Effect of Conservation Strips on the Abundance and Distribution of Natural Enemies and Predation of *Agrotis ipsilon* (Lepidoptera: Noctuidae) on Golf Course Fairways

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ABSTRACT Habitat manipulation in the form of beetle banks and flowering insectary strips has been a successful method to increase natural enemy and alternative prey abundance. In this study, beetle banks and flowering insectary strips were combined to create conservation strips as refuge for a variety of natural enemies in golf course ecosystems. Conservation strips were installed in the roughs next to golf course fairways. Pitfall traps were used to monitor the abundance of predatory, parasitoid, alternative prey, and pest insects in the roughs and fairways near conservation strips and in roughs and fairways without conservation strips (controls). In addition, *Agrotis ipsilon* (Hufnagel) larvae were placed in the roughs and fairways to evaluate the effect of conservation strips on the predation of pests. Conservation strips were successful at increasing predator, parasitoid, and alternative prey abundance in golf course fairways and roughs overall. Increases were most evident within 4 m of conservation strips. Moreover, predation of *A. ipsilon* larvae was greater in fairways adjacent to conservation strips than fairways adjacent to roughs only. Differences in predation did not correspond to differences in predator abundance in the fairways, suggesting "predator abundance" may not be the most reliable estimate of the effect of habitat manipulations. These results suggest conservation strips could be an important new tool in conservation biological control on golf courses and may be applicable in other agro-ecosystems. Other methods of estimating and enhancing the effects of conservation strips are discussed.

KEY WORDS habitat manipulation, conservation biological control, turf

MANIPULATION OF HABITAT COMPLEXITY, a form of conservation biological control, has been found to influence natural enemy and herbivore populations in a variety of ecosystems (Gurr et al. 2000, Landis et al. 2000). Two types of habitat manipulations that have received 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. 2004). Recent work has shown that large numbers of carabid beetles, staphylinid beetles, and spiders can be attracted to, and maintained in, beetle banks (Thomas et al. 1991, 1992). Beetle banks, strips of bunch grass installed within agricultural fields, provide shelter to predators from routine disturbances agricultural fields incur, protection from extreme temperature variations, and are overwintering sites (Thomas et al. 1991, 1992). Carabids, staphylinids, and spiders have also been found to be important and abundant predators in turfgrass systems (Terry et al. 1993, Smitley et al. 1998, Frank 2003, Jo et al. 2003). However, no research to our knowledge has examined the use of beetle banks in turfgrass systems.

Flowering insectary strips, beds or rows of flowering plants, have also been shown to attract a diversity and abundance of natural enemies such as *Geocoris* spp., *Orius* spp., Coccinellids, and parasitoid wasps (Patt et al. 1997, Chaney 1998, Long et al. 1998, Braman et al. 2002, Shrewsbury et al. 2004). In addition to the benefits provided to natural enemies by beetle banks, flowering insectary strips also provide floral resources (Landis et al. 2000). Flowering insectary strips have been shown to reduce pest populations in ornamental and agricultural systems (Patt et al. 1997, Chaney 1998, Long et al. 1998, Braman et al. 2002, Shrewsbury et al. 2004).

Few studies have examined the role of flowering plants in attracting natural enemies and regulating pests 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 were spiders, *Geocoris* spp., and *Orius* spp. Although Braman et al. (2002) did not show an increase in predation in turf adjacent to wildflowers, these predators have been observed to feed on fall armyworms, *Spodoptera frugiperda* (J. E. Smith), in turf (Braman et al. 2002), and on other pests common

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to turf such as armyworms, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae), in no-till corn (Clark et al. 1994) and black cutworms, *Agrotis ipsilon* (Hufnagel), in laboratory feeding trials of turf predators (Frank and Shrewsbury 2004). The value of parasitoids in turf systems is not well studied. However, the turf pest *S. frugiperda* is susceptible to parasitoids in agricultural systems (Ashley 1979, 1986, Gross and Pair 1986). Tiphia wasps (Hymenoptera: Tiphiidae), ectoparasites of two scarab beetles that are major pests of turfgrass, also consume flower nectar (Potter 1998). Adding flowering plants to a habitat can also increase the abundance of alternative prey. Alternative prey items can be useful in attracting natural enemies and retaining them in times of low pest abundance (Settle et al. 1996, Leddy 1996, Symondson et al. 2002). These studies suggest that adding flowering insectary strips may increase generalist predator and parasitoid abundance by providing floral resources and alternative prey.

In this study, the concepts of beetle banks and flowering insectary strips were combined to create natural enemy refuges, now referred to as conservation strips. Bunch grasses have been shown to increase the abundance of ground dwelling predators (Thomas et al. 1991, 1992), whereas flowering plants 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 broad range of foraging behaviors and preferences. The objectives of this research were (1) to determine if conservation strips, installed next to golf course fairways, could increase arthropod natural enemy abundance and reduce pest abundance, (2) to determine what distance into the fairway conservation strips are effective at increasing natural enemy and reducing pest abundance, and (3) to determine whether an increase in predator abundance results in greater predation of *A. ipsilon*, a key golf course pest. Pitfall trap sampling was conducted to evaluate the effect of conservation strips on arthropod abundance and distribution. *A. ipsilon* larvae and pupae were used in field predation experiments to evaluate the effect of conservation strips on predation. This research provides fundamental knowledge on the effect of a habitat manipulation, specifically increasing vegetational complexity and plant species diversity using conservation strips, on natural enemy-herbivore dynamics and the potential of habitat manipulations to be used as an effective pest management approach.

