



# Comparative impacts of white grub (Coleoptera: Scarabaeidae) control products on the abundance of non-target soil-active arthropods in turfgrass

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Non-target effects;  
Soil insects;  
Trichlorfon

## Summary

A study was conducted over 3 years on an experimental home lawn to detect, measure and contrast the effects of white grub (Coleoptera: Scarabaeidae) control products on the abundance of soil-active arthropods. Both short-term effects (those caused by a single application) and cumulative effects (those attributed to repeated yearly applications) were evaluated for five different control regimes: trichlorfon, imidacloprid, halofenozide, entomopathogenic nematodes and elemental sulfur. Treatments were applied to replicated plots (10 m × 10 m) from 2000 to 2002. Invertebrates were sampled monthly from July to October in 2001 and 2002 by extracting soil cores in modified Tullgren funnels. All 293,868 captures were identified to class (arthropods) and order (hexapods). Overall extraction rate was 37,772 individuals/m<sup>2</sup> of turf and associated topsoil. The ten most abundant taxa were analyzed in more detail to compare impacts across treatments. A consistent short-term effect due to individual applications was not detected. But when data were examined across both seasons, a significant cumulative effect of treatment was detected for total hexapods, Collembola, Thysanoptera and Coleoptera adults, but not oribatid mites, non-oribatid mites, Hymenoptera, Hemiptera, Coleoptera larvae or Diptera. Contrary to predictions, only imidacloprid – a systemic neonicotinoid applied early in the life cycle to target neonate white grubs – had a discernible impact on non-target abundance. Relative to the untreated check, it suppressed the abundance of those broad taxonomic groups by 54–62%. The implications of these results are discussed with respect to their functional relevance and to the role of neonicotinoids for white grub management in turfgrass.

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## Introduction

Soil-inhabiting white grubs (Coleoptera: Scarabaeidae) are the most injurious and widespread pest complex in turfgrass of the United States (Vittum et al., 1999). In the northeastern United States, four of the eight pest species are introduced exotics, including the Asiatic garden beetle (*Maladera castanea* [Arrow]), European chafer (*Amphimallon majale* [Razoumowsky]), Japanese beetle (*Popillia japonica* Newman) and oriental beetle (*Anomala orientalis* [Waterhouse]). Since its introduction in 1916 (Fleming, 1976), *P. japonica*, for instance, has become the most ubiquitous pest of turfgrass and ornamentals in the eastern United States, resulting in economic losses of >\$460 million/year (USDA-Aphis, 1998; Potter and Held, 2002). The most recent immigrant, *A. majale*, was introduced into New York in 1940 (Gambrell et al., 1942) and has probably now displaced *P. japonica* as the predominant turf pest in New York State, at least in home lawns.

Residential lawns and other managed turf habitats are a prominent component of urban and rural landscapes in the United States. The magnitude of this land use is revealed by a recent study, which estimated that the turfgrass industry in New York State contributed \$5.1 billion to the state economy and managed 3.4 million acres in 2003 (NASS, 2004). Private home lawns comprised 65% of that acreage, far exceeding other sectors such as golf courses, sod farms, parks and schools. All of these managed habitats require decision-making strategies to maintain them for their intended uses, and all are susceptible to white grub infestations.

In New York, the list of available chemical control options has dwindled to essentially one curative and two preventive products. As a curative, the organophosphate trichlorfon is the only fast-acting material remaining that can be used to reduce white grub populations after damage becomes apparent (e.g., Heller and Walker, 2004; Smitley and Davis, 2004; Swier and Rollins, 2006). The two preventive alternatives to trichlorfon have lower vertebrate toxicity and were given an accelerated registration by the United States Environmental Protection Agency. The insect growth regulator halofenozide is an ecdysteroid mimic that induces premature and lethal molt in scarab larvae (Dhadialla et al., 1998). There is low reliance on this compound due to high application cost and reduced efficacy against species other than *P. japonica* (Cowles and Villani, 1996; Cowles et al., 1999; Vittum et al., 2000). The neonicotinoid imidacloprid functions as an agonist on post-synaptic membranes in the nerves of insects

(Mullins, 1993). It is most effective when applied as a preventive early in the life cycle where residues kill neonate larvae through contact or ingestion (Potter, 1998). Positive attributes include its systemicity, a long half-life that means a broader window of application, efficacy against most turf-infesting white grub species and a relatively low application cost. Because of these characteristics, it is the most widely used product for white grub control in most turf situations. The ideal application window around the time of egg hatch, however, is too early for sampling populations and thereby precludes an assessment of thresholds. Lacking any non-arbitrary way to decide that an application can be withheld, turfgrass managers in risk-adverse situations are compelled to make repeated yearly applications over widespread areas.

