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An Inordinate Fondness for Beetles: A Study of Insect Species Diversity and Abundance in Mazumbai Forest Reserve Versus Nearby Agricultural Areas

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"If one could conclude as to the nature of the Creator from a study of creation, it would appear that God has an inordinate fondness for stars and beetles."
- J. B. S. Haldane

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Abstract

This study investigates how human disturbance of ecosystems alters insect diversity and abundance, specifically exploring how insect communities inside Mazumbai Forest Reserve in Tanzania differ from insect communities in agricultural areas near the reserve. Following methods of previous studies on the effect of disturbance on insect populations (Bellamy et al. 2018; McLaughlin & Mineau 1995; Perry et al. 2016), this research utilizes pitfall traps and yellow bowl traps in multiple locations throughout the two study areas to catch insects, which are then identified to their specific order. The collected data support the hypothesis that insect order diversity and abundance vary per location. Insect communities in agricultural areas are more diverse, likely explained by the intermediate disturbance hypothesis. However, insects are significantly more abundant in the forest reserve than agricultural areas; areas subject to less human disturbance have larger insect communities, an important signifier of a habitat viability.

Keywords: Agriculture, Arthropods, Fragmentation, Insects, Mazumbai, Protected Areas.

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Introduction

As the global population continues to increase, humans frequently convert "natural" ecosystems (forest, prairie, etc.) into agriculture and silviculture areas, residential and urban developments, and other highly disturbed spaces. This loss of habitat area threatens biological diversity, as shown by the species-area curve, which formalizes the relationship between the area of a habitat and the number of species found within that area. As habitat area decreases, the number of species found in that area also decreases (Sherry 2016). Human disturbance of natural ecosystems is the leading cause of habitat fragmentation, the process by which natural landscapes are subdivided into parcels of natural habitat, isolated from each other by matrix of hostile lands created by human activities. This fragmentation leads to smaller habitat areas and decreased biodiversity (Sherry 2016).

Agricultural intensification, characterized by activities such as tilling, draining and use of chemical pesticides and fertilizers, is a leading cause of habitat fragmentation and decreased biodiversity (Thrupp 2000). This loss of biodiversity in agricultural areas not only affects the flora and fauna that inhabit these areas, but humans as well. Agriculture relies heavily on ecosystem services provided by insects, including pollination, soil nutrient cycling and conditioning, and pest control (Bellamy et al. 2018). When these services are eliminated due to species loss, it may be impossible for humans to replace them, making intensified agricultural systems problematic for humans and other species alike.

Areas suffering from habitat fragmentation are also often subject to microclimate changes in wind, sun and soil desiccation levels. These factors cause reduced demographic success in areas experiencing heavy human interaction, greatly altering flora and fauna populations (Sherry 2016). Additionally, disturbed areas often experience increased exposure to foreign predators and parasites that are well adapted to disturbed climates. Native species may have difficulty fending off these unfamiliar predators because they have no prior evolutionary experience with these organisms (Sherry 2016). Therefore, even those few species that can adapt to human altered ecosystems are limited both by levels of disturbance and the loss of other species they may have evolved relationships with (McLaughlin & Mineau 1995).

The above issues are especially prevalent for tropical species. The life histories of tropical organisms often include ecological specialization and poor dispersal ability, making them particularly vulnerable to habitat fragmentation and climate change (Sherry 2016). Additionally, many are ultimately supported by biological interactions, including highly complex layers of competitive, parasitic, and predatory relationships. These interactions are less frequent in ecosystems of higher latitudes, and make the tropics an especially vulnerable biodiversity hotspot. If one species is eliminated from a tropical habitat due to forest fragmentation, changing microclimates, reduced area, or other human disturbances, it is highly likely other species in the habitat will be negatively affected by the loss. In such areas, population decline can quickly lead to extirpation or extinction (Sherry 2016). Paired with the reality of global climate change and ecosystem destruction, the effects of altered community structure could be disastrous for communities in the tropics. Because many global change phenomena reduce biological diversity synergistically (the effect of one phenomenon exacerbates the effect of another), it is especially important to conserve insect biodiversity in tropical biomes.

The following paper compares insect and arachnid populations (Phylum *Arthropoda*) in the interior of Mazumbai Forest Reserve (MFR) versus populations in agricultural areas near the forest reserve. Because insect and arachnid populations are important bio-indicators of habitat health, this study examines whether areas subject to high levels of human disturbance (agricultural areas) have differing ecosystem vitality than protected areas inside of MFR, a protected montane evergreen rainforest in the West Usambara mountain range in Tanzania (*Mazumbai* 2017). As this study compares populations in the forest interior and agricultural areas, the results have important implications for the further division and fragmentation of protected areas.

This study is applicable to all species biodiversity, but focuses specifically on insect and arachnid communities. Insects (Phylum *Arthropoda* Class *Insecta*) are the most diverse group of animals, including over one million described species. They are characterized by a hard exoskeleton, three-part body segmentation, six jointed legs, compound eyes, and antennae (Price 1997). Phylum *Arthropoda* also includes Class *Arachnida*, comprising over 100,000 named species. Arachnids are characterized by eight jointed legs, chelicerae for feeding and defense, and pedipalps for feeding, movement, and reproduction (Price 1997). Though arachnids are not in Class *Insecta*, they are included in the study due to their abundance in the area and ecological importance.

Insects and arachnids were chosen as the study organisms for a variety of reasons. First, arthropods are easy and inexpensive to collect, making them a good choice for a study of shorter duration. Insects are also “ideal indicators for biodiversity” as their survival is closely tied to the viability of the environment they live in (Perry et al. 2016, 82). Factors such as vegetation cover, overall climate, and habitat disturbance level can have a huge impact on insect populations because of their quick reproductive cycles and large number of interspecies relationships. Additionally, insects have an extremely high level of diversity; there could be as many as 30 million species of tropical arthropods (Stork 1988). Insects are thought to comprise 90% of the organismal variability of all species (Bellamy et al. 2018). Because of this huge abundance and variability, insects often dominate the structure of the ecosystems in which they reside (Pimentel et al. 1992).

Broadly, this study aims to explore how human disturbance in ecosystems alters insect communities. Specifically, it explores how insect communities of agricultural areas near MFR differ in composition from insect communities inside of the reserve. In line with previous research on the effect of human disturbance on insect community diversity (Bellamy et al. 2018; McLaughlin & Mineau 1995; Perry et al. 2016), I hypothesize that insect order diversity and abundance will vary per location (forest interior or agricultural area) due to human interaction with the environment. I predict that insect diversity will be greater in agricultural areas, while abundance will be greater in MFR. Areas subject to frequent human disturbance will have smaller insect communities, and therefore be categorized as less viable habitats.

This paper consists of seven sections. The first details the methodology of the study. The second describes the study sites used. The third section briefly reports on the results of the data analysis. The fifth section discusses possible reasons for these results and their implications. The sixth section concludes the statistical analysis and details future considerations on the topic. Tables and figures referred to in the paper can be found in the seventh section.

Methods

Methods for this study were modeled on Bellamy et al.'s 2018 study of insect community composition along an agricultural production gradient in Costa Rica. Yellow bowl traps and pitfall traps were placed at each of the sites. Yellow bowl traps are used to attract and catch flying insects, especially *Diptera* and *Hymenoptera*, which are attracted to the bright yellow color of the traps. Pitfall traps are most effective for capturing surface dwelling insects such as *Coleoptera*, *Blattodea*, and *Hemiptera* (Bellamy et al. 2018).

