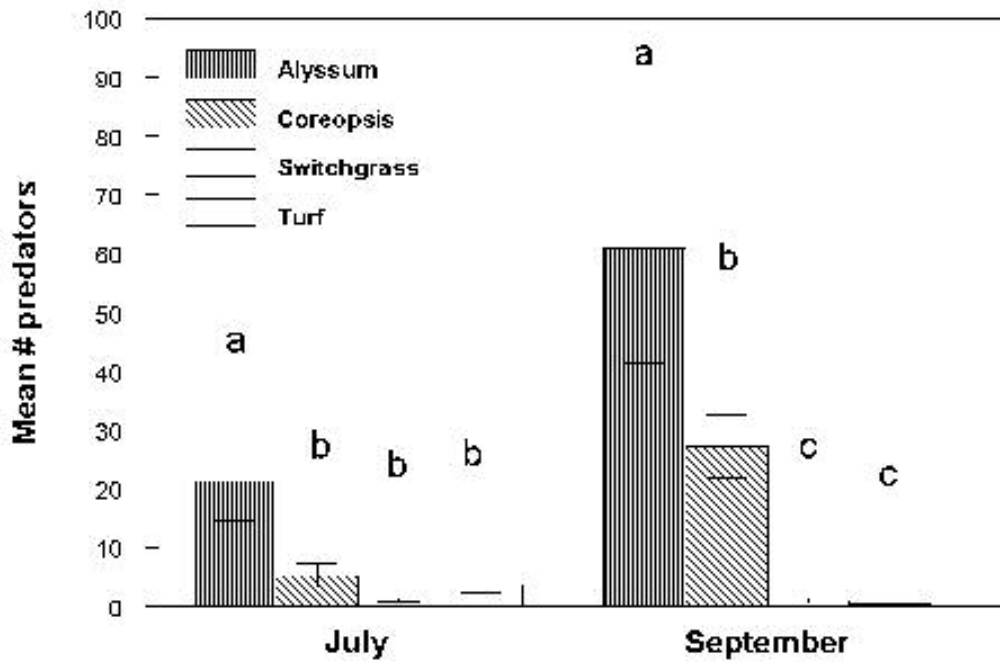


Figure 1. Mean \pm SE number of predators caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

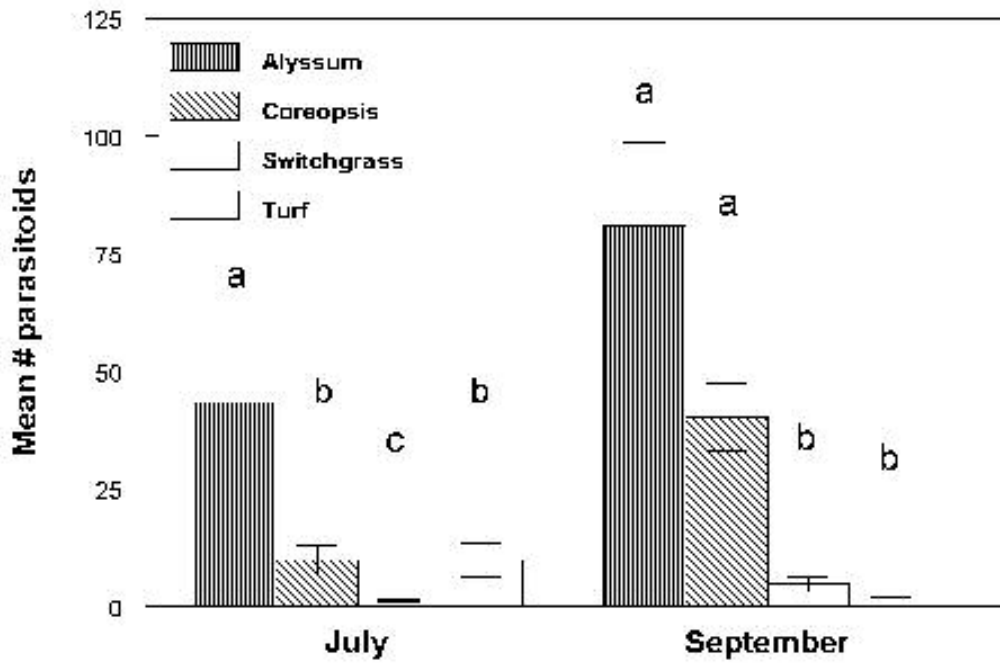


Figure 2. Mean \pm SE number of parasitoids caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

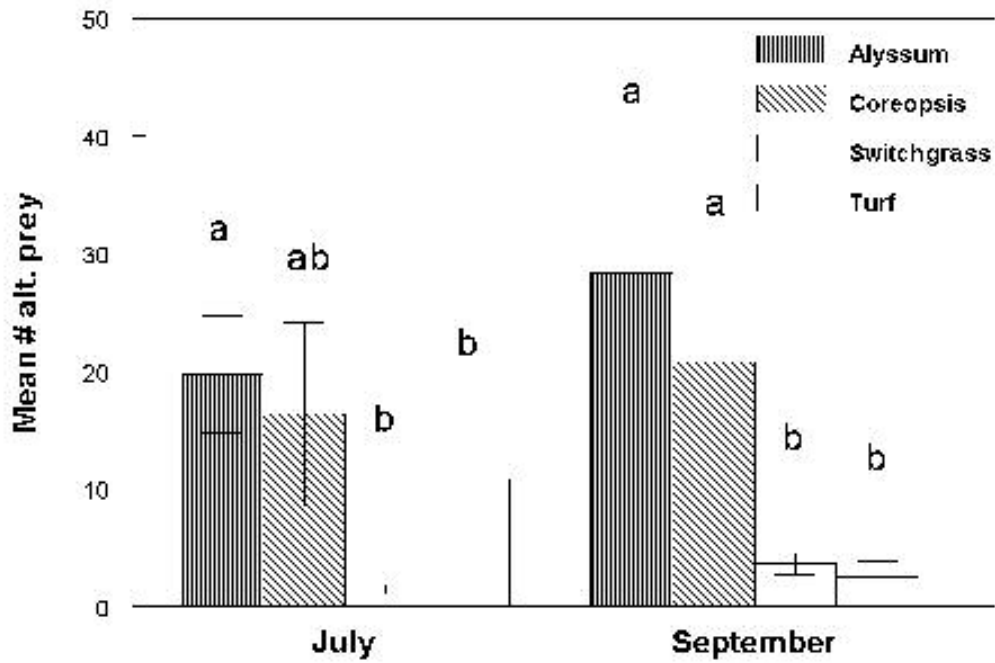


Figure 3. Mean \pm SE number of alternative prey caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

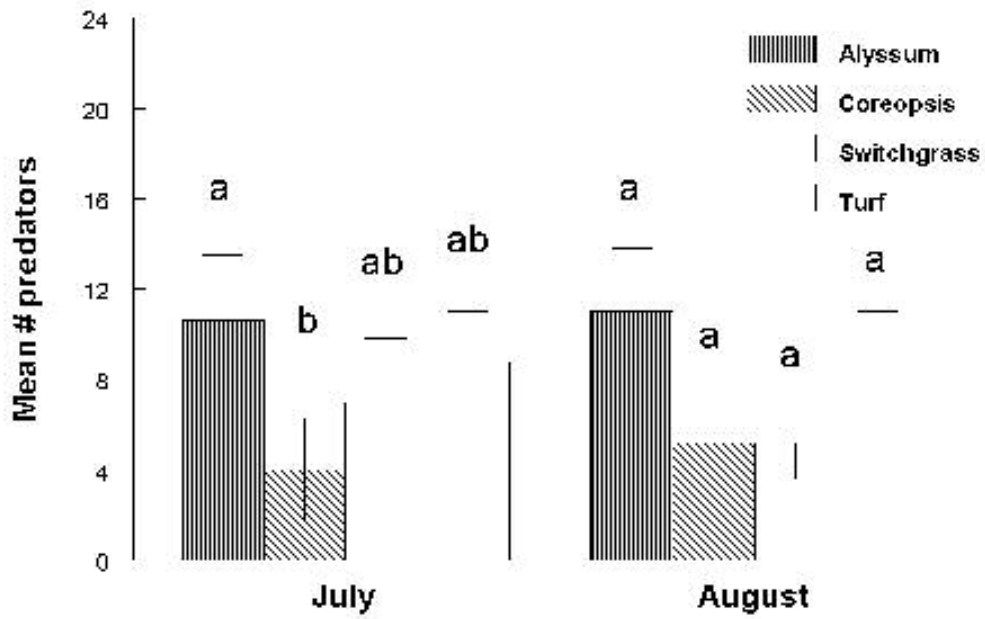


Figure 4. Mean \pm SE number of ground dwelling predators caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

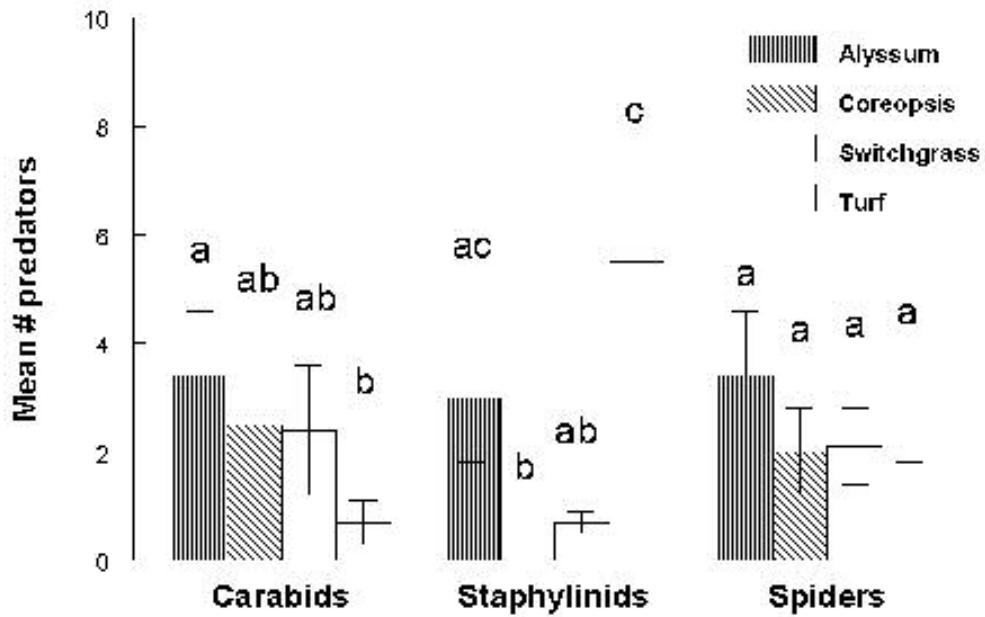


Figure 5. Mean \pm SE number of ground dwelling carabid and staphylinid beetles and spiders caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a taxa, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

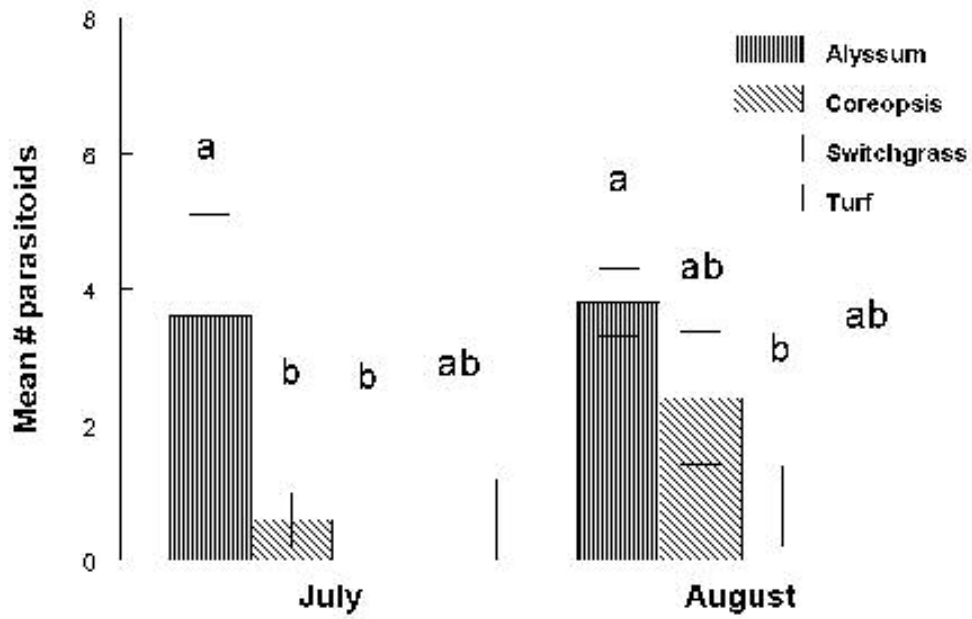


Figure 6. Mean \pm SE number of ground dwelling parasitoids caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

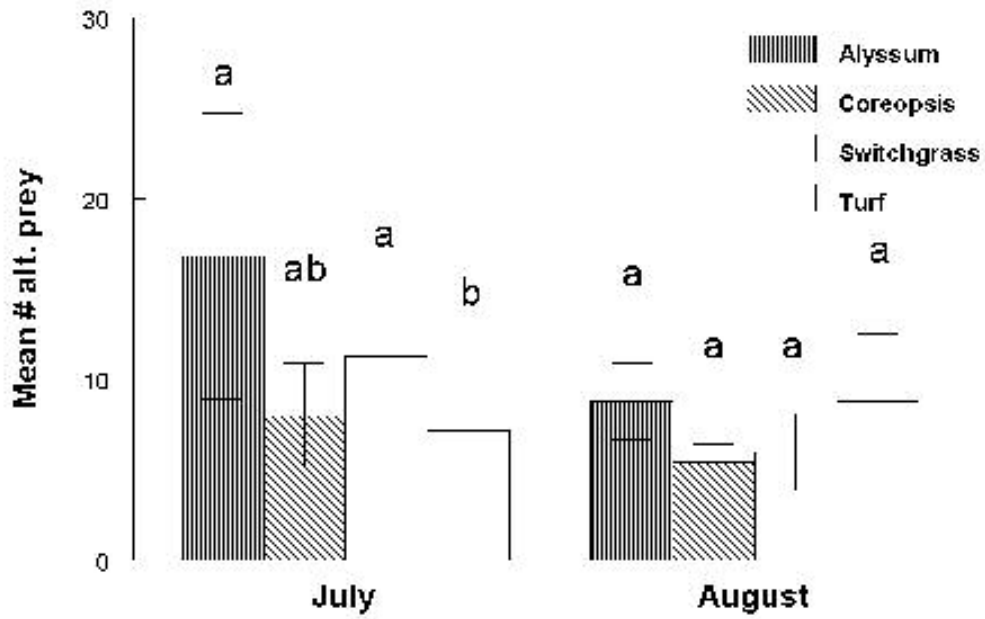


Figure 7. Mean \pm SE number of ground dwelling alternative prey caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

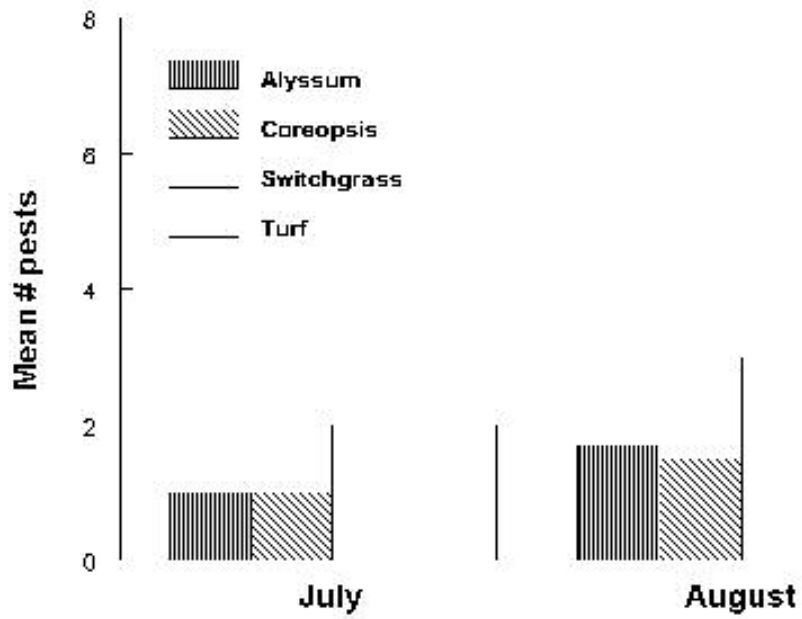


Figure 8. Mean \pm SE number of ground dwelling pests caught in alyssum, coreopsis, switchgrass, and turf. Bars, within a date, with the same letter are not significantly different at $P < 0.05$ level as determined by *LSD* comparisons.

CHAPTER 2

Evaluating the Effect of Conservation Strips on the Abundance and Distribution of Natural Enemies, Alternative Prey, and Pests on Golf Course Fairways

Introduction

Manipulation of the vegetational community has been found to influence natural enemy and herbivore populations in a variety of ecosystems (reviewed in Gurr et al. 2000, Landis et al. 2000). Two areas of habitat manipulations that have received increasing attention in recent years are beetle banks (Thomas et al. 1991, 1992) and flowering insectary strips (Patt et al. 1997, Chaney 1998, Shrewsbury et al. *in press*).

Recent work has demonstrated that large numbers of predatory beetles and spiders can be attracted to, and maintained in beetle banks (Thomas et al. 1991, 1992). Beetle banks are strips of bunch grass 1.5m wide that are installed within agricultural fields. Beetle banks provide shelter to predators from the routine disturbance agricultural fields incur, protection from extreme temperature variations, and over wintering sites. Predator densities in beetle banks reached over 1500m^{-2} in the second year the bank was established (Thomas et al. 1991, 1992). From the beetle banks carabid beetles dispersed 60m toward the edge of the fields where they were met by carabids emigrating from the field border into the fields (Thomas et al. 1991). Carabids, staphylinids, and spiders have been found to be important and abundant predators in turfgrass systems (Terry et al. 1993, Smitley et al. 1998).

