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POTENTIAL ECONOMIC BENEFITS AND COSTS OF THE RED IMPORTED FIRE ANT IN SOUTHEASTERN COTTON

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Abstract

The red imported fire ant, *Solenopsis invicta* (Buren) (Hymenoptera: Formicidae), is abundant in cotton throughout much of the southern United States. This voracious predator reaches extremely high densities and may have widespread effects on other arthropods in cotton. We conducted a two-year sampling study and a series of greenhouse and field experiments to document the impact of red imported fire ants on beneficial insects in cotton. We found that the density of 12 out of 13 natural enemies sampled on cotton plants in 1999 and eight out of eight sampled in 2000 were negatively correlated with the density of foraging fire ant workers. We found that red imported fire ants reduced the survival of ladybird beetles (*Coccinella septempunctata* and *Hippodamia convergens*) by 50% and green lacewing larvae (*Chrysoperla carnea*) by 38% in greenhouse experiments. Fire ants did not, however, reduce the survival of spiders (Oxyopidae, Thomisidae, and Clubionidae). We used a commercially available fire ant bait to suppress fire ant populations in cotton fields during the 2000 growing season and compared the densities of beneficial arthropods in treated versus control fields. Densities of ladybird beetles and big-eyed bugs were significantly higher in fields with reduced fire ant populations than in fields with relatively large fire ant populations. The effects of fire ants on the abundance of minute pirate bugs, damsel bugs, and hooded beetles were more complicated, but their overall abundances were higher in control fields than in fire ant suppressed fields. The results of this study suggest that red imported fire ants are major intraguild predators of several important biological control agents and emphasize the possibility of ants as intense intraguild predators in cotton.

Introduction

The red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), was introduced into the southeastern United States approximately 70 years ago. After a fairly slow initial range expansion, this species has spread across the southern tier of the United States to California and continues to expand its range northward along the east coast (Mackay and Fagerlund 1997; Vinson 1997; Anonymous 1999). As well as being a direct health threat to humans and a nuisance pest of landscapes, these ants have pervasive ecological effects due to their voracious predatory habits and ability to out-compete other surface-dwelling arthropods.

Their biggest effect on agroecosystems, however, may be a result of their consumption of other arthropods. Red imported fire ants have been reported as significant predators of a wide variety of cotton pests including boll weevils (Sterling 1978; Jones and Sterling 1979; Sturm et al. 1990). As a consequence, many cotton growers in the southeastern U.S. regard fire ants as beneficial insects.

Some studies, however, raise questions about the beneficial impact of red imported fire ants (Negm and Hensley 1967, 1969; Sterling 1978; Sturm et al. 1990; Vinson 1994). Most notably, red imported fire ant workers are relatively indiscriminant, omnivorous predators that attack beneficial insects as well as pests (Wilson and Oliver 1969; Ricks and Vinson 1970; Morrill 1977; Lee et al. 1990; Vinson 1994). For example, red imported fire ant workers attack predators of horn flies and other pests in pastures (Hu and Frank 1996) and predators of aphids and scale insects in pecans (Bugg and Dutcher 1989; Tedders et al. 1990; Dutcher 1998). Red imported fire ants may also decrease the efficacy of parasitic wasps, primarily by consuming wasp larvae and pupae (Lopez 1982; Sturm et al. 1990; Vinson and Scarborough 1991). Although several studies maintain that red imported fire ants are relatively benign, beneficial predators in cotton (Sterling et al. 1979; Reilly and Sterling 1983a, 1983b), our experience in Alabama cotton fields suggested that fire ant workers routinely attack other predators and may interfere with biological control of cotton pests (Eubanks 2000, 2001). To help elucidate the effects of red imported fire ants on insects in cotton, we conducted a series of field and greenhouse studies to quantify the effects of red imported fire ants on important beneficial arthropods commonly found in cotton. Understanding the impact of red imported fire ants on natural enemies is essential for the development of effective pest management strategies in areas already infested with fire ants and will help predict the impact of fire ants on agricultural systems as this invasive species expands its range.