Materials and Methods

Experimental Design. A field study was conducted on two golf courses in Maryland: Glenn Dale Golf Course (Glenn Dale, MD) and Timbers of Troy Golf Course (Elkridge, MD) in 2002 and 2003. Six fairways (replicates) were used in this study: three were located at Glenn Dale and three at Timbers. The fairways at Glenn Dale contained Bermuda grass, *Cynodon dactylon* L., and the fairways at Timbers contained creeping bent grass, *Agrostis stolonifera* L. Each fairway contained a conservation strip and a no conservation strip treatment. Conservation strips were installed in June 2002. Each conservation strip was situated in the rough, 4 m from the edge of the fairway. The conservation strips varied in size but had minimum dimensions of 3 by 8 m and maximum dimensions of 4 by 16 m. Conservation strips were always positioned with the long side parallel to the fairway. Six plots without conservation strips (control plots) were also selected in every fairway. Control plots were a minimum of 60 m away from the plots with conservation strips and contained rough mown (10 cm) turfgrass, which was a blend of tall fescue, *Festuca arundinacea* (Schreber), and Kentucky bluegrass, *Poa pratensis* L. Fairways and roughs used in this experiment were maintained under standard cultural practices (fertilizer, irrigation, mowing); however, no insecticides were applied.

Three species of plants were installed in the conservation strips: alyssum, *Lobularia maritima* L., 'Easter Basket Mix'; coreopsis, *Coreopsis verticillata* L., 'Moonbeam'; and switchgrass, *Panicum virgatum* L., 'Northwind'. These flowering plant species were selected because of their ornamental value and because alyssum (Chaney 1998) and coreopsis (Al-Doghairi and Cranshaw 1999) were found to be attractive to beneficial insects in other studies. Bunch grasses have been used in beetle banks to attract beneficials (Thomas et al. 1991, 1992). Switchgrass was used in the conservation strips because it is a bunch grass native to Maryland, and it is not considered to be invasive. Plants were always installed in the conservation strips in the same pattern. 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 because of the very wet conditions. Three subsequent plantings of alyssum all succumbed to rot. Therefore, in 2003, the conservation strips had only coreopsis and switchgrass.

Arthropod Sampling. Pitfall traps were used to sample arthropod abundance at six distances into the fairway from conservation strips and control plots (Fig. 1). Pitfall traps were installed in two transects that were 4 m apart and ran perpendicular to the fairways from the conservation strips and control plots. The first pair of pitfall traps was installed at the front edge of the conservation strips (distance, 0 m), which was 4 m into the rough from the edge of the fairway. Likewise, the first pair of traps in the control plots were installed in the rough 4 m from the edge of the fairway (distance, 0 m). In each conservation strip and control treatment pair, traps were installed at 2, 4, 6, 8, and 12 m from the 0-m trap positions.

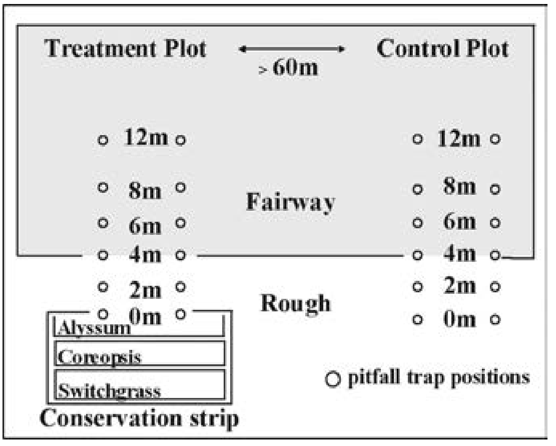

Fig. 1. Layout of conservation strips, control plots, and pitfall traps on golf course fairways (represents one replicate).

Pitfall traps were glass vials with a mouth diameter of 19 mm. Vials were inserted into holes made by a 21-mm soil probe. The lip of the vial was just below the soil surface. The traps were filled one-third full with a 20% propylene glycol (preservative) solution with soap added to reduce surface tension. Arthropod sampling was conducted for 7-d intervals. In 2002, sampling was conducted four times (the dates listed are the dates each 7-d trapping period ended for Glenn Dale and Timbers, respectively): 22, 23 and 29, 30 July and 5, 7 and 19, 20 August. Pitfall trap sampling was only conducted on two dates in 2003 because of heavy rains and consistent flooding of the golf courses. In 2003, sampling was conducted on 1, 2 and 29, 30 July at Glenn Dale and Timbers, respectively. At the end of each sampling period, vials were returned to the laboratory. Vial contents were rinsed through a 125-μm sieve to remove soap and preservative from the specimens. All specimens were stored in 70% ethanol. Specimens were sorted into trophic groups of predator, pest, alternative prey, or parasitoid. The most abundant taxa from each trophic group were identified to family. Ants (Formicidae) are a diverse group that contains representatives of several trophic groups. Therefore, in this study, ants were analyzed and presented as a unique group.

Statistical Analysis. Data for each year were analyzed separately. Data were summed across dates and $\log_{10}(y + 1)$-transformed before analysis. Data were analyzed as a randomized complete block design using the MIXED procedure in SAS (2001). Each fairway was a block. Distance was included in a "repeated" statement within the MIXED procedure. A least significant difference (LSD) test was used to compare each distance in plots with conservation strips to the same distance in plots without conservation strips.

Predation of *A. ipsilon* Larvae and Pupae. Before the larval predation experiment in the field, a laboratory trial was conducted to determine whether *A. ipsilon* larvae pinned to the soil could escape. Ten *A. ipsilon* larvae were pinned through their last abdominal segment with a 00 insect pin (Morpho, Prague, Czech Republic) to turf soil cores taken with a golf course cup cutter. *A. ipsilon* larvae were left in place for 24 h. The trial was conducted twice. The survival and presence of *A. ipsilon* larvae were recorded after 12 and 24 h.