Turfgrass habitats harbor a diverse and abundant assemblage of non-pest invertebrates (Potter, 1994). Unimpeded by insecticides, this fauna can promote long-term stability by buffering turf from pest outbreaks and from thatch accumulation (Potter, 1993). Natural regulation of insect pest populations is attributed to the activities of soil- and surface-active generalist predators, such as spiders, beetles and predaceous mites (Kunkel et al., 2001). Decomposition of thatch is attributed to the degradative activities of earthworms and certain microarthropods (Potter et al., 1990b). Thatch accumulation is undesirable because it reduces water infiltration, impedes penetration of soil insecticides and fertilizers, enhances habitat for certain herbivores, and causes shallow rooting that weakens turfgrass, increasing susceptibility to insect damage (Potter et al., 1990a; Emmons, 2000; Sachs and Luff, 2002). For both processes – natural regulation of pest populations and thatch degradation – experimental data were gathered in the 1980s demonstrating that insecticides can reduce the populations of beneficials and thereby compromise or disrupt their favorable ecological function (Cockfield and Potter, 1983, 1984; Potter et al., 1990b; Vavrek and Niemczyk, 1990). Two decades later, the chemistries tested in the aforementioned studies (e.g., short-residual carbamates and organophosphates) have largely been removed, replaced or supplanted with newer, more selective alternatives, presumably with less potential for adverse ecological consequences.

This study was originally conceived to help home owners and lawn care providers make more informed pest management decisions by exposing any secondary effects of white grub control products. Aligned with a public outreach program, emphasis was put on the soil microarthropod

community as it constitutes an unfamiliar dimension of beneficial turf fauna. The specific research objective was to detect, measure and contrast the effects of controls on the abundance of arthropods extracted from soil cores. The goal was to evaluate short-term effects, i.e., those caused by a single application, as well as cumulative effects, i.e., those attributed to repeated yearly applications. The working hypothesis was that the range of control products could be ranked with respect to their impact on non-targets, and that the curative control, trichlorfon, would harbor the greatest negative effects, followed by imidacloprid and halofenozide.

## Materials and methods

### Field site

The experiment was conducted on a 1.3-ha lawn at the Crittenden Farm of the New York State Agricultural Experiment Station, Cornell University (Geneva, NY). As a low-maintenance lawn, the experimental area received no irrigation, fertilization, pesticides or overseeding since its conversion in 1997 from a vineyard and orchard fallow. Grass was mown to a height of 6.3 cm every 4–10 d as needed, with clippings left on the surface. The dominant grass species were fine fescue (*Festuca rubra* L., 38% cover), perennial ryegrass (*Lolium perenne* L., 22.7%) and Kentucky blue grass (*Poa pratensis* L., 0.7%). The other major components were weedy grass species (0.8%) and broad-leaf weeds (37.9%). The lawn was divided into 24 experimental plots, each 10 m × 10 m and separated from one another by a 10-m untreated border. Control regimes (treatments) were replicated four times in a randomized complete block design.

### Control regimes

Six treatments were evaluated, based on a variety of options for the control of white grubs. Each was applied to the same experimental plots over three consecutive years (2000–2002):

1. Trichlorfon, an organophosphate contact insecticide, represented a late season curative control (Dylox 6.2 G, Bayer Environmental Science, Research Triangle Park, NC, USA). Following product recommendations, applications were made once each season, in mid-August, at the label rate for white grub control (9.19 kg (AI)/ha), with a drop spreader (Model 36, Gandy, Owatonna, MN, USA).

2. Imidacloprid, a neonicotinyl systemic insecticide, represented an early season preventive control (Merit 0.5 G, Bayer Environmental Science, Research Triangle Park, NC, USA). Following product recommendations, applications were made once each season, in mid-July, at the label rate for white grub control (0.37 kg (AI)/ha; recommended range is 0.34–0.44 kg (AI)/ha), with a drop spreader. Post-treatment irrigation is recommended, but our plots received natural precipitation, which amounted to a weekly total of 42, 9 and 12 mm after the three application dates.
3. Halofenozide, an insect growth regulator insecticide, represented an alternative preventive control (Mach 2 1.5 G, Dow Agrosciences, Indianapolis, IN, USA). Following product recommendations, applications were made once each season, in mid-July, at the label rate for white grub control (1.70 kg (AI)/ha), with a drop spreader.
4. The entomopathogenic nematode *Heterorhabditis bacteriophora*, represented a biological control (Heteromask, BioLogic, Willow Hill, PA, USA). It was applied once each season, in mid-August, at the rate of 2 billion AU/ha, and in conjunction with rain events that washed the product off foliage and into the thatch. Applications to each plot were made with 7.5 L of water dispensed with a watering can.
5. A dispersible, granular form of elemental sulfur fertilizer, represented an experimental control. This commercial plant nutrient was included because of its putative insect control benefits (SulFer 95, 42.68 kg (AI)/ha, Agrimax, Irricana, Alberta, Canada). It was applied twice each season, in mid-July and mid-August, with a drop spreader.
6. An untreated check, where no insecticidal products were applied, was also included.