Flowering insectary strips have also been shown to attract an abundance and variety of predatory arthropods and parasitoid wasps. Moreover, flowering insectary strips have also been shown to reduce pest populations in ornamental and agricultural systems (Patt et al. 1997, Chaney 1998, Long et al. 1998, Braman 2002, Shrewsbury et al. *in press*). Chaney (1998) found increased abundance of spiders, *Geocoris spp.*, *Orius spp.*, and parasitic hymenoptera and a reduction in aphids where flowering insectary strips, containing alyssum were added next to lettuce fields. This increase in predators and resultant decrease in aphids was detected for 11m into the lettuce crop. Patt et al. (1997) demonstrated significant increases in the number and diversity of coccinellid beetles in fields of eggplant where flowering plants (dill and/or coriander) were present compared to no flowering plants. In a mark and release study, Long et al. (1998) recovered marked parasitoids and coccinellids as far as 75m into adjacent crops from insectary strips. Shrewsbury et al. (*in press*) found adding flowers, Shasta daisy and coriander, to landscape beds containing azaleas increased natural enemy abundance and reduced azalea lace bug survival compared to beds without flowers added.

Fewer studies have examined the role of flowering plants in herbivore – natural enemy dynamics in turfgrass systems. Braman et al. (2002) found that commercially available wildflower mixes attracted large numbers of foliar dwelling predators into wildflower plots adjacent to turf. Predators attracted to the wildflowers, again, were spiders, *Geocoris spp.*, and *Orius spp.*. Although Braman et al. (2002) did not demonstrate an increase in predation in turf adjacent to flowers, *Geocoris spp.* have been observed to feed on fall armyworms in turf (Braman et al. 2002) and other turf pests

(Potter 1998). Spiders and coccinellids have also been shown to feed on the armyworm *Psuedaletia unipuncta* (Lepidoptera: Noctuidae) in no-till corn (Clark et al. 1994).

The value of parasitoids in turf systems is not well studied. However, fall armyworms are susceptible to parasitoids in agricultural systems. (Ashley 1979, 1986 and Gross et al. 1986). *Spodoptera frugiperda* is also a pest in turf systems as are several members of the family Noctuidae (black cutworms, *Agrotis ipsilon*, armyworms). Tiphia wasps are ectoparasites of some scarab beetles and also consume flower nectar (Potter 1998). Therefore, it may be possible to increase their abundance by installing conservation strips.

The studies described above suggest it may be possible to manipulate turf grass systems to enhance natural enemy and reduce pest abundance. In this study, the concepts of flowering insectary strips and beetle banks were combined to create a habitat, referred to as conservation strips, that would enhance the abundance of natural enemies in golf course systems. The integration of flowering insectary strips and beetle banks to create conservation strips should increase the pest management benefits to golf courses. Bunch grasses used in beetle banks have been shown to increase the abundance of ground dwelling predators (Thomas et al. 1991, 1992), whereas flowers have been found to increase the abundance of foliar predators and parasitoids (Braman et al. 2002). Therefore, conservation strips should support a suite of natural enemies with a broader range of foraging behaviors and preferences than either flowering insectary strips or beetle banks alone. They should also be more effective at suppressing pests since several turf pests may be susceptible to parasitoid as well as predatory control.

The spatial arrangement and composition of plant species grown in conservation strips on golf courses could be critical to the success of this pest management approach. Conservation strips should be aesthetically pleasing and in a location that does not interfere with golf play. At the same time they should be close enough to fairways to increase the likelihood that natural enemies can forage between the conservation strips and fairways. In beetle banks in Europe, the bunch grass *D. glomerata* was used successfully. However, this grass is considered an invasive exotic plant in Maryland, U.S.A. Therefore, I selected switchgrass (*Panicum virgatum*), which has a similar growth habit and is native to Maryland, to use in the conservation strips.

The two flowering plants, alyssum ‘Easter Basket Mix’, *Lobularia maritima* and Coreopsis, *Coreopsis verticillata* ‘Moonbeam’ used in the conservation strips were selected for several reasons. They have different growth habits. Alyssum is a low growing ground cover and coreopsis has an upright habit. Alyssum has been used in several other experiments and has been successful at attracting large numbers of predators and parasitoids (Chaney 1998). Coreopsis has received less attention in research but has the benefit of being perennial, an ornamental already used on some golf course landscape beds, and the reputation of being ‘deer proof’. Both of these plants bloom for long periods of time: early spring (alyssum) and early summer (coreopsis) until mid-fall. Also, adding flowering plants to the conservation strips makes them more visually appealing and look more like traditional ornamental plant beds.

In this study conservation strips were installed to attract and conserve natural enemies on golf courses. The objectives of this experiment were to determine if conservation strips installed next to golf course fairways increased the abundance of

arthropods in different trophic groups compared to fairways without conservation strips and at what distance out into the fairway conservation strips were effective at increasing natural enemies and reducing pests. The hypotheses for this experiment were that in study plots that contained a conservation strip, predators and parasitoids, and alternative prey would be more abundant and pests would be less abundant. Also, I hypothesized that predator, parasitoid, and alternative prey populations will remain more abundant, and pests less abundant, at each distance from the conservation strip that they are measured compared to the same locations in plots without a conservation strip.

Methods

Experimental design. The study was conducted in 2002 and 2003 on two golf courses in Maryland, Glenn Dale Golf Course (Glenn Dale, MD) and Timbers of Troy Golf Course (Elkridge, MD). The study was a Randomized Complete Block Design with repeated measures. The treatment was conservation strips (with and without a conservation strip) and repeated measures were taken at 6 distances (0, 2, 4, 6, 8, 12 m) from the conservation strip or corresponding locations in plots without a conservation strip. Six conservation strips (replicates) were installed in June of 2002 on six fairways (block) on two different golf courses. Three fairways were located on Glenn Dale Golf Course (Glenn Dale, MD) and three were on Timbers at Troy Golf Course (Elkridge, MD). The fairway at Glenn Dale contained Bermuda grass, *Cynodon dactylon*, and the fairway at Timbers contained creeping bent grass, *Agrotis stolonifera*. Each fairway consisted of a conservation strip and no conservation strip treatment. Each conservation strip was situated in the rough, 4m from the edge of the fairway. The conservation strips

varied in size but had the minimum dimensions of 8x3m and maximum dimensions of 4x16m. The conservation strips were always positioned with the long side parallel to the fairway. Six plots without conservation strips (control plots) were also selected in a comparable position to the conservation strip treatment in every fairway. Control plots were always at least 60m away from the plots with conservation strips and contained rough mown (10cm) turf grass which was a blend of tall fescue, *Festuca arundinaceae*, and Kentucky bluegrass, *Poa pratensis*.

Three species of plant were installed in the conservation strips: alyssum 'Easter Basket Mix', *Lobularia maritima*; Coreopsis, *Coreopsis verticillata* 'Moonbeam'; switchgrass, *Panicum virgatum* 'Northwind'. Plants were always installed in the conservation strips in the same manner. The bed was longitudinally divided into three sections. Alyssum, being the shortest species, was planted on the side of the bed closest to the fairway. Coreopsis was planted in the middle section, and switchgrass was planted on the side of the bed furthest from the fairway.

In 2003, the switchgrass and coreopsis, which are perennial plants, came up in late spring. Alyssum, an annual, was planted the third week in April. However, 2003 had above average rainfall in Maryland and the alyssum quickly rotted and died due to the very wet conditions. Three subsequent plantings of alyssum succumbed to the same fate. Therefore, in 2003, the conservation strips had only coreopsis and switchgrass. This resulted in a different treatment in 2003 than was present in 2002.

Arthropod sampling. Pitfall traps were used to sample arthropod abundance at each of the six distance treatments in plots with and without conservation strips. Pitfall traps were set up in two transects that were 4m apart and ran perpendicular to the

fairways from the conservation strips. The first pair of pitfall traps were installed at the edge of the conservation strips (distance 0m), which was 4m into the rough from the edge of the fairway. Likewise, the first pair of traps in the plots without conservation strips were installed in the rough 4m from the edge of the fairway (distance 0m). From this first trap position (0m), pairs of traps were installed at 2m intervals. Therefore, the next traps (2m) were halfway between the conservation strips (or the 0m position in control plots) and the edge of the fairway. The next traps (4m) were placed on the edge of the rough and the fairway. The remaining traps –all in the fairway- were installed at 6m, 8m, and 12m from the 0m trap position.

Pitfall traps were made of glass vials with a mouth diameter of 19mm. Vials were inserted into holes made by a 21mm soil probe. The lip of the vial was just below the soil surface. Traditional pitfall traps made of large cups were not an option on golf courses, as they would interfere with play and aesthetics on the course. The vials were installed on June 17, 2002. On June 24, 2002, weekly arthropod sampling began. The traps were filled one third full with a 20% propylene glycol solution with soap added to reduce surface tension. After seven days the traps were removed and immediately replaced with new vials. In 2002, sampling was conducted four times (the dates listed are the dates each seven day trapping period ended for Glenn Dale and Timbers respectively): July 22, 23 and 29, 30 and August 5, 7 and 19, 20. Pitfall trap sampling was only conducted on two dates in 2003 due to heavy rains and consistent flooding of the golf course. In 2003, sampling was conducted on July 1, 2 and July 29,30.

At the end of each sampling period vials were returned to the laboratory. In each plot, the contents of both traps within each distance were combined and rinsed through a

125-micron sieve to remove soap and preservative from the specimens. All specimens were then stored in a vial containing a 70% ethanol solution. The specimens were sorted and identified using a stereo-microscope. Specimens were sorted into trophic groups of predator, pest, alternative prey, parasitoids, or 'other'. The most abundant taxa from each trophic group were identified to family or more specific 'morpho-types'.

Statistical analysis. Data for each year were analyzed separately. Data were summed across dates. Data were analyzed as a Randomized Complete Block design using the MIXED procedure in SAS (2001). Each fairway was a block. Distance was a repeated measure. Raw data was $\log_{10}(y+1)$ transformed prior to analysis. An LSD test was used to compare each distance in plots with conservation strips to the same distance in plots without conservation strips.

Results

Overall, 5,337 arthropods were captured over 4 sampling dates and included in the 2002 analysis (Table 1). The predator, alternative prey, and, pest trophic groups each made up a similar percentage (17.8, 12.3, and 16.9 percent, respectively) of the total arthropods caught. Parasitoids made up 3.9% of the total. Ants made up 26.4% of the total insects caught which is the highest of any designated group (Table 1). In 2003, 2,876 total arthropods were captured over 2 sampling dates (Table 2). Each trophic group's relative percentage of the total number of arthropods caught was similar to 2002 (Table 2) with the exception of Formicidae (ants), which were more abundant in 2002 and Diptera which were more abundant in 2003.

Predator abundance and distribution in 2002 and 2003. In 2002, predators were significantly more abundant in plots where conservation strips were present ($F=12.93$ $df=1$, 33.7 $P=0.0010$; Table 3). Predators were significantly more abundant at trap position 0m (LSD ; $P=0.0339$) and at 2m (LSD ; $P=0.0157$) when conservation strips were present (Fig. 1). Of the predator trophic groups, carabids, staphylinids, and spiders were the most abundant taxa. Carabids were significantly more abundant in plots where conservation strips were present ($F=6.93$ $df=1$, 48.9 $P=0.0113$; Table 4) but staphylinids ($F=2.26$ $df=1$, 24.9 $P=0.1457$; Table 4) and spiders ($F=2.61$ $df=1$, 29.5 $P=0.1169$; Table 4) were not. Carabid beetles were significantly more abundant at position 0m (LSD ; $P=0.0414$) and marginally so at 2m (LSD ; $P=0.0574$) when conservation strips were present (Fig. 2). Staphylinids were not significantly more abundant at any trap position although at position 2m staphylinids were numerically more abundant (LSD ; $P=0.0853$ Fig. 3). Spiders were significantly more abundant at trap position 2m when conservation strips were present (LSD ; $P=0.0462$, Fig. 4).

In 2003, there was no significant difference in predator abundance between the two treatments ($F=0.03$ $df=1$, 32.7 $P=0.8698$; Table 5). There was also no significant difference at any trap position (LSD ; $P>0.05$) though predators were marginally more abundant at position 0m when conservation strips were present (LSD ; $P=0.0890$, Fig. 5). Carabid abundance was not significantly different overall ($F=0.38$ $df=1$, 34.7 , $P=0.5426$; Table 6) or at any trap position (LSD ; $P>0.05$, Fig. 6). Staphylinid beetle abundance was not significantly different overall ($F=0.26$ $df=1$, 22.1 , $P=0.6160$; Table 6) but they were significantly more abundant at position 2m when conservation strips were not present (LSD ; $P=0.0244$, Fig. 7). There was no significant difference in spider abundance

between treatments ($F=0.01$ $df=1$, 49.2, $P=0.9123$; Table 6) Spiders were significantly more abundant at position 0m (LSD ; $P=0.0279$, Fig. 8) when conservation strips were present and 4m (LSD ; $P=0.0359$, Fig. 8) when conservation strips were absent.

There was a significant effect of distance on predator abundance in 2002 ($F=24.92$ $df=5$, 22, $P<.0001$; Table 3) and 2003 ($F=8.39$ $df=5$, 21.7, $P=0.0002$; Table 5). There was also a significant distance effect on spider ($F=8.27$ $df=5$, 20.6, $P=0.0002$; Table 4) and staphylinid ($F=18.52$ $df=5$, 20.9, $P<0.0001$; Table 4) abundance in 2002 and on spider ($F=5.04$ $df=5$, 21.5, $P=0.0033$; Table 6) and staphylinid ($F=22.37$ $df=5$, 21.3, $P<0.0001$; Table 6) abundance in 2003.

Parasitoid abundance and distribution in 2002 and 2003. In 2002 there was a significant treatment by distance interaction of parasitoid abundance ($F=11.52$ $df=1$, 35.4 $P=0.0017$; Table 3). Parasitoid abundance was not significantly different in 2003 ($F=0.22$ $df=1$, 43.9 $P=0.6413$; Table 5). In 2002, parasitoids were significantly more abundant at position 0m (LSD ; $P=0.0001$, Fig. 9) when conservation strips were present, however there was not a significant difference at any trap position in 2003 (LSD ; $P>0.05$ Fig. 10).

Alternative prey abundance and distribution in 2002 and 2003. Alternative prey were significantly more abundant in plots where conservation strips were present in 2002 ($F=7.24$ $df=1$, 46.7 $P=0.0099$; Table 3) and in 2003 ($F=15.63$ $df=1$, 39.3 $P=0.0003$; Table 5). In 2002, alternative prey were not significantly different at any trap positions (LSD ; $P>0.05$ Fig. 11). In 2003, alternative prey were significantly more abundant at positions 0m (LSD ; $P=0.0247$), at 4m (LSD ; $P=0.0168$), and at 6m (LSD ; $P=0.0460$) when conservation strips were present (Fig. 12). The most abundant alternative prey taxon in both years was collembola. Collembola were significantly more abundant when

conservation strips were present in 2002 ($F=16.07$ $df=1$, 48.6 $P=0.0002$; Table 7) They were also significantly more abundant at trap position 0m (LSD ; $P=0.0119$) and marginally so at 2m (LSD ; $P=0.0815$) and at 4m (LSD ; $P=0.0693$) when conservation strips were present (Fig. 13). In 2003, there was no significant difference in collembola abundance between the two treatments ($F=3.50$ $df=1$, 52.9 $P=0.0670$; Table 7) or at any trap position (LSD ; $P>0.05$ Fig. 14).

There was a significant effect of distance on alternative prey abundance in 2002 ($F=5.51$ $df=5$, 21.2 , $P=0.0021$; Table 3) and 2003 ($F=4.52$ $df=5$, 22.3 , $P=0.0054$; Table 5). There was also a significant distance effect on collembola abundance ($F=12.26$ $df=5$, 21.8 , $P<.0001$; Table 7) in 2002 and in 2003 ($F=3.70$ $df=5$, 22.7 , $P=0.0134$; Table 7).

Pest abundance and distribution in 2002 and 2003. There was no significant difference in pest abundance between plots where conservation strips were present and where they were absent in 2002 ($F=0.38$ $df=1$, 39.3 $P=0.5410$; Table 3) or at any trap position (LSD ; $P>0.05$ Fig. 15). In 2003 there was also no significant difference in pest abundance, though marginal differences were detected overall ($F=3.14$ $df=1$, 48.8 $P=0.0824$; Table 5), and at trap position 2m (LSD ; $P=0.0921$ Fig. 16). There was no significant difference in curculionid abundance in 2002 ($F=0.02$ $df=1$, 34.8 $P=0.8909$; Table 8), 2003 ($F=0.26$ $df=1$, 37.9 $P=0.6121$; Table 9), or at any trap position (LSD ; $P>0.05$ Fig. 17,18). Though there was a marginal difference in 2002 at 2m (LSD ; $P=0.0567$ Fig.17). Likewise, there was no significant difference in scarabaeid abundance in 2002 ($F=0.03$ $df=1$, 36.2 $P=0.8616$; Table 8), 2003 ($F=0.91$ $df=1$, 41.4 $P=0.3467$; Table 9), or at any trap position (LSD ; $P>0.05$ Fig. 19, 20).

However, there was a significant effect of distance on pest abundance in 2002 ($F=5.65$ $df=5$, 21.4, $P=0.0035$; Table 3). There was also a significant distance effect on scarabaeid abundance ($F=6.19$ $df=5$, 22, $P=0.0010$; Table 8) in 2002 and on curculionid ($F=3.14$ $df=5$, 21.1, $P=0.0283$; Table 9) and scarabaeid ($F=3.52$ $df=5$, 18.1, $P=0.0213$; Table 9) abundance in 2003.

