Bird Predation Decreases Arthropod Abundance and Biomass in Three Coffee Farms in the Blue Mountains, Jamaica.

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Abstract Shaded coffee farms can supply habitat for native biodiversity, especially forest birds attracted to over-story shade trees. However, short term profitability can encourage modern cultivation techniques with few to no over-story trees and little conservation value. Ecosystem services provided by arthropod-feeding birds could provide incentives for farmers to retain traditional, environmentally friendly cultivation techniques. This project focused on the impact of birds on arthropods in Jamaica’s Blue Mountains where the intensification of coffee agriculture threatens native biodiversity. To study this trophic interaction, in summer 2006, arthropods were sampled in 19 paired bird exclosures and controls on three coffee farms located in the Blue Mountains, at an elevation of ~1525 meters. I hypothesized that there would be a higher abundance and biomass of arthropods inside the bird exclosures, and that the difference between the exclosures’ and controls’ arthropod abundance would be positively correlated with higher amounts of shade cover. The results showed that the abundance and biomass of arthropods and arthropod herbivory were significantly higher in the exclosures than in controls. However the difference between the exclosures’ and the controls’ arthropod abundance was not significantly correlated with percent shade cover. These results indicate that birds are providing the farmers an ecological service by reducing arthropod abundance and biomass, but that the effect of bird predation on arthropods was not related to the amount of local shade cover at the site of predation.

Introduction

With an increasing human population, billions of hectares of forested habitat are being converted for agricultural use all over the world (Hole et al. 2005). In the tropics, a large portion of forested habitat is being converted into coffee agriculture (Nicholas 1988 and Rappole et al. 2005). Coffee production in the tropical coffee growing regions of the world is a very lucrative business, bringing in $10 billion dollars in revenues annually (Hole et al. 2005, Nicholas 1988 and Rappole et al. 2005).

With increasing economic opportunities for growing coffee in these tropical regions, there has been a continued shift away from more traditional and sustainable coffee farming practices, known as shade coffee, to sun coffee agriculture which focuses entirely on high yield coffee production (Faminow & Rodriguez 2001, Philpott & Dietsch 2003 and Perfecto et al. 2003).

Shade coffee agricultural practices focus on sustainability and provide long term economic benefits to farmers (Faminow & Rodriguez 2001 and Florian Rivero 2005). In this agricultural system *Coffea arabica* is grown below a mixture of shade providing trees that provide habitat for diverse and abundant wildlife species (Faminow & Rodriguez 2001 and Florian Rivero 2005). Shade coffee agriculture can also provide farmers with other economic resources by growing an over-story of other valuable timber and fruit tree species, such as Fabaceae, *Cecropia* sp. and *Musa* sp. (Faminow & Rodriguez 2001 and Florian Rivero 2005). Growing other plant species also helps to reduce the farmer's economic dependence on coffee market prices (Beer et al. 1998, Faminow & Rodriguez 2001 and Philpott & Dietsch 2003).

The alternative agricultural practice, known as sun coffee, is a monoculture system where only *Coffea arabica* plants are grown in full sunlight (Faminow & Rodriguez 2001 and Florian Rivero 2005). This monoculture system focuses on high-yield coffee production that is profitable from season to season with no focus on long term economics (Faminow & Rodriguez 2001 and Florian Rivero 2005). This agricultural method can reduce the biological diversity of both plant and animal species, as well as reduce habitat niches, disrupting food web interactions (Faminow & Rodriguez 2001, Florian Rivero 2005, and Pineda et al. 2005).

A good example of a region where there is a shift to sun coffee agriculture is the Blue Mountains of Jamaica. In this tropical region thousands of hectares of forested habitats have continued to be cut down for conversion to sun coffee plantations (M. Johnson pers. comm.). This increase in sun coffee plantations has occurred due to a drive by the farming community to convert these forested areas into a more economically profitable resource (M. Johnson pers. comm.). This increase in sun coffee plantations and the decrease in forested habitats has direct effects on the structure of the ecosystem (Faminow & Rodriguez 2001, Florian Rivero 2005 and Perfecto et al. in press).

With more forested habitats in the Blue Mountains projected to be converted to sun coffee plantations, there are ecological concerns about the effects of habitat change on the foraging behaviours, the food web interactions, and the biodiversity of organisms in this region, particularly of birds, which are a main predatory species in this environment (Faminow & Rodriguez 2001, Florian Rivero 2005 and Perfecto et al. in press). In particular, there is concern about birds' abilities to forage on arthropods that are pests on coffee agriculture.