Larval predation field trials were conducted at two time intervals: during the day and the night on each of three dates in 2003: 16 June, 14 and 24 July at Glenn Dale and on 14, 24, and 29 July at Timbers. A third-instar *A. ipsilon* was pinned to the ground at each of four distances from the conservation strip or the corresponding positions in the control plots. The first position was just inside the conservation strip (0 m) or control plot. From this position (0 m), a cutworm was pinned at 2, 6, and 10 m in each plot. A total of 36 larvae (6 fairways $\times$ 3 dates $\times$ 2 times/date = 36 larvae) were pinned at each position of each treatment. The day interval trial was conducted at Glenn Dale from 1000 to 1900 hours and at Timbers from 1100 to 2000 hours. Survival of the cutworms was recorded at the end of the 9-h interval. At this time, all *A. ipsilon* larvae were replaced with fresh larvae, and night trials began. These cutworms were left in the field for 11 h, and survival was recorded early the following morning at 0600 (Glenn Dale) and 0700 hours (Timbers). *A. ipsilon* larvae that were missing or partially eaten were recorded as eaten. There was little or no indication that birds or other vertebrates consumed larvae (i.e., insect pins missing, bird activity observed on study site).

A similar field predation experiment was conducted with *A. ipsilon* newly eclosed (<5 d) pupae. The same distance positions described for larvae were used for pupae. The pupae were inserted abdomen first into slanted holes (made with a large nail) until the pupae were even with the soil surface. The pupae were placed in the field at 1000 or 1100 hours, marked with flags, and checked at 0600 or 0700 hours (Glenn Dale and Timbers, respectively) the following morning (20 h). The pupae were carefully removed from the hole with forceps and inspected for feeding damage. Any damaged or missing pupae were recorded as eaten. Pupae trials were conducted on 14 July and 24 and 28 August at Glenn Dale and 14 July and 24, 29 August at Timbers. A total of 18 pupae (6 fairways $\times$ 3 dates $\times$ 1 time/date = 18 pupae) were placed at each position of each treatment. To show that moths did not emerge during the field trials, 10 pupae were held at the ambient daytime temperature in an environmental chamber for the duration of each trial.

Statistical Analysis. Predation data of *A. ipsilon* larvae and pupae were analyzed using the same methods. Data were pooled across dates and time of day (day, night) and analyzed using χ^2 2 by 2 contingency tables in the FREQ procedure (SAS Institute 2001). Contingency tables were constructed for each distance (0, 2, 6, and 10 m) and treatment. That is, position 1 in the conservation strip plot was compared with position 1 in the no conservation strip plot and so forth.

Table 1. Summary of arthropod trophic groups captured in pitfall traps during 2002 and 2003 on golf course fairways

Trophic group taxa	2002		2003	
	Total individuals	Percent trophic group	Total individuals	Percent trophic group
Predators	949		595	
Araneae	251	26	268	45
Carabidae	227	24	181	31
Staphylinidae	435	46	139	23
Other predators[a]	36	4	7	1
Parasitoids	206	100	46	100
Alternative prey	907		628	
Collembola	495	55	304	48
Other alternative prey[b]	412	45	86	51
Pests	655		415	
Curculionidae	215	32	47	11
Noctuidae	35	5	22	5
Scarabaeidae	405	63	346	84
Formicidae	1,411	100	481	100

[a] Other predators include Histeridae, Anthocoridae (minute pirate bugs only), Lygaeidae (big-eyed bugs only), Dermaptera, and Chilopoda.
[b] Other alternative prey include miscellaneous Diplopoda, Isopoda, Coleoptera, Orthoptera, and Heteroptera.

Results

In 2002, 4,128 arthropods were captured over the four sampling dates (Table 1). The predator, alternative prey, and pest trophic groups each represented a similar percentage (17.8, 12.3, and 16.9%, 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. In 2003, 2,165 arthropods were captured over two sampling dates (Table 1). Each trophic group's relative percentage of the total number of arthropods caught was similar to that of 2002.

Predator Abundance and Distribution. In 2002, predators were significantly more abundant in plots where conservation strips were present (15.13 ± 1.8) compared with no conservation strips present (11.25 ± 1.3; Table 2). Likewise, predators were significantly more abundant at trap positions 0 and 2 m when conservation strips were present compared with not present (Fig. 2). Within the predator trophic group, carabids, staphylinids, and spiders were the most abundant taxa. Carabids were significantly more abundant in plots where conservation strips were present (3.82 ± 0.4) compared with plots without conservation strips (2.48 ± 0.3), but staphylinids and spiders did not differ between conservation strip and no conservation strip plots (Table 3). Carabid beetles were significantly more abundant at trap positions 0 and 2 m when conservation strips were present compared with no conservation strip present (Fig. 2). Staphylinid abundance did not significantly differ when conservation strips were present compared with no conservation strip present at any trap position except at 2 m (Fig. 2). Spiders were significantly more abundant at trap position 0 m when conservation strips were present compared with not present (Fig. 2).

In 2003, there was no significant difference in predator abundance between plots where conservation strips were present (1.91 ± 0.2) and not present (1.89 ± 0.1; Table 2). There was also no significant difference at any trap position (Fig. 3). Carabid abundance did not significantly differ between conservation strip and no conservation strip treatments overall (Table 3) or at any trap position (Fig. 3). Staphylinid beetle abundance did not significantly differ overall (Table 3), but they were significantly more abundant at position 2 m when conservation strips were not present compared with present (Fig. 3). There was no significant difference in spider abundance between plots with and without conservation strips (Table 3).