Twelve study sites were used; six sites in MFR and six sites in agricultural areas. Sites were chosen non-randomly by myself and my guide due to accessibility and time constraints. Sites in MFR were placed alongside a rarely used walking path in the Southern half of the reserve at 1500 m above sea level. Agricultural sites were found in and around Mazumbai village; three sites grew bean plants and three grew tea plants. MFR sites were all at least 100 m interior to the forest edge and agricultural sites were all at least 50 m interior to the plantation edge. At each of the 12 sites four pitfall traps and four yellow bowl traps were placed in the same latitudinal line, alternating trap types (pitfall, yellow bowl, pitfall, yellow bowl, etc.) with 5 m in between each trap.

Hard yellow plastic bowls 10 cm deep with a circumference of 14 cm were used to make yellow bowl traps. After clearing debris from the trapping area, the bowls were placed on flat ground. Water mixed with unscented detergent was poured in to the bowl, approximately 5 cm deep. To make pitfall traps, hard plastic bowls 14 cm deep with a circumference of 31 cm were placed in a hole dug in the soil so that the lip of the bowl was even with ground level. The bowl was filled with water mixed with unscented detergent, approximately 5 cm deep. A plastic cover, propped approximately 5 cm above the lip of the bowl by four wooden sticks was used to keep debris from falling into the bowl.

Traps were emptied and the detergent mixtures from both trap types containing insect samples were sieved through a mesh strainer, rinsed, identified to their order name, and recorded. Due to the abundance of insects and time constraints, species were not differentiated.

The eight traps at each site were set up for 48 hours and specimens collected every 24 hours, totaling 384 collective trapping hours at each site (48 hours x eight traps). Trapping and identification were conducted for 18 days from April 6 to April 24, 2018. Sites were studied in pairs (e.g. MFR Sites 1 and 2 were surveyed at the same time, MFR Sites 3 and 4 were surveyed at the same time), totaling 16 traps set up for each three-day period. Traps were set up, collected, and taken down in the morning, from 8am to 12pm. Insect identification and data analysis were conducted in the afternoons.

At one MFR site and one agricultural site, a yellow bowl trap was broken, making the data unusable. Therefore, data from 10 sites were used. The two sites with broken traps (M3 and A3) are included in the site descriptions, but the data collected from these sites will not be discussed further and their results will not be included in calculations or data analysis.

Statistical methods

To calculate statistical values, I used 2016 Microsoft® Excel for Mac and 2018 Past v3.20.

Two diversity indices were used to analyze the collected data. Simpson's Diversity (*D*) is a dominance index, meaning the value of *D* is more heavily weighted on dominant or common orders. So, rare orders with few representatives will not affect the value of *D*. Simpson’s Diversity takes into account the number of orders present and the relative abundance of each order. *D* measures the probability that two individuals randomly selected from a sample will belong to the same order. D=0% represents infinite diversity and D=100% no diversity. Conversely, the Shannon index is an information statistic index, meaning the calculation assumes all orders are represented in the sample and that specimens are randomly sampled. The Shannon Index is less heavily weighted on dominant or common orders. The value of the Shannon index increases as both the richness and the evenness of the community increase. So, a higher value generally denotes a more diverse community.

Sørensen coefficient of community similarity was used to calculate order similarity between sites.

I ran Student’s t-tests to compare population sizes and diversity indices between agricultural sites and MFR sites (α=0.05).

Ethical Considerations

Ethical considerations for the capture and killing of insects followed The Amateur Entomologists' Society’s (AES) “Code of Conduct for Collecting Insects and Other Invertebrates.” The 12 general guidelines for ethical insect collection can be found on the AES website (www.amentsoc.org).

Site Description

MFR is owned and maintained by Tanzania's Sokoine University of Agriculture. Composed of 320 hectares of relatively pristine tropical forest, MFR is arguably the best preserved example of a montane evergreen rainforest in East Africa. The area is ecologically important as a sanctuary for numerous endemic species and an essential source of water and other resources to surrounding human communities (*Mazumbai* 2017). MFR is located in the West Usambara mountains, part of Tanzania's Eastern Arc Mountain Range. MFR receives approximately 2 m of rainfall a year, with most water falling in the months of December, March, April and May. The reserve exists from 1300 to 1900 m above sea level. The vegetation of MFR is stratified into communities located in five different altitudinal bands. Two of the five bands existed in the MFR sites sampled. At 1515 m is forest composed of *Strombosia scheffleri*, *Craibea brevicaudata*, *Pachysteh msolo*, and *Isoberlina scheffleri*. At 1527 m is forest composed of *Syzygium guineense*, *Sorindeia usambarensis*, *Parinari exelsa*, and *Newtonia buchananii*. Emergent trees in MFR can be up to 50 m tall and have diameters up to 2 m. Plants typically found in the lower story are species of *Dracaena*, *Maytenus* and *Rauvolfia* (*Mazumbai* 2017*)*. All MFR sites are located in the southern half of the reserve.

Mazumbai village is composed of the residential and farm areas adjacent to the reserve. The main crop cultivated in Mazumbai village is tea, through beans, cassava, sugarcane, and bananas are also common crops.

Vegetation is categorized according to the U.S. Department of Agriculture's Growth Habit Codes and Definitions. Graminoids are all grasses and grass-like plants. Herbs are vascular plants lacking woody tissue. Shrubs are multi-stemmed woody plants that are below 5 m. Subshrubs are multi-stemmed woody plants below 1 m. Trees are perennial, woody plants with a trunk and a height exceeding 5 m. Vines are woody or herbaceous climbing plants with long stems. All descriptions of site characteristics are approximate.

Specific site descriptions are below, followed by maps of the study area.

MFR Site 1

Located near the northeast edge of the reserve, 400 m from the border of Sagara and Mazumbai forests at 1500 m above sea level. Canopy cover and ground cover both exceed 80%. Vegetation is largely made up of herbs and a few very large trees. Leaf litter is 2 cm deep. The site is rather steep with a grade of 45% to the north. Rain fell for 16 of the trapping hours at MFR Site 1.

MFR Site 2

Located 400 m south from MFR Site 1 in the northeast quadrant of the reserve at 1500 m above sea level. Canopy cover ranges from 40-50% and ground cover from 70-80%. Vegetation is made up of many small trees, graminoids, and shrubs. The ground is flat, with leaf litter 2 cm deep. Rain fell for 16 of the trapping hours at MFR Site 2.

MFR Site 3

Located 400 m south from MFR Site 2 in the center of the southern half of the reserve. At 1500 m above sea level, canopy cover ranges from 50-60% and ground cover from 80-90%. Vegetation is made up of many small trees, vines, graminoids, and herbs. Two large trees were noted in the site. Leaf litter is 6 cm deep. The site is very steep with a grade of 80% to the south. Rain fell for two of the trapping hours at Site 3; weather was hot and sunny for the majority of trapping hours. One of the yellow bowl traps at MFR Site 3 broke, making the data collected at this site unusable.

MFR Site 4

Located 400 m south from MFR Site 3 in the southeastern corner of the forest, 400 m from the southern edge of the reserve at 1500 m above sea level. Canopy cover ranges from 50-60% and ground cover is 60%. Vegetation is composed of small and medium trees and shrubs. Leaf litter is 7 cm deep. The site is steep with a grade of 50% to the south. Rain fell for two of the trapping hours at MFR Site 4; weather was hot and sunny for the majority of trapping hours.