The bird populations found in the Blue Mountains are from both resident and migratory bird species. Loss of habitat can have profound effects on these birds' diversity and abundance (Johnson et al. 2005). These bird species need habitats that can be found in forested areas and shade coffee agriculture. These habitats provide them with shelter, foraging locations, nesting sites, and food resources to survive (Beer et al. 1998, Faminow & Rodriguez 2001, Florian Rivero 2005, Johnson et al. 2005, Mas & Dietsch 2004, Perfecto et al. 2003 and Pineda et al. 2005).

Changes in bird biodiversity can have direct effects on the food web by changing the abundance and biomass of the organisms that they feed on, such as arthropods (Faminow & Rodriguez 2001, Florian Rivero 2005, Greenberg et al. 2000, Perfecto et al. 2004 and Perfecto et al. in press). In the Blue Mountains the arthropod species found here can have different effects on the environment. Some can be biological controls while others can be pests on coffee (M. Johnson pers. comm.).

In the tropics, it has significantly been shown in both agricultural and forested landscapes that insectivorous birds can have a positive impact by acting as pest control agents, and therefore providing an ecological service to their environment (Sekercioglu 2006). Sekercioglu (2006) suggests that insectivorous birds are able to provide this ecological service because of the reduced seasonality in the tropics, which results in fewer and less severe insect outbreaks. Therefore tropical environments allow the effectiveness of insectivorous birds as pest control agents to be more significant year round. Having a diversity of insectivorous birds also helps to increase the probability that they can effectively reduce arthropod pest populations. It was shown that when insectivorous birds were removed from the environment that an increase in herbivory or consumption of plants occurs and can reduce the production or yield of the plant species (Sekercioglu 2006).

To understand how the trophic interactions of birds and coffee arthropod pests are changing in different shade providing coffee agricultural systems, past studies done by Greenberg et al. (2000) and Perfecto et al. (2004) were reviewed. In both of these studies a mesh bird exclosure and control method was used in two tropical coffee growing regions, Guatemala and Mexico. In these studies the mesh bird exclosures were used to keep birds out of sections of coffee, while still allowing arthropods to freely enter into and out of these same areas. This method allowed a comparison of the abundance and biomass of arthropods inside and outside the bird exclosures, where birds were able to forage and not able to forage, at locations with varying amounts of shade, from deep shade to full sunlight.

In order to determine if birds in the Blue Mountains were providing an ecological service to farmers by decreasing the amount of coffee arthropod pests, and to also determine whether lower amounts of coffee arthropod pests was correlated with higher amounts of shade providing plants, to encourage farmers to use shade grown coffee agriculture as a means for conserving bird biodiversity, the method from the Greenberg et al. (2000) and Perfecto et al. (2004) papers was used.

I hypothesized that that there would be a higher amount of total arthropod abundance and herbivore abundance, total arthropod biomass and herbivore biomass and arthropod leaf damage inside the bird exclosures than in the control coffee plants. I also hypothesized that the presence of shade providing trees would equate to more foraging habitats for birds, or that the areas with higher amounts of shade would be negatively correlated with amounts of arthropod and herbivore abundance/biomass and arthropod leaf damage (Beer et al. 1998, Greenberg et al. 2000 and Perfecto et al. 2004).

Methods

Site Description Three coffee farms, with a gradient of shade cover, were used to sample arthropods in 19 pairs of bird exclosures and controls. The three farms were located in the Blue Mountains on the southeastern portion of the island of Jamaica at an elevation of ~1524 meters. The three farms sampled were Clifton Mount Farm, Mc Graham Farm, and Campbell Farm (Figure 1).