Abundance and distribution of other groups in 2002 and 2003. There was no significant difference in chrysomelid (flea beetles) abundance in 2002 ($F=0.74$ $df=1$, 34 $P=0.3966$ Table 10), 2003 ($F=2.48$ $df=1$, 42.7 $P=0.1230$ Table 10), or at any trap position (LSD ; $P>0.05$) in 2002. In 2003, flea beetles were significantly more abundant at trap position 12m (LSD ; $P=0.0357$) when conservation strips were present. There was a significant effect of distance on chrysomelid abundance in 2002 ($F=4.80$ $df=5$, 20.4, $P=0.0047$; Table 10).

Ant abundance was not significantly different between the two treatments in 2002 ($F=0.02$ $df=1$, 52 $P=0.8786$ Table 11), 2003 ($F=0.04$ $df=1$, 45.4 $P=0.8446$ Table 11), or at any trap position (LSD ; $P>0.05$) in either year. There was not a significant effect of distance on ant abundance in either year of the study.

Discussion

Predator, parasitoid and alternative prey populations were enhanced by the addition of conservation strips on golf courses in one of the two study years. Results regarding the effect of conservation strips on predator abundance from 2003 were also somewhat different from those of 2002. Pest populations, on the other hand, do not seem to be influenced by the presence of conservation strips.

Differences in abundance within a trophic group from 2002 to 2003 may be due to dramatic differences in climatic conditions, differences in plant material in the conservation strips, and temporal differences in sampling. There was no alyssum present in the conservation strips in 2003, as there was in 2002, due to the almost daily rainfall that caused it to rot and die. Other studies have demonstrated that alyssum attracts an abundance of arthropods (Chaney 1998) which suggests that the presence of alyssum one year and its absence the next would likely result in variation in trophic group abundance between years. Rainfall itself was another major difference between the two years. In 2002 there was persistent drought that resulted in rainfall that was well below average for our region. In contrast, 2003 brought record rainfall and low temperatures. The rainfall of 2003 resulted in three of the fairways and one conservation strip spending periods of time submerged under water. These two extreme environmental conditions may influence trophic groups in very different ways, also resulting in variation in abundance from year to year (Frampton et al. 2000). Sampling in 2002 was conducted on 4 dates, whereas in 2003 sampling was conducted on only 2 dates due to wet weather conditions. Temporal differences from year to year may lead to variation in abundance of trophic groups.

Overall, predator populations were enhanced by the presence of conservation strips in 2002. Carabid beetles seem to have played an important role in this increase because they were also significantly more abundant in plots with conservation strips. Further support for this comes from sampling the different plant species in the conservation strips (see Chapter 1), which indicated that carabids were more abundant in alyssum, coreopsis, and switchgrass than in the rough. Carabid beetles also seemed to be

the most evenly distributed group of predators across trap positions (Fig. 2, 6) where as the abundance of staphylinids and spiders appears to decline sharply at the edge of the fairway (4m) (Fig. 3, 4). This is the same distribution pattern Smitley et al. (1998) found for predators on golf courses. Samples taken in the fairway (short grass) contained more pest insects and fewer predators as distance from the rough (tall grass) increased. Likewise, sampling yielded fewer pest insects in the rough further from the fairway (Smitley et al 1998). Smitley's work demonstrates how minor changes in the structural complexity of golf course habitat, such as increased mowing height, can result in a greater abundance of predators and fewer pests.

In 2003, predator abundance was similar in plots with and without conservation strips. Sampling of plants in conservation strips found alyssum was the plant species with the greatest abundance of arthropods in the predator trophic group (see Chapter 1). In addition, each specific group of predators was also more abundant in alyssum than in the other plant species. Not having alyssum in the conservation strips would seemingly reduce the overall attractiveness of the strips and also reduce the total area of refuge in the strips because the space where alyssum should have been was bare ground.

As discussed in Chapter 1, the great abundance of parasitoids in and near the conservation strips is not surprising. Whether, this abundance would result in greater parasitism of pests is not known. Future work should focus on this neglected aspect of turf systems and turf pest management. Two species of wasps in the family Tiphidae are ectoparasites of turf infesting scarab beetle grubs. *Tiphia vernalis* parasitizes Japanese beetle, *Popillia japonica* and *Tiphia pygidialis*, are parasites of the masked chaffer, *Cyclocephala spp.* (Coleoptera:Scarabaeidae) grubs (Rogers et al. 2003). Tiphia wasps

also feed on nectar from flowers (Potter 1998) and therefore conservation strips may be able to increase tiphia abundance.

Alternative prey populations were higher in plots with conservation strips in 2002 and 2003. The most abundant group of alternative prey was collembola. Collembola have been shown to be prey for carabids (Bauer 1982,1985; Bilde et al. 2000), staphylinids (Bauer and Pfeiffer 1991), and spiders (Sunderland et al. 1986). Collembola were also numerically more abundant at most trap positions in plots with conservation strips. Collembola distribution has been shown to be governed in part by moisture (Frampton et al. 2000), and also by food, soil type, and population density (Bengtsson et al. 1994). Many of these factors may have been different within the conservation strips such as the soil texture from cultivating it with shovels in the process of installing plant material. Also, mulch was applied to the conservation strips, which may have changed moisture levels and also the quantity of fungus available to be eaten. Shade and pollen were also available in the conservation strips. These factors may have resulted in greater collembola abundance. However, what promoted the dispersal of collembola away from the conservation strips into the fairways is unknown. Perhaps population size within the strips resulted in density dependent dispersal, or pollen, which is food for many collembola (Kevan and Kevan 1970, Takeda and Ichimura 1983, Ponge 2000) could accumulate in the turf outside of the conservation strips and result in greater food availability. This, in turn, could result in dispersal from the conservation strips or emigration from other parts of the fairway to the areas containing pollen. If pollen accumulated in the fairways near conservation strips collembola populations may have grown in response to increased food rather than dispersal from the conservation strips.

This accumulation of prey items may also influence the distribution and abundance of predators in the conservation strips and fairways.

The presence of conservation strips did not influence pest populations as measured by pitfall traps. Pitfall traps efficiently capture the adult scarab beetles and billbugs. However, these pests are not destructive to turf as adults and it is not known whether they are susceptible to arthropod predation. Egg and larval stages of scarab turf pests have been shown to be susceptible to arthropod predation (Terry et al. 1993, Lopez and Potter 2000, Zenger and Gibb 2001). Attempts were made to sample the larval stages of scarabs, by taking soil samples, and cutworms, using a disclosing solution. These attempts were unsuccessful for several reasons. The main one being that both of these methods are very inefficient when pest populations are low. The number of soil samples or patches of fairway soaked with disclosing solution required to find any insects is exceedingly high and even higher to detect differences.

Overall, pest abundance was higher in the fairway than in the rough for both years of the study. This trend was also found for scarabs in 2002 and 2003 though not for curculionids. Previous studies have found similar distributions of pests (Smitley et al. 1998, Rothwell and Smitley 1999). In these studies greater numbers of the scarab black turfgrass ateanius (*Ataenius spretulus*) were found in the fairway of golf courses than in the rough. Rothwell and Smitley (1999) suggest that female oviposition preference for short fairway turf and increased predator activity in the rough are probable reasons for this difference. In addition, the incidence of *A. spretulus* grubs infected with milky spore disease was higher in the tall mown rough than in the fairway.

Flea beetles (Coleoptera: Chrysomelidae) are not a pest in turf grass. There is a species of flea beetle (*Chaetocnema repens*) that is a pest of dichondra lawns (a broad leaf plant, not turf) of southern California and its range is restricted to southern California (Potter 1998). However, many species of flea beetles are potential pests in agricultural and ornamental systems and for this reason they were analyzed separately. If large numbers of flea beetles were attracted to or supported by conservation strips their use would be limited in agricultural and ornamental landscapes. Fortunately, this does not appear to be the case. Conservation strips did not reduce adult flea beetle abundance in this experiment but it did not encourage their populations either.

Ants were a major portion, 26% and 17%, of the total arthropods caught in this experiment. Ants are some times included in the predator trophic group in studies like this one (Cockfield and Potter 1984, Smitley et al. 1998, Kunkel et al.1999) however, I chose to treat them separately. There are several species of ants that occur in Maryland, and may be found on golf courses. Some of these species are predators, but others are omnivores or herbivores. In addition, ants are sometimes cited as a pest on golf courses due to the mounds that they build, which interfere with play and can dull mower blades. With the myriad of roles ants can play in the golf course system, I was hesitant to combine them with any other group. Ants do not seem to be affected by the presence of conservation strips. Ants can be an effective and important predatory force in golf courses (Lopez and Potter 2000, Zenger and Gibb 2001). Future research might consider whether refuges can be constructed to enhance ant nest building outside of the fairways and greens. These refuges could be constructed with soil types and plants that ants favor to encourage their populations and colonization. They would also maintain a source

population so that predatory ants could rapidly recolonize fairways and greens after insecticides are applied.

Conservation strips were successful at increasing predator, parasitoid, and alternative prey abundance in golf course fairways and roughs. This increase was the most evident within 4m of the conservation strip such as was seen in carabids and collembolla. However, both of these taxa also occurred in higher numbers at every trap position when conservation strips were present. While there was no effect of conservation strips on the pest populations I measured it is reassuring that conservation strips did not increase pest abundance. Future research should focus on ways to entice predators to move further from the conservation strips, perhaps by increasing alternative prey even more. Another possibility would be to install conservation strips on both sides of a fairway. This arrangement may encourage predators to traverse the fairway while traveling between the two refuges. The optimal size, shape, and arrangement of conservation strips also need to be determined. The conservation strips I installed were actually quite small relative to a typical golf course fairway. Conservation strips show potential as tools in an IPM and conservation biological control program on golf courses.

Table 1. Summary of arthropod trophic categories captured during 2002 on golf course fairways, and the predominate groups in those trophic levels.

Trophic group Taxa	Total no. of individuals	% of total	% of trophic group
Predators	949	17.8	
Araneae	251		26.5
Carabidae	227		23.9
Staphylinidae	435		45.8
Other predator taxa ¹	36		3.8
Parasitoids	206	3.9	
Alternative prey	907	16.9	
Collembola	495		28.3
Elateridae	257		54.6
Other alt. prey taxa ²	155		17.1
Pests	655	12.3	
Curculionidae	215		32.8
Noctuidae	35		5.3
Scarabaeidae	405		62.9
Acari³	522	9.8	
Diptera³	411	7.7	
Chrysomelidae³	276	5.2	
Formicidae³	1411	26.4	
Total	5337	100	

¹ 'Other predators' includes: Anthocoridae (minute pirate bugs only), Lygaeidae (big-eyed bugs only), Dermaptera, Chilopoda,

² 'Other alt. prey' includes: miscellaneous Coleoptera, Diplopoda, Isopoda, Orthoptera, Heteroptera

³ Families or groups that have unknown or multiple functions in the ecosystem

Table 2. Summary of arthropod trophic categories captured in pitfall traps during 2003 on golf course fairways, and the predominate groups in those trophic levels.

Trophic group Taxa	Total no. of individuals	% of total	% of trophic group
Predators	595	20.7	
Araneae	268		45.0
Carabidae	181		30.4
Staphylinidae	139		23.4
Other predator taxa ¹	7		1.2
Parasitoids	46	1.6	
Alternative prey	628	21.8	
Collembola	304		48.4
Elateridae	110		17.5
Heteroptera	81		12.9
Orthoptera	47		7.5
Other alt. prey taxa ²	86		13.7
Pests	415	14.4	
Curculionidae	47		11.3
Noctuidae	22		5.3
Scarabaeidae	346		83.4
Acari³	148	5.1	
Diptera³	512	17.8	
Chrysomelidae³	51	1.8	
Formicidae³	481	16.8	
Total	2876	100	

¹ 'Other predators' includes: Anthocoridae (minute pirate bugs only), Lygaeidae (big-eyed bugs only), Dermaptera

² 'Other alt. prey' includes: miscellaneous Coleoptera, Diplopoda, Isopoda

³ Families or groups that have unknown or multiple functions in the ecosystem

Table 3. 2002 Results of ANOVA for the abundance of arthropods in plots with or without conservation strips and at different distances into the fairway¹

Trophic Group	Effect	F Value	ndf, ddf	Pr > F
Predators	Treatment	12.93	1, 33.7	0.0010
	Distance	24.92	5, 22	<.0001
	Treatment*Distance	1.58	5, 22	0.2064
Pests	Treatment	0.38	1, 39.3	0.7406
	Distance	5.65	5, 21.4	0.0035
	Treatment*Distance	0.53	5, 21.4	0.5499
Alternative Prey	Treatment	7.24	1, 46.7	0.0099
	Distance	5.51	5, 21.2	0.0021
	Treatment*Distance	0.31	5, 21.2	0.9003
Parasitoids	Treatment	11.52	1, 35.4	0.0017
	Distance	15.04	5, 22.2	<.0001
	Treatment*Distance	6.00	5, 22.2	0.0012

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 4. 2002 Results of ANOVA for the abundance of different predator groups in plots with or without conservation strips and at different distances into the fairway¹

Predator Group	Effect	F Value	ndf, ddf	Pr > F
Araneae	Treatment	2.61	1, 29.5	0.1169
	Distance	8.27	5, 20.6	0.0002
	Treatment*Distance	1.19	5, 20.6	0.3480
Carabidae	Treatment	6.93	1, 48.9	0.0113
	Distance	0.57	5, 20.8	0.7252
	Treatment*Distance	0.65	5, 20.8	0.6626
Staphylinidae	Treatment	2.26	1, 24.9	0.1457
	Distance	18.52	5, 20.9	<.0001
	Treatment*Distance	1.14	5, 20.9	0.3726

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 5. 2003 Results of ANOVA for the abundance of arthropods in plots with or without conservation strips and at different distances into the fairway¹

Trophic Group	Effect	F Value	ndf, ddf	Pr > F
Predators	Treatment	0.03	1, 32.7	0.8698
	Distance	8.39	5, 21.7	0.0002
	Treatment*Distance	1.39	5, 21.7	0.2657
Pests	Treatment	0.65	1, 48.8	0.0824
	Distance	1.18	5, 19.9	0.3295
	Treatment*Distance	1.07	5, 19.9	0.6060
Alternative Prey	Treatment	15.63	1, 39.3	0.0003
	Distance	4.52	5, 22.3	0.0054
	Treatment*Distance	1.28	5, 22.3	0.3080
Parasitoids	Treatment	0.22	1, 43.9	0.6413
	Distance	1.77	5, 21.9	0.1617
	Treatment*Distance	0.77	5, 21.9	0.5823

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 6. 2003 Results of ANOVA for the abundance of different predator groups in plots with or without conservation strips and at different distances into the fairway¹

Predator Group	Effect	F Value	ndf, ddf	Pr > F
Araneae	Treatment	0.01	1, 49.2	0.9123
	Distance	5.04	5, 21.5	0.0033
	Treatment*Distance	2.77	5, 21.5	0.0441
Carabidae	Treatment	0.38	1, 34.7	0.5426
	Distance	0.87	5, 22.0	0.5145
	Treatment*Distance	0.56	5, 22.0	0.7320
Staphylinidae	Treatment	0.26	1, 22.1	0.6160
	Distance	22.37	5, 21.3	<.0001
	Treatment*Distance	1.66	5, 21.3	0.1884

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 7. 2003 Results of ANOVA for the abundance of collembola in plots with or without conservation strips and at different distances into the fairway¹

Alternative prey group	2002			
	Effect	F Value	ndf, ddf	Pr > F
Collembola	Treatment	16.07	1, 48.6	0.0002
	Distance	12.26	5, 21.8	<.0001
	Treatment*Distance	0.96	5, 21.8	0.4613
2003				
Collembola	Treatment	3.50	1, 52.9	0.0670
	Distance	3.70	5, 22.7	0.0134
	Treatment*Distance	0.66	5, 22.7	0.6603

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 8. 2002 Results of ANOVA for the abundance of different pest families in plots with or without conservation strips and at different distances into the fairway¹

Pest Group ²	Effect	F Value	ndf, ddf	Pr > F
Curculionidae	Treatment	0.02	1, 34.8	0.8909
	Distance	1.18	5, 18.8	0.3537
	Treatment*Distance	1.55	5, 18.8	0.2212
Scarabaeidae	Treatment	0.03	1, 36.2	0.8616
	Distance	6.19	5, 22	0.0010
	Treatment*Distance	0.24	5, 22	0.9405

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

² ANOVA was not performed on Noctuidae data because the low numbers captured violated ANOVA assumptions.

Table 9. 2003 Results of ANOVA for the abundance of different pest families in plots with or without conservation strips and at different distances into the fairway¹

Pest Group ²	Effect	F Value	ndf, ddf	Pr > F
Curculionidae	Treatment	0.26	1, 37.9	0.6121
	Distance	3.14	5, 21.1	0.0283
	Treatment*Distance	0.62	5, 21.1	0.6846
Scarabaeidae	Treatment	0.91	1, 41.4	0.3467
	Distance	3.52	5, 18.1	0.0213
	Treatment*Distance	0.43	5, 18.1	0.8193

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

² ANOVA was not performed on Noctuidae data because the low numbers captured violated ANOVA assumptions.

Table 10. 2003 Results of ANOVA for the abundance of chrysomelid beetles in plots with or without conservation strips and at different distances into the fairway¹

Taxon	2002			
	Effect	F Value	ndf, ddf	Pr > F
Chrysomelidae	Treatment	0.58	1, 34.2	0.4525
	Distance	4.80	5, 20.4	0.0047
	Treatment*Distance	0.93	5, 20.4	0.4844
2003				
Chrysomelidae	Treatment	2.48	1, 42.7	0.1230
	Distance	0.79	5, 22	0.5703
	Treatment*Distance	1.71	5, 22	0.1741

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

Table 11. 2003 Results of ANOVA for the abundance of ants in plots with or without conservation strips and at different distances into the fairway¹

Taxon	2002			
	Effect	F Value	ndf, ddf	Pr > F
Formicidae	Treatment	0.02	1, 52.0	0.8786
	Distance	1.81	5, 23.1	0.1512
	Treatment*Distance	0.16	5, 23.1	0.9730
2003				
Formicidae	Treatment	0.92	1, 47.1	0.3413
	Distance	1.75	5, 19.5	0.1698
	Treatment*Distance	0.54	5, 19.5	0.7420

¹ Experiment was a Randomized Complete Block Design with spatial repeated measures. Two treatments (conservation strip present or absent) and six repeated measure sampling distances (0, 2, 4, 6, 8, 12m). Data was $\text{Log}_{10}(y + 1)$ transformed prior to analysis.