Table 2. ANOVA statistics for the abundance of arthropods in plots with or without conservation strips (treatment) and at different distances into the fairway in 2002 and 2003

Trophic group	Effect	2002			2003		
		F	ndf, ddf	P	F	ndf, ddf	P
Predators	Treatment	12.93	1, 33.7	0.001	0.03	1, 32.7	0.870
	Distance	24.92	5, 22	<0.001	8.39	5, 21.7	<0.001
	Treatment × distance	1.58	5, 22	0.206	1.39	5, 21.7	0.266
Pests	Treatment	0.38	1, 39.3	0.741	0.65	1, 48.8	0.082
	Distance	5.65	5, 21.4	0.004	1.18	5, 19.9	0.330
	Treatment × distance	0.53	5, 21.4	0.550	1.07	5, 19.9	0.606
Alternative prey	Treatment	7.24	1, 46.7	0.009	15.63	1, 39.3	<0.001
	Distance	5.51	5, 21.2	0.002	4.52	5, 22.3	0.005
	Treatment × distance	0.31	5, 21.2	0.900	1.28	5, 22.3	0.308
Parasitoids	Treatment	11.52	1, 35.4	0.002	0.22	1, 43.9	0.641
	Distance	15.04	5, 22.2	<0.001	1.77	5, 21.9	0.162
	Treatment × distance	6.00	5, 22.2	0.001	0.77	5, 21.9	0.582

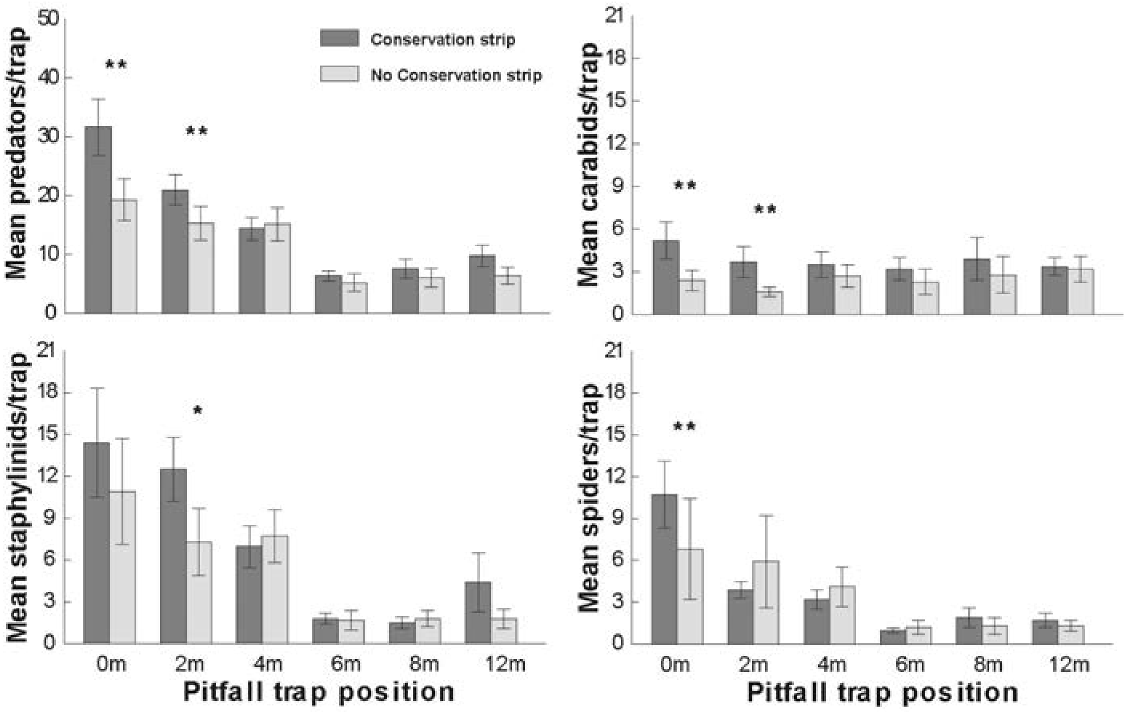

Fig. 2. Abundance of predators (all families combined), carabids, staphylinids, and spiders at different distances from conservation strips or corresponding positions in the rough in 2002. At 0 m, the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. Four meters is the edge of the fairway. $*P < 0.10$, $**P < 0.05$, $***P < 0.01$, significant differences in *LSD* comparisons of treatment means at each trap position. Values represent the mean ± SE of six fairways on four dates for each trap position.

However, spiders were significantly more abundant at position 0 m when conservation strips were present and 4 m when conservation strips were absent (Fig. 3).

There was a significant effect of distance on predator abundance in 2002 and 2003 (Table 3). There was also a significant distance effect on spider and staphylinid abundance in 2002 and 2003, but there was no effect of distance on carabid abundance (Table 3).

Parasitoid Abundance and Distribution. In 2002, there was a significant interaction of treatment (conservation strip) and distance on parasitoid abundance (Table 2). Parasitoid abundance was not significantly different in plots with and without conservation strips in 2003 (Table 2) or between treatments at any distance (Fig. 4).

Alternative Prey Abundance and Distribution. Alternative prey was significantly more abundant in plots where conservation strips were present (20.69 ± 1.9, 2.08 ± 0.22) than in plots without conservation strips (15.94 ± 1.6, 1.38 ± 0.09) in 2002 and 2003, respectively (Table 2). In 2002, alternative prey abundance was not significantly different at any trap positions (Fig. 5). In 2003, alternative prey was significantly more abundant at positions 0, 4, and 6 m when conservation strips were present compared with not present (Fig. 5). The most abundant alternative prey

Table 3. ANOVA statistics for the abundance of carabids, staphylinids, and spiders in plots with or without conservation strips (treatment) and at different distances into the fairway in 2002 and 2003