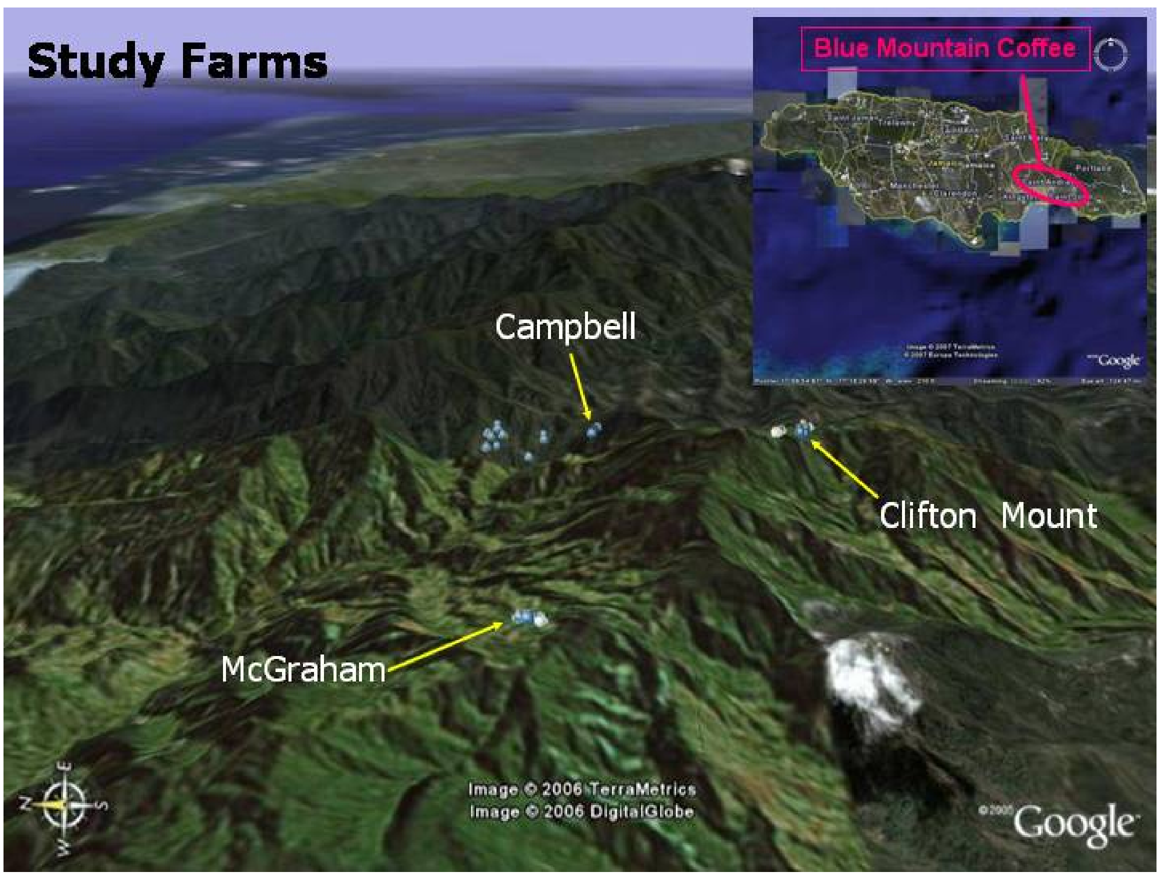

Figure 1: Google Earth map of the three coffee farms used for the field sampling in the Blue Mountains of Jamaica.

Clifton Mount Farm and Mc Graham Farm are farms that had more sparse amounts of shade providing trees grown in the area. They are not organic farms and pesticides for berry borer (*Hypothenemus hampei*) were being applied irregularly. The last application of pesticides occurred 4½ months prior to our arthropod sampling. At Clifton Mount Farm there were nine pairs of bird exclosures and controls that were used for arthropod sampling. And at Mc Graham Farm there were five pairs of bird exclosures and controls that were used for arthropod sampling.

Campbell Farm had other agricultural crops, such as pineapples, asparagus, and bananas, being grown there. These other agricultural plants were being grown in a relatively small quantity, in proportion to the coffee plants, which dominated this farm. Campbell Farm did not use any form of pesticides and was considered to be an organic farm (Dr. Matt Johnson pers. comm.). Campbell Farm had five pairs of bird exclosures and controls used for arthropod sampling.

Arthropod Data Collection The coffee plants used for the bird exclosures were selected at random. And the bird exclosures were made of transparent monofilament nylon gill netting, with 6 cm diagonal mesh. The gill netting was held up around a single coffee plant using four wooden poles approximately 2 meters in height (Greenberg et al. 2000). The control plants were spatially chosen and were adjacent to the bird exclosures, at an average distance of half a meter. The control coffee plants were also chosen to be of comparable height and size to the exclosure coffee plants.

The arthropod samples were collected from the 19 pairs of bird exclosures and controls between the hours of ten am and two pm during the days of June 19^{th} to June 21^{st}. Before the arthropod samples were collected, two one foot by one foot holes were cut on opposite sides of the bird exclosures. The holes were left open for two hours to correct for any disturbances made during the opening of the exclosure.

Arthropods were sampled from the exclosures and controls using Glad-O plastic garbage bags. The bags were quickly placed over an area of branches to capture the arthropods. The branches were cut from the tree into the plastic bag and 3-4 cotton balls with either ethyl acetate or alcohol were added to the bag for two hours to kill the arthropods.