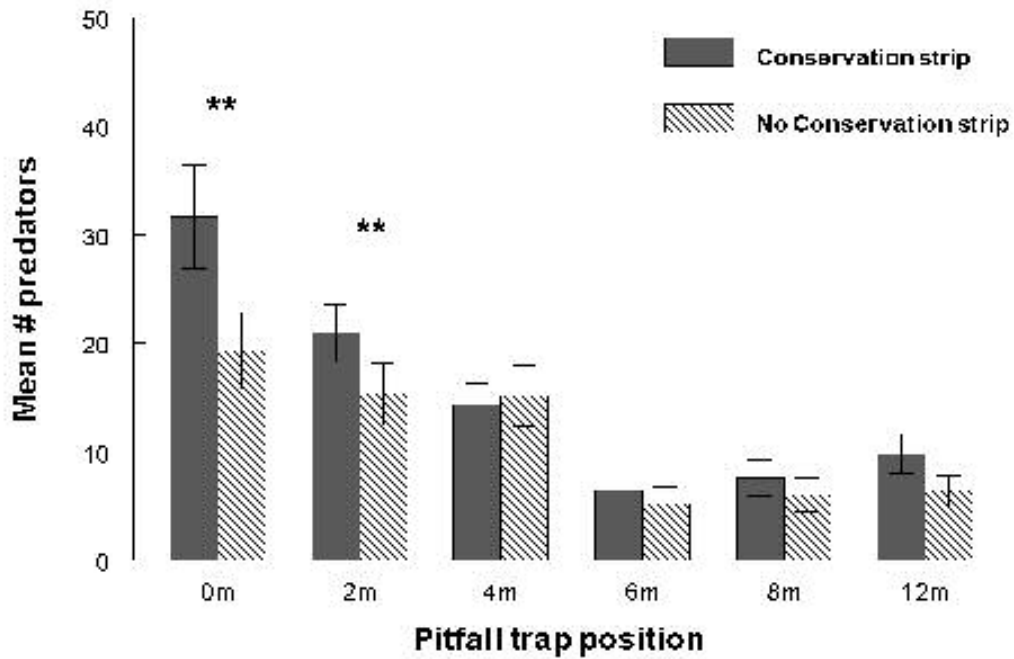


Figure 1. 2002 abundance of predatory arthropods at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

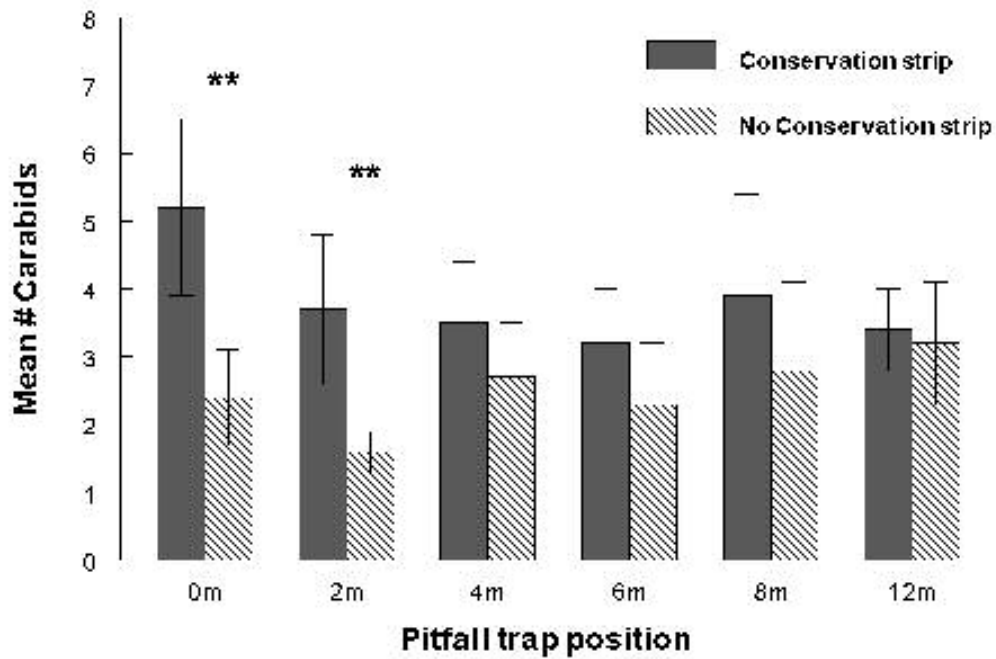


Figure 2. 2002 abundance of carabid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

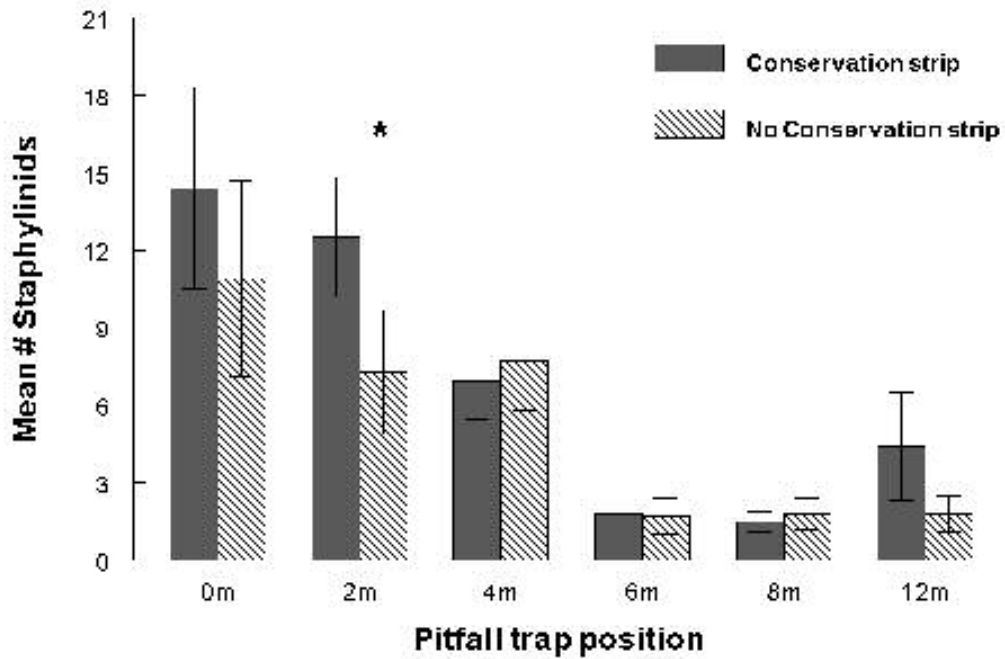


Figure 3. 2002 abundance of staphylinid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

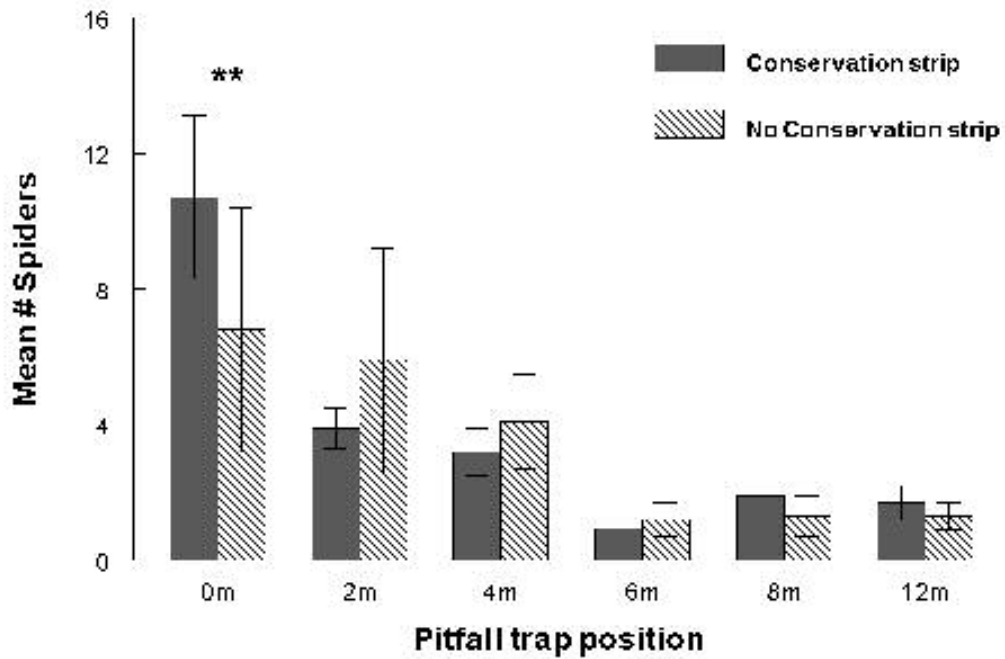


Figure 4. 2002 abundance of spiders at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

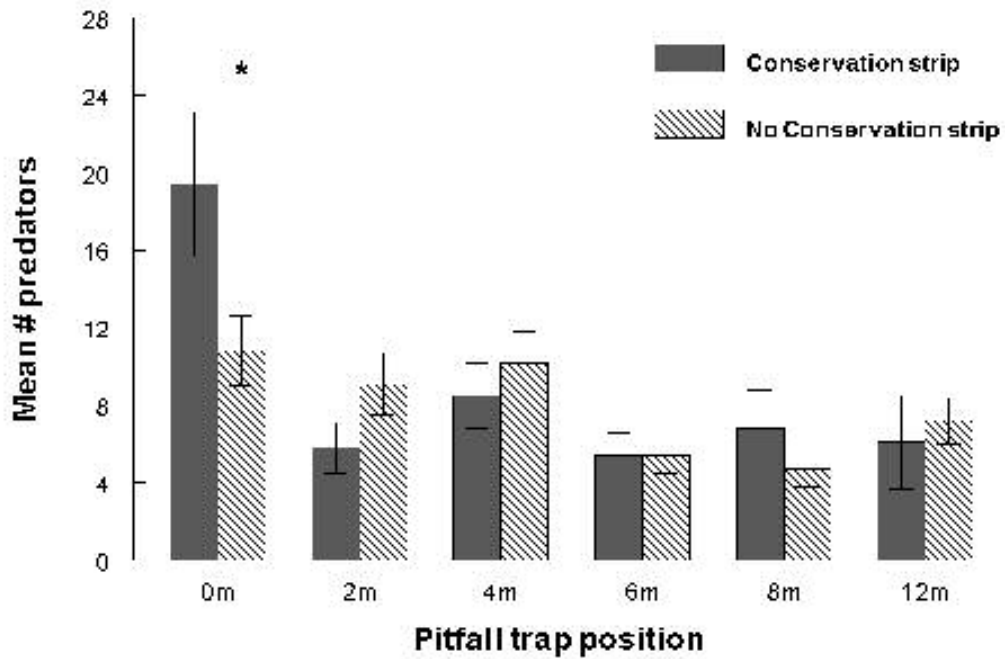


Figure 5. 2003 abundance of predatory arthropods at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

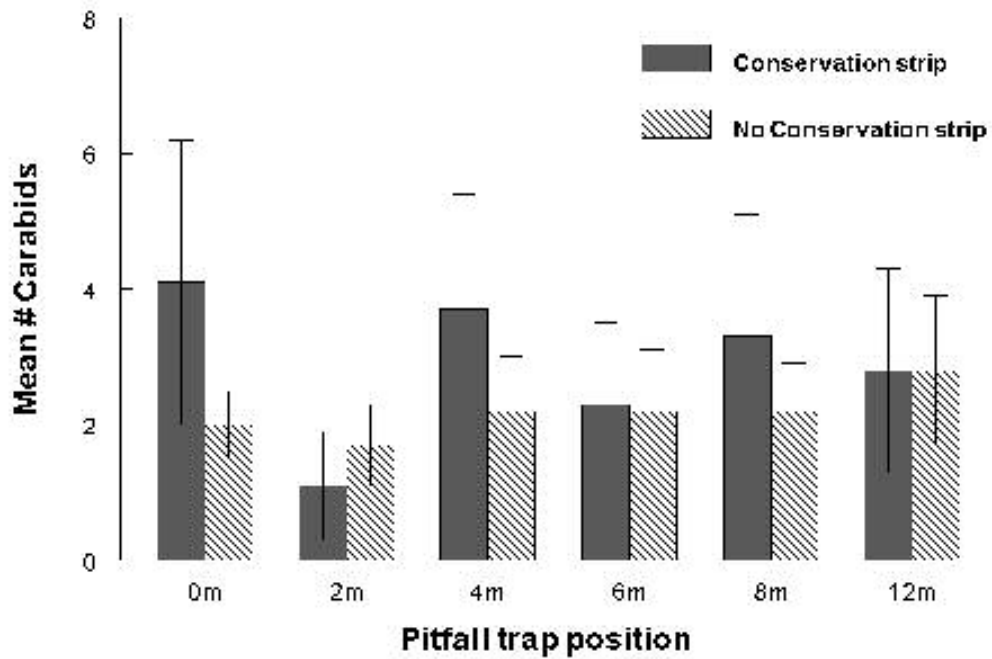


Figure 6. 2003 abundance of carabid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

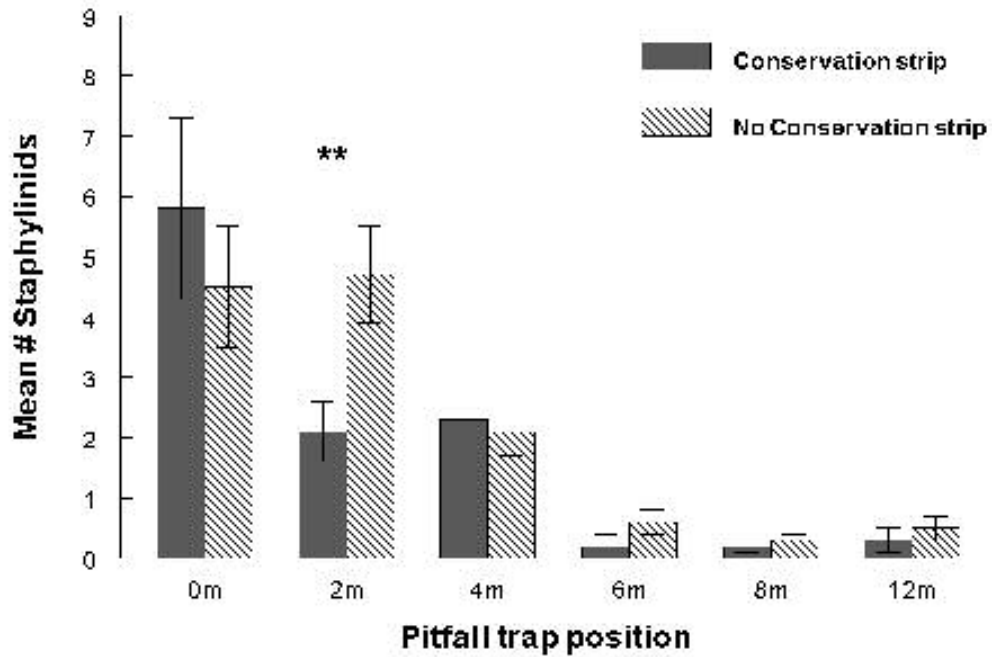


Figure 7. 2003 abundance of staphylinid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

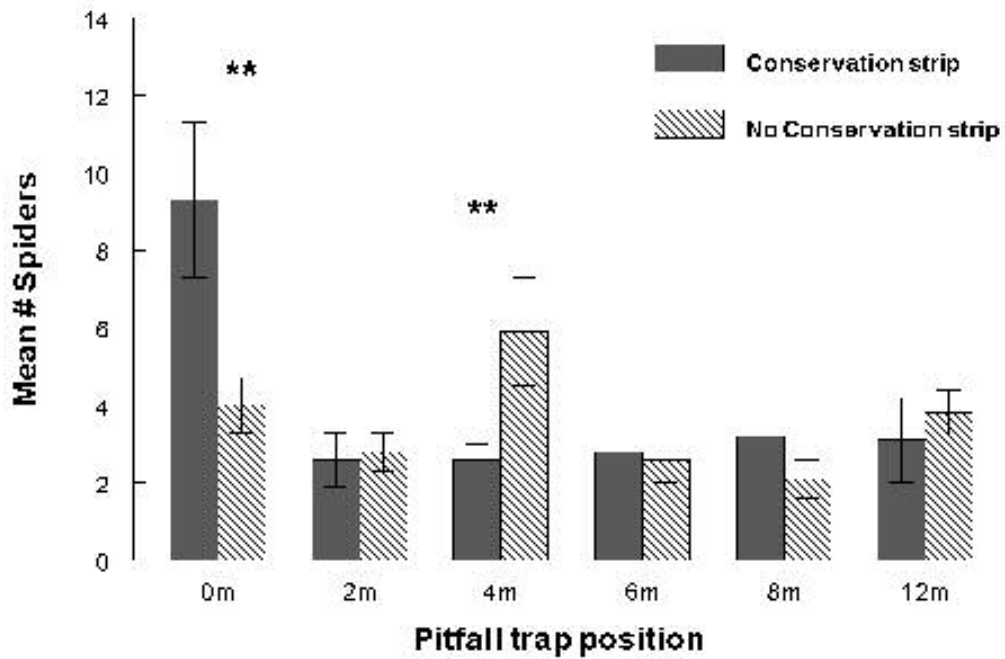


Figure 8. 2003 abundance of spiders at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