Materials and Methods

Sampling Data

In 1999, three cotton fields at the E.V. Smith Substation of the Alabama Agricultural Experiment Station in Shorter, Alabama were sampled throughout the growing season. The three cotton fields were approximately 25 hectares each and were separated by two to five kilometers. Plants were sampled approximately every other week (May through August) with a 40-cm diameter sweep net (12 samples per field, 25 sweeps per sample). Samples were returned to the laboratory and arthropods were identified and counted. In 2000, we switched to a combination of beat cloth sampling and visual searches to sample cotton plants in four large fields at the E.V. Smith Substation. We used beat cloth sampling/visual searching so that our data collection would follow the scouting protocols used to develop action thresholds and economic injury levels in southeastern cotton (Knutson and Ruberson 1996). We spread a 1 m^2 cloth on the ground between two rows of cotton. Six cotton plants, three from each row, were vigorously shaken over the cloth. All insects that fell on the cloth were quickly identified and counted. We took ten samples in each field on each sampling date. Data from 1999 and 2000 were log (n + 1) transformed prior to analyses (Sokal and Rohlf 1995). We regressed fire ant density on the density of each natural enemy to estimate the effects of fire ants on beneficial arthropods. Separate analyses were performed for each year.

Greenhouse Experiments

We quantified the survival of three of the most important natural enemies found in cotton in the presence or absence of foraging fire ant workers in a greenhouse experiment. We chose ladybird beetles (*Coccinella septempunctata* and *Hippodamia convergens*), green lacewings (*Chrysoperla carnea*), and spiders (Oxyopidae, Thomisidae, and Clubionidae) as our focal beneficial arthropods because of their importance as biological control agents and their relative ease of collection or commercial availability to facilitate replication of the experiment. Individual cotton plants (five node size) were placed within cages constructed of mosquito netting (75 cm x 30 cm x 33 cm). Cages were attached to a 53 cm x 43 cm x 13 cm plastic pan with 0.5 cm diameter plastic tubing that mimicked a foraging tunnel. The lip of each plastic pan was coated with liquid teflon. The plastic pan contained a small laboratory-maintained fire ant colony containing approximately 500 fire ant workers. We opened the foraging tunnels (plastic tubes) to approximately half the cages. Plants exposed to ant colonies were monitored to ensure that fire ant workers initiated foraging on plants prior to the start of the experiment. We found that the average density of foraging workers on plants exposed to ants was 2.2 ± 1.8 individuals per visual search, well within the range observed in the field (see field results). Vinson and Scarborough (1989, 1991) have successfully used similar experimental protocols to document the impact of fire ants on the survival of other arthropods. At the start of the experiment, two ladybird beetles (one larva and one adult), two green lacewing larvae, or two spiders were placed into each cage. Ladybird beetles and spiders were collected from the weedy edges of agricultural fields and fence lines. Green lacewing larvae and some adult ladybird beetles were obtained from a commercial supplier to supplement our field collections. Ladybird beetles were randomly selected for each replicate of the experiment to mimic the mix of *C. septempunctata* and *H. convergens* beetles found in cotton. Likewise, two adult spiders were randomly chosen from our collections to represent a mix of the common Clubionid, Oxyopid, and Thomisid species abundant in cotton. The primary Clubionid we used was the winter spider, *Chiracanthium inclusum*. The Oxyopid spiders were the striped (*Oxyopes salticus*) and the green (*Peucitia viridans*) lynx spiders. The most common crab spider (Thomisidae) in cotton and the species used in our experiment was the Celer crab spider, *Misumenops celer*. All of these spiders have been documented as important predators of cotton insect pests (Breene et al. 1993). Cages were monitored to ensure that natural enemies initiated foraging on cotton plants after they were placed on the plant surface. We returned 24 hours after placing natural enemies in cages and intensively searched the cotton plant, soil surface, and the cage for living natural enemies. Missing natural enemies were considered killed by ants. Observations during preliminary experiments suggested that most insects killed by foraging fire ant workers were taken to the mound in the teflon-lipped pan. We conducted 29 replicates of ladybird beetle larvae without ants, 28 replicates of ladybird beetle larvae with ants, 34 replicates of lacewing larvae without ants, 30 replicates of lacewing larvae with ants, 30 replicates of spiders without ants and 25 replicates of spiders with ants during the late summer and early fall of 2000. We compared the number of alive and dead ladybird beetles, lacewing larvae, and spiders in the presence and absence of ants with three 2 x 2 contingency tables (Sokal and Rohlf 1995).