After allowing each bag to sit for two hours arthropods were counted, measured and identified to either order or family, no arthropod leaf miners or borers were identified in this study (Borror et al. 1992). The coffee branches were then weighed and the presence of flowers and fruits were noted.

Arthropod Leaf Damage Data Collection There are two identified coffee arthropods pests in the Blue Mountains, the coffee berry borer (*Hypothenemus hampei*) and the coffee leaf miner (*Perileucopter coffeela*) a lepidopteran larva (M. Johnson pers. comm.). This study, due to the low count of berries on the coffee plants was not able to measure the coffee berry borer, and due to time constraints was also not able to measure the coffee leaf miner. We measured the effects of general herbivorous arthropods, which included leaf chewers and sap suckers.

Arthropod leaf damage was sampled at each of the 19 paired bird exclosures and controls. To standardize this data collection and for accurate identification of arthropod leaf damage all of the leaf sampling was completed by the PI of the project, Dr. Matt Johnson. Dr. Johnson was the most experienced individual of the group, having worked in Jamaica for the last 15 years, he was familiar with the leaf damage differences in coffee plants. Dr. Johnson took a representative sample of two-hundred leaves from all sides of the plant and from the top, middle and bottom sections of the plant. He identified the leaves' condition as either physical damage, which included leaf tears from weathering; biological damage, which included leaf damage due to nutrient deficiencies; arthropod damage, which included any herbivory; leaf spot damage due to a fungus; and no damage. After the leaves with arthropod damage were tallied, they were added up for each exclosure and control to determine the total amount of arthropod leaf damage at each location.

Shade Data Collection The local amount of shade was determined at each of the 19 pairs of bird exclosures and controls using a Solar Pathfinder Assistant manufactured by the Solar Pathfinder company (http://www.solarpathfinder.com/). The Solar Pathfinder Assistant was used to measure the amount of sunlight the area around the exclosures and controls received at each month of the year using a specialized drawing apparatus and paper. And those monthly measurements of sunlight were then added up to give the yearly total percentage of sunlight that hits the area, with 100 % being complete sunlight.

For this study because we were interested in the amount of shade at these locations the percentage of sunlight was subtracted from 100 to get the percent shade. Due to time constraints no measurements of farm wide percent shade cover were taken for any of the three farms.

Data Analysis To determine arthropod abundance it was necessary to divide the abundance of arthropods by the grams of wet vegetation for each sample. To determine arthropod biomass, abundance per sample was converted to biomass using length-weight relationships specific to Jamaican arthropods (Johnson & Strong 2000). For five of the arthropods that were collected, length-weight relationships could not be found in the Johnson & Strong 2000 paper. Comparable arthropod length-weight relationships were found in the paper and were used. For Psocoptera and Neuroptera, Hymenoptera was used, for red termites, Formicidae was used, for ticks, Aranae was used and for Blattodea, Hemiptera was used. The arthropods collected in this study were tabulated in two ways. The first tabulation was total arthropods, which included all the orders and families of arthropods collected in the samples. The second tabulation was herbivorous arthropods, which included all of the orders and families of arthropods whose main food source was plant material.

Paired t-tests were used to determine the significance of total arthropod and herbivore abundance, total arthropod and herbivore biomass and insect leaf damage between the exclosures and the controls. Regression analysis was used to determine the relationship between the difference in the exclosures' and the controls' total arthropod and herbivore abundance, total arthropod and herbivore biomass and arthropod leaf damage, against the amount of average percent shade. Regression analysis was also used to determine the relationship between the controls' total arthropod and herbivore biomass and arthropod leaf damage, against the amount of average percent shade. And lastly regression analysis was used to determine the relationship between the controls' total arthropod and herbivore biomass, against arthropod leaf damage.

The Number Cruncher Statistical System (NCSS) was used to complete all of the statistical analyses (www.ncss.com). It was necessary to log transform all data to normalize the values for paired t-test analyses. A Wilcoxon Signed-Rank Test was used to analyze herbivore abundance data.

Results

In the 19 pairs of bird exclosures and controls total arthropod abundance per gram of vegetation (Figure 2) was significantly higher in the exclosures (0.202 ± 0.059 individuals/gram) (mean ± SE) than the controls (0.063 ± 0.013) (t= 5.10, df= 18 and p <0.001). The herbivore abundance per gram of vegetation (Figure 2) was also significantly higher in the exclosures (0.117 ± 0.033) than the controls (0.038 ± 0.010)(t= 3.38, df=18 and p <0.001).