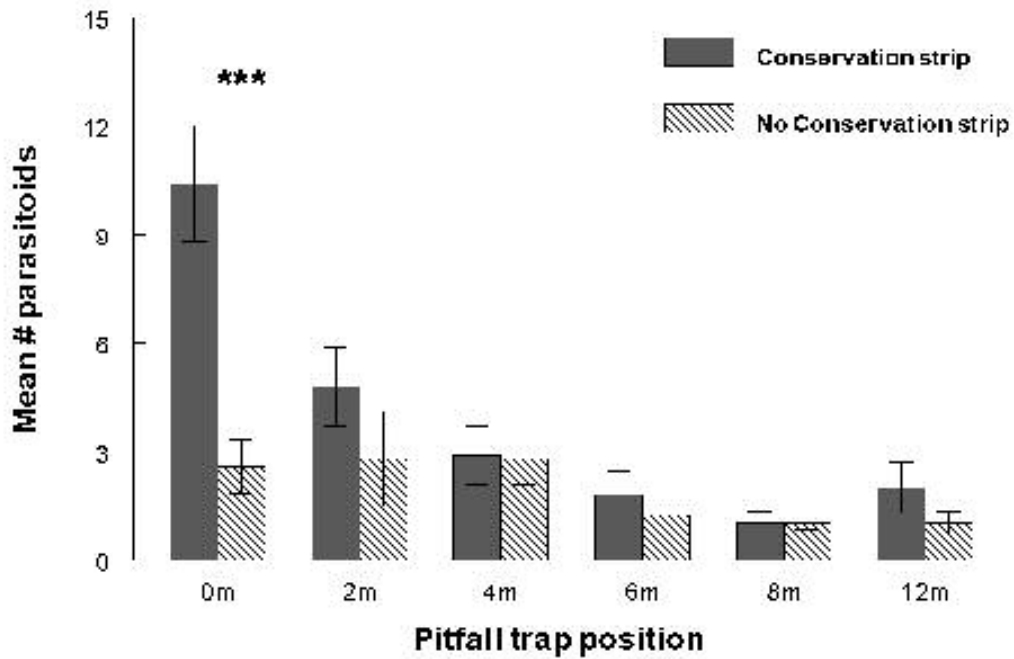


Figure 9. 2002 abundance of parasitoids at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

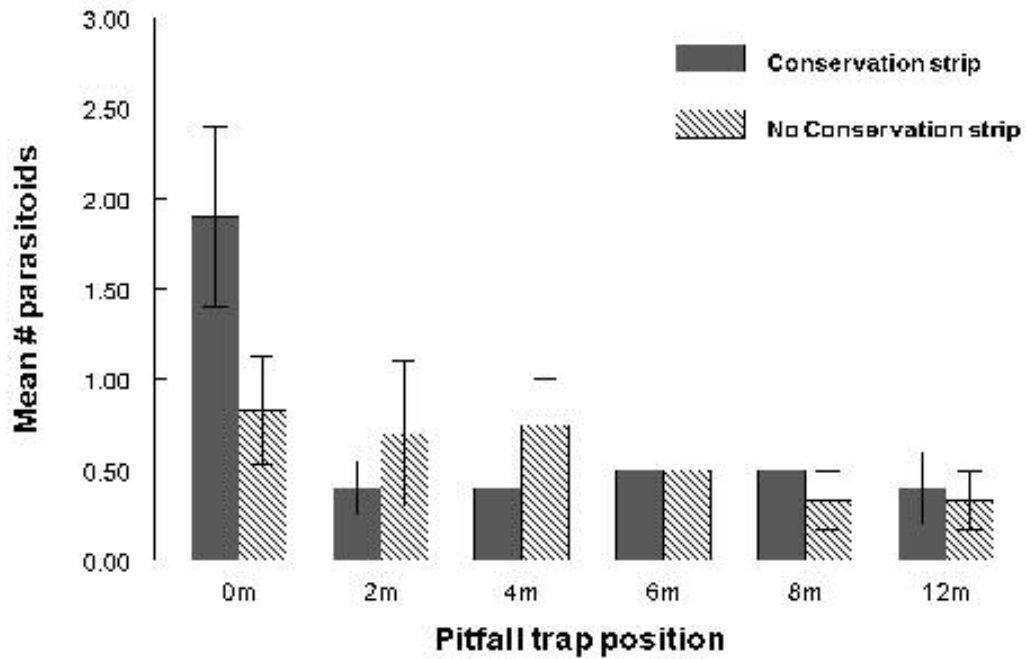


Figure 10. 2003 abundance of parasitoids at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

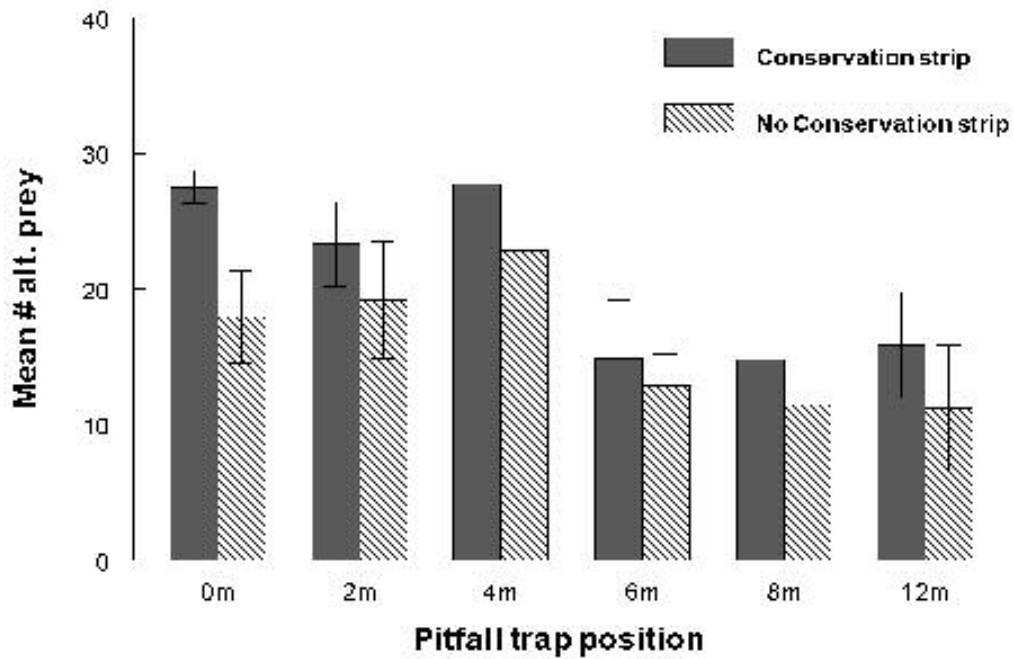


Figure 11. 2002 abundance of alternative prey at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

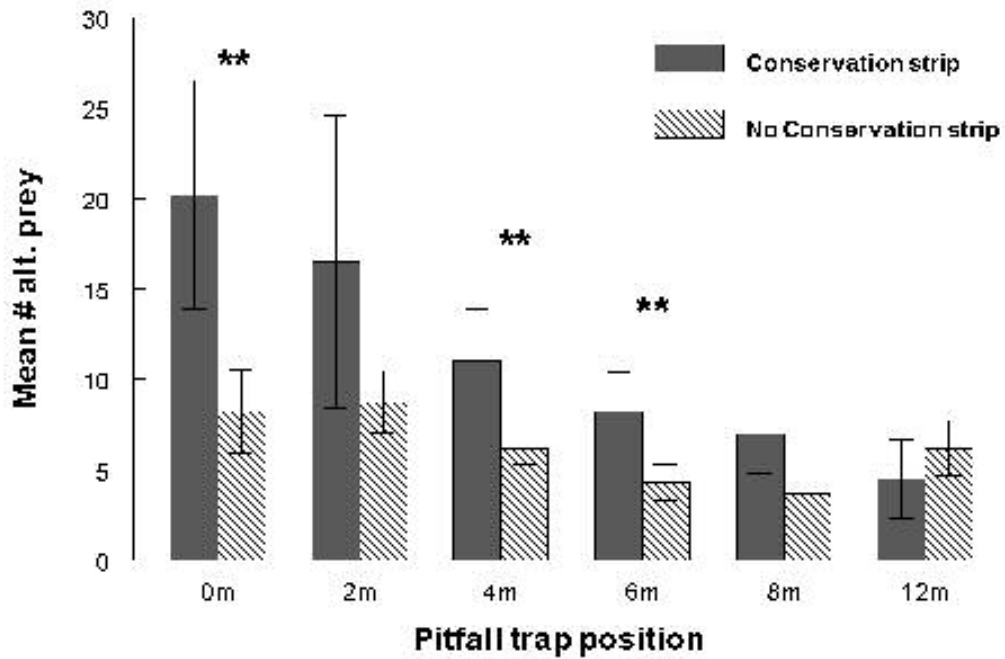


Figure 12. 2003 abundance of alternative prey at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

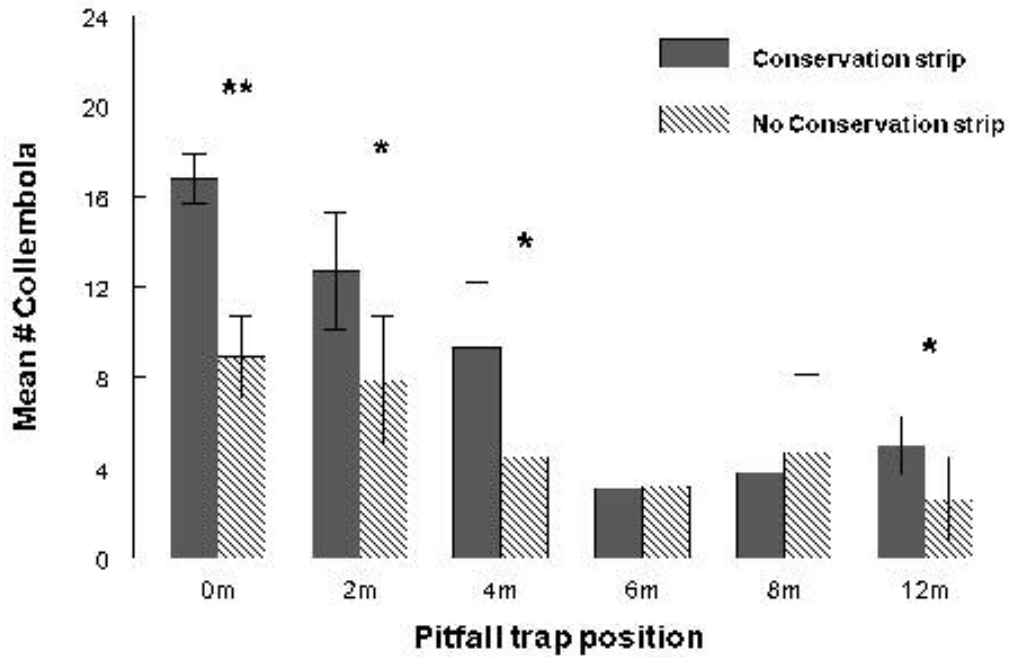


Figure 13. 2002 abundance of collembola at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

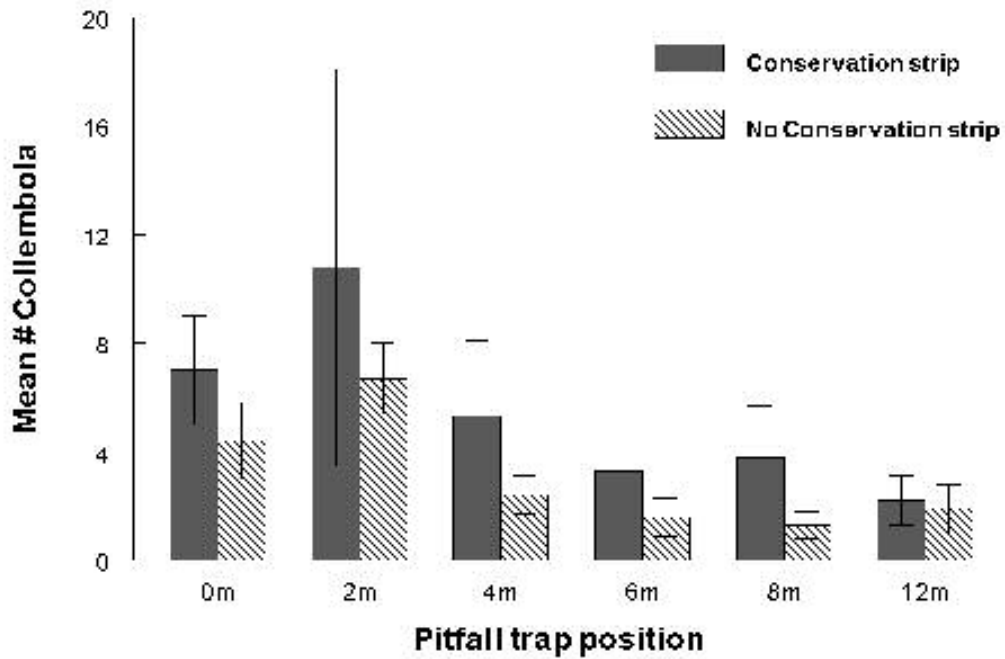


Figure 14. 2003 abundance of collembola at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

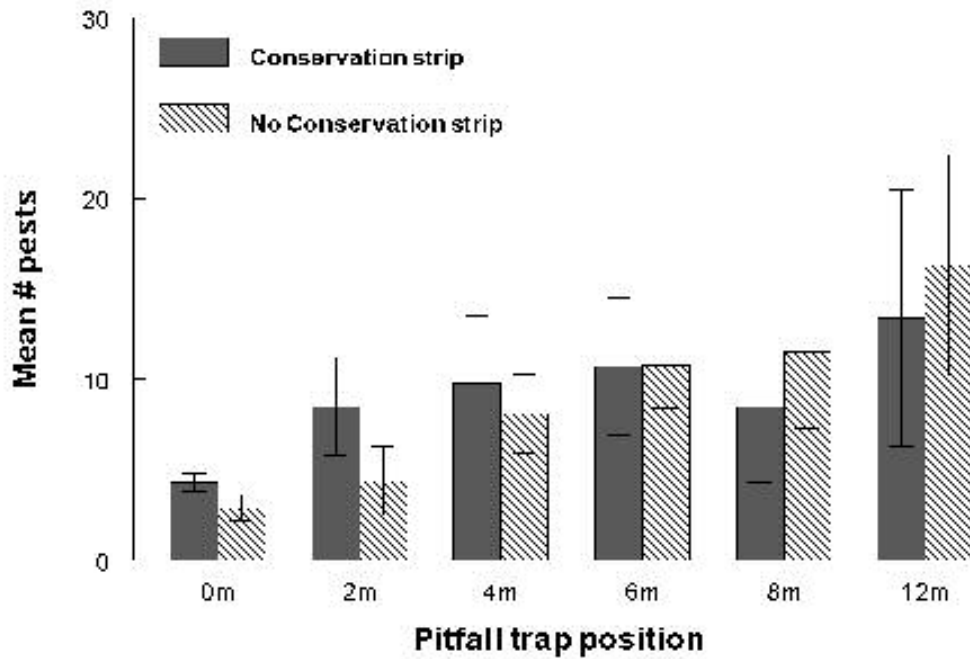


Figure 15. 2002 abundance of turf pests at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

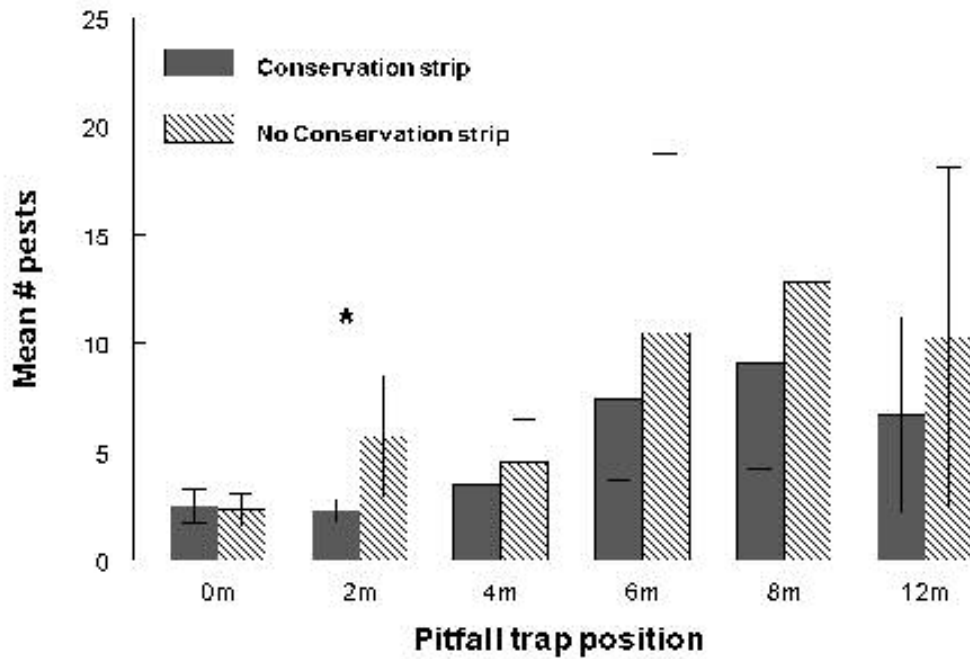


Figure 16. 2003 abundance of turf pests at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