Predator group	Effect	2002			2003		
		F	ndf, ddf	*P*	*F*	ndf, ddf	*P*
Araneae	Treatment	2.61	1, 29.5	0.117	0.01	1, 49.2	0.912
	Distance	8.27	5, 20.6	<0.001	5.04	5, 21.5	0.003
	Treatment × distance	1.19	5, 20.6	0.348	2.77	5, 21.5	0.044
Carabidae	Treatment	6.93	1, 48.9	0.011	0.38	1, 34.7	0.543
	Distance	0.57	5, 20.8	0.725	0.87	5, 22.0	0.515
	Treatment × distance	0.65	5, 20.8	0.663	0.56	5, 22.0	0.732
Staphylinidae	Treatment	2.26	1, 24.9	0.146	0.26	1, 22.1	0.616
	Distance	18.52	5, 20.9	<0.001	22.37	5, 21.3	<0.001
	Treatment × distance	1.14	5, 20.9	0.373	1.66	5, 21.3	0.188

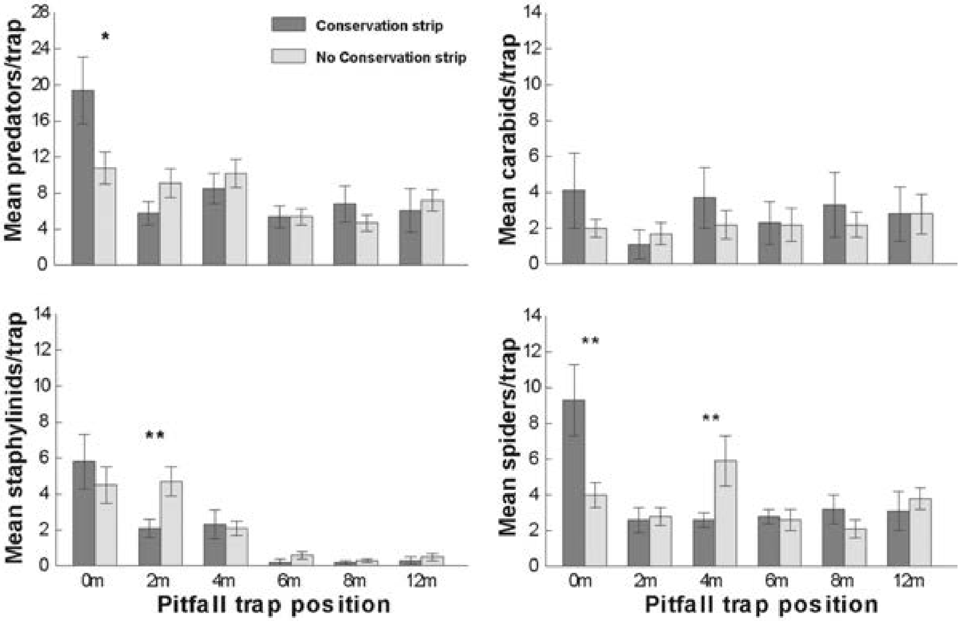

Fig. 3. Abundance of predators (all families combined), carabids, staphylinids, and spiders at different distances from conservation strips or corresponding positions in the rough in 2003. At 0 m, the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. Four meters is the edge of the fairway. $*P < 0.10$, $**P < 0.05$, $***P < 0.01$, significant differences in *LSD* comparisons of treatment means at each trap position. Values represent the mean ± SE of six fairways on both dates for each trap position.

taxa in both years was Collembola (Table 1). In 2002, collembolans were significantly more abundant in plots with conservation strips than in plots without conservation strips ($F = 16.07$; df = 1,48.6; $P < 0.001$). They were also significantly more abundant at trap position 0 m when conservation strips were present (Fig. 5). In 2003, there was no significant difference in collembola abundance between plots with and without conservation strips ($F = 3.50$; df = 1,52.9; $P = 0.067$) or at any trap position (Fig. 5).

There was a significant effect of distance on alternative prey abundance in 2002 and 2003 (Table 2). There was also a significant distance effect on collembolan abundance in 2002 ($F = 12.26$; df = 5,21.8; $P < 0.001$) and 2003 ($F = 3.70$; df = 5, 22.7; $P = 0.013$). The analysis of variance (ANOVA) interaction term (treatment × distance) was not significant in the analysis of collembola from 2002 ($F = 0.96$; df = 5,21.8; $P = 0.461$) or 2003 ($F = 0.66$; df = 5,22.7; $P = 0.660$).

Pest Abundance and Distribution. There was no significant difference in mean pest abundance between plots with and without conservation strips 2002 (9.19 ± 1.64, 9.02 ± 1.49) or 2003 (0.67 ± 0.08, 0.84 ± 0.11; Table 2). There was also no significant difference in pest abundance between treatments at any distance except at 12 m in 2003 (Fig. 6). However, there was a significant effect of distance on pest abundance in 2002 (Table 2).

Formicidae Abundance and Distribution. Ant abundance was not significantly different between the plots with and without conservation strips in 2002 (22.65 ± 6.0, 16.56 ± 2.8; $F = 0.02$; df = 5,52.0; $P = 0.879$) or 2003 (7.90 ± 1.3, 6.94 ± 1.1; $F = 0.92$; df = 5,47.1; $P = 0.341$). There was not a significant effect of distance on ant abundance or a significant interaction term in 2002 ($F = 1.81$; df = 5,23.1; $P = 0.151$ and $F = 0.16$; df = 5,23.1; $P = 0.973$) or 2003 ($F = 1.75$; df = 5,19.5; $P = 0.170$ and $F = 0.54$; df = 5,19.5; $P = 0.742$).

Predation of *A. ipsilon* Larvae and Pupae. The laboratory experiment showed *A. ipsilon* larvae could not escape from pins. All *A. ipsilon* larvae were present and alive after 24 h. Third-instar *A. ipsilon* larvae at positions 0 and 2 m were heavily preyed on, but predation did not differ between plots with and without conservation strips (Table 4). Significantly more *A. ipsilon* larvae were eaten in plots with conservation strips compared with plots without conservation strips at the 6- and 10-m positions (Table 4). No *A. ipsilon* moths emerged from pupae held in growth chambers during field experiments. The trials that examined predation on *A. ipsilon* pupae did not result in significant differences in predation between conservation strip and no conservation strip treatments at any distance (Table 4).