### Invertebrate sampling

The abundance of soil-active invertebrates was measured with soil cores on four sampling dates over the months of July–October in both 2001 and 2002. Sampling in July and August took place about 1 week before the treatment applications scheduled for those months. Invertebrates were collected by taking cores with a lever action hole cutter (Par Aide, Lino Lakes, MN, USA) with 10.2-cm diameter to a depth of approximately 13 cm. On the morning of each sampling date, five cores were taken from randomly chosen sites in each experimental plot (> 1 m from the border) and enclosed

in individual plastic bags. Two or three samples from each plot were immediately transferred to a battery of modified Tullgren funnels equipped with 40-W light bulbs. To reduce the chances of animals being trapped inside the block of soil, cores were broken up into at least four sections and placed grass-side down on the support screen, one core per funnel. Mobile invertebrates fell through the screen and were collected at the bottom in 70% ethyl alcohol over a period of 48 h. The remaining samples were stored in a walk-in climate chamber at 10 °C until they could be processed immediately after the first group. To avoid any variation attributed to extraction during the first or second round of processing, the cores from each plot were divided (two or three) between the two groups.

To facilitate efficient and accurate sample evaluation, organisms were further separated from contaminants after the Tullgren extraction. This was done using a standardized processing protocol for each sample whereby arthropods were separated from residual organic and mineral materials by floating and decanting using a saturated salt solution. All specimens were stored in 70% ethyl alcohol at 10 °C until they could be assessed taxonomically.

### Taxonomic analysis

To quantify and classify all captures, specimens from individual core samples were plated onto counting trays with shallow wells that could be assessed one by one. The study was not guided by any *a priori* prediction of which taxa were most likely to be affected by the treatment regimes. Therefore, the overall taxonomic assessment was broad. All mature and immature invertebrates were identified to class, and all hexapods were further classified to order. There was a tremendous number of captures and the majority of these were microarthropods that complicated manipulations and identifications. It was therefore beyond the scope of this work to increase taxonomic resolution beyond the level of order or other pooled groups, such as differentiating wolf spiders (Lycosidae) from other Araneae, seed mites (Oribatidae) from other Acari, hexapods to order, and beetles (Coleoptera) to adult or larval life stage.

### Data analysis

Seasonal and yearly fluctuations in populations of the major taxonomic groups were examined graphically. For each plot, data were pooled from the five soil cores examined on each sampling date. For each

treatment, the mean number of individuals captured per plot was plotted against sampling date.

For the ten most represented taxonomic groups, statistical analyses were performed in two stages to assess treatment effects on abundance. First, data were analyzed to test for short-term effects, i.e., whether single-treatment applications suppressed abundance. This effect was tested by determining the significance of the interaction term (treatment  $\times$  date) in analysis of variance (ANOVA). The overall mixed model also included block (random), treatment, date, block  $\times$  treatment (random) and block  $\times$  date (random). Each treatment was tested separately with respect to the untreated check and the analysis was performed only on the pre- and post-treatment sampling dates that corresponded to each treatment. Those dates were July and August for imidacloprid, halofenozide and sulfur-1 (first sulfur application), and August and September for trichlorfon, nematodes and sulfur-2 (second sulfur application). This approach allowed for a test of treatment effects even if pretreatment differences existed. Untransformed count data (rather than transformed data) were used because they better preserve the type I error rate in tests of interaction (Payton et al., 2006). A separate analysis was conducted for each year given the decline in overall abundance of many taxa from 2001 to 2002.

Second, data were analyzed to test for cumulative effects, i.e., whether treatments led to an overall difference in arthropod populations over the three application seasons. This effect was tested with repeated measures ANOVA where multiple measures over time (eight measures across 2001 and 2002) in the same plot were taken into account. For each arthropod group where a significant effect was detected, post-ANOVA contrasts were used to separate means. This was followed by a one-way ANOVA on each date and treatment to test for differences in abundance relative to the untreated check. A logarithmic transformation ( $\log [x+1]$ ) was used to stabilize the normality of capture totals (pooled across the five samples for each plot) for the ANOVA. All statistical calculations were conducted with JMP Statistical Discovery software (SAS Institute, 2003) and assessed with a type I error rate of 5% ( $P = 0.05$ ). Untransformed means were reported along with their standard errors.

## Results

### Material examined

In 2001 and 2002, 187,239 and 106,629 invertebrates were collected, counted and classified from

the soil cores, respectively. There were means of  $390 \pm 12.6$  and  $234 \pm 8.2$  individuals per core in 2001 and 2002, or an extraction rate of 48,133 and 27,411 individuals/m<sup>2</sup> of turf and associated topsoil. Over the 4 mo of the study, the extraction rate varied 3.8-fold (17,583–67,766 individuals/m<sup>2</sup>) in 2001 and 2.0-fold (18,270–36,950 individuals/m<sup>2</sup>) in 2002. The months of greatest and least captures were July and October in 2001, and July and September in 2002.

In order of the greatest to lowest abundance, the major taxa present in soil core samples were Acarina (mites), Collembola (springtails), Hymenoptera (largely ants) and Hemiptera (largely Pseudococcidae) (Table 1). These groups together accounted for >95% of total soil core captures over the season and were the only groups to each constitute >1% of captures in both years. Although non-oribatid mites were the most abundant group both years, their proportional contribution to overall captures fell by a third from 2001 to 2002. The contribution of Hemiptera halved over the same period. On the other hand, the contribution of Hymenoptera doubled and Collembola tripled.