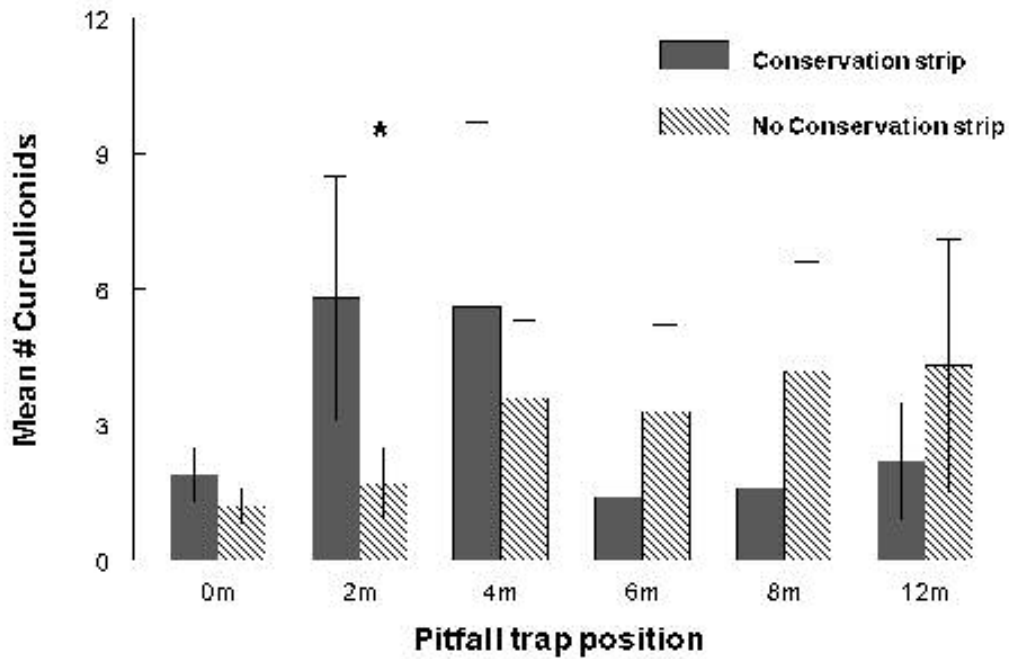


Figure 17. 2002 abundance of curculionids at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

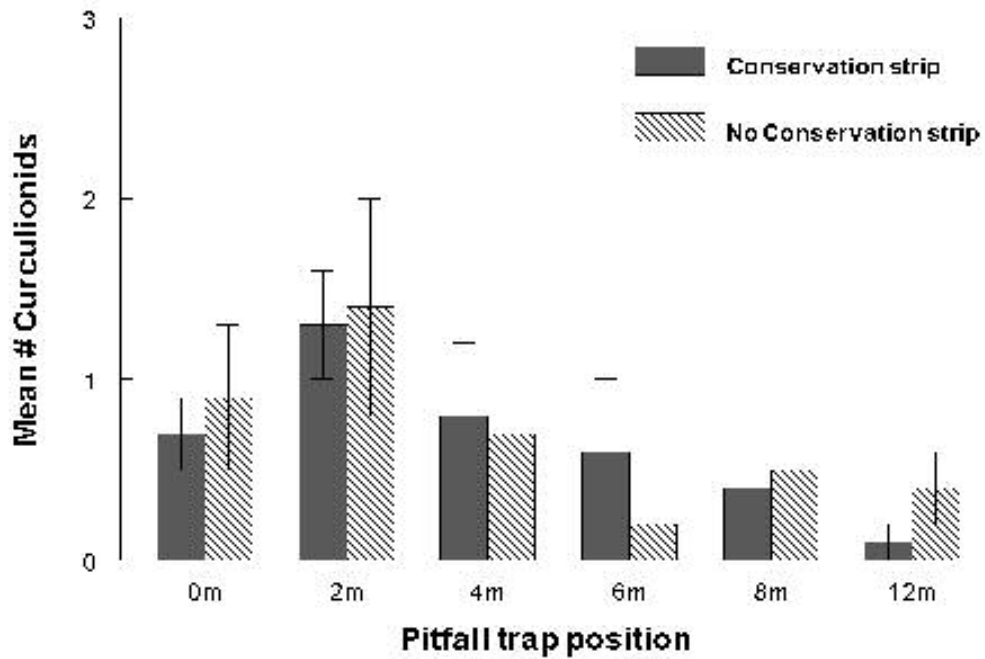


Figure 18. 2003 abundance of curculionids at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

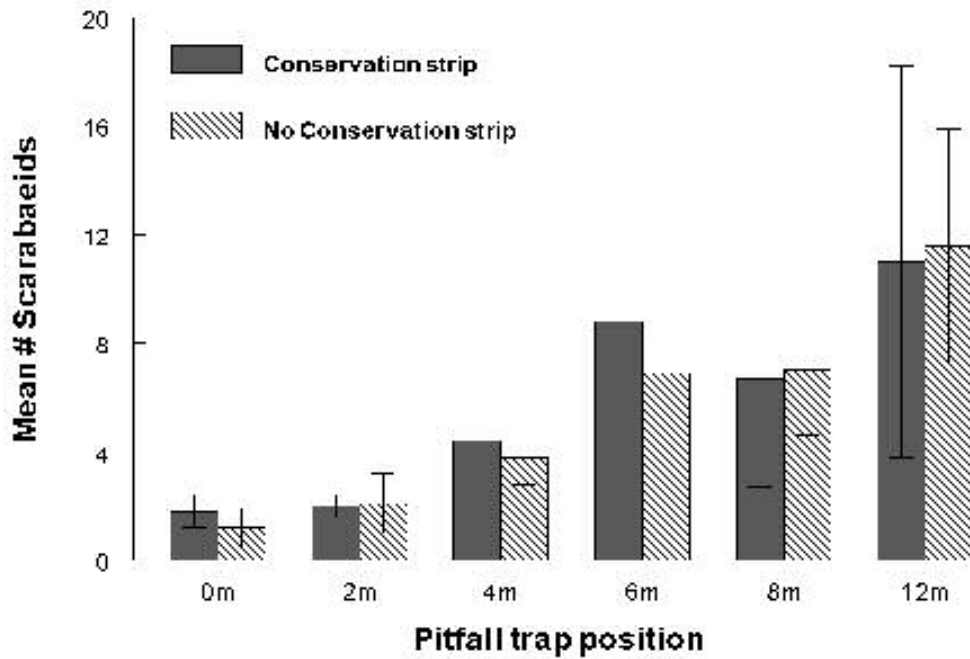


Figure 19. 2002 abundance of scarabaeid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on all four dates for each trap position.

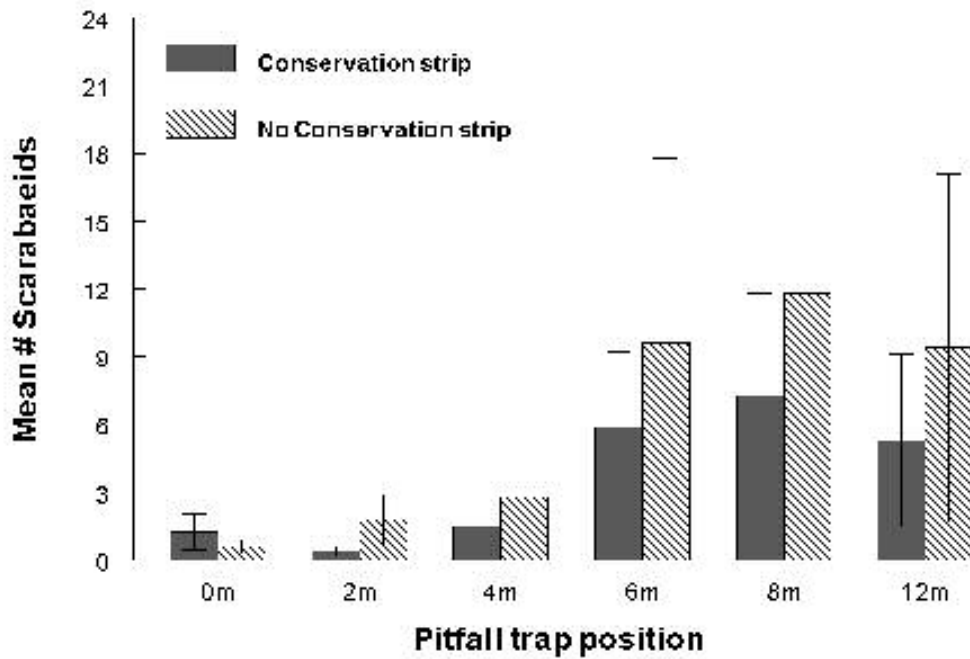


Figure 20. 2003 abundance of scarabaeid beetles at different trap positions in plots with and without conservation strips. At 0m the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. 4m is the edge of the fairway. *, **, *** indicate significant differences at $P < 0.10$, 0.05, and 0.01 levels respectively in *LSD* comparisons of treatment means at each trap position. Values represent the mean \pm SE of six fairways on both dates for each trap position.

CHAPTER 3

Evaluating common predators from golf courses to determine their ability to consume black cutworms and alternative prey items

Introduction

Turfgrass ecosystems are endowed with a variety of arthropods representing various functional groups. Of particular interest to conservation biological control are predacious arthropods that may influence insect pest populations in turf and arthropods that may serve as alternative prey items for these predacious arthropods. If habitat manipulations, such as conservation strips can increase the abundance of alternative prey and predators in golf course fairways this could contribute to a reduction in pest insect abundance. However, it is important to know whether the alternative prey that are increasing are palatable to the predators we are trying to attract. It is also important to know whether predators that are increasing are capable of consuming key golf course pests.

The most common predacious arthropods in turfgrass ecosystems are generalist predators such as carabid beetles, staphylinid beetles, and spiders (Cockfield and Potter 1984, Terry et al. 1993, Smitley et al. 1998). Although carabids, staphylinids, and spiders are often lumped together as ‘predators’ or ‘natural enemies’ in agricultural and turf research, this is not strictly the case. Carabid beetles in particular, while members of a predominantly predacious family, are often suspected of being omnivores, herbivores (primarily seeds), or scavengers rather than strict predators capable of reducing pest

insect populations (Barney and Pass 1986). Barney and Pass (1986) found that two *Amara* species fed on weevil and lepidopteran larvae but also on crabgrass seeds and chickweed seeds. In fact, only one of the five species (representing four genera) of beetles tested fed exclusively on larvae. Less research has been done on the diets of staphylinid beetles. However, some members of this family are thought to be scavengers, detritivores, or fungivores (Cameron 1930, Dennis et al.1991). The entirety of the order Araneae are predacious, and as such are easily categorized. So, while it is most efficient to lump all of these groups together as “predators” in large sampling experiments, it must be done with caution and with the knowledge that some species will likely be misclassified. Therefore, in the experimental system of interest (turf, corn, etc), it is important to determine whether the most common members of these ‘predacious’ families are interested in, or capable of, killing and consuming a key pest.

Despite their omnivorous tendencies, many carabid beetles have a voracious appetite for the eggs, larvae, and adults of several key pests. Most of the research regarding carabids has been conducted in corn, alfalfa, or other agricultural systems. However, the similarity of the pest species and of the common carabid genera found in agriculture and turfgrass systems lends merit to the assumption that the carabid fauna of turfgrass will be similarly voracious. Many species of pests in the family Noctuidae occur in agriculture and have been used as prey items in laboratory feeding trials. The eggs of the red-backed cutworm (*Euxoa ochrogaster* Guené) were readily found and eaten by 20 of 21 species of carabids tested by Frank (1971). These included several *Amara*, *Pterostichus*, and *Bembidion* species, all of which were found in golf course sampling (see Chapter 2). Frank (1971) also found larger fifth instar cutworm larvae

were attacked by many species of carabids but only successfully killed and consumed by six of the larger species, which again included two species of *Pterostichus*. Black cutworm, *Agrotis ipsilon*, (Lepidoptera:Noctuidae) a pest in corn and turf is readily consumed, live or dead, by a variety of carabid genera (Best and Beegle 1977a and b).

Staphylinid beetles and spiders have also been included in laboratory feeding trials. In a large experiment that tested consumption of armyworm, *Psuedaletia unipuncta* (Lepidoptera:Noctuidae), Clark et al. (1994) included two species of staphylinid, two lycosid spiders, and a coccinellid species amidst nine species of carabids. All of the species tested, except one of the carabids, attacked and consumed at least one stage of armyworm larvae. Staphylinids were also included in the broad feeding trials conducted by Frank (1971) and three genera of staphylinids consumed the eggs of *E. ochrogaster*.

Laboratory feeding trials of predators collected from turfgrass systems are much more rare than those related to agriculture. However, the research that has been done includes a broader sample of predatory families. Cockfield and Potter (1984) conducted experiments to examine predation of sod webworm (*Crambus* and *Pediasia* spp.) eggs by carabids and staphylinids. Five carabid species were tested, including two species of *Amara* and one *Stenolophus* species, all of which consumed eggs. Five of seven staphylinid taxa also consumed sod webworm eggs. Terry et al. (1993) conducted similarly extensive trials using another turfgrass pest, the Japanese beetle, *Popillia japonica* (Coleoptera: Scarabaeidae). Eleven of the twelve carabid taxa consumed at least one of the *P. japonica* eggs presented to them. Of six staphylinid taxa tested, five also consumed the eggs with varying levels of intensity. Fewer taxa from each family were

used in trials with live first instar larvae of *P. japonica*. All members of each family tested successfully killed and consumed at least some of the larvae presented to them.

In addition to feeding on pest insect species, generalist predators may also feed on other insects (alternative prey) in the turfgrass habitat. Large numbers of beneficial arthropods may be attracted to, and enticed to stay in areas with abundant food resources. Alternative food resources can take several forms and can be provided in a number of ways. Pollen and nectar resources from flowering plants can attract a variety of predatory beetles (eg. coccinellids, cantharids), syrphid flies, and parasitic hymenoptera. For these beneficials, the installation of flowering plant material produces a direct and usable food resource. The addition of flowers and other habitat modifications also attracts a myriad of non-pest herbivores and detritivores. These non-pest arthropods may serve as alternative prey for generalist predators. Collembola, crickets, and various Heteropterans are some of the potential alternative prey items found on golf courses (Kunkel et al. 1999, see Chapter 2). Studies in agricultural and ornamental systems have examined the influence of alternative prey on predator abundance. Settle et al. (1996) found that by adding organic matter to rice fields, predator populations increased in response to an increase in detritivores in rice fields. Common detritivores eaten by generalist predators included flies, fly larvae, and collembola. This demonstrates how a simple habitat manipulation can lead to higher alternative prey and predator populations that results in some level of biological control. Similarly, Robertson et al. (1994) found the density of predators in no-till grain fields was significantly and positively correlated with the density of detritivores.

In ornamental landscapes, increased vegetational complexity has resulted in greater numbers of alternative prey and predators than simple habitats (Shrewsbury 1996). Shrewsbury (1996) found a positive correlation between the number of anyphaenid spiders and the number of potential alternative prey. More complex landscapes also had fewer azalea lace bugs (pest) than simple landscapes. Studies, such as these, that have attempted to quantify the relationship between predators and alternative prey are relatively few for any system. The role of alternative prey in turf is mostly unexplored.

In this study, 11 arthropod predators, commonly found in these golf courses representing five families and two orders, were tested for their ability to consume live black cutworm larvae and pupae. In addition, 5 alternative prey items, also commonly found in golf courses, were evaluated for their ability to serve as prey for these golf course predators. Especially unique to these studies is that turfgrass predators were evaluated across several life stages of the black cutworm. Previous research of this kind has focused on eggs, pupae, or first instar larvae, the most defenseless and immobile stages, of turfgrass pests. The ability of predators to kill active and inactive stages of pests is important in understanding the potential impact natural enemies may have on pest populations. The ability of predators to feed on alternative prey is important to understanding the role of alternative prey in attracting and retaining predators in the turfgrass system. This, to my knowledge, is the first time that predators from turfgrass were tested in this manner and to this extent for their efficacy as natural enemies of black cutworm, in combination with identifying the potential role of alternative prey as food

items for predators in the turfgrass habitat. These studies will assist in more accurately assessing the benefit of adding conservation strips to golf course environments.

Laboratory feeding trials are often used to make assertions about the diet and feeding behavior of predators observed in field experiments. The following experiments were carried out for these same reasons. The experiments described in Chapters 1 and 2 of this thesis produced an inventory of many insects and spiders that are potentially predacious on turfgrass insects. The overall objective of the experiments described here was to evaluate the most common of these predators for their potential to consume a common golf course pest. Additionally, five non-pest arthropods, common to golf courses, were evaluated for their value as alternative prey for predators. Collembola, crickets, grasshoppers, cercropids, and isopods were included in the trial because they were common in turf or in the conservation strips. The specific objectives were: 1) to test predators for their ability to consume live black cutworms of several instars, and 2) to test predators' for their ability to consume various alternative prey items.

Methods

Consumption of black cutworms by common golf course predators. In the experiments presented here, the same genera and morpho-types of predators that were most frequently captured in pitfall traps from golf course turf (see Chapter 2) were evaluated in the laboratory for their ability to consume black cutworms (*Agrotis ipsilon*), a common golf course pest. For the remainder of this chapter the unqualified use of the term 'cutworm' refers to the black cutworm, *Agrotis ipsilon*. The families and genera or morpho-types of predators involved were: the carabids *Amara*, *Pterostichus*, *Bembidion*,

Stenolophus-1, *Stenolophus-2* and *Clivina*; three different staphylinid morpho-types staphylinid-1, staphylinid-2, staphylinid-3; a Lycosid spider; and the Coccinellid, *Hippodamia convergens*. Adult beetles and spiders used in the feeding trials were caught using dry pitfall traps with the exception of the coccinellids that were caught by hand on grass or flowers. All trapping was done at the University of Maryland Turfgrass Research Facility (College Park, MD). Taxa collected in dry pitfall traps were identified to genus level or given a morpho-type number. The different genera were compared with a reference collection established during pitfall trapping on golf courses (Chapter 2) to confirm the same genera and morpho-types of arthropods caught on the golf courses were tested in laboratory feeding trials.

Collection of predators began in April 2003 and continued, as needed, through July 2003 when all feeding trials were completed. Carabid and staphylinid beetles were retained in the laboratory in shallow plastic bins containing moist potting soil. They were fed cat food (Purina Cat Chow, St. Louis, MS) and kept at room temperature in the laboratory. Spiders were kept individually in glass jars containing moist potting soil and fed black cutworm larvae. Coccinellid beetles were housed in a closed plastic container and provided with water and a sugar-water solution. New individuals of all taxa were continuously trapped and added to the colonies to replace ones that died and to ensure healthy predators were available for the feeding trials.

