INTRODUCTION

Forest succession patterns create an interesting landscape for researching forests in flux versus more stable climax forests. The University of Michigan Biological Station is a large-scale forest succession experiment entitled the *Forest Accelerated Succession Experiment (FASET)* in Pellston, Michigan, which is located off the southern edge of Douglas Lake (Nadelhoffer lecture 2009). The forest is recovering from major logging events that occurred from 1870 to 1911. After the logging, forests were burned (Karowe 2009). Currently, the forests are dominated by aging pioneer species of Aspen (*Populus grandidentata*) and Birch trees (*Betula papyrifera*), with under-story growth of Pine (*Pinus strobus*, *Pinus resinous*), Red Oak (*Quercus rubra*), and Maple (*Acer rubrum*, *Acer sacchrum*). In the FASET project, which began in 2008, researchers girdled all the birch and aspen trees in one 33 ha stand and three two ha replicate stands, constituting approximately 40% of the of the total leaf area. This will speed succession from a birch and aspen dominated forest to a more diverse deciduous and coniferous forest. Researchers at the Biological station have several objectives with the FASET experiment. Objectives are as follows: quantify C exchange processes during and after succession of a mature aspen forest to a young mixed conifer/deciduous forest. Secondly, investigate how disturbance and succession interact and finally continue measuring mass and energy exchange over a maturing aspen forest. (Nadelhoffer lecture 2009).

This study focuses on beetle diversity in matched plots in the FASET area and in a control site - Ameriflux – an ecologically similar untreated forest. Our Study is designed to be part of an ongoing, comparative study of arthropods in the FASET and Ameriflux plots headed by Mike Grant, an analytical chemist at the Biological Station. His initial collection occurred in the fall of 2008 using similar methods focused on all collected arthropods, rather than our focus on beetles. His collections from the fall have not yet been fully sorted and compiled. He will have access to our collection for further comparisons as he moves forward with this research.

Beetles were chosen for this study as bioindicators of how the FASET plots may be responding to disturbance and changes in carbon storage. McGeogh et al. (1998) define a bioindicator as a species that is indicative of particular changes in an ecosystem, which can be categorized as ecological indicators, environmental indicators, and biodiversity indicators. Environmentally, bioindicators can be used to detect, exploit, and accumulate potential harmful substances and disturbances before the entire ecosystem is affected (Spellerberg 1991). Ecologically, bioindicators act as a "surrogate" species, representing an entire ecosystem (Meffe and Carroll 1994). By determining the species richness of an indicator functional group, bioindicators can serve to model the total diversity of the ecosystem (Noss 1990). Bioindicator species offer a time and money efficient method of answering ecological questions, although with a caveat. McGeogh et al. caution against making inappropriate inferences based on indicator species, and stresses the need for extensive hypothesis testing (1998).

Because insects are distributed worldwide and play a large role in all ecosystems, they serve as good bioindicators (Resfeth 1980). Beetles (Coleoptera) are the most abundant insect order. Beetles are often used as bioindicators to study forest ecosystems after significant natural and non-natural disturbances. One such study employed beetles to measure species diversity in a spruce forest recovering from a high intensity forest fire.

Researchers found a significant correlation between beetles and the age of the forest. They also found higher species richness in early succession plots than in late successional plots (Paquin 2008). Similar studies showed that beetle species richness was higher in early succession forests following periods of non-natural disturbances (e.g. clear cutting, plantations) (Niemela et al. 1998, Butterfield 1997, Heliola et al. 2001). Using these experiments as models, with the cautions of scientists like McGeogh et al., this study focused on the influence of forest succession on beetle community composition at the University of Michigan Biological Station.

In this study we aim to collect data on beetle diversity at three height levels in two forests at different stages in succession (FASET versus Ameriflux). We will study correlations between the variations in beetle diversity as related to the relative overall health and stage of the forest. We will also look at the various levels for observable patterns between abundance of specific species and the height of the traps.

Our hypotheses are: 1) There will be a difference in beetle diversity and density between the FASET and Ameriflux plots. 2) There will be a greater difference between the two plots at the canopy level than at the two lower levels. 3) Density and diversity of beetles will differ at each level.

METHODS AND MATERIALS

Study Area

The University of Michigan Biological Station is located in Pellston, Michigan, on roughly 14 square miles of forest including lakefront footage on Douglas Lake (Figure 1).

The FASET and Ameriflux plots are located west of the station (Figure 2.), in forests recovering from logging and burning events dating back to the early 1900s.

The sites are equipped with eddy covariance towers which are constantly studied for changes in carbon cycling (Curtis). The sites have similar soil composition, and before the FASET experiment, similar vegetation. For this experiment, we followed previous transects laid within a 60 meter radius that surrounds the two meteorological towers in each plot (Figure 3).