Among the other arthropod taxa collected (in alphabetical order) were beetle larvae, caterpillars, centipedes, click beetles, diplurans, leaf

beetles, millipedes, pillbugs, root aphids, rove beetles, sowbugs, spiders, symphylans and weevils. These included six classes of arthropods (Arachnida, Chilopoda, Diplopoda, Hexapoda, Malacostraca and Symphyla) and ten orders of hexapods (Coleoptera, Collembola, Diplura, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Protura and Thysanoptera) (Table 1). The non-arthropod taxa collected included earthworms, enchytraeids, nematodes and snails. Along with total hexapods, nine taxonomic groups were analyzed in more detail because they each comprised  $\geq 0.5\%$  of the total individuals recovered: non-oribatid mites, oribatid mites, Collembola, Hymenoptera, Hemiptera, Thysanoptera, Diptera, Coleoptera adults and Coleoptera larvae. No scarab larvae were detected in the soil samples, so an effect of treatments on the target species (i.e., white grubs) was not possible given the lack of meaningful populations at the field site.

### Seasonal and yearly fluctuations

Graphical examination of the fluctuation curves showed a similarity in seasonal and year-to-year trends for many taxa, regardless of treatment

**Table 1.** Seasonal captures of arthropod classes, hexapod orders and other taxa extracted from turfgrass soil cores.

Taxa collected	2001		2002		2001–2002
	Total	Percent total	Total	Percent total	Percent total
Arachnida	145,469	77.69	54,491	51.10	68.04
Non-oribatid mites	128,899	68.84	43,944	41.21	58.82
Oribatid mites	16,372	8.74	9996	9.37	8.97
Other arachnids	198	0.11	551	0.52	0.25
Hexapoda	39,876	21.30	50,621	47.47	30.80
Collembola	18,043	9.64	33,380	31.30	17.50
Hymenoptera	8311	4.44	10,675	10.01	6.46
Hemiptera	7776	4.15	2661	2.50	3.55
Thysanoptera	1398	0.75	1840	1.73	1.10
Coleoptera	1730	0.93	1474	1.38	1.09
Adults	802	0.43	1022	0.96	0.62
Larvae	928	0.50	452	0.42	0.47
Diptera	2300	1.23	208	0.20	0.85
Protura	138	0.02	272	0.26	0.14
Lepidoptera	128	0.07	31	0.03	0.05
Diplura	49	0.03	77	0.07	0.04
Orthoptera	3	<0.01	3	<0.01	<0.01
Chilopoda	157	0.08	170	0.16	0.11
Malacostraca	84	0.04	102	0.10	0.06
Symphyla	42	0.02	110	0.10	0.05
Diplopoda	8	<0.01	0	0.00	<0.01
Non-arthropods	1603	0.85	1136	1.06	0.93
<b>Total</b>	<b>187,239</b>		<b>106,630</b>		

(Figure 1). Four overall trends emerged. First, the abundance of Coleoptera larvae and Diptera declined precipitously after the first sampling date and remained low but persistent through the end of the second year. Second, the abundance of non-oribatid mites and Hemiptera fell dramatically from 2001 to 2002. Third, Collembola had large early season (July) peaks in both years while Thysanoptera showed large mid-season (August and September) peaks and Coleoptera adults showed large late season (October) peaks. Fourth, Hymenoptera exhibited the greatest variation in abundance from one sampling date to the next and from one treatment to the next.

The seasonal abundance curves also revealed some apparent population suppression of certain arthropod groups by specific treatments when compared to the curves of the untreated check and the other treatments. Most notable are the low-lying curves for trichlorfon with respect to oribatids and for imidacloprid with respect to total hexapods, Collembola, Thysanoptera and Coleoptera adults.

### Short-term effects of single-treatment applications

For the ten taxonomic groups analyzed in more detail, a significant effect of single-treatment application was detected in only four out of 120 circumstances. In 2001, this included total hexapods in response to nematodes ( $F = 11.83$ ;  $df = 1, 7$ ;  $P = 0.041$ ) and non-oribatids in response to trichlorfon ( $F = 10.60$ ;  $df = 1, 7$ ;  $P = 0.047$ ). In 2002, this included oribatids in response to sulfur-2 ( $F = 16.64$ ;  $df = 1, 7$ ;  $P = 0.027$ ) and Hymenoptera in response to halofenozide ( $F = 11.61$ ;  $df = 1, 7$ ;  $P = 0.042$ ). The interaction terms for all other possible combinations of taxonomic group and treatment were not significant ( $df = 1, 7$ ;  $P > 0.05$ ) when the least-squared means of the pre- and post-treatment populations were compared relative to the untreated check.

### Cumulative effects of overall treatment regimes

An overall cumulative effect of treatment was detected for four of the ten taxonomic groups. These included total hexapods ( $F = 1.64$ ;  $df = 5, 15$ ;  $P = 0.007$ ), Collembola ( $F = 4.14$ ;  $df = 5, 15$ ;  $P = 0.0001$ ), Coleoptera adults ( $F = 1.32$ ;  $df = 5, 15$ ;  $P = 0.017$ ) and Thysanoptera ( $F = 3.06$ ;  $df = 5, 15$ ;  $P = 0.0004$ ). Abundance of all four taxonomic groups was significantly lower under the imidaclo-

prid regime, whereas there were no significant differences between the untreated check and the trichlorfon, halofenozide, nematodes and sulfur regimes (Figure 2). With respect to the untreated check, imidacloprid suppressed captures of total hexapods 2.2-fold, Collembola 2.6-fold, Coleoptera adults 2.4-fold and Thysanoptera 2.4-fold.