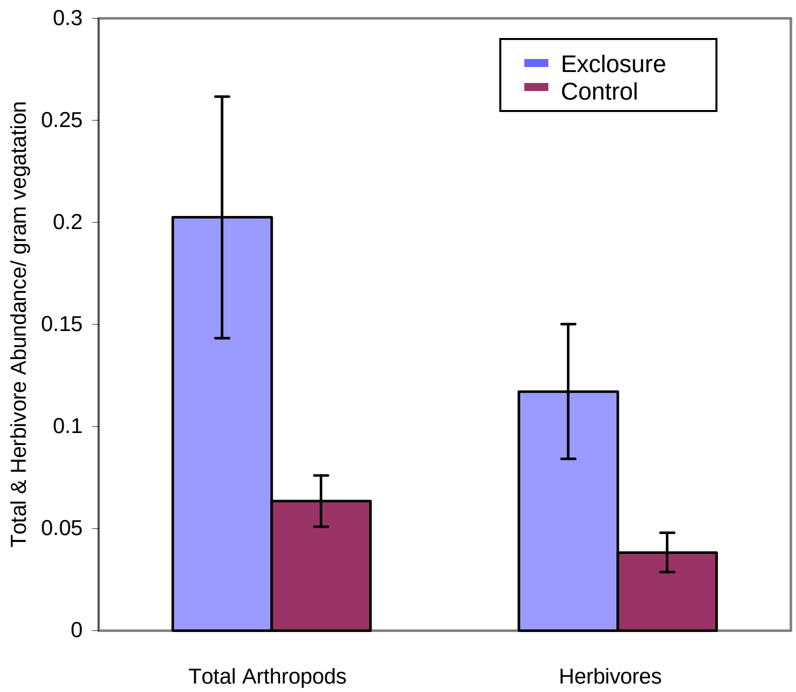

Figure 2: Abundance of total arthropods and herbivores (p value <0.001) and herbivores (p value <0.001) (mean ± standard error).

From the measurements of biomass in the 19 pairs of bird exclosures and controls, the total arthropod biomass sampled per gram of vegetation (Figure 3) was significantly higher in the exclosures (.235 ± .057) than the control plants (.106 ± .025) (t= 4.86, df= 18 and p< 0.001). Herbivore biomass (Figure 3) in the exclosures was also significantly higher (.164 ± .043) than the control plants (.065 ± .021) (t= 3.19, df= 18 and p< 0.003).

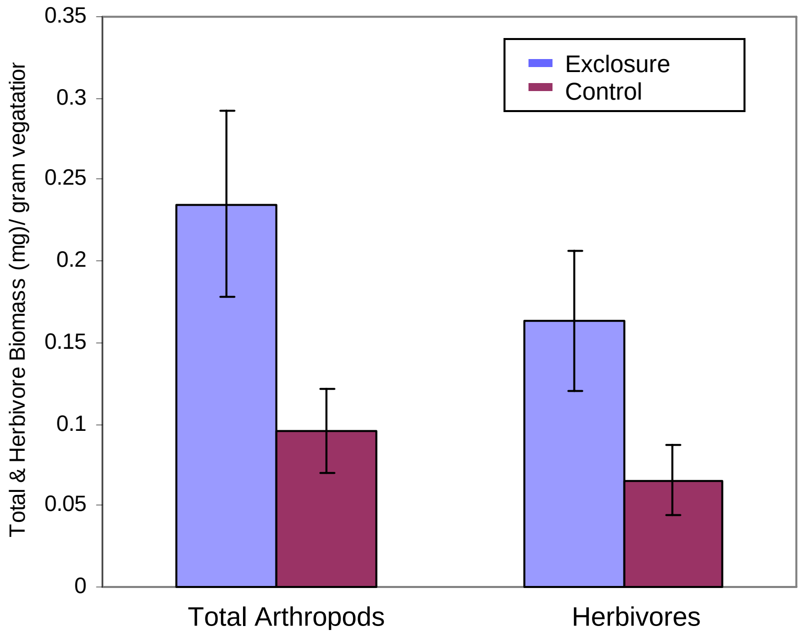

Figure 3: Biomass of total arthropods and herbivores (p value <0.001) and herbivores (p value <0.003) (mean ± standard error).

Arthropod leaf damage per gram of vegetation was measured on the 19 pairs of bird exclosures and controls and it was found to be significantly higher in the exclosures (.080 ± .010) than the controls (.044 ± .007) (t= 3.78, df=18, and p< 0.001).