Discussion

Predator, parasitoid, and alternative prey populations were enhanced by the addition of conservation strips on golf courses in 1 of the 2 study yr. Differences in abundance between plots with and without conservation strips within a trophic group from 2002 to 2003 may be caused by dramatic differences in climatic conditions, differences in plant material in the

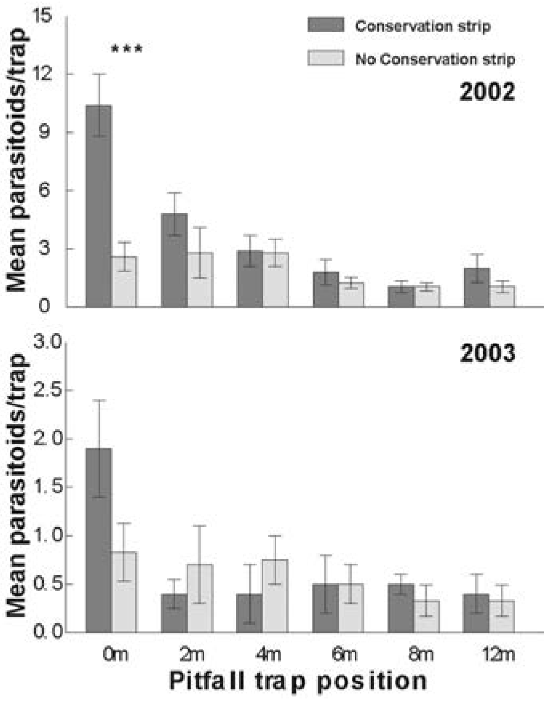

Fig. 4. Abundance of parasitoid wasps at different distances from conservation strips or corresponding positions in the rough in 2002 and 2003. At 0 m, the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. Four meters is the edge of the fairway. $*P < 0.10$, $** P < 0.05$, $***P < 0.01$, significant differences in *LSD* comparisons of treatment means at each trap position. Values represent the mean ± SE of six fairways on all dates within 1 yr for each trap position.

conservation strips, or temporal differences in sampling. In 2002, persistent drought resulted in rainfall that was below average for this region. In contrast, 2003 brought record rainfall and low temperatures. Other research has shown that differences in rainfall and other environmental conditions can alter the suitability of plots to predators and alternative prey, resulting in variation in abundance from year to year (Frampton et al. 2000). There was no alyssum present in the conservation strips in 2003 as there was in 2002, because of the almost daily rainfall that caused it to rot and die. Other studies have shown that alyssum attracts an abundance of natural enemies (Chaney 1998, Frank 2003). A related study found alyssum to have the greatest abundance of predatory arthropods compared with other plants in conservation strips (Frank 2003). This suggests that the absence of alyssum in conservation strips in 2003 may result in fewer natural enemies, and thus, no detectable treatment effect, whereas in 2002, when alyssum was present, predator abundance was enhanced by the presence of conservation strips.

Staphylinid abundance in particular could have been affected by the lack of alyssum. A survey of the arthropods that inhabit each plant species in the conservation strips found that staphylinid beetles were highly abundant in alyssum. Staphylinids also preferred rough mown turf to coreopsis and switchgrass (Frank 2003). This may explain why there were more staphylinids at 2 m in plots without conservation strips than in plots with conservation strips in 2003. The habitat at trap position 2 m in the control plots was 2 m from the fairway in one direction but was continuous rough (preferred habitat) in the other direction, whereas the 2-m position in plots with conservation strips was a strip of rough between the fairway and the conservation strip, which, without alyssum, is also not preferred by staphylinid beetles.

In examining the distribution of arthropods across trap positions, carabid beetles seemed to be the most evenly distributed group of predators. The abundance of staphylinids and spiders declined sharply from the rough into the fairway, whereas carabid abundance remained relatively even. This is similar to the pattern of predator distribution found on golf courses by Smitley et al. (1998). Fairways (short grass) contained more pest insects and fewer predators as distance from the rough (tall grass) increased (Smitley et al. 1998). Likewise, in our studies, sampling yielded fewer pest insects in the rough than in the fairway. The work of Smitley et al. shows 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. Moreover, our research shows how more dramatic changes in the structural complexity, installing conservation strips, can increase predator abundance even more.

The greater abundance of parasitoids in and near the conservation strips is not surprising because other research has shown that alyssum, and flowering plants in general, can be very attractive to parasitoids (Chaney 1998, Frank 2003). 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 Tiphiidae are ectoparasites of turf-infesting scarab beetle grubs. Tiphia wasps also feed on nectar from flowers (Potter 1998), and therefore, conservation strips may be able to increase tiphia abundance and reduce scarab grub abundance and damage.

Alternative prey populations were higher in plots with conservation strips compared with plots without 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 compared with those without conservation strips. Collembola distribution is influenced by moisture (Frampton et al. 2000), food, soil type, and population density (Bengtsson et al. 1994). Although not tested in this study, the presence of conservation strips could have influenced any of these factors. For example, soil compaction may have differed within the