Sampling

In the fall of 2008, UMBS researchers conducted previous research on insect diversity in Ameriflux and FASET. Though these data are still under analysis, we used the same transects and distances in this study (Table 1). At each site, we set traps at the ground, one meter, and canopy levels. Ground level traps were pitfall traps that consisted of a plastic container fitted into forest floor with gates (approximately 40cm x 10 cm) placed at 90° angles around container to funnel in nearby insects. We placed small plastic squares above these traps to prevent rainfall and debris from getting into traps (Figure 4). Our flight-interception traps consisted of Plexiglas rectangles (approximately 25cm x 50 cm) which we fused at 90° angles attached by wires to coffee cans. These Plexiglas sheets served to intercept flying insects dropping them into the coffee can filled with antifreeze. Traps at one meter above the soil surface were hung from PVC pipe posts (Figure 5). At the canopy level, we attached a weight to fishing line and flung the weight over high and open limbs to hoist traps up. We determined the height of the canopy traps by measuring the fishing line used to hoist the trap. The average height of all the canopy traps was 12.1

meters. In each trap at every level, we added approximately 150 mL of antifreeze (glycerol) to kill and preserve specimens. We set the traps for five days (May 23rd – May 28th), and we collected 29 traps, as one fell during collection. We transferred the contents to the lab, where beetles (Coleoptera) were separated from other invertebrates and sorted by species. Each species was identified to family.

Data Analysis

We analyzed species diversity across the two plots and at various levels, which was calculated using the Shannon-Wiener Index and Simpson's Index. The Shannon- Wiener index measures both diversity and evenness. The equation is $H' = -\sum_{i=1}^{S} p_i \ln p_i$ where p_i is the proportion of individuals of species *i* of the total population. A higher Shannon-Wiener value indicates more diversity within a system. We also calculated Simpson's Index of diversity. This index incorporates both species diversity and abundance. It denotes the probability that two individuals chosen at random will belong to the same species. It can be calculated by the equation $D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$ where n_i is the number of individuals of species *i* and *N* is the total number of individuals. A lower Simpson's value indicates higher diversity. The values of Simpson's Index range between 0 and 1.

To determine the number of shared species between plots (i.e. similarity in species composition), we calculated Sorenson's quotient of similarity. The value was calculated by the equation $QS = \frac{2 \cdot C}{A + B}$ where *C* is the number of species common to both plots, *A* is the number of species found only in one plot, and *B* is the number of species found only in the other. The more similar the two plots, the higher the Sorenson value.

We statistically analyzed the data using SPSS version 15.0. We compared FASET and Ameriflux and the three forest levels (ground, 1-meter, and canopy). Variables were family types, number of individuals, and number of species. We tested each data set for normality, and then compared mean values using the appropriate parametric or non-parametric test (student's t-test, Mann-Whitney, Kruskal-Wallis).

RESULTS

There were 157 individual beetles identified, representing 28 species and 14 different families (Table 2). There were 89 individuals in the FASET plot representing 21 species and 12 families. There were 68 individuals represented 14 species and 14 families in Ameriflux (Figures 6 and 7). The average temperature over the five day period was 10.92 °C and the average relative humidity was 69.48% (Table 3)

Diversity and Similarity

We summarized species richness calculations based on the Shannon-Wiener Index (Table 4, Figure 8). The Shannon-Wiener index value for all levels of FASET was 2.84, and for all levels of Ameriflux was 1.48. In both FASET and Ameriflux, the Shannon-Wiener index values were highest at the canopy level and lowest at the 1-meter level.

Similarly, we compiled Simpson's index values (Table 5, Figure 9). The value for all levels of FASET was 0.090 and for all levels of Ameriflux was 0.335. Simpson's index values in FASET were highest at the 1-meter level and lowest at the ground level. In Ameriflux, values were highest at the 1-meter level and lowest at the canopy level.

Similarities between FASET and Ameriflux at three forest heights (ground, 1-meter, and canopy) were determined by calculating Sorenson's index of similarity by species. Comparing Ameriflux and FASET, they were most similar at the 1-meter level and least similar at the high level (Figure 10). Comparing the three levels of the forest the 1-meter and canopy level were most similar, and the ground and 1-meter level were least similar (Figure 11).

Statistical Analysis

We statistically compared FASET and Ameriflux for several variables. Our data were not normal, so we performed a non-parametric Mann-Whitney Test to compare the mean number of individuals of the families Cucujidae, Nitidulidae, and Tenebrionidae in FASET versus Ameriflux. There was not a significant difference for any family (Table 6).

We also compared the three families at each forest level (ground, 1-meter, and canopy). The data were not normal, so we ran a non-parametric Kruskal-Wallis Test. There was no significant difference in number of individuals between levels for the family Nitidulidae and Tenebrionidae, however the mean number of individuals of the family Cucujidae was significantly different between the three levels (see Table 6).

We performed a comparison of total individuals and total number of species between FASET and Ameriflux by doing a student's t-test. We found no significant difference between the two (Table 7). We also compared the total number of individuals and total number of species between the three forest levels (ground, 1-meter, and canopy). The data were not normal, so we performed a non-parametric Kruskal-Wallis test. We found a significant difference between the three levels for both total number of individuals and number of different species (Table 7).