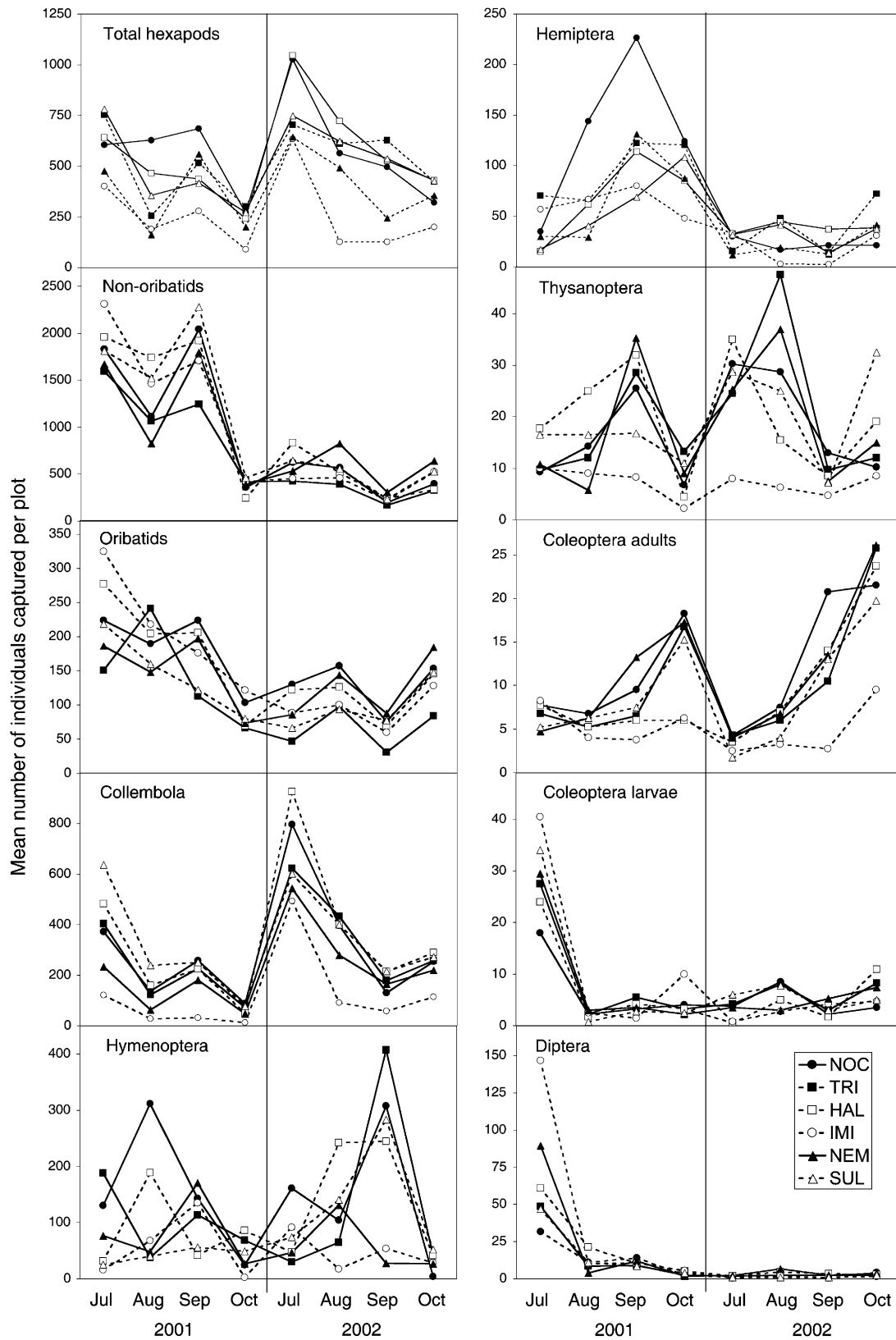
In 2001, total hexapods were significantly suppressed on the last two sampling dates (Figure 3). By the first sampling date in 2002, that difference became non-significant. In the two sampling dates after imidacloprid application, significant differences appeared again, but these disappeared by the third sampling date after application. Collembola populations were suppressed at each sampling date in 2001 relative to the untreated check. Between October 2001 and July 2002, however, abundance rebounded and no significant difference was detected in the July sampling date. After treatment in 2002, populations declined again and remained significantly lower for the rest of the season. Thysanoptera populations were suppressed at the end of 2001 relative to the untreated check, and this difference continued through the first half of 2002. Coleoptera adult populations were suppressed in imidacloprid in both 2001 and 2002. In each year, the population increase exhibited in the untreated check from August to October was delayed until October in imidacloprid.