MFR Site 5

Located directly between MFR Sites 1 and 2 in the northeast quadrant of the forest at 1500 m above sea level. Canopy cover ranges from 70-90% and ground cover is 50%. Vegetation is composed of many of medium-sized trees, herbs and shrubs. The ground is flat with leaf litter 5 cm deep. Rain fell for 24 of the trapping hours at MFR Site 5.

MFR Site 6

Located directly between MFR Sites 2 and 3 in the northeastern quadrant of the forest at 1500 m above sea level. Canopy cover is 50% and ground cover is 80%. Vegetation is composed of medium and large trees and shrubs. Leaf litter is 3 cm deep. The site is very steep with a grade of 80% to the south. Rain fell for 24 of the trapping hours at MFR Site 5.

Agricultural Site 1

Located at 1600 m above sea level and due west of MFR Site 1, Agricultural Site 1 is a one-acre monoculture farm growing tea. Chemical pesticides and fertilizers are in use at this farm. Canopy cover is 10% and ground cover 100%. Vegetation consists of tea plants, small trees and graminoids. The average tea plant height is 85 cm. Leaf litter is 1 cm deep. The site is rather steep with a grade of 55% to the west. Light rain fell for four of the trapping hours at Agricultural Site 1.

Agricultural Site 2

Located slightly west of the research center at 1600 m above sea level, Agricultural Site 2 is a one-acre farm growing beans and tea, but all traps were set in areas growing tea. Chemical pesticides and fertilizers are in use at this farm. Canopy cover is 5% and ground cover 100%.

Vegetation consists of a tea plants, a few large trees, ferns, and graminoids. The average tea plant height is 80 cm. Leaf litter is 1 cm deep. The site is rather steep with a grade of 40% to the west. Light rain fell for four of the trapping hours at Agricultural Site 2.

Agricultural Site 3

Located in Mazumbai village, due east of Agricultural Site 2 at 1400 m above sea level, Agricultural Site 3 is a two-acre farm growing beans, sugarcane, and banana, but all traps were set in areas growing beans. Chemical pesticides and fertilizers are not in use at this farm. Canopy cover is nonexistent and ground cover is 30%. Vegetation consists of bean plants and a few small trees. The average bean plant height is 16 cm. Leaf litter is nonexistent. The site is rather steep with a grade of 50% to the west. Rain fell for eight of the trapping hours at Agricultural Site 3. One of the yellow bowl traps at Agricultural Site 3 broke, making the data collected at this site unusable.

Agricultural Site 4

Located in Mazumbai village, northeast of Agricultural Site 3 at 1400 m above sea level, Agricultural Site 4 is a two-acre farm growing beans, sugarcane, and banana, but all traps were set in areas growing beans. Chemical pesticides and fertilizers are not in use at this farm. Canopy cover is nonexistent and ground cover is 80%. Vegetation consists of bean plants, a few small trees, ferns, and graminoids. The average bean plant height is 19 cm. Leaf litter is nonexistent and the site is flat. Rain fell for eight of the trapping hours at Agricultural Site 3.

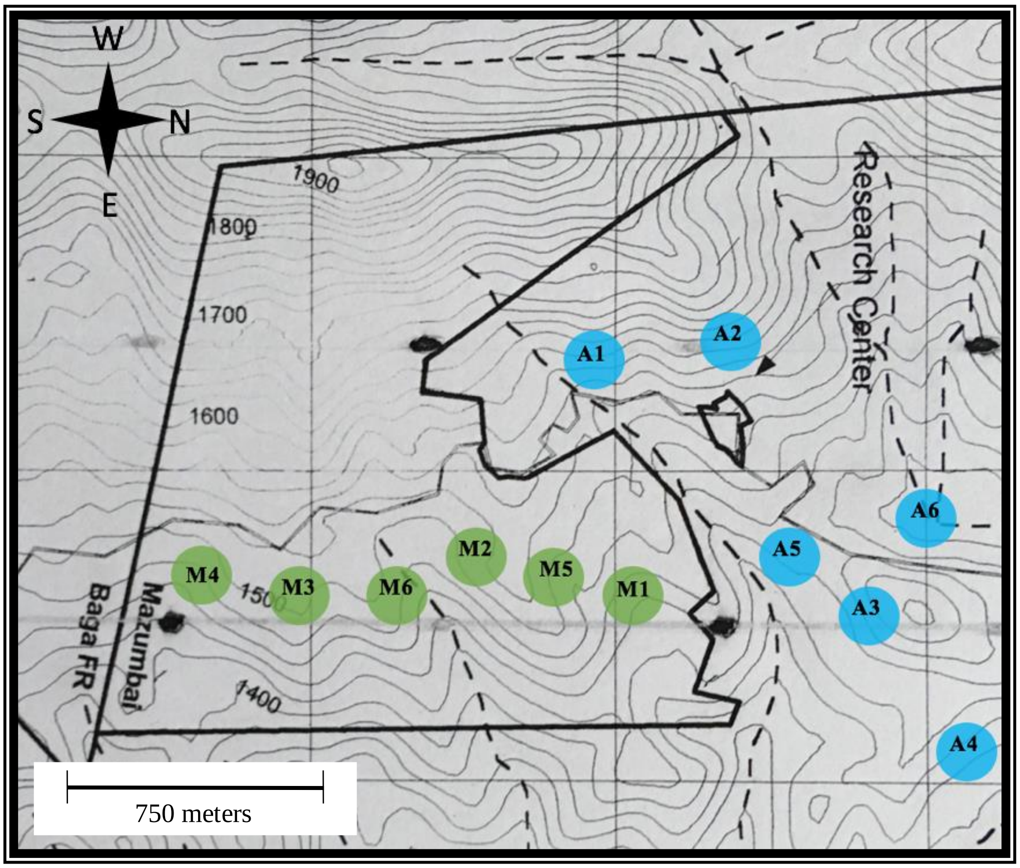
Agricultural Site 5

Located in Mazumbai village, due east of Agricultural Site 2 at 1500 m above sea level, Agricultural Site 5 is a two-acre farm growing tea. Chemical pesticides and fertilizers are not in use at this farm. Canopy cover is nonexistent and ground cover is 100%. The vegetation in Agricultural Site 5 is extremely overgrown; the ground is matted with dead ferns, and graminoids. Tea plants, small trees, and herbs are also present. The average tea plant height is 83 cm. Leaf litter is nonexistent and the site has a grade of 27% to the north. Rain fell for four of the trapping hours at Agricultural Site 5.

Agricultural Site 6

Located in Mazumbai village, slightly north of Agricultural Site 5 at 1500 m above sea level, Agricultural Site 5 is a two-acre farm growing beans. Chemical pesticides and fertilizers are not in use at this farm. Canopy cover is nonexistent and ground cover is 50%. Vegetation consists of bean plants, ferns, one large tree, and a few sugarcane plants interspersed throughout the plot. The average bean plant height is 40 cm, and the plants were flowering during trapping. Leaf litter is nonexistent. The site is rather steep with a grade of 45% to the west. Rain fell for four of the trapping hours at Agricultural Site 6.