Field Experiment

To experimentally estimate the effect of fire ants on beneficial arthropods in the field, we suppressed fire ant populations with a commercially available ant-specific bait (Amdro®) and compared beneficial arthropod abundance in bait-treated cotton plots with their abundance in control plots during the 2000 growing season. Commercially available fire ant baits are excellent tools for this type of experiment because they are composed of an inert, corn "grit" carrier impregnated with soybean oil that is very attractive to foraging fire ant workers but ignored by other insects. A toxicant, in this case hydramethylnon, is incorporated into the oil. Foraging workers find the bait and carry it back to the colony where the toxicant is spread throughout the mound and all members of the colony are affected. We used four large cotton fields (> 20 hectares each) at the E.V. Smith Substation in this experiment. We established two 1.2 hectare plots at opposite ends of each field. Plots were separated by at least 75 meters and often by 100 meters or more. The plots were randomly assigned to either the control or treatment group. Treated plots received application of fire ant bait (2.2 kg/0.4 hectare) approximately one week and eight weeks after planting. We sampled each field weekly throughout the growing season using the beat cloth sampling protocol described above (10 samples per field, per week). Data were log (n + 1) transformed and the densities of beneficial arthropods were compared among control and treated fields with repeated measures analysis of variance with field as a blocking factor (SAS Proc Mixed; Khattree and Naik 1999).

Results

Fire ants were very abundant at our field sites; fire ants were present in every cotton field on every sampling date in both years. Fire ant abundance ranged from zero to 5.5 foraging workers per plant in 1999 and zero to 17 foraging workers per plant in 2000. Fire ants were the third most abundant natural enemy on cotton plants in 1999 (ladybeetles and big-eyed bugs were more abundant) and the most abundant natural enemy in 2000.

The abundance of 12 out of 13 natural enemies in 1999 and eight out of eight natural enemies in 2000 were negatively correlated with the abundance of fire ant workers on cotton plants (Table 1). These arthropods included the most abundant and economically important natural enemies in cotton such as ladybird beetles, green lacewings, and spiders. The effect of red imported fire ants on natural enemy abundance was often strong and variation in fire ant abundance frequently explained a large percentage of variation in natural enemy abundance. For example, the regression coefficient estimating the effects of fire ant abundance on ladybird beetle abundance was –0.24 and the R^2 was 0.18 in 1999 (Table 1). In general, estimates of fire ant effects on natural enemy abundance were lower in 2000 than in 1999 (Table 1). For example, in 2000 the regression coefficients estimating the effects of fire ant abundance on green lacewings, spiders, big-eyed bugs(*Geocoris punctipes*), minute pirate bugs(*Orius insidious*), damsel bugs(*Nabis* spp.) and lacewings were all substantially less than in 1999(Table 1).

To a large extent the results of our greenhouse experiment mirrored our field results. Fire ant workers inflicted significant mortality on ladybird beetles and green lacewing larvae. Ladybird beetles suffered the highest mortality from ant predation. Ladybird beetle survival was 50% lower in the presence of fire ants than in the absence of ants ($G = 16.24$, $df = 1$, $p < 0.001$). Green lacewing larvae were also hit relatively hard by fire ants: lacewing survival was 38% lower in the presence of fire ants than in ant-free controls ($G = 3.94$, $df = 1$, $p < 0.05$). Surprisingly, spider survival was totally unaffected by exposure to foraging fire ants ($G = 0$, $df = 1$, $p = 0.00$).

Baits were very effective at reducing fire ant populations during our field experiment. Fire ant populations were, on average, three times larger in untreated (control) plots than in treated plots (6.19 ± 1.25 ants per sample in control fields versus 2.03 ± 1.22 ants per sample in treated fields) (treatment: $F_{1,3} = 64.94$, $p = 0.004$). The effect of fire ant bait, however, was not consistent across fields and across dates (date x treatment interaction, $F_{4,128} = 2.49$, $p = 0.046$). In some fields, the effect was dramatic and persisted throughout the growing season. In other fields, the effect of the bait was relatively small and fire ant suppression lasted only a few weeks. As a result, fire ant densities in bait-treated and control plots were approximately equal in some fields on some dates. To help ensure that we were testing for an effect of fire ant density on natural enemy abundance, we only included a given field on a given sampling date in our analyses if there was at least a 25% difference in fire ant abundance between the bait-treated and control plots. Unfortunately, there were not enough lacewings and damsel bugs present in enough fields on enough dates to include them in the statistical analysis.