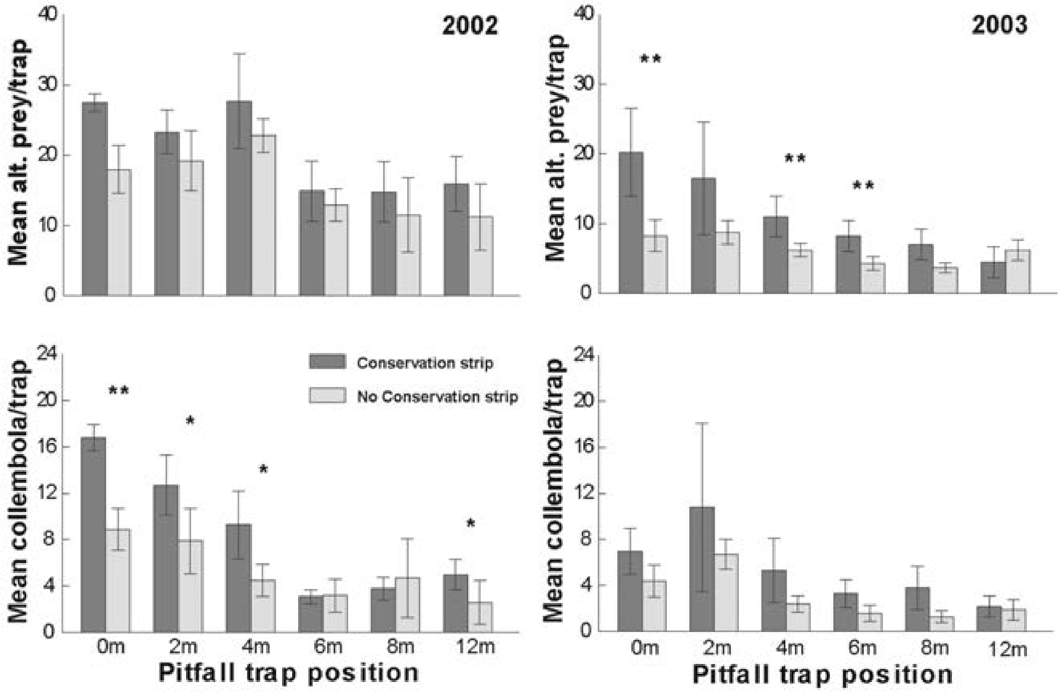

Fig. 5. Abundance of alternative prey (all families combined) and collembola at different distances from conservation strips or corresponding positions in the rough in 2002 and 2003. At 0 m, the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. Four meters is the edge of the fairway. $*P < 0.10$, $**P < 0.05$, $***P < 0.01$, significant differences in *LSD* comparisons of treatment means at each trap position. Values represent the mean ± SE of six fairways on all dates within 1 yr for each trap position.

conservation strips, compared with roughs, from cultivating it with shovels in the process of installing plant material. In addition, mulch was applied to the conservation strips, which along with shade from tall plants, may have increased moisture levels and the quantity of fungus available to be eaten. Pollen from all three plant species was available in the conservation strips. Pollen is consumed by some collembola species (Kevan and Kevan 1970, Takeda and Ichimura 1983, Ponge 2000). These factors may have resulted in a greater abundance of collembola at the edge of the conservation strips (position, 0 m). However, what promoted the dispersal of collembola away from the conservation strips into the fairways is unknown. Large population size within the strips may have led to density-dependent dispersal, or pollen could have accumulated in the turf outside of the conservation strips and resulted in greater food availability. This, in turn, could result in dispersal from the conservation strips in to the fairway or emigration from other parts of the fairway to areas containing pollen. This accumulation of collembola may have influenced the distribution and abundance of predators in the conservation strips and fairways, as has been shown in other systems (Potts and Vickerman 1974) and with other alternative prey (Settle et al. 1996, Shrewsbury 1996, Symondson et al. 2002).

The presence of conservation strips did not seem to influence pest populations. However, life history characteristics of the pest species in this system, nearly all of which were black turfgrass ataenius, *Ataenius spretulus* (Haldeman) (Coleoptera: Scarabaeidae), and billbugs, *Spenophorous* spp. (Coleoptera: Curculionidae), suggest that pitfall trap sampling may not be the optimal method to detect the effect of conservation strips on herbivore abundance. For example, pitfall traps captured only adult beetles that are active at the turf surface, whereas larvae of scarab and curculionid beetles are subterranean and are not sampled by pitfall traps. Although egg and larval stages of scarab turf pests have been shown to be susceptible to arthropod predation (Terry et al. 1993, López and Potter 2000, Zenger and Gibb 2001, Jo et al. 2003), it is not known whether adults of these species are susceptible. Additionally, billbugs are univoltine, and black turfgrass ataenius have only two generations per year, which suggests a possible lag time of 1 yr or more before an effect of predation on beetle abundance would be observed. Therefore, sampling of adult life stages may not truly represent the effect of conservation strips on beetle pest species.

In general, pest abundance was higher in the fairway than in the rough for both years of the study. Other studies have found similar distributions of pests (Smitley et al. 1998, Rothwell and Smitley 1999). In these studies, greater numbers of *A. spretulus* were found in the fairway of golf courses than in the rough. Rothwell and Smitley (1999) suggested that female

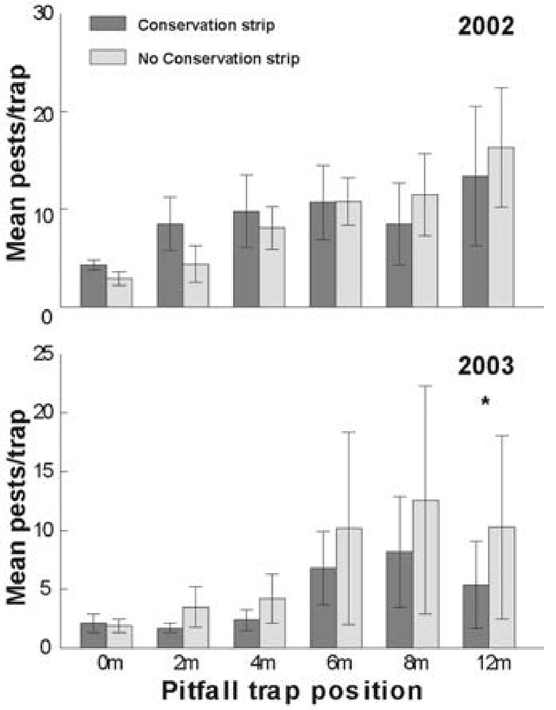

Fig. 6. Abundance of pests at different distances from conservation strips or corresponding positions in the rough in 2002 and 2003. At 0 m, the pitfall trap is in the conservation strip or in the rough in plots without conservation strips. Four meters is the edge of the fairway. $*P < 0.10$, $** P < 0.05$, $***P < 0.01$, significant differences in *LSD* comparisons of treatment means at each trap position. Values represent the mean ± SE of six fairways on all dates within 1 yr for each trap position.

oviposition preference for short fairway turf and increased predator and pathogen activity in the rough account for this difference.