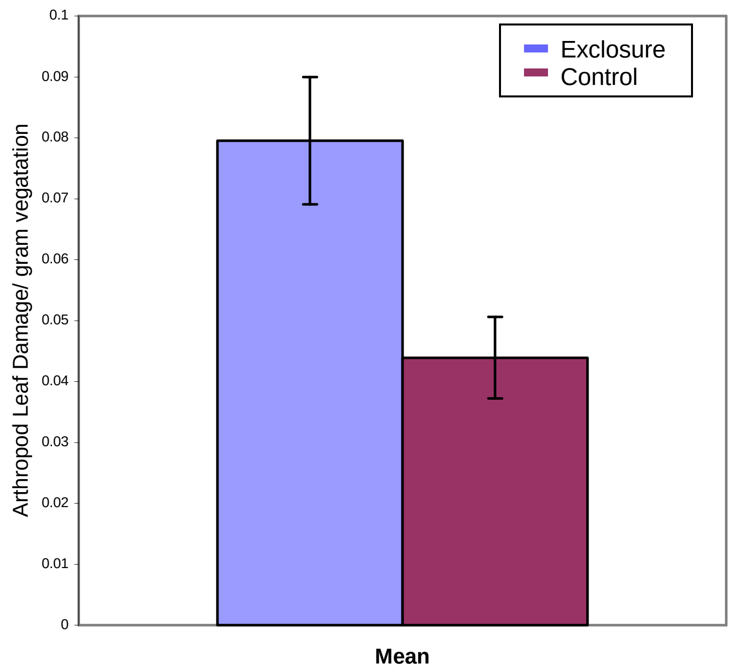

Figure 4: Arthropod leaf damage (p value <0.001) (mean ± standard error).

The regression analyses for the difference in the 19 pairs of bird exclosures' and controls' total arthropod abundance, herbivore abundance, total arthropod biomass, herbivore biomass and arthropod leaf damage were not significantly correlated with average percent shade, across the shade gradient ranging from 0%-91% found at the 19 pairs of exclosures and controls (Table 1). The regression analyses of the 19 control plants' total arthropod biomass, herbivore biomass and arthropod leaf damage were also not significantly correlated with average percent shade, across a shade gradient ranging from 0%-91% (Table 2). Lastly the regression analyses of the 19 control plants' total arthropod biomass and herbivore biomass were not significantly correlated with arthropod leaf damage (Table 3).

Difference in Excl and Cntrl vs. % Shade Cover	F (1,19)	R2	p
Total Arthropod Abundance	0.023	0.001	0.882
Herbivore Abundance	0.024	0.001	0.877
Total Arthropod Biomass	0.551	0.031	0.468
Herbivore Biomass	2.61	0.133	0.125
Arthropod Leaf Damage	0.112	0.007	0.742

Table #1: Regression analysis of the difference in the exclosures' and the controls' total arthropod abundance, herbivore abundance, total arthropod biomass, herbivore biomass and arthropod leaf damage, versus the percentage of shade cover.

Control Plants vs. % Shade Cover	F (1,19)	R2	p
Total Arthropod Biomass	0.273	0.016	0.609
Herbivore Biomass	0.248	0.017	0.626
Arthropod Leaf Damage	2.38	0.123	0.141

Table #2: Regression analysis of the control plants' total arthropod biomass, herbivore biomass and arthropod leaf damage, versus the percentage of shade cover.

Control Plants vs. Arthropod Leaf Damage	F (1,19)	R2	p
Total Arthropod Biomass	0.438	0.012	0.512
Herbivore Biomass	0.064	0.002	0.802

Table #3: Regression analysis of the control plants' total arthropod biomass, and herbivore biomass, versus arthropod leaf damage.

Discussion

The findings of this study indicate that birds can provide a significant ecological service to their environment, as well as to the agricultural community by significantly reducing potential coffee arthropod pests in coffee farms. From the results we saw that the exclosures' total arthropod abundance was ~220% higher than the control plants' and the exclosures' herbivore abundance was ~206% higher than the controls', or that the exclosures had over three times the amount of abundance (Figure 2). For biomass the exclosures' total arthropod biomass was ~145% higher than the control plants' and the exclosures' herbivore biomass was ~150% higher than the control plants', or the exclosures had two and a half times the amount of biomass (Figure 3). And for arthropod leaf damage the exclosures' were ~81% higher than the control plants' or almost two times the amount of arthropod leaf damage was found in the exclosures than the control plants (Figure 4).