Map 1: Tanzania's Eastern Arc Mountain Range. The West Usambara Mountains are marked in yellow.
Image Source: Eastern Arc Mountains Conservation Endowment Fund



Map 2: Placement of sites in Mazumbai Forest Reserve and Mazumbai Village. MFR sites are marked by green circles. Agricultural sites are marked by blue circles.
Image source: Sokoine University of Agriculture

Results

Overall, 5,142 insects were sampled, comprising 11 orders: *Arachnida* (spiders), *Blattodea* (roaches and termites), *Coleoptera* (beetles), *Dermaptera* (earwigs), *Diptera* (flies), *Hemiptera* (true bugs), *Hymenoptera* (bees, ants, and wasps), *Lepidoptera* (butterflies and moths), *Orthoptera* (grasshoppers and crickets), *Thysanoptera* (thrips), and *Zygentoma* (silverfish) (Fig. 1). Significantly more insects were trapped in MFR than in agricultural areas ($t=2.745$, $df=8$, $p<0.05$) (Table 1).

Insect communities in agricultural sites were more diverse than communities in MFR. For agricultural sites, $H'=1.509$, $D=26.9\%$; for MFR Sites: $H'=1.415$, $D=30.4\%$ (Table 2). The difference is significant between H' values when outlying data from MFR Site 6 and Agricultural Site 6 are removed ($t=4.547$, $df=6$, $p<0.05$) (Table 3). The difference is not significant between values of D ($t=1.051$. $df=8$, $p=0.324$) (Table 4).

MFR sites had an order richness of 10. *Hymenoptera* were most common (43.2%), followed by *Coleoptera* (29.9%), *Diptera* (15.5%), *Arachnida* (4.6%), *Orthoptera* (3.8%), *Thysanoptera* (1.9%), *Zygentoma* (0.4%), *Dermaptera* (0.3%), *Blattodea* (0.2%), and *Hemiptera* (0.1%) (Table 5; Fig. 2). No *Lepidotera* were trapped in MFR sites.

Agricultural sites had an order richness of nine. *Hymenoptera* were most common (42.9%), followed by *Diptera* (20.8%), *Coleoptera* (14.4%), *Arachnida* (12%), *Orthoptera* (8.6%), *Thysanoptera* (0.6%), *Blattodea* (0.3%), *Hemiptera* (0.2%), and *Lepidoptera* (0.1%) (Table 6; Fig. 3). No *Dermaptera* or *Zygentoma* were trapped in agricultural sites.

Sørensen coefficient of community similarity comparing insect orders found in agricultural sites and MFR sites is 84.2%.

Discussion

The data presented in this study confirm the hypothesis that that insect order diversity and abundance vary between the forest interior and agricultural areas.

Though there were some differences in the insect population makeup between the two areas, Sorensen's Index of community similarity showed a high level of order similarity between the two areas. In both sites, *Hymenoptera, Diptera,* and *Coleoptera* were the three most common orders. This is likely due to trap types used as well as the feeding and habitat ecology of the three orders. Yellow bowl traps are highly effective at trapping *Hymenoptera* and *Diptera*; 61.34% of all insects trapped in yellow bowl traps across all sites were *Hymenoptera*; 23.19% were *Diptera*. Conversely, pitfall traps are effective for collecting ground-dwelling *Coleoptera*; 32.56% of all insects trapped in pitfall traps across all sites belonged to order *Coleoptera*. In addition to the effect of trap types on the insect orders collected, the ecology of these three orders also explains why their abundance in the studied habitats.

Insects of order *Hymenoptera* accounted for 43.01% of all collected insects, with the majority of *Hymenoptera* collected coming from family *Formicidae*, the ant family. Ants likely contribute a whopping 25% of all tropical animal biomass and are abundant across the globe, found on all continents except Antarctica. Ants can occupy a wide range of niches, avoiding interspecific competition and exploiting a variety of food resources. They can thrive as herbivores, predators and scavengers, though most species omnivorous generalists (Schultz 2000).

Coleoptera made up 23.84% of all collected insects in this study. *Coleoptera* is the largest order of insects, comprising roughly 40% of all described insect species, with approximately 1.5 million species. Beetles generally need only vegetative foliage to thrive and can feed on dead plant tissue, making them adaptable to a huge range of feeding conditions (Maddison 2000). In the MFR areas particularly, where *Coleoptera* made up 29.9% of all sampled insects, rove beetles (family *Staphylinidae*) made up the majority of the *Coleoptera* specimens. *Staphylinidae* live in forest leaf litter and other decaying plant matter, the habitat type found most abundantly in MFR. Due to their sheer abundance in the MFR pitfall traps, I hypothesize that some or all of the trapping periods took place during a *Staphylinidae* influx, possibly during a mating period. Additionally, this study took place during a rain season, and *Staphylinidae* thrive specifically in moist environments (Maddison 2000).

Lastly, *Diptera* are found in almost all terrestrial habitats. They made up 17.56% of all collected insects in this study. Over 150,000 species of *Diptera* have been catalogued, with more being described every year. Their diverse feeding ecology makes them well-suited to a variety of habitats; they can live as herbivores, scavengers, decomposers, predators or parasites. Additionally, *Diptera*'s flight capabilities make them adept at avoiding predation (Picker 2004).

Though both areas had the same three orders found most frequently, agricultural sites had significantly higher Shannon's Diversity (*H'*), when outlying data from Agricultural and MFR Sites 6 were removed. In MFR and Agricultural Sites 1 through 5, *H'* values were higher for Agricultural Sites than MFR Sites. This trend was reversed in MFR Site 6 (*H'*=1.554) and

Agricultural Site 6 (*H'*=1.289). These two *H'* values were found to be outliers and thus excluded from the Student's t-test for significant difference in *H'* values between the two habitats. The unexpected *H'* values for these sites are possibly due to a large difference in rainfall at the two sites; MFR Site 6 received 24 hours of rainfall while Agricultural Site 6 got only four. Rainfall has a huge effect on insect trapping (Bellamy et al. 2018), and this variable could be one of the reasons for these results. However, MFR Site 5 and Agricultural Site 5 were collected during the same 48-hour trapping period and subject to the same rainfall difference as Site 6, but their *H'* values were not found to be outliers. It is also possible that the Site 6 values are due solely to sampling error. Outlying data points such as these would carry less weight if the study was conducted for a longer time period and more data collected.

Overall, a higher value of *H'* means a more diverse community. This finding is likely explained by the intermediate disturbance hypothesis (IDH). IDH proposes that diversity increases when ecological disturbances occur at an intermediate level, that is, neither too rarely or frequently. Diversity is maximized at this intermediate level because species that are adapted to multiple successional stages can coexist in the same habitat. This hypothesis is based on the theory that interspecific competition results from one species driving a competing species to extinction, thus becoming dominant in the ecosystem. This process of competitive exclusion is eliminated when intermediate disturbances limit interspecific competition. If IDH holds true, species richness decreases at low levels of disturbance as competitive exclusion increases. Species richness increases at intermediate levels of disturbance as diversity is maximized because different successional stage species can coexist. This theory is particularly relevant to agricultural practices, as when an area is first cleared (e.g. a forest is converted to a farm for tilling), there is a progressive increase in species diversity before competitive exclusion sets in. Because most of the farms surveyed in this study are low impact (small-scale, farmed by hand, forgoing the use of chemical pesticides or fertilizers), the human disturbance these farms are subjected to is not high enough to decrease diversity. Rather, more diverse groups of insects can thrive in these agricultural areas because of mild, consistent levels of disturbance.

