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Ants (*Azteca* sp.) as potential biological control agents in shade coffee production in Chiapas, Mexico

John Vandermeer[1,*], Ivette Perfecto[2], Guillermo Ibarra Nuñez[3], Stacy Phillpott[1] and Alvaro Garcia Ballinas[3]
[1]*Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, Michigan, USA;*
[2]*School of Natural Resources and the Environment, University of Michigan, Ann Arbor, Michigan, USA;*
[3]*Escuela de la Frontera Sur (ECOSUR), Tapachula, Chiapas, Mexico; *Author for correspondence*

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Abstract

The role of *Azteca* sp. ants as potential biological control agents was studied in an organic coffee farm in Chiapas, Mexico. Individual larvae of *Pieris rapae* were placed on trees with artificially enhanced ant activity and both time to disappearance of the larvae and ant activity were recorded. There was a general negative relationship between time to disappearance and ant activity. A census of spiders was made of coffee bushes with and without foraging *Azteca*, encountering a negative relationship between ants and spiders. These results indicate that *Azteca* ants have potential as pests through their positive effect on scale insects, but also have potential as biological control agents, through their negative effect on potential herbivores. Furthermore, the correlation between ant and spider densities suggests a complicated relationship between these two predatory organisms, implying a more complicated food web structure than simply ants, homoptera and other herbivores.

Introduction

Traditional production techniques for coffee include an overstory of shade trees, usually dominated by legumes in the genera *Inga* or *Erythrina* (Perfecto et al. 1996; Moguel and Toledo 1999), but in many cases include a variety of fruit and timber species as well. It is not surprising that arboreal ants are frequently found nesting in these trees. The question arises as to what role the ants may play in the overall function of this ecosystem. On the one hand many are known to tend homopterans which may at times reach pest proportions, thus making the ants a pest species. On the other hand, ants are predators and may very well have a net positive effect as biocontrol agents. In natural systems it has frequently been shown that the energy taken from the plant by the homopterans is less than the energy potentially lost to the herbivores that would be in the system were it not for the effect of the ants (Room 1972; Dixon 1971; Cushman et al. 1998). Additionally, other predators, such as spiders, may succumb to the same harassment pressure as herbivores, thus leading to more complicated indirect negative effect (for example, ants may reduce beneficial spider populations thus generating a negative effect) (Figure 1).

Recently ecologists have become interested in this sort of indirect effect. Ants have an obvious indirect negative effect on coffee because they tend homopterans. However, ants may also have indirect positive effects on coffee because they either eat herbivores or harass them to the point that the herbivores leave the coffee bush, known respectively as a density-mediated versus trait-mediated indirect interaction (Abrams 1995; Abrams et al. 1996; Werner and Anholt 1996). Furthermore, by harassing or preying on spiders or other predators, ants may exert an even more complicated indirect negative effect on the coffee. From a practical point of view it makes a great deal of difference which of these indirect effects may be actually operative, dictating whether a manage-

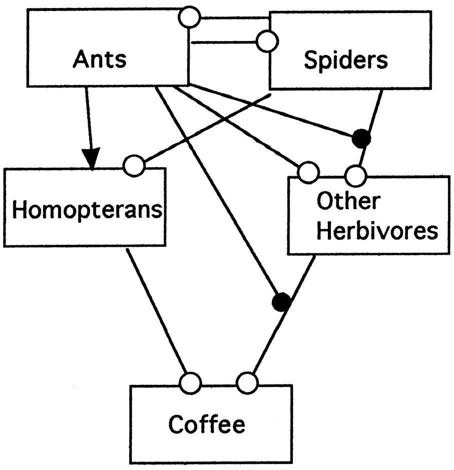

Figure 1. Diagrammatic representation of ant, spider and insect herbivore interactions in an organic coffee farm in southern Chiapas, Mexico. Each box is connected to a box that it affects, the small circles at the end of each connecting line representing a negative effect, the arrowhead indicating a positive effect. The ants potentially have a negative trait-mediated effect on the herbivores and the spiders, indicated by a closed circle attaching to the connection between ″other herbivores″ and coffee or spiders.

ment program should aim at elimination or encouragement of the ants.

Coffee production in this area is relatively free of herbivorous pests (with the exception of the coffee berry borer). However, in three years of observations we have encountered over 20 species of lepidoptera that are able to eat and prosper on coffee in the laboratory – but they are all very rare and not considered pests. These are obviously species that are potentially pests for the future, whenever the natural controls that currently maintain their population densities so low are eliminated, either naturally or artificially. It is possible that some of them are held in check by a combination of parasites and predators, one of which could be *Azteca* ants. Other herbivores, especially scale insects, are known to be devastating pests in outbreak years.