Black cutworms were reared by Dow Agrosience (Indianapolis, IN). Cutworms were shipped to the laboratory in plastic containers (10 cm diameter x 4 cm height) containing artificial diet. Cutworms were maintained on artificial diet and stored in a growth chamber at 18 ° C until needed.

Feeding trials were conducted in from April to July of 2003. Feeding trials used 1st, 3rd, 5th, 7th instars and pupae of the cutworms as prey. All 11 predator taxa were used in the 1st instar trials. If fewer than 40% of a taxon consumed cutworms of a given instar then that taxon was not used in trials of the next larger instar. All available taxa were used in trials with pupae because they are immobile and even small predators may have been capable of consuming them. Twenty replicates of each predator taxon were conducted for most trials. However, only ten replicates were conducted with *Clivina* for all but the 3rd instar trials due to a shortage of individuals from this genus. Ten replicates were conducted for staphylinid-2 and staphylinid-3 1st instar cutworm trials and for *Pterostichus* and Lycosid cutworm pupae trials. Though the number of taxa tested on a particular day varied with availability of predators and cutworms, trials were always conducted in groups of ten replicates of each available taxon.

All predators were starved in individual 9 cm petri dishes with moist filter paper for 24 hours prior to the trials. Starvation and the subsequent trials took place in growth chambers at 25°C under a photo-period of 16:8 hours (light: dark). Feeding trials were conducted during the dark phase. Following starvation, one cutworm of the appropriate instar was added to each dish. Petri dishes were returned to the growth chamber and then checked every hour for five hours. Petri dishes were examined at each time interval and cutworms were recorded as either 'eaten' or 'not eaten'. If cutworms were partially consumed they were scored as eaten.

Statistical analysis. Only the hour five data was used in the analysis. Data were analyzed using Chi-Square tests in 2x2 contingency tables in the FREQ procedure of SAS (2001). 2x2 contingency tables were constructed to compare each predator taxon to

every other predator taxon within a given cutworm instar. No comparisons were made across cutworm instars.

Consumption of alternative prey by common golf course predators. In the experiments presented here, non-pest arthropods that were most frequently found in golf course turf (see Chapter 2) were evaluated in the laboratory as potential alternative prey items for six common predators of golf turf. Five categories of alternative prey items were used in this experiment: collembola (Collembola: Entomobryidae), crickets (Orthoptera: Gryllidae), grasshoppers (Orthoptera: Acrididae), isopods (Isopoda), and froghoppers (Heteroptera: Cercropidae). The prey items were caught the day of each trial using a D-Vac, insect vacuum.

The size of the individuals used in the trials was kept consistent within each category but not necessarily between categories. For instance, all crickets used in the trials were 4-6mm in length but this is considerably larger than the collembola that were 2mm. Isopods were 4-6mm, grasshoppers were 7-9mm, and delphacids were 3-4mm. Freshly frozen (dead) prey was used in all alternative prey feeding trials. Initial trials with live prey indicated that the predators had a difficult time catching active prey such as crickets or grasshoppers in the barren petri dishes. Collembola, on the other hand, would sit on the lid of the dish where they were inaccessible to the predators.

Ten replicates of each prey type were conducted for each predator. Six different predator genera/morphs were used in the collembola trials: *Pterostichus*, *Stenolophus-1*, *Bembidion*, *Amara* Staphylinid-1 and Staphylinid-2. Only *Pterostichus*, *Stenolophus-1*, *Amara*, and Staphylinid-1 were used in the other alternative prey trials. Feeding trials to

determine the palatability of the five prey items were conducted as described for the cutworm feeding trials.

Statistical analysis. Only the hour five data was used in the analysis. Data were analyzed using Chi-Square tests in 2x2 contingency tables in the FREQ procedure of SAS. 2x2 contingency tables were constructed to compare each predator taxon to every other predator taxon within a given prey type. This same procedure was used to compare the frequencies that the five prey items were eaten by a given predator.

Results

Consumption of black cutworm by common golf course predators. All of the predator taxa used in this trial consumed some cutworm larvae or pupae (Table 1).

In trials with first instar cutworm larvae, staphylinid-2, staphylinid-3, and *Clivina* had the fewest number of beetles consume larvae (Table 1). Staphylinid-2 and staphylinid-3 had only one beetle each consume the larvae which is significantly less than all other taxa, save *Clivina* and *Stenolophus-2* where 3 (of 10) and 7 individuals respectively consumed larvae (Table 2). The taxa that had the highest frequency of consumption of 1st instar cutworms were Staphylinid-1, *H. convergens*, and Lycosid (Table 1). Staphylinid-1 and Lycosid had all 20 individuals consume larvae, which is significantly more than any taxon besides *H. convergens*, in which *H. convergens* 18 individuals consumed larvae (Table 2).

Trials using third instar larvae produced different results between predator taxa (Table 1). For this instar *Clivina*, *Pterostichus*, and Staphylinid-1 had the highest frequencies of consumption 20, 20, and 18 respectively, which were significantly more

than all other taxa (Table 3). The frequency that *Bembidion* consumed larvae was the lowest of this trial and significantly less than all other taxa except *Stenolophus-2* (Table 3). *Bembidion* that had ten beetles consume first instar larvae had no individuals that consumed third instar larvae. All taxa, except *Pterostichus* and *Clivina*, had lower consumption frequencies of third instar larvae than first instar larvae (Table 1).

Pterostichus and *Clivina* consumed fifth instar larvae as readily as thirds. All of the individuals from these two genera consumed fifth instar larvae (Table 1). Only 4 of the 20 *Amara* beetles consumed the larva in this trial, which is significantly less than any of the other taxa (Table 4). Staphylinid-1 and Lycosid individuals ate similar numbers of fifths as they did thirds but both consumed significantly less than *Pterostichus* and *Clivina* (Table 4).

Taxa in the seventh instar trials fell neatly into two groups. *Pterostichus* and *Clivina* had 9 and 13 individuals respectively consuming the larvae, which is significantly more than Staphylinid-1 and Lycosid that each had one individual eat the larvae (Tables 1, 5).

Again, *Clivina* beetles all consumed the pupae which is significantly more than all the other taxa tested except *Pterostichus* (Table 1, 6). About half of the individuals from the other four taxa involved in this trial consumed pupae. None of the ten spiders tested consumed a cutworm pupa which is significantly less than all other taxa except *Stenolophus-1* (Table 1, 6).

Consumption of alternative prey by common golf course predators. In general, all of the beetle genera and morpho-types tested readily consumed all of alternate prey types (Table 7). There were few differences in the frequency that each prey type was

consumed by the predators. All ten *Pterostichus* consumed every type of prey item except the cercropids. Only four of the ten *Stenolophus-1* beetles consumed Collembola. This is significantly less than *Pterostichus*, *Amara*, and *Staphylinid-1* ($\chi^2 = 8.57$, $P = 0.0034$) where all ten beetles consumed collembola. Nine *Bembidion* and nine *Staphylinid-2* beetles ate collembola which is also significantly more than *Stenolophus-1* ($\chi^2 = 5.49$, $P = 0.0191$). Six *Stenolophus-1* beetles consumed Isopods. This was also significantly fewer than the ten *Pterostichus* that consumed isopods ($\chi^2 = 5.00$, $P = 0.0253$).

No single beetle morpho-type consumed the five prey types at significantly different frequencies ($P > 0.05$). The *Stenolophus-1* beetles showed the most variable feeding between prey types. Four *Stenolophus-1* beetles consumed collembola while 8 *Stenolophus-1* beetles consumed grasshoppers (Table 6). This difference was not significant ($\chi^2 = 3.33$, $P = 0.0679$) but was larger than the other beetle morpho-types that only differed by 1 (*Pterostichus*) or 2 (*Amara*, *Staphylinid-1*) between prey types (Table 7).

Discussion

While the consumption of prey items in laboratory studies does not necessarily reflect a species' natural feeding tendencies in the field, it does demonstrate the ability of a species to consume prey and the palatability of that prey. Every predator species tested in this experiment killed and consumed at least one life stage of black cutworm. From a biological control perspective this is encouraging.

The ability of predators to consume cutworms varied with the size of the predator and the size of the cutworms. As would be expected, larger beetles always consumed

more cutworms and larger cutworms than smaller beetles. The smallest beetles, staphylinid-2 and staphylinid-3 (4-5mm each), were either incapable of consuming even first instar larvae (2mm) or perhaps did not find them acceptable to eat as only one beetle of each species consumed a cutworm. Perhaps these minute beetles typically scavenge dead material or eat small defenseless items such as insect eggs. However, 10 of 20 *Bembidion* beetles (5mm), which are similar in size to staphylinid-2 and staphylinid-3, consumed first instar larvae.

The largest beetle, *Clivina* (22mm), may have had difficulty detecting the small 1st instar larvae as only 3 of the 10 *Clivina* tested consumed 1st instar larvae while for the rest of the instars every larva was eaten. A similar result was seen for *Pterostichus melanarius* by Hagley et al. (1982). Only 33% of these large beetles ate first instar codling moth larvae where as they ate considerably more of the larger stages. Similarly, the *Pterostichus* (13-14mm) beetles used in my experiments consumed fewer first instar larvae (14) than third (20) and fifth (20) instar larvae. Staphylinid-1 and *Amara* were the most successful at consuming larvae larger than themselves. While Staphylinid-1 and *Amara* measure only 9mm and 11mm, respectively, they were each able to kill fifth and even seventh instar larvae which measure 30mm and 40mm.

Lycosid spiders (5mm body) were within the top consumers for almost every instar. Like staphylinid-1 and *Amara* beetles, Lycosid spiders would attack prey larger than themselves, even the seventh instar cutworms, repeatedly and seemed mechanically limited rather than unwilling. Spiders, in general, were very abundant in the pitfall traps from the conservation strips but also from the rough and fairways (see Chapters 1 and 2).

Spiders are exclusively predators and therefore may be a particularly important force in the suppression of pests on golf courses.

This experiment did not examine the preference of predators for alternative food types, so it is hard to say what choices the various types of beetles would make if presented, in the field, with cutworms and grass seed, or cutworms and collembola. However, from these experiments it can be said that some of the most common predator taxa found in turf and in conservation strips on golf courses, such as *Amara*, Staphylinid-1, and *Stenolophus-1*, consumed considerable numbers of cutworms in the lab. This suggests that these predators will likely consume cutworms under natural conditions and therefore, could have an impact on pest populations.

The exploration of what types and species of arthropods serve as alternative prey for predatory beetles and spiders has not been well explored. Research has been conducted that demonstrates the palatability of alternative prey items to predators in several agricultural systems yet, this information is missing from the turf literature. Collembola have been shown to be prey items for linyphiid spiders (Sunderland et al 1986) and carabid beetles (Bauer 1982,1985; Bilde et al 2000). Research has also demonstrated that carabid beetles will consume fly larvae in field experiments (Anthomyiidae: Wright et al 1960, Coaker 1965, Grafius and Warner 1989; Chyromiidae and others: Settle et al. 1996). Staphylinid beetles were seen eating fly larvae by Coaker (1965). Several other non-pest arthropods were fed to carabid beetles in the lab by Best and Beegle (1977b). Four species of carabids were fed a variety of live and dead prey items including crickets, lepidoptera larvae, isopods, and slugs. Most of these items were not eaten in large amounts except dead crickets and live or dead

lepidopteran larvae (Best and Beegle 1977b). Carabids have also consumed earthworms and slugs in field observations (Mair and Port 2001).

This experiment established the palatability of some potential alternative prey, not the vulnerability of or preference for prey. This is an important step however, before more elaborate experiments are carried out. Some potential alternative prey that have been examined by others were found to not be palatable to certain predators. One species of collembola (*Folsomia candida*) has been found to be toxic to certain carabid beetles (Bilde et al. 2000) and lycosid spiders (Toft and Wise 1999). Similarly, an aphid species has been found to reduce the fecundity and survivorship of some carabid beetles and spiders and is suspected of being toxic (Toft and Nielson 1997). Prey items such as these would obviously be of limited value to predators and perhaps should be left out of gross alternative prey estimates. Unlike these studies, my studies on alternative prey found all of those tested to be palatable to the range of predators examined.

All of the prey types presented were eaten by a majority of each type of beetle. All of the prey items tested in my studies were common in and around conservation strips on golf courses (see Chapter 1 and 2). The palatability of these five prey items in the laboratory to predators commonly found in turf on golf courses strongly suggests that they would be eaten in the field by these predators. For instance, it is conceivable that if carabids are capable of capturing collembola which are small and very fast that they would also find it worth while to eat small isopods or heteropterans.

The palatability and vulnerability of insect pest species and potential alternative prey to predators is important information to have when trying to design and implement habitat manipulations in conservation biological control. Only a handful of studies have

addressed these relationships. Positive correlations have occasionally been demonstrated between alternative prey (collembola) and carabid beetles (Potts and Vickerman 1974). In one instance, a negative correlation between early season Collembola abundance and late season aphid abundance was found suggesting that the presence of alternative prey early in the season increased predator populations to the point that aphid populations were reduced (Gravesen and Toft 1987). However, as knowledge about the breadth of generalist predator diets increases –this includes not only prey items but also seeds and scavenged material– there may be other correlations to be made that have been overlooked in the past.

In summary, previous data demonstrated that the populations of generalist predators and alternative prey taxa examined in this study were enhanced on golf courses when conservation strips were added (see Chapter 1 and 2). This study demonstrated black cutworms are palatable and vulnerable to a number of common predatory taxa that can be found on golf courses. These results suggest that increasing the abundance of these common predators through habitat manipulation, such as the installation of conservation strips, could translate into increased predation of black cutworms and a reduction in the populations of this golf course pest.

Table 1. Number of individuals, out of 20, that consumed black cutworms of various stages¹.

Predator	Black Cutworm Instar				
	1 st	3 rd	5 th	7 th	Pupae
Carabidae					
<i>Pterostichus</i>	14 (ade)	20 (a)	20 (a)	13 (a)	9* (ac)
<i>Clivina</i>	3* (cf)	20 (a)	10* (a)	9* (a)	10* (c)
<i>Amara</i>	16 (ae)	9 (b)	4 (b)		12 (ad)
<i>Stenolophus-1</i>	12 (ac)	7 (bc)			5 (be)
<i>Stenolophus-2</i>	7 (cf)	2 (cd)			10 (de)
<i>Bembidion</i>	10 (cd)	0 (d)			
Staphylinidae					
Staphylinid-1	20 (b)	18 (a)	14 (c)	1 (b)	11 (ad)
Staphylinid-2	1* (f)				
Staphylinid-3	1* (f)				
Coccinellidae					
<i>H. convergens</i>	18 (be)	7 (bc)			
Lycosidae					
	20 (b)	11 (b)	13 (c)	1 (b)	0* (b)

¹Frequencies were compared using 2x2 contingency tables across species for each cutworm instar. Frequencies with the same letter (within a column) are not significantly different at the P<0.05 level.

* indicates only 10 individuals were used in a trial.

Table 2. Chi-Square and probability values for 1st instar cutworm feeding trials¹.

<i>Predator</i>		<i>Ptero- stichus</i>	<i>Lycosid</i>	<i>Clivina*</i>	<i>Amara</i>	<i>Steno-1</i>	<i>Steno-2</i>	<i>Bemb- idion</i>	<i>H. conv- ergens</i>	<i>Staph-2</i>	<i>Staph-3*</i>
<i>Staph-1</i> ²	X²	7.059	-	18.261	4.444	10.000	19.259	13.333	2.105	25.714	25.714
	P	0.008	-	<.0001	0.035	0.002	<.0001	6.000	0.147	<.0001	<.0001
	n=	40	40	30	40	40	40	40	40	30	30
<i>Pterostichus</i>	X²		7.059	4.344	0.533	0.440	4.912	1.667	2.500	9.600	9.600
	P		0.008	0.037	0.465	0.507	0.027	0.197	0.114	0.002	0.002
	n=		40	30	40	40	40	40	40	30	30
<i>Lycosid</i>	X²			18.261	4.444	10.000	19.259	13.333	2.105	25.714	25.714
	P			<.0001	0.035	0.002	<.0001	0.000	0.147	<.0001	<.0001
	n=			30	40	40	40	40	40	30	30
<i>Clivina</i>	X²				7.177	2.400	0.075	1.086	11.429	1.250	1.250
	P				0.007	0.121	0.784	0.297	0.001	0.264	0.264
	n=				30	30	30	30	30	20	20
<i>Amara</i>	X²					1.905	8.286	3.956	0.784	13.303	13.303
	P					0.168	0.004	6.047	0.376	0.000	0.000
	n=					40	40	40	40	30	30
<i>Steno-1</i> ²	X²						2.506	0.404	4.800	6.787	6.787
	P						0.113	0.525	0.029	0.009	0.009
	n=						40	40	40	30	30
<i>Steno-2</i> ²	X²							0.921	12.907	2.131	2.131
	P							0.337	0.000	0.144	0.144
	n=							40	40	30	30
<i>Bembidion</i>	X²								7.619	4.593	4.593
	P								0.006	0.032	0.032
	n=								40	30	30
<i>H. converg</i> ²	X²									18.373	18.373
	P									<.0001	<.0001
	n=									30	30
<i>Staph-3</i> ²	X²										0.000
	P										1.000
	n=										20

¹Degrees of freedom for all comparisons = 1.

² These morpho-type names have been abbreviated to conserve space

* indicates 10 individuals used in trial.

Table 3. Chi-Square and probability values for 3rd instar cutworm feeding trials. Degrees of freedom for all comparisons = 1.