However, more insect diversity does not necessarily mean healthier ecosystems. In fact, the data conclude that MFR sites have a much larger insect community than agricultural sites, which probably indicates a more viable ecosystem. Past research (Bellamy et al. 2018; McLaughlin & Mineau 1995; Perry et al. 2016), as well as basic ecological intuition indicate that protected ecosystems are healthier than farmed ones. It seems likely that the ecosystem with a more abundant insect population is healthier than one with a lower population. It is also important to note that while there was a significant difference in Shannon's diversity between the two areas, there was not a significant difference in Simpson's diversity, which more heavily weights dominant orders. Combining these two analyses, I conclude that the large insect population in MFR likely indicates that this is the healthier ecosystem.

More data collection could yield different results about the diversity of the habitats; I recommend that this study be regarded as a preliminary exploration of the insect communities in MFR and Mazumbai Village. Doubling the time of specimen collection would likely yield more conclusive statistics. It is possible that the lack of significant difference in the *D* values between the two habitats is due partially to the specific characteristics of Simpson's Diversity Index. Because it is a dominance index rather than an information statistic index, the value of *D* is not largely effected by rare orders with few representatives, which made up a much of the data collected. This is partially because of the short duration of the study; not enough data was collected to beef up the counts of insects in less common orders. Many orders were found to be rare only because the trapping time allotted was not enough to get a representative sample of all the insects living in each habitat. If the study was carried out for a longer time period, more insects of every order would be collected and it is possible that a significant difference between *D* values would be found.

Conducting this study during a different time of year could also lead to interesting variation. The amount of rainfall hugely influenced what kind and how many insects were found in the traps. It was much rainier during the trapping week in MFR than the agricultural trapping week. Collecting insects during a drier season might lead to more consistent conditions between the two trapping areas. Also, agricultural areas were surveyed after planting had concluded. This means that the farm sites were subject to less disturbance than they were during the beginning of the planting season, when farmers visited the sites every day to till, plant, and weed their fields. Additionally, this study examined insect order diversity and not species diversity. It is highly possible that examining species diversity would lead to different conclusions.

Another methodological issue occurred with the categorization of the MFR sites as wholly undisturbed. Upon arriving at the MFR sites, I had to dig multiple holes to place pitfall traps, clear debris, and walk around the sites multiple times to collect qualitative data. Additionally, each site was visited three times during the trapping period. This consistent contact with humans during data collection made these sites less than pristine and likely impacted the amount and type of insects collected.

There were also difficulties with specimen identification. Many extremely small and abundant insects were caught across all sites, particularly ants and flies. It was difficult to correctly identify and count all of them. I attempted correctly classify all insects, but invariably made some mistakes.

Any future studies should include a rainfall measuring system in their methodology, so the exact amount of rainfall during trapping periods can be recorded. Additionally, putting pitfall trap covers lower to the ground (no more than 1-2 cm above the soil) could mitigate the issue of rodents and reptiles falling in to the traps and potentially acting as confounding variables. Future research in the area could include the following: the effect of rainfall on insect community diversity and abundance; the effect of agricultural planting cycles on insects; and a comparative study of the insect populations found in small-scale, organic farms versus commercial, non-organic farms. This study peripherally addresses the importance of small-scale, lower disturbance farming, but nothing can be proved conclusively because no data was collected on higher impact farms.

Conclusion

Overall, insect order diversity and abundance varied in both sites studied, though I hypothesize that the increased abundance in non-disturbed ecosystems is a better indicator of ecosystem health than the higher values of *H'* for disturbed ecosystems. The data presented in this paper are consistent with previous research on insect ecology, distribution, and abundance in tropical ecosystems (Iversen 1999; Maddison 2000; Picker 2004; Schultz 2000). However, the data presented do not follow the conclusion that agricultural areas always have lower diversity than non-disturbed areas (Bellamy et al. 2018; McLaughlin & Mineau 1995; Perry et al. 2016). This interesting conclusion should be explored further, as the agriculture sites in this area are almost all small-scale and don't use chemicals. This has implications for the potential sustainability and success of smaller scale agriculture and food security across the globe. The observations and subsequent conclusions drawn from this study suggest that not all agriculture is created equally, and that arthropod abundance and diversity is an ever-evolving, important field of study to monitor ecosystem health. This is an exciting prospect, suggesting conflicts between agriculture and ecosystem health may be preventable. Implementation of sustainable farming practices and innovative policies that integrate the maintenance of biodiversity with farming can lead to both healthier ecosystems and continued agricultural success.

Tables and Figures

t	Degrees of Freedom	Standard Error	p-value
2.7447	8	82.923	0.0253

Table 1: t, degrees of freedom, standard error, and p-value from Student's t-test run for number of insects found in MFR sites versus agricultural sites. More insects were found in MFR than agricultural areas.

Site	Shannon's Diversity Index (*H'*)	Simpson's Diversity Index (*D*)
MFR 1	1.361	32.0%
MFR 2	1.396	29.5%
MFR 4	1.272	43.3%
MFR 5	1.301	32.8%
MFR 6	1.554	25.5%
All MFR Sites	*1.415*	*30.4%*
Agricultural 1	1.455	29.2%
Agricultural 2	1.454	28.6%
Agricultural 4	1.466	25.2%
Agricultural 5	1.474	28.9%
Agricultural 6	1.289	34.0%
All Agricultural Sites	*1.509*	*26.9%*

Table 2: *H'* and *D* values for MFR sites and agricultural sites.

t	Degrees of Freedom	Standard Error	p-value
4.5473	6	0.029	0.0039

Table 3: t, degrees of freedom, standard error, and p-value from Student's t-test run for *H'* values from MFR sites and agricultural sites. Agricultural sites have a significantly higher *H'* value than MFR sites when outlying data from MFR Site 6 and Agricultural Site 6 are removed.

t	Degrees of Freedom	Standard Error	p-value
1.0507	8	3.274	0.3241

Table 4: t, degrees of freedom, standard error, and p-value from Student's t-test run for *D* values from MFR sites and agricultural sites. There is no significant difference in *D* values between the two sites. Agricultural sites are more diverse than MFR sites when outlying data from MFR Site 6 and Agricultural Site 6 are removed.