Our goals in this study were two-fold: 1) to understand the influence of ants on herbivores via predatory and/or trait-mediated indirect effects; and 2) to investigate whether ants may indirectly influence herbivores through their interactions with predatory spiders.

In general, the level of ant activity on a given coffee bush is proportional to the population density of scale insects or other homoptera on the tree. Furthermore, casual observation leaves little doubt that scale insects are frequently concentrated on particular branches of the bush, where ant activity is notably elevated, leaving other branches of the bush with little apparent ant activity. To determine whether the potential exists for biological control, we first compared bushes with and without *Azteca* ants with respect to the disappearance rate of artificially placed lepidopteran larvae, and second attempted to determine the quantitative relationship between ant activity and disappearance rate of lepidopteran larvae. Our hypothesis was first, larvae placed on bushes that have active *Azteca* foragers will disappear more frequently than larvae placed on bushes that have no active foragers, and second, there will be a negative relationship between ant activity and time to removal (either by dropping off the tree to escape ant harassment or being removed by active predation by the ants).

Finally, we systematically surveyed the spiders on 18 pairs of coffee bushes, each pair containing one bush with ants and one without ants, expecting a negative correlation between ants and spiders if the effects of ants on spiders were significant.

Methods

The study was conducted on *Finca Irlanda*, a world-famous organic coffee farm with diverse shade, located in the Soconusco region of southern Chiapas, Mexico, in July, 2001. The farm is situated on a mountain mass just north of the Tacaná volcano, near the border with Guatemala (15°10′ N and 92°20′ W). Among the approximately 200 species of shade trees planted on this farm are many that provide suitable habitat for ants in the genus *Azteca*.

Individual larvae of the cabbage butterfly (*Pieris rapae*) were obtained from a local garden and used as experimental animals (actual coffee herbivores are not abundant enough currently to be used in such trials). Single larvae (about 2 cm in length) were placed on lateral branches of coffee bushes and the time necessary for disappearance of the larvae was recorded. Disappearance was usually a result of the larva voluntarily falling off the branch in response to harassment from the ants, but occasionally the ants were successful in subduing the larvae and carrying it off. Ant activity was artificially elevated by placing bits of tunafish on various branches of the bush. *Azteca* recruit actively on this food source and thus create zones of very active ant activity on particular branches of the bush.

During the time the larva was actively crawling on the branch, the number of individual ants that crossed its path were counted. Thus the number of ants per second represents the actual ant activity experienced by that particular larva. Larva were left on the tree for 6 minutes unless they disappeared sooner. Six minutes was deemed sufficient to determine whether or not a pattern of activity could be discerned. Individual larvae were used for repeated trials, unless the attack from ants damaged the individual. No obvious effect of the trials could be seen and the behavior of lepidoptera larvae was remarkably consistent on each trial.

Eight coffee bushes were used in these trials, four with active *Azteca* ants and four with no ant activity, and seven different larvae were used for anywhere from two to nine trials. General conditions (aspect, shade, surrounding vegetation) were seemingly the same for all eight individuals. All observations were made between 9 and 11 AM. Separate analysis for each larva failed to detect any intra-larval difference. Separate analyses suggested that one of the four ant-occupied trees differed from the other three, but this suggestion was not statistically significant and all trees are treated as identical (but see discussion below).

A census of shade trees in part of the farm was made in July of 2001, determining which trees housed *Azteca* colonies (approximately 25% of seemingly appropriate trees actually housed a colony in the area of the farm we worked). In all cases, when a colony was located, a nearby coffee bush was located with active *Azteca* foragers. Additionally, a paired bush with no foraging ants was located nearby, attempting to pair it in size and foliage density with the occupied bush. Subsequently, each of the paired bushes was surveyed by sight for the presence and abundance of spiders, A total of 18 pairs of trees were used for the spider census.

Results

There was a dramatic difference between ant-occupied and non-occupied bushes with respect to lepidopteran larva behavior (Table 1). Indeed, on the non-occupied bushes, the larvae showed no signs of distress and continued to crawl on the branch, demonstrating not the slightest tendency to fall.

Table 1. Effect of ant occupation on persistance of lepidopteran larvae on coffee bushes in an organic plantation in southern Chiapas, Mexico. Disapperance represents cases where ants either preyed upon or harassed the experimental larva to the point that it dropped off the bush.

	With ants	Without ants
Cases of disappearance	40	0
Cases of no disappearance	12	7

There is a clear inverse non-linear relationship that approximates a power function of the rate of disappearance as a function of ant activity (Figure 2).

The difference between ant-occupied and not-occupied was significant for both the number of spider nymphs and number of spider adults, but the direction of the difference reversed for the nymph versus adult comparison (Table 2). Nymphs correspond to the expectation that ants have a negative effect on spiders, but adults have the opposite relationship; more adults occur in coffee bushes where ants are active, in particular the Linyphiidae. Indeed, if the Linyphiids are removed from the data set, the statistical significance of the adult comparison is lost. Spiders were mainly in five families (Tetragnathidae, Theridiidae, Salticidae, Linyphiidae and Araneidae).