## Discussion

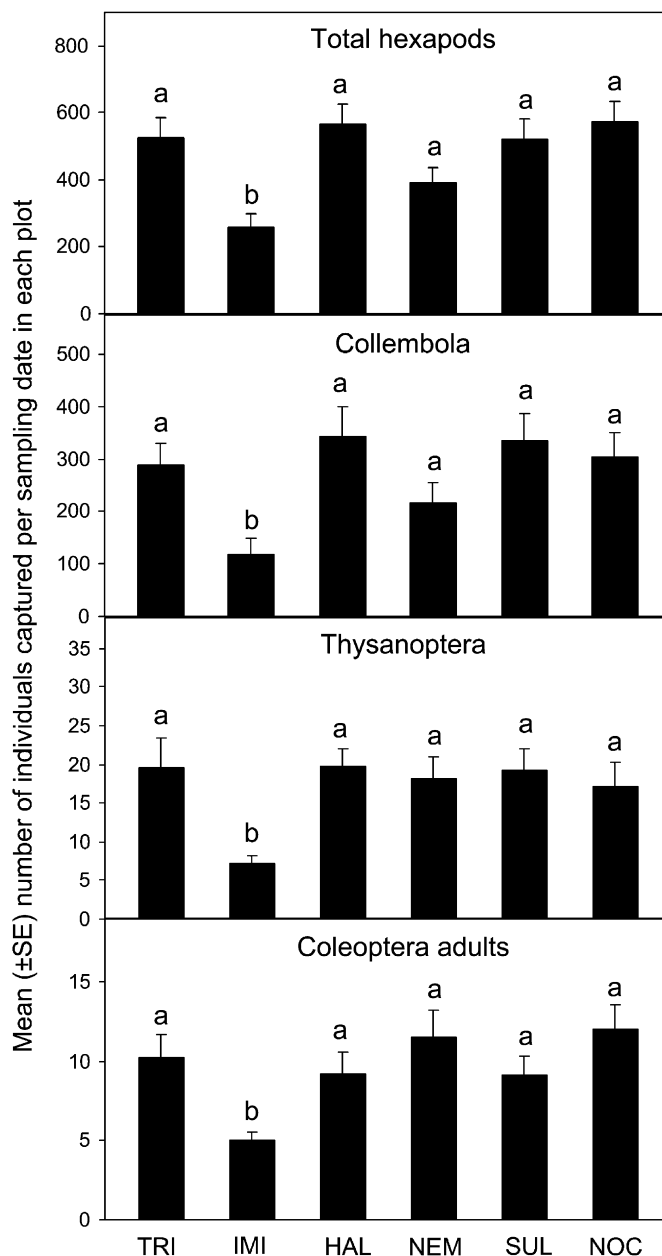
Under the conditions of this study, no consistent short-term effects were detected for any of the treatments evaluated. A significant cumulative effect was detected, but contrary to our predictions, it was imidacloprid that suppressed the abundance of non-target fauna, not trichlorfon or any other alternatives evaluated. Therefore, only imidacloprid can be reported here as having any discernible negative impact on the abundance of non-target soil fauna.

### Comparative treatments effects

The cumulative results of three consecutive yearly applications to the same field plots showed that imidacloprid suppressed numbers of total hexapods, Collembola, Thysanoptera and Coleoptera adults by 54–62%. No effect was observed on the other broad taxonomic groups that were assessed: non-oribatid mites, oribatid mites, Hemiptera (largely pseudococids), Hymenoptera



**Figure 1.** Seasonal and yearly variation in the abundance of major soil arthropods across treatments, expressed as the mean number of individuals captured per treatment plot sampled with five soil cores in 2001 and 2002. NOC = untreated control, TRI = trichlorfon, HAL = halofenozide, IMI = imidacloprid and SUL = sulfur.