DISCUSSION

Most of our data are either too sparse or too variable to be statistically analyzed, though we find trends using diversity indices, highlighting clear differences in species abundance between the two plots. The Shannon-Wiener and Simpson's indices (Table 5, Figure 8) illustrate several conclusions. We observe FASET to be more diverse overall, indicative of possible mechanisms of change that need more research to predict. These indices also show that FASET and Ameriflux are both most diverse in the canopy. This finding is supported by a body of recent research on the abundance of diverse life in the canopy (Ulyshen and Hanula 2007). The greatest difference in diversity indices between FASET and Ameriflux exists in the 1-meter traps, followed by the pit-fall traps, with the canopy traps exhibiting the least difference in diversity. We can explain this finding by noting that Ameriflux is the least diverse at the 1m height and that the indices at FASET vary by only a value of .02. This comparison of diversity represents only the mathematical difference between the numerical diversity indices of each subgroup, but does not actually look at the compositional differences. Though the 1m height traps display the greatest difference in diversity, the hypothesis that most of the current changes in the FASET forest are happening in the canopy is not disproved. We can only draw the conclusion that FASET is more diverse than Ameriflux at the ground and midlevel traps and that the greater diversity at FASET is more significant at the 1-meter height than on the forest floor. Our findings show Ameriflux to be more diverse than FASET only in the canopy. Due to our small sample size and because abundance is part of the index for diversity, the dropped trap in FASET likely decreases the total abundance from the FASET canopy enough to account for the lower diversity in FASET than Ameriflux at that height. This may also affect the comparison of diversity ratios between the levels at both plots.

Our data from the Sorensen's index show that Ameriflux and FASET are most similar at the 1m height and least similar at the canopy. This is in line with our hypothesis that the FASET forest is undergoing the most change in the canopy at this stage. As the roots lose nutrients, the aspen will allocate fewer resources to leaf production, principally affecting the canopy composition. Fewer common species between the two plots at the ground level than at the 1-meter height could be explained by aspen allocating less to energy to leaf production, with a decrease in leaf litter and an increase in sunlight reaching the forest floor. More data collection is necessary to explore these hypotheses.

We analyzed the combined data from both plots to determine which heights are the most and least unique in species composition. Looking at the similarity index for each pair, we can determine that ground-level-trap species are most distinct from the species diversity found at the other two heights. Based on the findings of Ulyshen and Hanula that the ground traps held the most distinct community, we are not surprised by these results

(2007). Species composition varies widely from the forest floor to the heights above the ground. Decomposing vegetation, dead wood, fungi, and carrion create a locally unique environment on the forest floor that plays host to different species composition of Coleoptera (Ulyshen and Hanula 2007). With further research it would be interesting to see if the level with the greatest difference in diversity changes in subsequent years of forest succession.

We chose to identify beetles only to family, since we were not working with an entomologist. Of the 14 families collected, Staphylinidae is the most abundant family overall. Our collection contains seven unique species belonging to this family between the two plots, with most belonging to one species (sp. 3) (Figure 6). Staphylinidae are also known by their common name, Rove beetles. There are over 300 known species within the family, many of which are widely distributed and commonly found. Rove beetles are generally ground dwellers, found under bark, on fungi, or in decaying matter and feed primarily on decaying organic matter (Borror and White 1970). We find no significant differences between the Rove beetle abundance in FASET and Ameriflux; however, their overall abundance made them of interest none-the-less. Our data suggest that Rove beetles are more frequent in the lower two levels than in the canopy, but statistical analysis does not support this observation due to the small sample size. Tenebrionidae, commonly referred to as the Darkling beetle, also occur in high abundance in our traps. The Darkling beetles feed primarily on decaying organic matter such as bark, fungus, and other vegetation. They are commonly found under logs, in fungi, under bark, and in rotten wood—more widely distributed in the western United States, though there are still 150 species that occur in the east (Borror and White 1970). The higher representation of Rove beetles in FASET may correspond with higher levels of decay in the girdled forest than in the control. In contrast, representations of the family Cucujidae, also a feeder on decaying material, are higher in Ameriflux than in FASET; likely there are more variables leading to this difference than this study can distinguish. Cucujidae is the only family with a statistically significant difference in the number of individuals found at different heights at both of the sites. The family Scarabaidae (Scarab beetle) is only represented in the FASET plot, and thus also of interest. Scarab beetles feed on live plants, flowers, and tree foliage (Borror and White 1970). We found Scarab beetles at all three levels in the FASET plot. It is unclear from our survey what this tells us about forest succession analysis.

Our data show trends in specific family abundance at different levels, supported by similar findings from Ulyshen and Hanula (2007). Our findings, pooling the Ameriflux and FASET collections together, show a high percentage of representatives from *Staphylinidae, Cucujidae, and Tenebrionidae* in primarily one or two levels. This further supports the evidence from Ulyshen and Hanula (2007) that many beetle species are adapted for the local environment of one level of the canopy and that species composition differs between levels in the same forest. These results support our hypothesis that beetle diversity and composition vary at different heights in the forest.