Discussion

Important trait-mediated indirect interactions associated with *Azteca* ants, were found in this study (Figure 1). Thus, the potential for *Azteca* as a biological control agent is suspect if only for the negative effect the ants seem to have on spiders, which are also potential biological control agents. However, the data also suggest that the general food web system is more complicated than what was represented in Figure 1. It should also be added that in practical terms, *Azteca* is regarded as a nuisance to coffee workers, who control them by placing lime on their nest entrance during times the shade trees must be ascended. They are not, on the other hand, as large a problem as the small stinging *Wasmania*, sp. so notorious to workers who pick the coffee.

The potential for *Azteca* to induce a trait-mediated effect on potential pests is a function of the activity level of the ants (Figure 2). A rapid survey of activity levels on seven bushes both in a region of concentration of scale insects (which the *Azteca* were actively

Table 2. Number of spiders (or webs) encountered in a sample of 18 pairs of trees in an organic coffee farm, southern Chiapas, Mexico.

	Bushes without ants	Bushes with ants	Significance[a]
Number of nymphs	103	74	0.024
Number of Adults	10	36	0.010
Number of webs	55	42	0.195
Foraging adults[b]	4	8	0.300
Foraging nymphs	26	8	0.005
Linyphiid adults	2	20	0.059

[a] Significance based on a paired t-test of the logs of the numbers. [b] Foraging adults or nymphs refer to those individuals encountered not in a web.

tending) and in a region of the same bush where there were no scales present showed that near the scales ant activity was 0.06 ants/sec (SE = 0.016) while at a point on the bush far from the scale concentration ant activity was 0.0076 ants/sec (SE = 0.002). Using the fitted power function (see Figure 2) we can make an approximate calculation based on these observed activities. Near the scale concentrations we can expect a larva that arrives at the plant to disappear due to ant harassment (or predation) in about 78 seconds [$8.078(0.06^{-0.807})$] while on the same plant away from the scale concentration the time to disappearance would be almost 7 minutes (414 seconds). The question, then, as to whether having scales on the plant is on balance negative or positive for the plant depends on how much damage can be done by a larva in 7 minutes compared to the damage done by the scales. For most larvae, that amount will be relatively small. And it should be recalled that when there are no ants, the larvae did not disappear at all.

It is also worth noting that this experiment was done with one size class of one species of lepidopteran larvae. Obviously the parameter values will be distinct for other species of insects of different sizes. But we expect the general pattern to be rather similar for all herbivores that the ants are capable of harassing (which seems to include most). Furthermore, it was quite obvious from casual observation that some of the *Azteca* colonies were far more aggressive than others, accounting for some of the spread in the data presented in Figure 2. While the differences between colonies was not statistically significant, it is nevertheless our strong impression that colony to colony variation is extremely high and could be very important in future calculations. This colony to colony variation could arise from various sources. There could be major genetic differences among colonies, a point worthy of further investigation both at the level of alpha taxonomy and the direct genetic level. Also there could be a change in colony behavior depending on the stage of development of the colony, smaller colonies having fewer larger than smaller casts and consequently being far less aggressive. Finally, it should be recalled that almost all of the ant colonies of this study were located in shade trees, not coffee bushes. This is the normal pattern. While it is not impossible to find *Azteca* nesting directly in coffee bushes, it is far more common that they nest in the shade trees and from those trees

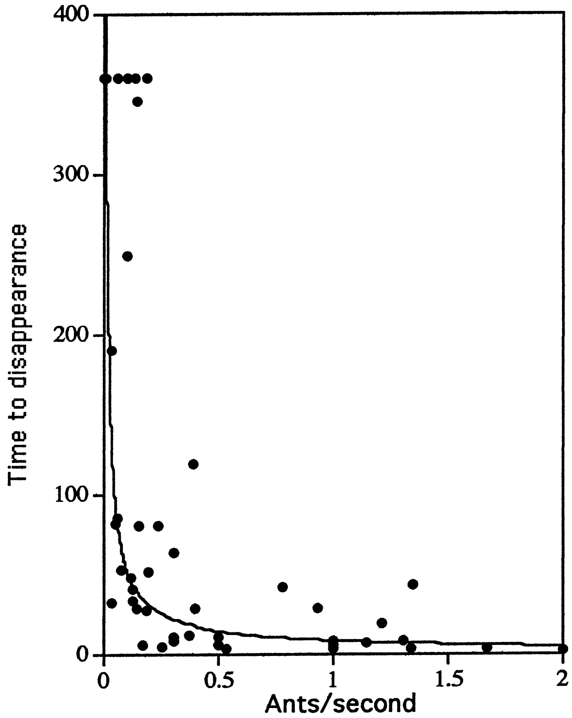

Figure 2. Rate of disappearance (in seconds) of lepidopteran larvae as a function of ant activity in Finca Irlanda, Chiapas, Mexico. Curve is a least-squares fitted power function ($y = 8.078\ x^{-0.807}$; with $r^2 = 0.453$, $p < 0.001$). The power function was fit only to those points that had a time to disappearance less than 6 minutes (360 seconds), since that was the time of each of the trials.