The results of my study of bird predation reducing levels of arthropods between bird exclosures and control coffee plants, correlated with the results of Greenberg et al. (2000) and Perfecto et al. (2004). In both of those studies it was shown that bird foraging did lower coffee arthropod pests' abundance and biomass, and the decreases in their populations were shown to be beneficial for coffee yields (Greenberg et al. 2000 and Perfecto et al. 2004). The presence of birds can be equated to an economic value by counting the increase in yields, or profits, they provide the farmer by lowering coffee arthropod pests that would otherwise decrease coffee yields (Chichilnisky & Heal 1998 and Ricketts et al. 2004). Therefore birds can be said to provide an ecological service to the farmers by decreasing coffee arthropod pests (Greenberg et al. 2000, Perfecto et al. 2004, Ricketts et al. 2004 and Sekercioglu 2006).

In this study, the effect of bird predation on arthropods was not significantly related to percent shade cover measured at the 19 pairs of exclosures and controls. The Solar Pathfinder method used in this study only allowed a measurement of local percent shade cover found at the 19 pairs of exclosures and controls on each of the three farms. So birds' ability to decrease arthropods in areas where there is more shade was only evaluated at these 19 individual locations and not on a farm wide basis or across the area of all three farms. This method of measuring only local percent shade cover and trying to understand how it affects birds' ability to forage on arthropods becomes a problem when we think of the nature in which birds use their environment. Birds are dynamic organisms that can fly and therefore tend to utilize their environment on a larger scale. To more accurately evaluate the relationship between bird predation and percent shade cover measurements of shade need to be taken on a wider scale across farms and possibly even across the Blue Mountain region. These wider scale shade measurements would help to determine the real effect of shade cover on bird arthropod predation.

From the bird exclosure method we are inferring that the differences seen in arthropod levels between the exclosure and control plants is due mainly to bird predation. This method does not, however, eliminate the possibility of other predators, such as reptiles, also foraging on the arthropods in the exclosure and control plants. The mesh size of the bird exclosures should only keep bird predators out, therefore predation by other organisms would affect both control and exclosure and standardize the results. In addition, birds are the highest trophic predators in this ecosystem and with the controls having such significantly lower levels of arthropod abundance, biomass and insect leaf damage than the bird exclosures it is fair to conclude that no other predator alone could be responsible for these results (Johnson pers. comm.).

In this study it was possible that birds were foraging on non-herbivorous arthropods. These non-herbivorous arthropods could have themselves potentially been predators of arthropods, one such identified arthropod was Aranaea (spiders). In the Perfecto et al. (in press) paper that studied the trophic structures of coffee farms using bird exclosures in Chiapas, Mexico, they identify spiders in the 4th level of the food web directly below birds that reside at the top of the food web in the 5th trophic level. The Perfecto et al. (in press) results indicate that in coffee agriculture systems spiders may be playing an important role as a trophic-level insectivorous carnivore. The Sekercioglu (2006) paper also suggests that arthropod control by bird species can be complemented by the predation of other arthropods, as well as some parasitoids. The results of these papers are important to consider within the context of my research study because they show the importance of understanding all of the pros and cons of bird predation on arthropods. This information can help to stimulate and guide the direction of further research within this study. A good example of where to continue research is to begin constructing a food web for the Blue Mountains. That information would help to inform us on the intricacies of the trophic interactions occurring in this region.

This study was conducted in June during the non-migratory bird season, which extends from April to September. Significantly more bird species are present in this environment during the migratory bird season, from October to March. Due to the major increase in abundance of bird species that occurs in the Blue Mountains during migration it is important to re-sample the paired bird exclosures and controls during this time to get a full understanding of the food web interaction that are occurring. Sampling during bird migration could produce a more significant effect of bird foraging on arthropods between the exclosures and controls as there will be more birds present in this location (Johnson et al. 2005).

In this study my research questions were built to create this positive feedback loop between birds providing an ecological service to farmers, therefore creating an incentive for bird conservation, and shade coffee agriculture as the method for increasing diverse bird populations within their farms. From the results of my study, the concept that was supported was that of insectivorous birds providing an ecological service to farmers by reducing coffee arthropod pests. But the result that was not conclusive was the relationship between increased bird predation in areas with higher amounts of shade.

After reviewing the shade cover results there was concern about the methodology used to gather the data. The measurement of local percent shade did not accurately correspond with an attempt to correlate a relationship between bird predation and shade cover as birds are dynamic in their environment and forage and function on a larger scale. It was determined that the shade cover data should be re-evaluated and re-measured on a farm wide scale to more accurately evaluate this relationship.

Although this study could not conclusively support all of the proposed hypotheses it has taken an important step in the right direction by significantly showing the importance of birds in reducing coffee arthropod pests within these coffee agricultural systems. This result can be used to encourage the farming community to conserve bird populations and biodiversity within their coffee farms. New research projects should be conducted to understand how best to increase and integrate bird biodiversity conservation with better measurements of the large scale effects of shade grown coffee on birds' ability to forage on arthropod pest.