Several similar studies have been conducted in the past comparing species richness, abundance, and diversity of beetles and other invertebrates at different levels of forest. Ulyshen and Hanula (2007) looked at beetle diversity at two heights above ground (0.5m and ≥15m) in deciduous forests in the Southeastern United States. Using the Shannon diversity index their findings show that diversity and evenness were higher at the ground level than in the canopy, however show no significant difference in total abundance between the two levels. Of all beetle species collected, they found 19% exclusively at the ground level and 31% only in the canopy (2007). Another study from the University of Montreal looks at the Carabid diversity in black spruce stands in subsequent years following fire disturbance. The data show clustering of beetle species at different stages of post-fire-succession, concluding that Carabidae diversity varies according to age of forest (Paquin 2008). Our study looks at many of these same questions and poses a unique lens for looking at beetle diversity as a function of forest succession.

The FASET experiment creates an opportunity to look at many aspects of forest health and growth. UMBS research surveys show that the Ameriflux plot, from where we took our control data, is comparable in soil composition, groundcover, tree cover, and location to the FASET experiment forest (Curtis ND). Both plots fall in the same category of soil type classified as excessively drained rubicon sand (US Department of Agriculture 1991). Pioneer species aspen and birch dominate the canopy, while red maples, sugar maples, red pines, white pines, beech, and red oaks are present to a lesser degree(C. Vogel pers.comm.). The girdling of the aspen and birch in spring 2008 (Curtis) places this experiment in the early stages of change. Most of the aspen are still standing, though their roots are beginning to rot as nutrients are withheld. Already, there are observed but unmeasured changes in the forest. An expected decrease in leaf coverage in the canopy may have several possible outcomes including increased sunlight to the forest floor, decrease in falling foliage, and changes in associated faunal communities.

This study is both part of a long-term body of studies at the FASET plot and part of an insect survey between FASET and Ameriflux begun by UMBS researchers in the fall of 2008 (Mike Grant pers.comm.). UMBS measurements recorded significant precipitation and a low average temperature during our five-day collection period (Table 4)(Vogel pers.comm.); this may have an effect on overall abundance and diversity in comparison to the survey from the fall. Beetle identification stands as an important possible source of error in our analysis since our identification relies primarily on field guides (Borror and White 1970, White 1983). Our sorting process of the collected beetles is limited by our basal understanding of beetle taxonomy. Researchers at the UMBS will work with a resident entomologist to further analyze and identify all specimens before moving forward with the umbrella study. The short time span and amount of data collected in this study stunt some possible conclusions. The Ulyshen and Hanula (2007) study, a previous study very similar to our own, collected 15,012 individual beetles from 41 families at 24 trap sites. They collected data every two weeks during two three-month periods. Our total collection of 157 individuals from 14 families at 29 trap falls short in statistical power comparatively. With further research and more data there may be more significance in this study, especially statistically, in the findings.

Coleoptera communities are frequently studied to gauge a number of biological factors due to their wide abundance in terrestrial habitats. Both significant documented understanding of beetle taxonomy, along with their ability to move around in response to changes in habitat, aid comparisons of beetle diversity across habitats (Refeth 1980). Species composition and abundance is another factor that correlates with habitat changes and forest succession. As the FASET experiment continues, this study provides a primary level of analysis. Future research could include continued sampling of insect diversity, and the change in Coleoptera communities over time. Isotopic analysis of insect communities could reveal feeding preferences, and how the loss of early succession plants may change communities.

Our study looks at two discreet stages of succession in a northern Michigan temperate forest to find trends and correlations with beetle diversity. We can draw some conclusions from this comparison: 1) beetle diversity and abundance vary to some degree at different forest heights; 2) beetle diversity is a function of forest succession stages; and 3) beetle diversity varies more at certain heights in the forest than others as forests change over time. Changes in Coleoptera communities are just one aspect that researchers will continue to observe as the structure, composition, and dynamics of the forests fluctuate.

TABLES AND FIGURES

FASET and Ameriflux Data Collection Sites

Table 1. The angle of transects and distance from meteorological towers for FASET and Ameriflux, based on UMBS research in fall, 2008.

FASET	Angle (°from North)	Distance (m)
1	250	20
2	260	40
3	300	60
4	200	60
5	240	60
Ameriflux		
1	115	40
2	105	60
3	95	40
4	135	60
5	155	40

Beetle Individuals by Species and Family

Table 2. Total number of beetle individuals by species and family in FASET and Ameriflux.