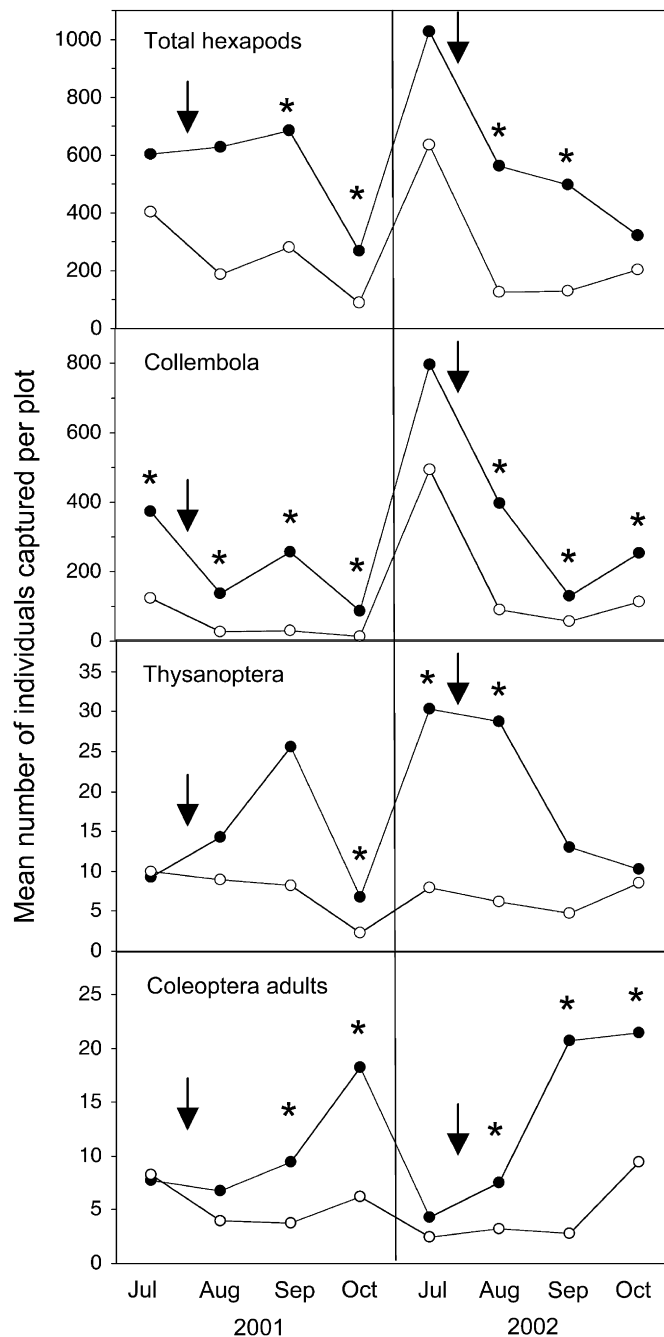


**Figure 2.** Mean ( $\pm$ SE) number of individuals extracted from five 10.2-cm diameter soil cores per treatment plot. For each taxon, means are averaged over eight sampling dates in 2001 and 2002 and columns with the same letter are not significantly different ( $P < 0.05$ ), LSD. TRI = trichlorfon, IMI = imidacloprid, HAL = halofenozide, SUL = sulfur and NOC = untreated control.

(largely ants), Diptera (largely larvae) and Coleoptera larvae.

To date, most studies assessing the unintended effects of imidacloprid on non-target organisms in turf have focused on natural enemies and pollinators. One examined the impact on earthworms and identified short-term suppressive effects (Kunkel et al., 1999), but none has assessed impacts on other decomposers or the broader microarthropod community. The few studies that have reported unintended effects in turf have identified deleter-

ious sublethal effects as measured through behavioral and fitness parameters. For instance, early spring applications of imidacloprid can interfere with the biological control of white grubs by *Tiphia vernalis* Rohwer wasps through an inhibition of host location, but applications later in the season are not disruptive (Rogers and Potter, 2003). For the predatory ground beetle *Harpalus pennsylvanicus* DeGeer, imidacloprid had no effect on abundance (Kunkel et al., 1999), but it did cause paralysis and impaired walking ability, thereby reducing its



**Figure 3.** Effect of imidacloprid (MANOVA,  $P < 0.05$ ) on suppressing total hexapod, Collembola, Thysanoptera and Coleoptera adult populations, recovered from soil cores, relative to the untreated check. Open circles indicate imidacloprid; closed circles indicate untreated check; arrows indicate application period; asterisks indicate significant differences at specific sampling dates ( $P < 0.05$ ).

effectiveness as a predator and increasing its susceptibility as prey to other arthropods (Kunkel et al., 2001). Imidacloprid is toxic to bees after direct exposure, and the vitality of bumble bee colonies can be impacted if workers are exposed to non-irrigated dry residues when imidacloprid is not properly watered in (Gels et al., 2002). Other studies were unable to discern negative non-target

effects of imidacloprid in turf. For instance, after a single application, Zenger and Gibb (2001) detected no effect of imidacloprid on either soil foraging ant abundance or white grub egg predation, while isofenphos and diazinon reduced both measures.

Studies conducted in other agricultural systems show that imidacloprid can be directly toxic to

beneficials such as predaceous arthropods and pollinators (Sterk et al., 2003). After 2–3 applications a year, imidacloprid suppressed non-target predator populations in cotton by 30% (Kilpatrick et al., 2005). In laboratory bioassays, James and Vogele (2001) reported that field rates of imidacloprid targeting aphids in stone fruits were highly toxic to a pentatomid bug and a mantid, partially toxic to a coccinellid beetle, and non-toxic to a reduviid bug, a melyrid beetle and two phytoseiid mites. Moreover, in an apricot orchard, a single application suppressed populations of two coccinellids and neuropteran larvae, but not the melyrid, spiders or parasitic wasps (James and Vogele, 2001). Other diverse direct and indirect effects include toxicity to earthworms (Mostert et al., 2002); reduced mobility, reduced survivorship and greater time to first oviposition in *Coleomegilla maculata* (DeGeer) (Smith and Krischik, 1999); reduced foraging ability and longevity of parasitic wasps after feeding on extrafloral nectaries in cotton (Stapel et al., 2000); and toxicity to the predatory stink bug *Podisus maculiventris* (Say) via direct topical exposure, residual contact and ingestion (De Cock et al., 1996). Despite these examples, beneficial arthropods vary greatly in their susceptibility to imidacloprid, even among species in the same family. Because of this, James and Vogele (2001) argue that impact should be assessed species by species and not overgeneralized across related taxa.