Predator		<i>Ptero- stichus</i>	<i>Lycosid</i>	<i>Clivina</i>	<i>Amara</i>	<i>Steno-1</i>	<i>Steno-2</i>	<i>Bemb- idion</i>	<i>H. conv- ergens</i>
Staph-1 ¹	X ²	2.1053	6.1442	2.1053	9.2308	12.9067	25.6000	32.7273	12.9067
	P	0.1468	0.0132	0.1468	0.0024	0.0003	<.0001	<.0001	0.0003
	n=	40	40	40	40	40	40	40	40
<i>Pterostichus</i>	X ²		11.6290	-	15.1724	19.2593	32.7273	40.0000	19.2593
	P		0.0007	-	<.0001	<.0001	<.0001	<.0001	<.0001
	n=		40	40	40	40	40	40	40
<i>Lycosid</i>	X ²			11.6129	0.4000	1.6162	9.2308	15.1724	1.6162
	P			0.0007	0.5271	0.2036	0.0024	<.0001	0.2036
	n=			40	40	40	40	40	40
<i>Clivina</i>	X ²				15.1724	19.2593	32.7273	40.0000	19.2593
	P				<.0001	<.0001	<.0001	<.0001	<.0001
	n=				40	40	40	40	40
<i>Amara</i>	X ²					0.4167	6.1442	11.6129	0.4167
	P					0.5186	0.0132	0.0007	0.5186
	n=					40	40	40	40
<i>Steno-1</i> ¹	X ²						3.5842	8.4848	0.0000
	P						0.0583	0.0036	1.0000
	n=						40	40	40
<i>Steno-2</i> ¹	X ²							2.1053	3.5842
	P							0.1468	0.0583
	n=							40	40
<i>Bembidion</i>	X ²								8.4848
	P								0.0036
	n=								40

¹ These morpho-type names have been abbreviated to conserve space

Table 4. Chi-Square and probability values for 5th instar cutworm feeding trials¹.

Predator		<i>Pterostichus</i>	<i>Lycosid</i>	<i>Clivina</i>*	<i>Amara</i>
Staphylinid-1	X²	7.059	0.114	3.750	10.101
	P	0.008	0.736	0.053	0.002
	n=	40	40	30	40
<i>Pterostichus</i>	X²		8.485	-	26.667
	P		0.004	-	<.0001
	n=		40	30	40
Lycosid	X²			4.565	8.286
	P			0.033	0.004
	n=			30	40
<i>Clivina</i>	X²				17.143
	P				<.0001
	n=				30

¹Degrees of freedom for all comparisons = 1.

* indicates 10 individuals used in trial.

Table 5. Chi-Square and probability values for 7th instar cutworm feeding trials¹.

Predator		<i>Pterostichus</i>	<i>Lycosid</i>	<i>Clivina</i> *
Staphylinid-1	X²	15.824	1.111	21.675
	P	<.0001	0.292	<.0001
	n=	40	40	30
<i>Pterostichus</i>	X²		10.417	2.131
	P		0.001	0.144
	n=		40	30
Lycosid	X²			15.625
	P			<.0001
	n=			30

¹Degrees of freedom for all comparisons = 1.

* indicates 10 individuals used in trials.

Table 6. Chi-Square and probability values for cutworm pupae feeding trials¹.

Predator		Ptero- stichus*	Lycosid*	Clivina*	Amara	Steno-1	Steno-2
Staph-1 ²	X²	3.6750	8.6842	6.4286	0.1023	3.7500	0.1003
	P	0.0552	0.0032	0.0112	0.7491	0.0528	0.7515
	n=	30	30	30	40	40	40
<i>Pterostichus</i>	X²		16.3636	1.0526	2.8571	11.3170	4.5933
	P		<.0001	0.3049	0.0910	0.0008	0.0321
	n=		20	20	30	30	30
Lycosid	X²			20.0000	10.0000	3.0000	7.5000
	P			<.0001	0.0016	0.0833	0.0062
	n=			20	30	30	30
<i>Clivina</i>	X²				5.4545	15.0000	7.5000
	P				0.0195	0.0001	0.0062
	n=				30	30	30
<i>Amara</i>	X²					5.0128	0.4040
	P					0.0252	0.5250
	n=					40	40
<i>Steno-1</i> ²	X²						2.6667
	P						0.1025
	n=						40

¹Degrees of freedom for all comparisons = 1.

² These morpho-type names have been abbreviated to conserve space

* indicates 10 individuals used in trials.

Table 7. Number of each predator type, out of ten, that consumed different potential alternative prey items¹.

	Alternative Prey Type				
	Collembola	Cricket	Isopod	Grasshopper	Cercropid
Carabidae					
<i>Pterostichus</i>	10 (a)	10 (a)	10 (a)	10 (a)	9 (a)
<i>Amara</i>	10 (a)	10 (a)	9 (ab)	9 (a)	8 (a)
<i>Stenolophus-1</i>	4 (b)	7 (a)	6 (b)	8 (a)	6 (a)
<i>Bembidion</i> ²	9 (a)				
Staphylinidae					
Staphylinid-1	10 (a)	8 (a)	8 (ab)	8 (a)	8 (a)
Staphylinid-2 ²	9 (a)				

¹Frequencies were compared using 2x2 contingency tables across species for each alternative prey type. Frequencies with the same letter (within a column) are not significantly different at the P<0.05 level.

²These genera were only included in the collembola trials

CHAPTER 4

Effect of Conservation Strips on the Predation of Black Cutworm Larvae and Pupae on Golf Courses

Introduction

Studies in agricultural and ornamental systems have demonstrated that increasing the complexity of a habitat frequently results in greater abundance of natural enemies and lower pest populations (Shrewsbury 1996, Tooker and Hanks 2000). Few studies have examined this form of habitat manipulation on golf courses. However, in a related field study, incorporating conservation strips containing flowering plants and ornamental grass into rough areas bordering the fairways of golf courses has resulted in increased abundance of generalist predators (see Chapter 2). Even fewer studies have examined the influence of increased natural enemy abundance on the predation of insect pests in turfgrass.

Field predation experiments are commonly used in turf and other systems to gauge the vulnerability of pests to attack by predators. In some cases, changes in the rate of predation on the pest involved are in agreement with changes in the predator population. For instance, Cockfield and Potter (1984) demonstrated that an application of chlorpyrifos insecticide that reduced the abundance of predators in turf resulted in lower predation rates of sod webworm eggs that were placed in the turf. Another study found a similar reduction in predation on Japanese beetle eggs as predators were reduced with insecticides (Terry et al. 1993). However, predation on fall armyworm pupae,

Spodoptera frugiperda (Lepidoptera: Noctuidae) did not change with the number of predators. Other studies have found mixed results with the use of field predation trials. When imidacloprid reduced the abundance of some groups of predators in turf, scavenging of dead cutworms was reduced briefly but predation of cutworm pupae and Japanese beetle eggs was unaffected. Conversely, eggs and larvae of fall armyworm and Japanese beetle eggs were consumed to extinction regardless of treatment or predator abundance (Braman et al. 2002). These studies suggest that predation trials in the field can provide some information about the fate of individuals in natural pest populations. However, it seems that different prey items suffer different rates of mortality so using more than one type of prey can give useful results.

In this research, black cutworm larvae and pupae were used in field predation experiments on golf courses. This is the first time to my knowledge that live third instar cutworms have been used for this purpose. In other research using fourth and fifth instar black cutworms, the prey were dead (Kunkel et al. 1999). Neonate armyworms and second instar armyworms have been used but recovery rates were low (Braman et al. 2002). Dead cutworms have the same inability to defend themselves as eggs so large prey are available to any size predator or to scavengers. While this is good in that it will measure overall predation rates it does not accurately measure the susceptibility of cutworms to predation

For these reasons live third instar *A. ipsilon* were used in this experiment that were held in place with fine insect pins. This allowed the larvae to maintain some defenses while preventing them from evading recovery for data collection. As a more sessile prey item, newly eclosed *A. ipsilon* pupae were also used in these trials.

In experiments that involve manipulations to enhance natural enemies as a means of pest management, it is important to demonstrate whether the manipulation one is studying, has the desired effect of increasing natural enemy abundance. However, it is also important to demonstrate whether an increase in natural enemies leads to a concomitant decrease in pest populations or pest survival. In this research, black cutworm larvae and pupae were used in field predation experiments on golf courses. The objective of this study was to determine whether the addition of conservation strips on golf courses, compared to no conservation strips, leads to an increase in the frequency of predation on two life stages of a common turf grass pest, the black cutworm.

Methods

To examine if predation rates differed between golf courses with conservation strips added and those without, a field study was conducted. Six golf course fairways (replicates), 3 in each of two golf courses Glenn Dale Golf Club, Glenn Dale, MD) and (Timbers of Troy, Elkridge, MD, were used that all contained plots with conservation strips and plots without conservation strips as described in previous chapters. Predation trials were conducted on third instar and pupae of black cutworms, *A. ipsilon*. Third instar *A. ipsilon* were pinned to the ground at four distances from the conservation strip or the corresponding positions in the control plots. Each of the trials were conducted at two time intervals, during the day and during the night. Trials were repeated on 3 dates in 2003.

Cutworm larvae were pinned to a styrofoam tray in the lab through their last abdominal segment with a '00' insect pin (Morpho, Czech Republic). The pinned

cutworms were taken immediately to the golf courses in a cooler to prevent struggling as their wounds dried. At the golf course the cutworms were placed at four locations in each plot. The first position was either right inside the conservation strip or in the corresponding position in the rough of the control plots. This was the same location as the pitfall trap at distance 0m described in Chapter 2 and is 4m from the edge of the fairway. From this position (0m) cutworms were pinned at 2m, 6m, and 10m in each plot. At each position a small area of grass was removed (2-3cm in diameter) so that the pin could be stuck in firm ground rather than through a layer of grass. A pinned cutworm was removed from the tray, pinned to the ground and marked with a flag. On days when cutworms were placed on both golf courses Glenn Dale was set up at 10:00h and Timbers was set up at 11:00h. Setting up the experiment late in the morning allowed golf course personnel to finish mowing so the experiment could remain undisturbed. Survival of the cutworms was recorded after nine hours (19:00h Glenn Dale, 20:00h Timbers). At this time all the cutworms were replaced and the night time trials began. These cutworms were left in the field for 11 hours and survival was recorded early the following morning at 6:00h (Glenn Dale), and 7:00h (Timbers). Larvae trials were conducted on June 16, July 14, and July 24, 2003 at Glendale and on July, 14, 24, and 29, 2003 at Timbers.

Cutworms that were missing or partially eaten were recorded as eaten. To determine whether pinned cutworms could escape, a small lab trial was conducted. Ten cutworms were pinned to turf soil cores taken from a golf course with a cup cutter. The cutworms were left in place for 24 hours. The trial was conducted on two occasions. The survival and presence of the cutworms was checked after 12 and 24 hours. All ten cutworms were present and alive in both trials after 24 hours, which is more than twice as

long as they were left in the field. This trial demonstrated that it is highly unlikely that cutworms were escaping from the pin.

Field predation trials with cutworm pupae were carried out in a similar manner as larvae. Only newly eclosed (< 5 days) pupae were used in these trials. The positions described for the larvae are the same as used for pupae. The same exact location was never used twice for larvae or pupae. The positions indicate distances from the conservation strip and at that distance a spot was chosen at random for each trial. The pupae were put in the ground by making a slanted hole with a large nail. The pupae were inserted, abdomen first, until the head was 2-3mm above the surface of the ground. The pupae were marked with flags and checked after 20 hours. They also were placed in the field at 10:00h or 11:00h and checked at 6:00h or 7:00h the following morning. The pupae were carefully removed from the hole with forceps and inspected for feeding damage. Any damaged or missing pupae were recorded as eaten. Pupa trials were conducted on July 14, 24 and August 28 at Glenn Dale and on July 14, 24, 29 at Timbers.

To control for the possibility that moths would emerge during the field trials ten pupae were held at the ambient daytime temperature in a growth chamber in the lab during each trial. Due to the youngness of the pupae, no moths emerged in these control trials.

Statistical analysis. Predation data of cutworm larvae and pupae were analyzed in the same way. Data were pooled across dates and time of day (day/night) and analyzed using Chi-square 2x2 contingency tables in the FREQ procedure of SAS (version 8.2 Cary, NC). Contingency tables were constructed for each distance (0m, 2m,

6m, 10m) and treatment. That is, position one in the treated plots was compared to position one in control plots and so forth.

Results

Third instar cutworm larvae in the conservation strips and in the rough were heavily preyed upon. At the 0m position (in the conservation strip and corresponding location in the control plot), 25 of 36 possible cutworms were eaten in the conservation strip and 28 were eaten in the no conservation strip control plot (Table 1). The next position (2m), where the larvae for both treatments are pinned in the rough, 21 and 27 cutworms fell prey in the treatment and control plots respectively. While small differences exist at these distances neither one was statistically significant at the $P < 0.05$ level. At 6m, significantly more cutworms were eaten in plots with conservation strips (19 cutworms) compared to no conservation strip control plots (10 cutworms) ($\chi^2 = 4.7687$, $P = 0.0290$). At 10m, a similar pattern was found. Significantly more cutworms (16) were eaten in plots with conservation strips while 8 were eaten in plots without conservation strips ($\chi^2 = 4.0580$, $P = 0.0440$).

The trials that examined predation on cutworm pupae did not result in significant differences in predation between conservation strip and no conservation strip treatments at any distance (Table 1).

Discussion

Black cutworms are key pests on golf course fairways. In this experiment there was more predation on cutworms in fairways when conservation strips were present than

when no conservation strip was present. Demonstrating that conservation strips can increase predation on cutworms, contributes to the results of this experiment in two ways. First, it helps to demonstrate the effect of conservation strips on a key pest that is not effectively sampled with pitfall traps. Second, it demonstrates that conservation strips can have a real impact on living pests in situ.

The third instar cutworms that were used in this experiment were shown in laboratory feeding trials (see Chapter 3) to be susceptible to many common predatory beetles (carabids and staphylinids) and lycosid spiders. The fact that there was no difference in the number of cutworms eaten at distance 0m (in the conservation strip or rough), or at 2m (both in the rough) could have several explanations. Predation rates overall, were higher in the rough than the fairway irrespective of whether a conservation strip was present. This is not surprising since there were more predatory arthropods in the rough than in the fairway in 2002. Smitley et al. (1998) also found significantly more carabid and staphylinid beetles in golf course roughs than in fairways. Although sampling dates of predators in 2003 did not exactly correspond with predation studies, there was no significant difference in the number of predators in fairways with conservation strips compared to those without (see Chapter 2). However staphylinids were found to be more abundant in the rough (trap position 2m) of plots *without* conservation strips.

Overall, there was less predation of black cutworms on the fairway, than in the rough but predation was significantly higher in the fairways when conservation strips were present. In 2003, when these predation trials were conducted there was no difference in predator abundance between plots with conservation strips and plots without. None of the predator groups analyzed (carabids, spiders, staphylinids) were

significantly more abundant either. However, there were numerically more carabid beetles caught at trap positions 4m, 6m, and 8m in plots with conservation strips than in plots without. There were also significantly more spiders in the 4m traps and numerically more spiders in the 6m and 8m traps in plots with conservation strips.

Predation on pupae over 24 hours was low in plots with and without conservation strips. And, there was no difference in predation of pupae between plots with conservation strips versus those without to corroborate the results of the cutworm larvae experiments. Terry et al. (1993) also found that predation rates of fall armyworm pupae did not differ between treatments even though predation on Japanese beetle eggs did. From lab trials (Chapter 3) it is clear that cutworm pupae are not vulnerable to predation by spiders, which made up nearly 25% of the potential predators trapped in pitfall traps during 2003. Also pupae were concealed below the ground where as larvae were placed on the surface of the ground. This leaves the pupae vulnerable only to the predators that are able to detect them.

Predation trials such as this provide an opportunity to evaluate the real world value of an experimental treatment. In this case, the presence of conservation strips led to higher a frequency of predation on black cutworm larvae in the fairways of the golf courses. This result indicates the potential of conservation strips to increase the predation and reduce survival of natural cutworm populations.

Table 1. Number of third instar black cutworm larvae or pupae eaten when pinned at different distances in plots with or without Conservation strips. For each treatment and distance 36 larvae or 18 pupae were placed in the field.

Prey Distance	Number Larvae Eaten		DF	Chi- Square Value	Probability
	Conservation strip	No Cons. strip			
0m	25	28	1	0.6435	0.4224
2m	21	27	1	1.8232	0.1769
6m	19	10	1	4.7687	0.0290
10m	16	8	1	4.0580	0.0440
	Number Pupae Eaten				
0m	7	9	1	0.4500	0.5023
2m	10	8	1	0.4444	0.5050
6m	4	4	1	0.0000	1.000
10m	2	1	1	0.3636	0.5465

CONCLUSIONS AND IMPLICATIONS

Conservation strips show great potential as a conservation biological control tactic on golf courses. The ornamental plants, alyssum, coreopsis, and switchgrass, attract a variety of predators, parasitoids, and alternative prey to the conservation strips and the surrounding turf. Conservation strips could reduce the need for insecticide use on golf courses by increasing natural enemy abundance and increasing the level of predation on pests such as cutworms.

As designed and implemented in this study, conservation strips require very little maintenance. The coreopsis and switchgrass are perennial plants, so only alyssum will require re-planting in the years after the conservation strips are installed. This saves time and money for golf course superintendents. Conservation strips are also aesthetically pleasing and resemble typical ornamental flowerbeds already found on golf courses. Future research may identify other plant species that would be suitable, or perhaps even better, for use in conservation strips. These other plant species may attract more specific groups of predators that target turf pests such as typhia wasps.

The use of conservation strips in conservation biological control is not limited to golf courses. The installation of conservation strips could be recommended to homeowners looking for an alternative to using insecticides on their lawns. Pest prone ornamental landscapes in general would be expected to benefit from the abundance of natural enemies attracted to, and retained in, conservation strips. Organic farms and other agricultural settings have already been shown to benefit from flowering insectary strips

and from beetles banks, so the combination of these provided by conservation strips may have added benefits.

Overall, conservation strips demonstrate the benefits that can be gained from increasing the complexity of golf course landscapes. This new conservation biological control tactic is a positive contribution to the goal of reducing insecticide use on golf courses.

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