species	family	common name	FASET	Ameriflux	Total
1	Scarabaeidae	Scarab beetle	6	0	6
2	Staphylinidae	Rove beetle	2	0	2
3	Staphylinidae	Rove beetle	22	50	72
4	Lampyridae	Lightning bug	2	3	5
5	Cucujidae	Flat bark beetle	3	10	13
6	Staphylinidae	Rove beetle	0	2	2
7	Nitidulidae	Sap beetle	1	0	1
8	Staphylinidae	Rove beetle	1	0	1
9	Elateridae	Click beetle	1	0	1
10	Tenebrionidae	Darkling beetle	5	6	11
11	Staphylinidae	Rove beetle	9	5	14
12	Tenebrionidae	Darkling beetle	3	0	3
13	Coccinellidae	Ladybird beetle	1	1	2
14	Staphylinidae	Rove beetle	1	0	1
15	Cisidae	Tree fungus beetle	1	0	1
16	Tenebrionidae	Darkling beetle	2	0	2
17	Nitidulidae	Sap beetle	0	1	1
18	Nitidulidae	Sap beetle	0	1	1
19	Tenebrionidae	Darkling beetle	3	2	5
20	Staphylinidae	Rove beetle	0	2	2
21	Chrysomelidae	Leaf beetle	0	1	1
22	Chrysomelidae	Leaf beetle	0	1	1
23	Schydmaenidae	Ant-like beetle	0	3	3
24	Curculionidae	Snout beetle	1	0	1
25	Nitidulidae	Sap beetle	1	0	1
26	Eucnemidae	False Click beetle	2	0	2
27	Lathridiidae	Scavenger beetle	1	0	1
28	Nitidulidae	Sap beetle	0	1	1
TOTAL			68	89	157

Weather Data

Table 3. Weather data for experiment dates. Temperature in °C and % relative humidity.

Date	Temp. (C)	Relative % Humidity
23-May	13.96	52.03
24-May	12.08	55.09
25-May	11.71	40.3
26-May	8.59	69.34
27-May	9.26	100.06
28-May	9.91	100.06
Average	10.9183333	69.48

Shannon-Wiener Index Values

Table 4. Shannon-Wiener values for FASET and Ameriflux for ground level, 1-meter level, canopy level, and total.

	FASET	Ameriflux
Ground	1.766	1.119
1-meter	1.754	1.061
Canopy	1.773	1.197
Total	2.844	1.475

Simpson's Index Values

Table 5. Simpson's index values for FASET and Ameriflux ground level, 1-meter level, canopy level and total.

	FASET	Ameriflux
Ground	0.219	0.372
1-Meter	0.298	0.542
Canopy	0.26	0.265
Total	0.09	0.335

Statistical Outputs: Comparison of Ameriflux and FASET by family

Table6. P-values for three analyzed families compared between FASET and Ameriflux.

Species	Comparison of FASET and Ameriflux P-value	Comparison of Forest Levels P-value
Cucujidae	0.127	0.001
Nitidulidae	0.689	0.162
Tenebrionidae	0.435	0.053

Statistical Outputs: Comparison of Levels by Family

Table 7. P-values for three analyzed families compared between the three forest levels: ground, 1-meter, and canopy.

	FASET v. Ameriflux P-value	Comparison of Forest Levels P-value
Total # Inidviduals	0.367	0.006
# different species	0.035	0.002

Map of UMBS

Figure 1. The location of the University of Michigan Biological Station in northern lower Michigan (Curtis).

Map of UMBS Property with Study Site

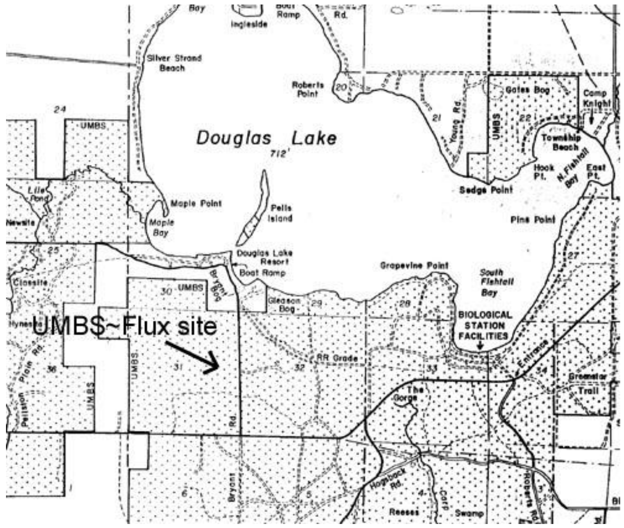

Figure 2. The sites of the FASET and Ameriflux sites, located west of camp (Curtis).