Table 4. Number of third-instar *A. ipsilon* larvae and pupae eaten when pinned at different distances in plots with and without conservation strips

Prey distance	Conservation strip	No conservation strip	df	χ^2	P
Number of larvae eaten at					
0 m	25	28	1	0.644	0.422
2 m	21	27	1	1.823	0.177
6 m	19	10	1	4.769	0.029
10 m	16	8	1	4.058	0.044
Number pupae eaten at					
0 m	7	9	1	0.450	0.502
2 m	10	8	1	0.444	0.505
6 m	4	4	1	0.000	1.000
10 m	2	1	1	0.364	0.547

Numbers of larvae or pupae (of 36) eaten by predators in plots with and without conservation strips were compared at each distance using 2 by 2 contingency tables.

Previous research showed that third-instar *A. ipsilon* larvae used in the predation experiment were susceptible to many predatory beetles (carabids and staphylinids) and lycosid spiders in laboratory feeding trials (Frank and Shrewsbury 2004). In this experiment, there was more predation on *A. ipsilon* larvae in fairways where conservation strips were present than where no conservation strips were present. This shows that the addition of conservation strips can have a real impact on predation of pests on golf course fairways. There could be several explanations for the lack of difference in predation of *A. ipsilon* at the conservation strip or rough locations. Overall, predation rates were higher in the rough than the fairway, irrespective of whether conservation strips were present or not. This corresponds with the greater abundance of carabid and staphylinid beetles in golf course roughs than fairways found in this and other research (Smitley et al. 1998). However, staphylinids were more abundant in the rough (position, 2 m) of plots *without* conservation strips, which could have resulted in the high predation seen in the rough of these plots. Overall, there was less predation of *A. ipsilon* larvae in the fairway than in the rough, similar to the predation of *A. spretulus* larvae reported by Jo et al. (2003). However, predation was significantly higher in the fairway when conservation strips were present than fairways where no conservation strips were present. In 2003, when these predation trials were conducted, there was no difference in overall predator abundance or of carabid, staphylinid, and spider abundance between plots with and without conservation strips. However, there were numerically more carabid beetles caught at trap positions 4 and 8 m in plots with conservation strips than in plots without. There were also more spiders in the 6- and 8-m traps in plots with conservation strips. These differences may have been biologically significant, even if not statistically so. In addition, it is possible that conservation strips increase the abundance of particular predator species that effectively consume *A. ipsilon* larvae but do not contribute large numbers of individuals to pitfall trap data. Therefore, future research should examine the difference in species and the diversity of species within conservation strips and compare that to the results of predator feeding trials to determine if conservation strips increase the abundance of particularly voracious or mobile predator species.

Field predation trials such as ours provide an opportunity to evaluate the real world value of an experimental manipulation. Predation on pupae was low overall and did not differ in plots with and without conservation strips. There are several possible explanations for low levels of predation on pupae. Laboratory feeding trials showed that immobile *A. ipsilon* pupae were not vulnerable to predation by spiders (Frank and Shrewsbury 2004), which made up nearly 25% of the predator taxa found in turf during 2003. Also, pupae were concealed below ground, whereas larvae were placed on the surface of the ground. This leaves the pupae vulnerable only to the predators that were able to detect them. However, the presence of conservation strips led to higher predation on *A. ipsilon* larvae in the fairways of golf courses. This result strongly suggests the use of conservation strips in golf courses may subject *A. ipsilon* populations to greater natural regulation.

Ants made up a major portion of the arthropods caught in this experiment. Ants are sometimes included in the predator trophic group in studies similar to this one (Cockfield and Potter 1984, Smitley et al. 1998, Kunkel et al.1999). However, this experiment did not allow us to separate out the role that ants were playing, and therefore, they were treated as a unique group. Ants can be an effective and important predatory force in golf courses (López and Potter 2000, Zenger and Gibb 2001) with the myriad roles they can play. This is an area well worth studying in the future.

Conservation strips were successful at increasing predator, parasitoid, and alternative prey abundance in golf course fairways and roughs. Increases were most evident within 4 m of conservation strips, as seen in carabids and collembola. Moreover, predation of *A. ipsilon* larvae was greater in fairways adjacent to conservation strips than fairways adjacent to roughs only. However, differences in predation did not correspond to differences in predator abundance in the fairways, suggesting "predator abundance" may not be the most reliable estimate of the effect of habitat manipulations. Future research should focus on identifying specific predator taxa that may be more voracious or have other characteristics that enhance their impact on turf pest insects. Laboratory feeding trials have shown that predators commonly found on golf courses varied in their consumption rate of turfgrass pest insects (Jo et al. 2003, Frank and Shrewsbury 2004). Other research should focus on ways to entice predators to emigrate further from the conservation strips, perhaps by increasing alternative prey abundance at greater distances from conservation strips. Another possibility would be to install conservation strips on both sides of a fairway, which may encourage predators to traverse the fairway. The optimal size, shape, and arrangement of conservation strips also needs further research. Conservation strips show potential as tools in an integrated pest management and conservation biological control program on golf courses and may also be applicable in other agro-ecosystems.

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