forage in nearby bushes. Thus the existence, species and spacing of shade trees could be an important determining factor. The farm where the present study was undertaken has an unusually large number of shade trees in the genus *Alchornia* (Euphorbiaceae) which seem to be a preferred tree for *Azteca* (16 of the 18 colonies we studied were localed in *Alchornia* trees), despite the fact that there is a greater abundance of several species of *Inga* (Leguminosae).

Before any meaningful assessment of the biological control potential of *Azteca* can be made it is important to deal with the role of spiders. As we have shown, the ants appear to have a general negative effect on spiders, with the seeming exception of Linyphiids. Whether this negative effect will translate into a meaningful negative trait-mediated effect on coffee (Figure 1) remains to be investigated. Furthermore, given the discovery of the seemingly positive relationship between ants and Linyphiids, it may be that the category ″spiders″ is simply too coarse to be meaningful in a quantitative analysis of biological control potential. In a previous study (Ibarra, unpublished data) it was determined that over 70% of food items taken from webs on this same farm were ants. It could thus be the case that the positive correlation between Linyphiids and *Azteca* has to do with predation of the later by the former. If Linyphiids then predate on other herbivores, their presence in bushes that have active colonies of *Azteca* could be another positive trait-mediated effect of *Azteca* (i.e. the ants attract the Linyphiids which then act as generalist predators). Of course these are all speculative questions that await further elaboration both theoretically and empirically.

These observations are in the same spirit as previous studies of the ecological relationship between ants and their tended homopterans (Room 1972; Dixon 1971; Cushman et al. 1998), where the potential indirect effects have long been acknowledged. However, most of those other studies have been in more-or-less natural settings where major swings in animal populations are perhaps less common than in the notoriously unpredictable agroecosystem. Indeed, scales are well known to be major potential pests of coffee, which is what causes some farmers and agronomists alike to assume that ants that tend them are automatically pests themselves. The work reported here suggests that such a simplistic conclusion may be short sighted. However, we cannot ignore the fact that scales are indeed sometimes major pests. We have seen major infestations of scale in coffee in other

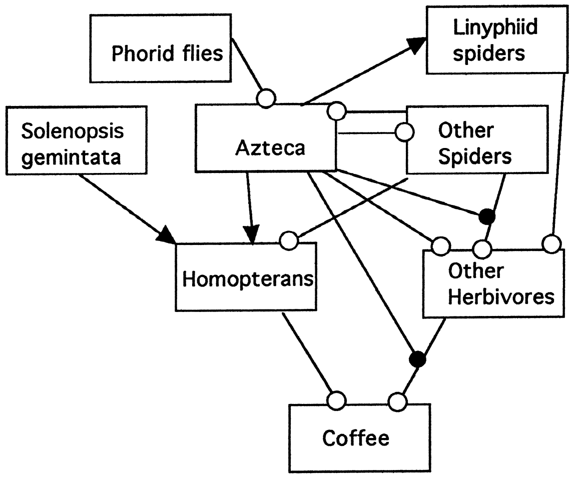

Figure 3. Diagrammatic representation of the system expanded to include the presumed effect of Linyphiid spiders, Phorid flies, and the fire ant, *Solenopsis geminata*. Clearly, with all these connections the decision as to whether *Azteca* has a positive or negative effect on coffee becomes a more difficult one.

regions (e.g. Puerto Rico, Nicaragua), but they are always seemingly associated with the ant *Solenopsis geminata*, which becomes more common as shade is eliminated from the production system (Perfecto et al. 1996; Perfecto and Vandermeer 1994). It is, nevertheless, not impossible that larger and more common colonies of *Azteca* could promote an outbreak of scales. In this study site the abundance of *Azteca* colonies has remained constant, at least over the past three years (personal observations). Phorid flies (which parasitize ants) sometimes appear on this farm when a swarm of *Azteca* becomes agitated. It could be that the Phorid flies are maintained in the highly diverse shaded organic system and prevent the *Azteca* population from exploding.

Based on all of these speculative observations, the simple diagram of the system (Figure 1) needs to be embellished (Figure 3) to get a picture of the possible dynamic consequences of the multitude of interactions that seem to be at least potentially operative here.

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