FASET and Ameriflux Plot Maps

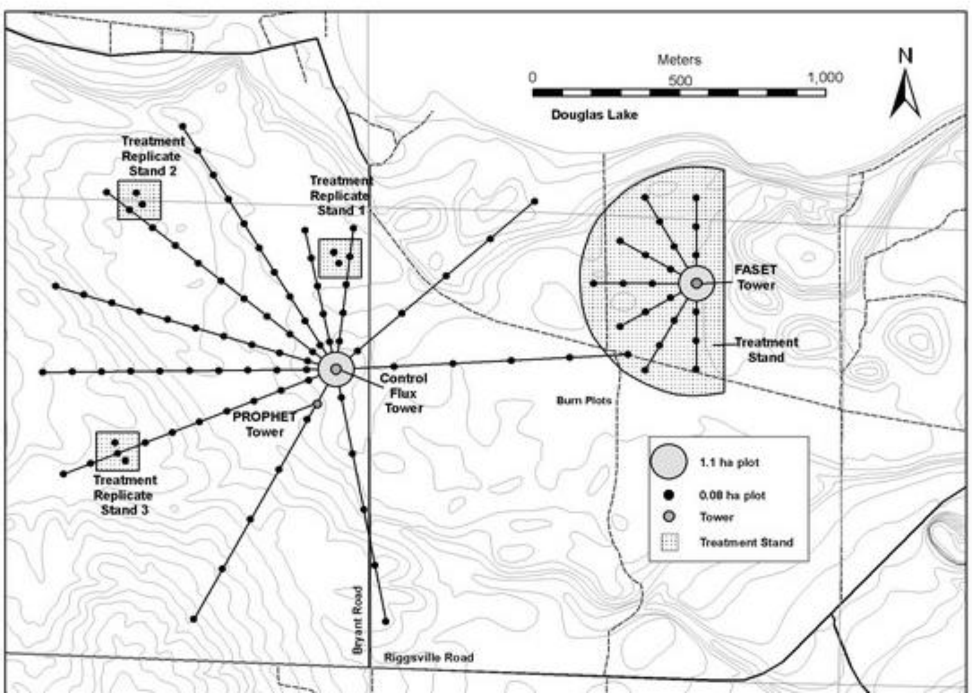

Figure 3. The FASET (right side) and Ameriflux (left side) plots, with 60 meter radius plots marked in grey (Curtis).

Pitfall Trap

Figure 4. Pitfall trap made of plastic gates and buried container with glycerol.

1-Meter Flying Insect Trap

Figure 5. 1-meter flying insect trap with Plexiglas sheets and coffee can with glycerol.

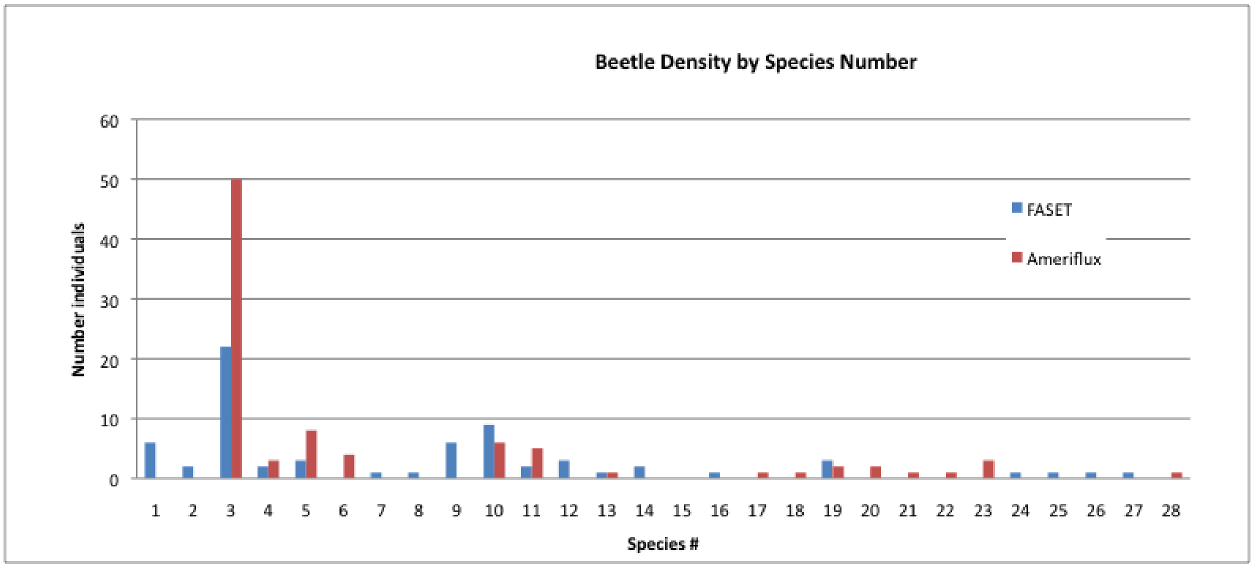

Figure 6. Beetle density by species number, split by FASET and Ameriflux.