Reference:

Beer, J., R. Muschler, D. Kass, and E. Somarriba. "Shade Management in Coffee and Cacao Plantations." Agroforestry Systems 38 (1998): 139-164

Borror, D.J., C.A., Triplehorn and N.F. Johnson. 1992. "An Introduction to the Study of Insects." 6th ed. Saunders College Publishing. Fortworth, TX.

Chichilnisky, Graciela, and Geoffery Heal. "Economic Returns from the Biosphere." Nature 391 (1998): 629-630.

Faminow, M. D. and Rodriguez, E. A. 2001. "Biodiversity of Flora and Fauna in Shaded Coffee Systems." Report Prepared for the Commission for Environmental Cooperation. International Centre for Research in Agroforestry Latin American Regional Office.

Florian Rivero, E. M. 2005. “Tropical Bird Assemblages in Coffee Agroforestry Systems: Exploring the Relationships between the Landscape Context, Structural Complexity and Bird Communities in Turrialba.” (PhD dissertation). Centro Agronómico Tropical de Investigación y Enseñanza (CATIE).

Greenberg, Russell, Peter Bichier, Andrea Cruz Angon, Charles Macvean, Ronaldo Perez, and Enio Cano. "The Impact of Avian Insectivory on Arthropods and Leaf Damage in Some Guatemalan Coffee Plantations." Ecology 81 (2000): 1750-1755.

Hole, D. G., Perkins, A. J., Wilson, J. D., Alexander, I. H., Grice, A. D. and Evans, A.D. 2005. Does Organic Farming Benefit Biodiversity? Biological Conservation 122: 113-130.

Johnson, Matthew D., Thomas W. Sherry, Allan M. Strong, and Amanda Medori. "Migrants in Neotropical Bird Communities: an Assesment of the Breeding Currency Hypothesis." Journal of Annual Ecology 74 (2005): 333-341.

Johnson, Matthew D., and Allan M. Strong. "Length-Weight Relationships of Jamaican Arthropods." Entomological News 111 (2000): 270-281

Mas, Alexander H., and Thomas V. Dietsch. "Linking Shade Coffee Certification to Biodiversity Conservation: Butterflies and Birds in Chiapas. Mexico." Ecological Applications 14 (2004): 642-654.

NCSS Statistical & Power Analysis Software." 5 Dec. 2006 <www.ncss.com

Nicholas, I. D. 1988. “26. Plantings in Tropical and Subtropical Areas.” Agriculture, Ecosystems & Environment 22-23: 465-482.

Perfecto, Ivette, Russell Greenberg, Guillermo Ibarra Nunez, Peter Bichier, Caleb E. Gordon, and Alvaro Garcia Ballinas. In press. "Trophic Structure in Coffee Farms: Counting Levels in a World of Intraguild Predation." Journal of Animal Ecology.

Perfecto, I., Mas, A., Dietsch, T. and Vandermeer, J. 2003. “Conservation of Biodiversity in Coffee Agroecosystems: a Tri-taxa Comaprison in Southern Mexico”. Biological Conservation 12: 1239-1252.

Perfecto, Ivette, John H. Vandermeer, Gustavo Lopez Bautista, Guillermo Ibarra Nunez, Russel Greenberg, Peter Bichier, and Suzanne Langridge. "Greater Predation in Shade Coffee Farms: the Role of Resident Neotropical Birds." Ecology 85 (2004): 2677-2681.

Philpott, Stacy M., and Thomas Dietsch. "Coffee and Conservation: a Global Context and the Value of Farmer Involvement." Conservation Biology 17 (2003): 1844-1846.

Pineda, Eduardo, Claudia Moreno, Federico Escobar, and Gonzalo Halffter. "Frog, Bat, and Dung Bettle Diversity in the Cloud Forest and Coffee Agrosystems of Vercruz, Mexico." Conservation Biology 19 (2005): 1-11.

Rappole, John H., David I. King, and George H. Vega Rivera. "Coffee and Conservation." Conservation Biology 17 (2003): 334-336.

Ricketts, Taylor H., Gretchen C. Daily, Paul R. Ehrlich, and Charles D. Michener. "Economic Value of Tropical Forest to Coffee Production." The Proceedings of the National Academy of Sciences 101 (2004): 12579-12582.

Sekercioglu, C. H. “Increasing Awareness of Avian Ecological Function.” Trends in Ecology and Evolution. 21 (2006): 464-471.

Solar Pathfinder." 5 Dec. 2006 <www.solarpathfinder.com