All of the beneficial arthropods that we monitored responded to the change in fire ant density. On average, ladybird beetles were 2.92 times more abundant in plots of cotton with suppressed densities of fire ants than in control plots with relatively high densities of fire ants (treatment: $F_{1,3} = 108.7$, $p = 0.002$). Likewise, spiders were 2.25 times more abundant in plots of cotton with suppressed fire ants (treatment: $F_{1,3} = 18.81$, $p = 0.022$) and big-eyed bugs were 1.64 times more abundant (treatment* date: $F_{4,128} = 3.72$, $p = 0.006$). The response of minute pirate bugs and hooded beetles (*Notoxus* spp.) to changes in fire ant density was much more complex. Overall, minute pirate bugs were 1.63 times more abundant in the control plots with high fire ant densities than in the fire ant suppressed plots (treatment * date: $F_{4,126} = 5.81$, $p = 0.0003$). The direction of the change in minute pirate bug density, however, changed during the course of the experiment. Minute pirate bugs were significantly more abundant in fire ant suppressed plots on July 28 (second sampling date of experiment), but their densities were significantly higher in control plots on two out of the three next sampling dates. Overall hooded beetle abundance was also higher in control plots, but this trend was not significant until the fourth sampling date of the experiment (August 11) (treatment * date: $F_{4,128} = 3.08$, $p = 0.018$).

Discussion

The results of this study suggest that intraguild predation involving red imported fire ants is pervasive and often intense. The density of fire ant workers was negatively correlated with almost all natural enemies sampled in cotton during 1999 and 2000, including ladybird beetles, green lacewings, and spiders (Table 1). In addition, foraging fire ant workers dramatically reduced the survival of ladybird beetles and green lacewings in greenhouse experiments. Most telling, beneficial arthropod populations were often two to three times larger in cotton plots with suppressed populations of fire ants. Evidence of such pervasive intraguild predation by a single higher order predator is almost unprecedented.

Our results are consistent with studies conducted in pasture and pecan agroecosystems that report significant levels of predation on other natural enemies by *S. invicta* workers (Bugg and Dutcher 1989; Tedders et al. 1990; Hu and Frank 1996; Dutcher 1998). Our results, however, are not consistent with previous studies in cotton asserting that fire ants do not interfere with other predators. Sterling et al. (1979) suggested that most predator taxa were unaffected by fire ants and Reilly and Sterling (1983a,b) found no evidence of negative interactions between fire ants and other predators when they examined predator distributions within cotton fields. We believe that a more thorough examination of the impact of fire ants (Lopez 1982; Vinson and Scarborough 1989; Vinson 1994) as well as the results of this study indicate that fire ants are major intraguild predators in most if not all agroecosystems they inhabit.

Although more work is needed to fully document the direct and indirect effects of fire ants on other arthropods, the results of this study support the conclusion that red imported fire ants are major intraguild predators. On-going work will determine if the intense levels of intraguild predation by red imported fire ants reported here disrupt the natural enemy guild's ability to exert strong top-down control of herbivore populations. Because of the high densities of red imported fire ants in many parts of the United States and their continued range expansion into California and other key agricultural states, continued effort to understand the impact of fire ants on managed and natural systems is imperative.

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Table 1. Regression analysis for the effects of fire ant abundance on natural enemy abundance in 1999 and 2000.

	1999				2000			
Natural Enemy	**Intercept**	**Slope**	**R^2**	**df**	**Intercept**	**Slope**	**R^2**	**df**
Ladybeetles	0.25	-0.24	0.18*	281	1.25	-0.30	0.18**	554
Green Lacewings	0.13	-0.19	0.15**	89	0.19	-0.09	0.08**	401
Spiders	0.47	-0.35	0.13**	202	0.83	-0.07	0.02*	510
Big-eyed Bugs	0.57	-0.45	0.12**	213	0.88	-0.24	0.15**	473
Minute Pirate Bugs	0.32	-0.38	0.17**	110	0.44	-0.13	0.08**	437
Damsel Bugs	0.27	-0.23	0.04*	142	0.19	-0.06	0.04**	405
Hooded Beetles	0.20	-0.29	0.21**	126	1.03	-0.23	0.11**	478
Brown Lacewings	0.10	-0.16	0.16**	91	0.10	-0.04	0.05**	399
Wasps	0.16	-0.22	0.13**	91				
Ground Beetles	0.14	-0.23	0.31**	95				
Rove Beetles	0.06	-0.10	0.15**	87				
Assassin Bugs	0.06	-0.10	0.11*	88				
Syrphid Larvae	0.003	0.0002	0.01^{ns}	84				