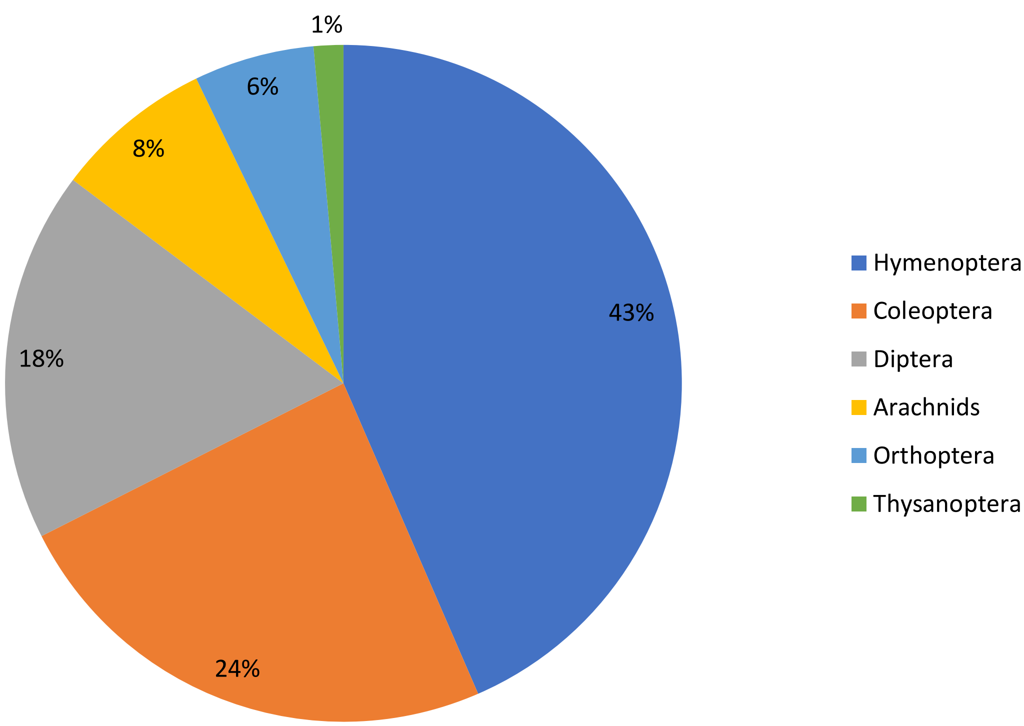


Fig. 1: All insects collected, categorized by order.

	Site 1	Site 2	Site 4	Site 5	Site 6	Total
Coleoptera	250	227	31	275	155	938
Blattodea	2	0	0	2	3	7
Dermaptera	2	0	7	0	1	10
Diptera	104	107	57	112	107	487
Orthoptera	19	37	16	18	30	120
Hymenoptera	330	267	265	317	179	1358
Thysanoptera	10	9	12	8	20	59
Zygentoma	3	1	1	3	3	11
Hemiptera	1	0	3	0	0	4
Lepidoptera	0	0	0	0	0	0
Arachnids	38	33	26	25	24	146
Total	759	681	418	760	522	3140

Table 5: Insects collected from MFR sites, categorized by order.

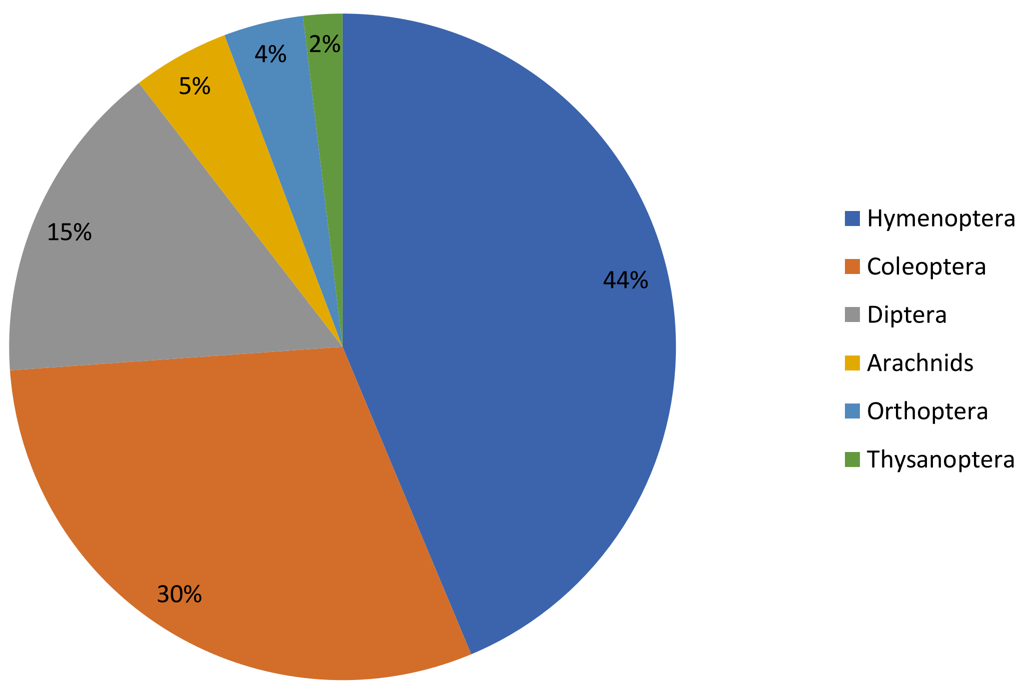


Fig. 2: Insects collected from MFR sites, categorized by order.

	Site 1	Site 2	Site 4	Site 5	Site 6	Total
Coleoptera	42	91	105	32	18	288
Blattodea	0	3	0	3	1	7
Dermaptera	0	0	0	0	0	0
Diptera	93	138	77	76	32	416
Orthoptera	24	46	62	20	21	173
Hymenoptera	151	255	144	142	166	858
Thysanoptera	10	0	0	3	0	13
Zygentoma	0	0	0	0	0	0
Hemiptera	0	2	0	1	1	4
Lepidoptera	1	2	0	0	0	3
Arachnids	22	43	20	39	116	240
Total	343	580	408	316	355	2002

Table 6: Insects collected from agricultural sites, categorized by order.

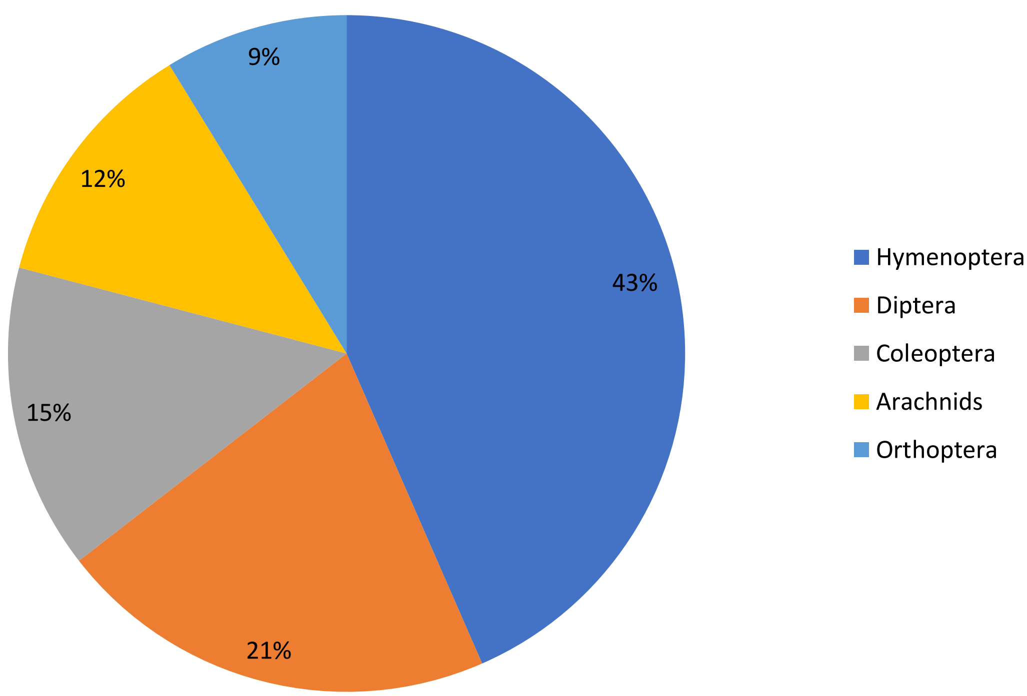


Fig. 3: Insects collected from agricultural sites, categorized by order.