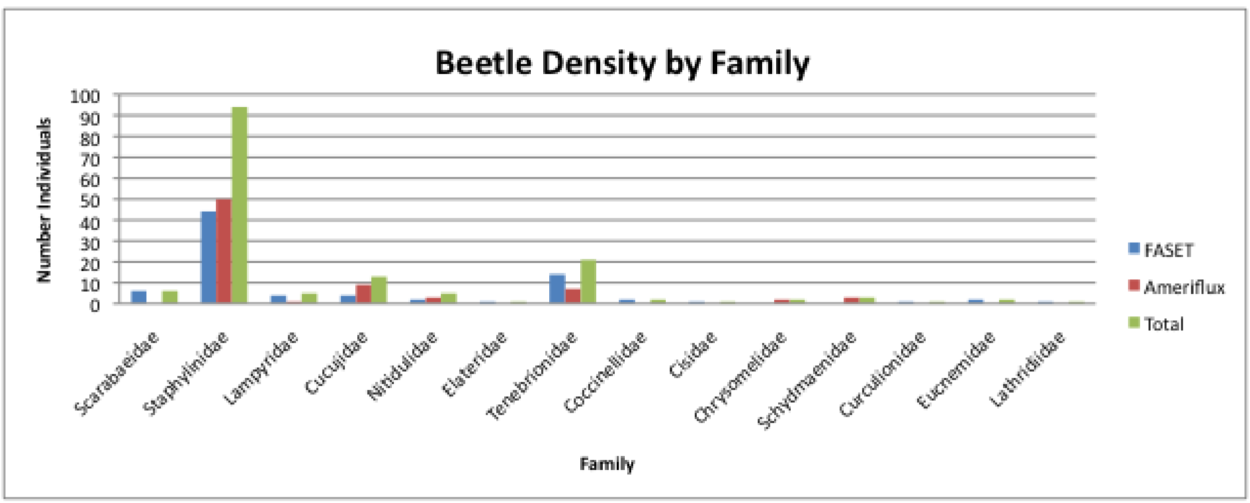

Figure 7. Beetle density by family, separated by FASET and Ameriflux.

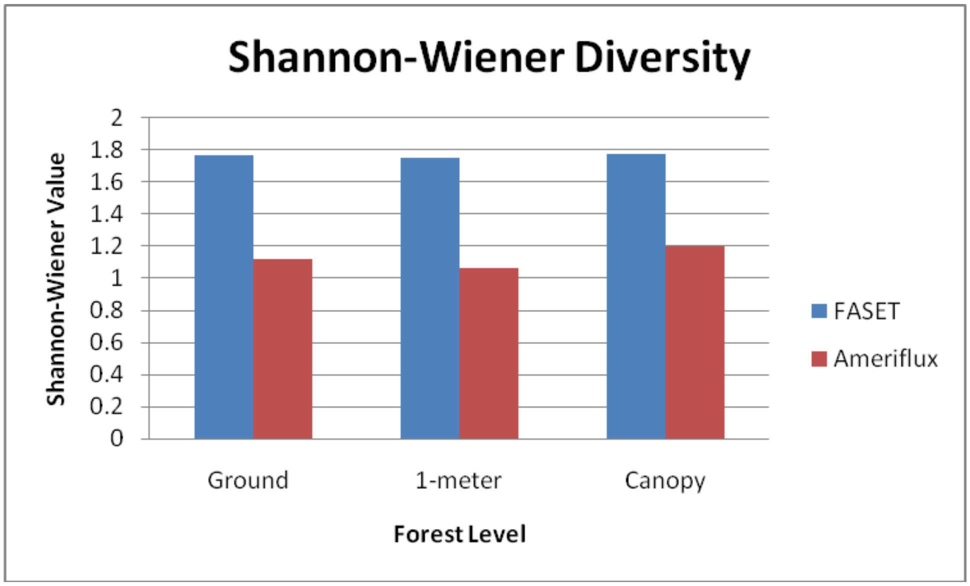

Figure 8. Shannon-Wiener index values comparing FASET and Ameriflux at the three forest levels. FASET is more diverse at all three (higher value).

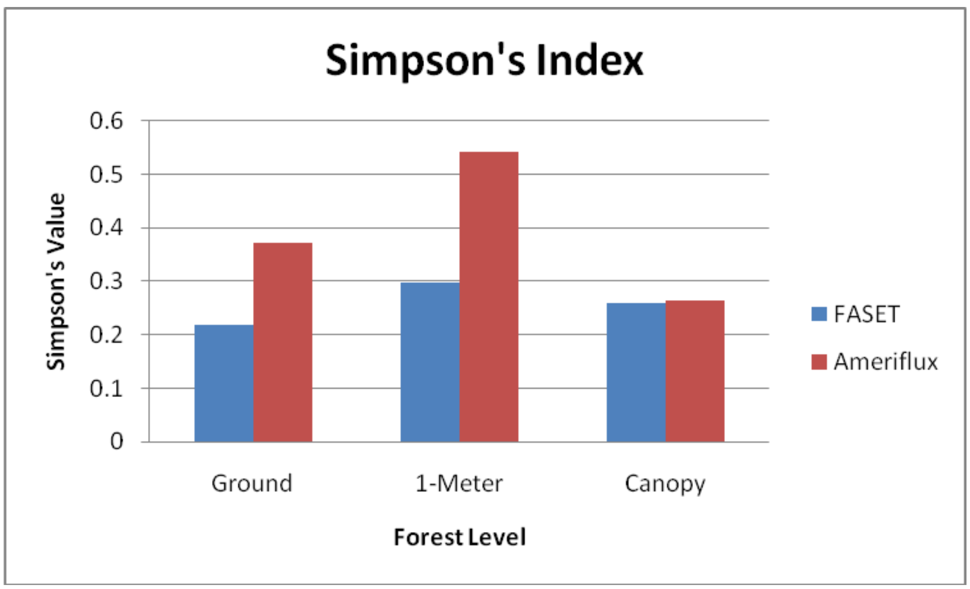

Figure 9. Simpson's Index values comparing FASET and Ameriflux at the three forest levels. FASET is more diverse at all three levels (lower value).