Trichlorfon, halofenozide, sulfur and nematodes had no discernible impact on the abundance of non-target arthropods as measured in this study. *A priori*, trichlorfon was expected to have the greatest measurable impact since it is an organophosphate contact insecticide, with a higher application rate of active ingredient. In addition, like plant-induced toxins (e.g., Bt), systemic insecticides such as imidacloprid are considered to have fewer nontarget effects than contact insecticides (Smith and Krischik, 1999). The fact that imidacloprid has a higher environmental impact quotient (a quantitative index that incorporates applicator, consumer and ecological components of impact) than trichlorfon (34.9 vs. 14.8) ([nysipm.cornell.edu/publications/EIQ.html](http://nysipm.cornell.edu/publications/EIQ.html)) may be due to persistence in the field. The DT<sub>50</sub> (degradation time to 50% loss) of imidacloprid is 49–190 d, and degradation is accelerated with groundcover. In soil cropped with grass, for instance, DT<sub>50</sub> is 69 d (Roberts and Hutson, 1999; EXTOKNET, <http://extoknet.orst.edu/>). In contrast, trichlorfon degrades rapidly in aerobic soils with an average DT<sub>50</sub> of 10 d, or between 3 and 27 d

(Wauchope et al., 1992; EXTOKNET, <http://extoknet.orst.edu/>).

The results corroborate the idea of halofenozide and entomopathogenic nematodes as more selective alternatives. Activity of the insect growth regulator is limited to arthropods that require molting hormones, and all studies revealing lethal effects have been conducted on the orders Coleoptera, Lepidoptera and Diptera (Dhadialla et al., 1998). Field studies involving halofenozide have shown no discernible impacts on non-target arthropods in turf such as abundance of predators (Kunkel et al., 1999), abundance of soil foraging ants (Zenger and Gibb, 2001) or parasitism of *P. japonica* by *T. vernalis* (Oliver et al., 2005). Regardless of mode of exposure, halofenozide had no negative effect on the survival, behavior or fecundity of adult *H. pennsylvanicus*, while imidacloprid and bendiocarb had significant sublethal and lethal effects, respectively (Kunkel et al., 2001). For entomopathogenic nematodes, impacts to non-target arthropod populations in the field can occur, but they are regarded as temporary or even negligible (Bathon, 1996). One study conducted in turfgrass detected an impact of two *Steinernema* nematodes on oribatid mites, but there was no discernible effect on any other arthropod group or species guild represented in pitfall captures (Wang et al., 2001). The experimental sulfur treatment has not emerged as a commercial product for turf insect control, and no data on its suppression of target or non-target arthropods was found in the scientific literature.

### Short-term vs. cumulative effects

When capture rates were compared pre- and post-treatment, there were no detectable effects of control products on the target groups recovered and analyzed from soil core samples. Therefore, none of the white grub control alternatives evaluated in this study are implicated in any reduction of non-target arthropods based on a single application. Despite the absence of detectable short-term effects, imidacloprid was nevertheless shown to significantly reduce the abundance of specific arthropod groups over the longer term, i.e., after 3 years of repeated use. Based on this result, some non-target effects may be cumulative and not readily detectable in short-term, single application or single season experiments. This situation is relevant in systems where preventive applications are made year after year, which is a prevailing scenario for white grub control

in turfgrass of the northeastern United States (Potter, 1998).

The protocol may have failed to detect short-term abundance effects because populations had up to 3 weeks to recover before post-treatment surveys. Because of its rapid degradation, trichlorfon is the treatment where it is most plausible that populations could recover in the sampling interval. It is least plausible for imidacloprid due to its slow degradation. In addition, short generation times and colonization dynamics may make it difficult to demonstrate treatment effects on some taxa when the study features small experimental plots (see Schulze et al., 2001). The 10 m × 10 m plot size was probably large relative to the dispersal capacities of most of the soil-active fauna sampled, but it is impossible to rule out that some or many taxa were affected differently. Rigorous tests to detect and measure the duration of short-term effects must involve more frequent post-treatment sampling.

## Implications

Low-maintenance lawns, like the one used in this study, are widespread landscapes in the northeastern United States. In New York State, alone, there are 974,000 ha of non-irrigated residential lawns (NASS, 2004). Defining the implications of these results could lead to better stewardship across vast areas. Studies that follow should move beyond abundance effects to assess diversity and ecological function. As a start, classification to family, genus and species would help explore any treatment effects in more detail. A greater taxonomic resolution would reveal effects on taxa that might have been obscured by pooling species into broader groups, help to formulate mechanistic hypotheses on how imidacloprid is linked to abundance declines in select groups, and ultimately permit us to assess changes in community assemblages as another diversity response variable (Dively, 2005). Eventually, we will need to answer whether a 2.6-fold suppression of Collembola populations, for instance, is relevant to ecosystem processes such as degradation of thatch and the regulation of pest populations by natural enemies. Given that every pest management tactic inevitably impacts the overall biological community and has unintended consequences, the desired effects of the technology (e.g., neonicotinoid insecticides) must be weighed against those of the practices it can potentially supplant (e.g., carbamate insecticides).

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