	Agricultural	MFR	Total
Coleoptera	57	69	126
Blattodea	0	1	1
Dermaptera	0	0	0
Diptera	182	227	409
Orthoptera	43	27	70
Hymenoptera	193	889	1082
Thysanoptera	0	2	2
Zygentoma	0	1	1
Hemiptera	0	0	0
Lepidoptera	1	0	1
Arachnids	33	39	72
Total	509	1255	1764

Table 7: Insects collected from yellow bowl traps, categorized by order.

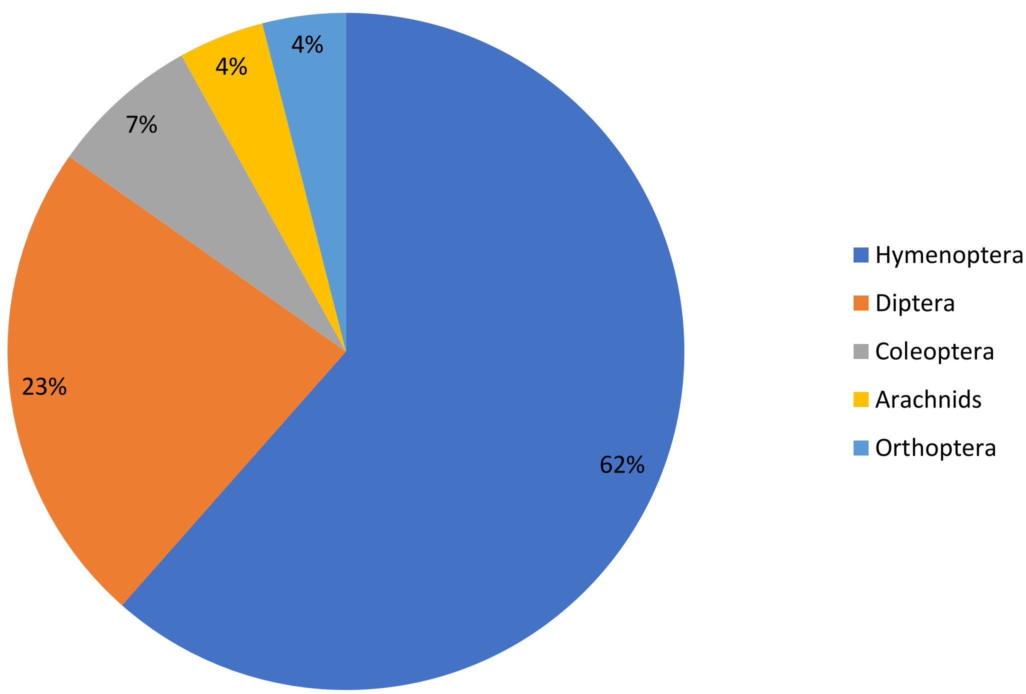


Fig. 4: Insects collected from yellow bowl traps, categorized by order.

	Agricultural	MFR	Total
Coleoptera	231	869	1100
Blattodea	7	6	13
Dermaptera	0	10	10
Diptera	234	260	494
Orthoptera	129	93	222
Hymenoptera	667	469	1136
Thysanoptera	13	57	70
Zygentoma	0	10	10
Hemiptera	4	4	8
Lepidoptera	2	0	2
Arachnids	206	107	313
Total	1493	1885	3378

Table 8: Insects collected from pitfall traps, categorized by order.

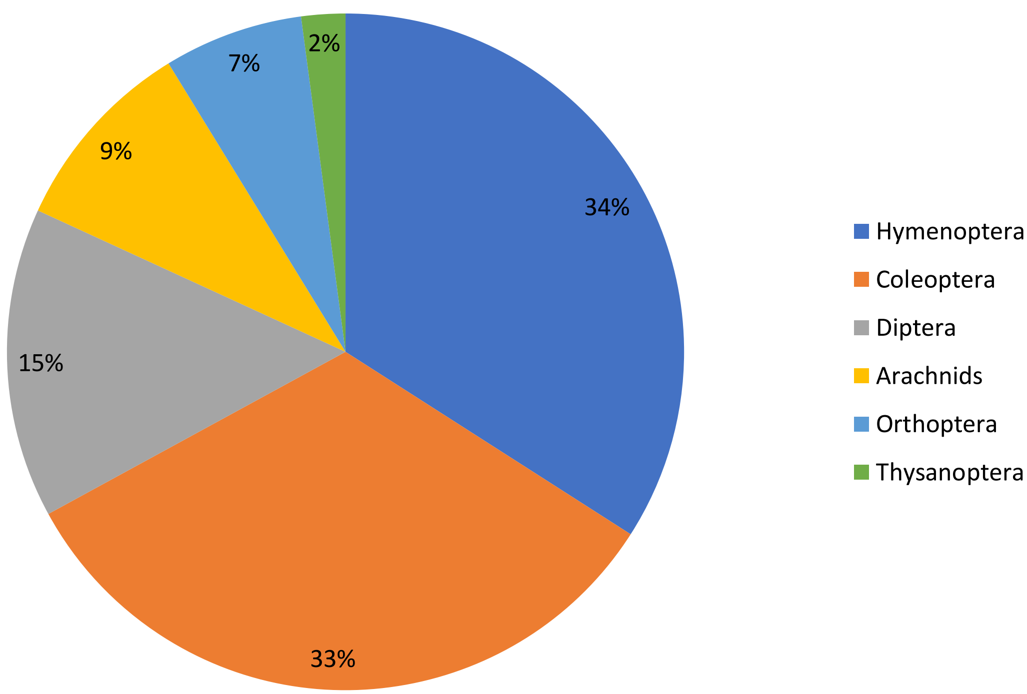


Fig. 5: Insects collected from pitfall traps, categorized by order.