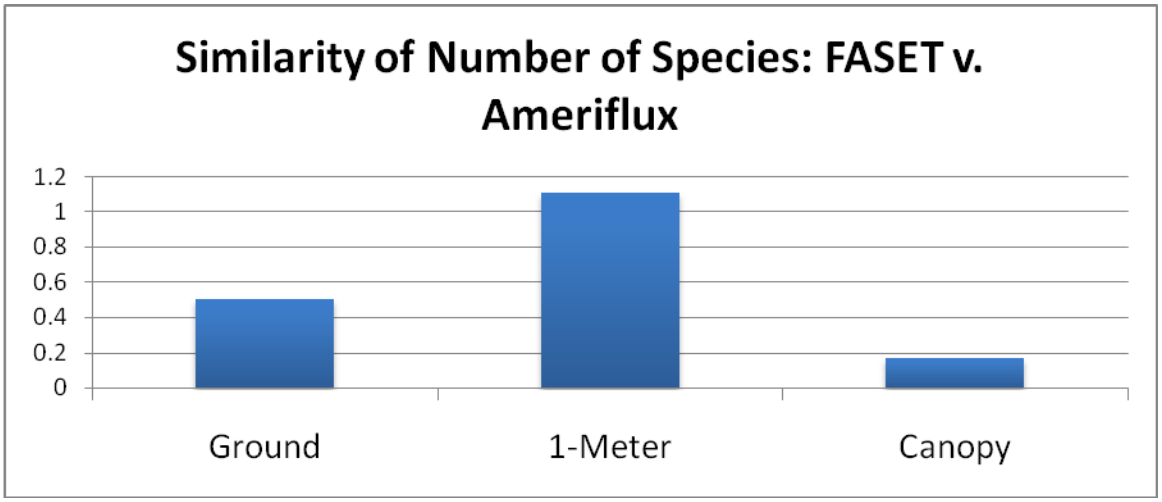

Figure 10. Comparison of the similarity of number of species in FASET and Ameriflux at the ground, 1-meter, and canopy levels.

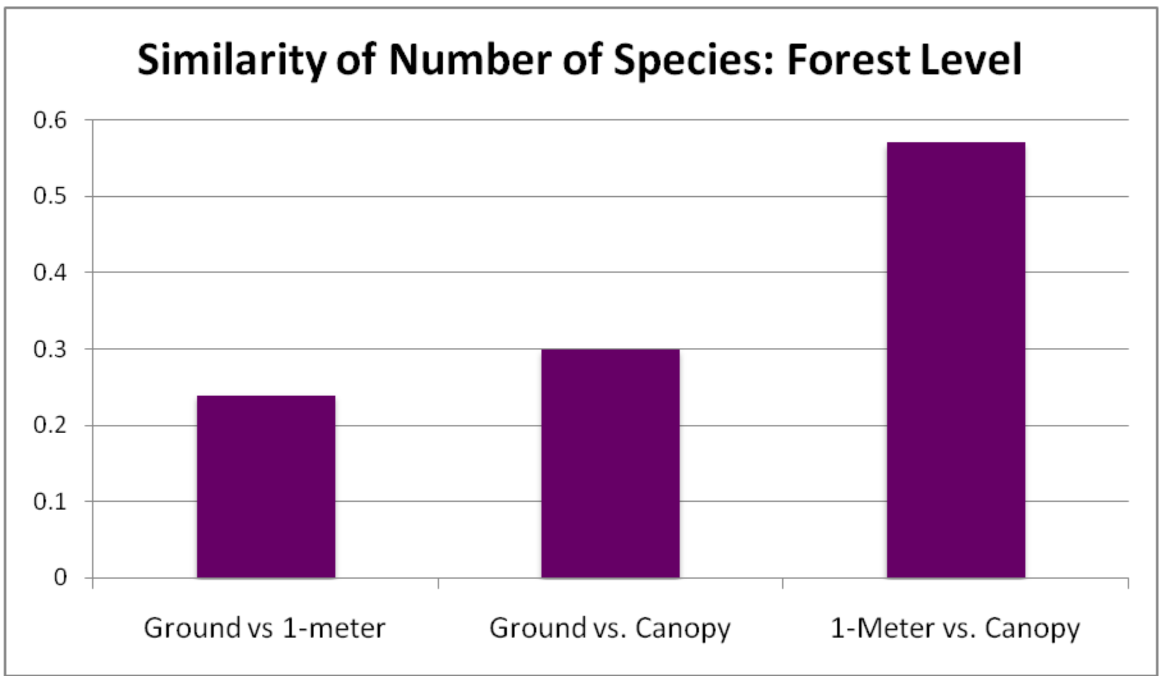

Figure 11. Comparison of the similarity of number of species at the 1-meter, ground, and canopy levels.

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