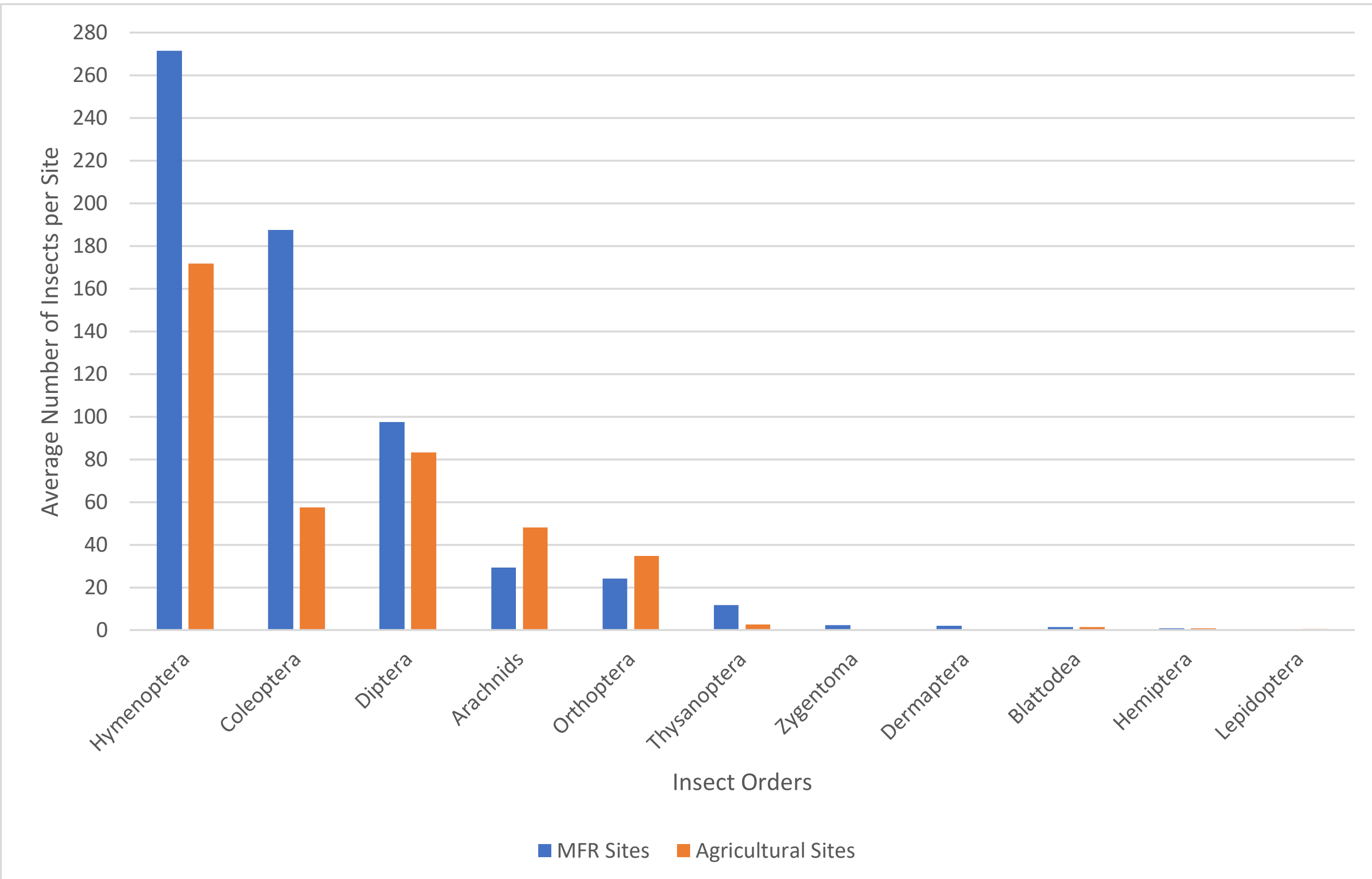


Fig. 6: Average number of insects found in each site categorized by order.

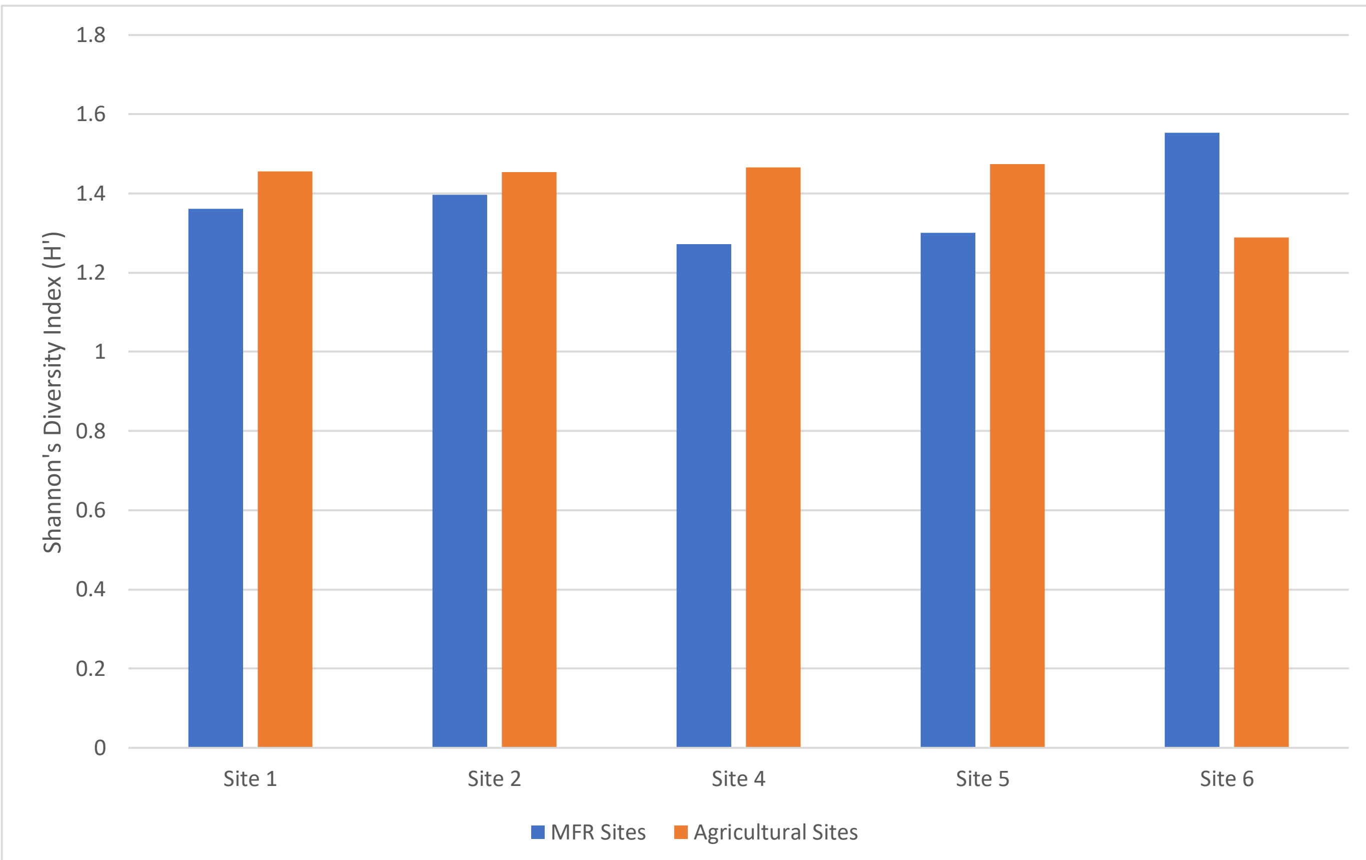


Fig. 7: Shannon's Diversity Index (*H'*) value for each site.

Appendix 1: Limitations and Recommendations

Limitations

- Trapping methods inherently create biased results; some insects are more likely to be caught in traps than others.
- Rainfall was a huge factor in amount and types of insects collected in each site.
- Identifying all insects without an expert present or formal entomological training was difficult; it is likely that some insects were incorrectly identified.
- Locations of all sites are approximate. I didn't have access to a GPS device or altimeter and did my best to estimate locations and altitudes.

Recommendations

- Purchase all supplies needed before ISP Prep Week so you can test methods before the project starts and adapt them if necessary.
- Use a rainfall measuring device to record exactly how much rain fell during the study period.
- It's nearly impossible to walk directly through the forest. Methods should include walking on a path as bushwhacking is time consuming and difficult.

Appendix 2: Materials

Traps

- 8 yellow plastic bowls (height 10 cm; circumference 14 cm)
- 8 plastic bowls (height 14 cm; circumference 31 cm)
- 8 square plastic covers (34 cm x 34 cm)
- 32 wooden stakes (30 cm long)
- Clear unscented detergent
- Shovel

Collection and Identification

- Large mesh strainer
- 4 plastic containers
- Tweezers
- Insect identification book (*Field Guide to Insects of South Africa*)

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