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Beetle Diversity in Temperate Deciduous Forests with Different Management History in Central Illinois

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Introduction

Biodiversity is one of the most important concepts in conservation biology. It represents the variety of life on Earth and can be described for three major levels: genetic, species, and ecosystem. Among the three levels, species diversity is most common for several reasons. Compared to the other levels, species diversity is more practical and accessible, with data being easily collected and measured. Collecting individual and identifying them is obvious straightforward than genetic or environmental data. Therefore, species diversity is considered the currency of biodiversity (Sigwart et al 2022).

Global biodiversity has been declining since the industrial revolution. For example, the average of abundance from 20,811 population of vertebrate animals have declined 68%. Factors contributing to the loss of biodiversity include climate change, pollution, invasive species and disease, species overexploitation, and anthropogenic habitat modification (WWF, 2016). Habitat loss and conversion around the globe are the most recognized extinction threat and might cause high portion of extinction happening in tropical areas (Thomas et al., 2004). In addition, insects in both tropical and temperate areas have similar susceptibility to climate warming (Johansson et al., 2020).

In order decrease this trend of species diversity loss, it is important to understand the factors that may affect biodiversity in various habitats, including temperate deciduous forests. The Midwestern United States is one of most anthropogenically modified landscapes with over 127 million acres of the landscape converted to agricultural land (Hatfield, 2012). This large-scale habit modification should have had profound impact on biological diversity across levels.

To offset these losses, nature conservation efforts in the United States began in natural in the 19th century with the establishment of a series of national parks and have since grown to include efforts of various scale throughout the country and the years (Reiger, 2001). Similar actions occur in other nations, although at different rates. These uneven conservation efforts have established various area and habitat at different scale gradually, offering a unique opportunity to investigate topics related to preservation of biological diversity, including 1) in what scope and what way biotic diversity of natural habitat can be affected by disturbances, and 2) how long does it take for species diversity of highly disturbed habitat to recover.

It is impossible to count all species on Earth or within a specific habitat. Therefore, it is necessary to use a certain taxon to indicate biodiversity, or as bioindicators, as a common practice in in biological survey projects (Rainio & Niemelä, 2003) research as well as in agriculture (Pizzolotto et al., 2018). Some taxa are more likely to be used as bioindicators because they contain tremendous numbers of species, such as the Coleoptera, which consists of over 30 million known species and represents approximately 30% of all biodiversity on the earth (Arnett, 1968). In his well-known study on possible global biological diversity, Erwin (1988) used beetle species in tropical rain forest tree canopies in Panama as bioindicators to surrogate for total local species diversity to extrapolate global species diversity.

Saproxylic beetles are a special feeding guild in forest ecosystems, using decaying wood directly. Several studies case show that saproxylic beetle diversity is significantly affected by forest management, and that forest management is reflected in the volume of decaying wood, living trees, dead trees, and stumps. The abundance and richness of coleoptera are related to decaying stages of wood (Muñoz-López et al., 2016). Saproxylic beetle richness in particular has been shown to be positively correlated with tree diameter, but not with tree abundance (Della

Rocca et al., 2014). Other than saproxylic beetles, other beetles depend on wood indirectly, such as mycetophagous and phytophagous beetles. Therefore, forest management not only affects saproxylic beetles but also has influences on other organisms at the same time.

Most studies of saproxylic beetles have been conducted in Europe (Della Rocca et al., 2014; Olsson et al., 2012; Parisi et al., 2019, 2020; Weiss et al., 2019) whereas few studies have been done in North America (Jackson et al., 2012; Ulyshen & Hanula, 2008), especially with regard to temperate deciduous forests in the Midwest. In this project, I investigated the association between beetle diversity and forest management history. Forests that have been preserved for an extended time should accumulate wood with varying degrees of decay as well as standing trees of varying vigor, which in turn should support a diverse array of beetle species that specialize on these diverse types of wood. In disturbed forests, on the other hand, removal of fallen trees or harvesting of larger individuals would not have such a diverse substructure and thus should support a much less species diversity of beetle. Thus, I hypothesized that forests with a longer history of preservation will have higher evenness and richness than forests with disturbance in their recent history.

Methods and Materials

Study Area

This study investigated beetle diversity and forest volume in two forests, Fox Ridge State Park and Warbler Ridge Conservation Area. Both study sites are connected and located in Charleston, IL, along Embarras River (*Figure 1*). Fox Ridge State Park has a relatively longer history of protection and bigger area, 835-ha, since the park was founded in the1920s, and it is famous for its thickly wooded ridges and lush valleys. It also provides multi-activities, such as camping, hiking, hunting and cannoning. On the other hand, Warbler Ridge Conservation Area has been protected and managed by Grand Prairie Friends since 2011, and it was a 428-ha private property, consisting of wetlands, woodlands, and prairies. In each study site, we choose 2-4 regions to set up 5-10 traps. Those regions should be easy to access, and each trap is at least 15m away from each other.

Beetle Sampling

Multiple methods can be used for collecting beetles, depending on use and purpose. An extraction cylinder is used in some of studies because saproxylic beetles depend on decaying wood (Gimmel & Ferro, 2018). Extraction cylinder is a well-known trapping method for sampling saproxylic beetles because it directly captures saproxylic beetles exiting decaying wood. However, decaying wood is often not evenly distributed in forests due to management activities and natural disasters (Heilmann-Clausen & Boddy, 2008). Consequently, the sampling method would create potential bias for estimating the diversity of saproxylic beetles and volume of decaying wood in the study area. In addition, the method would also ignore species living in dead parts of standing trees, living or dead. In fact, study comparing the extraction cylinder method with other frequently used sampling methods, window trap and trunk-window trap, and conclude that an extraction cylinder was the least effective method in terms of both the richness and abundance of species collected (Økland, 1996). In the present project, window traps and pitfall traps were employed; window trap is a flight interception trap that captures flying beetles, while pitfall traps target crawling insects.

Twenty sampling points were chosen in each study site, and every point was installed with a window and a pitfall trap and stayed away with each other at least 15m. The total number of traps was 80, including 40 window traps and 40 pitfall traps. Window traps were hung on a tree around 1.5m. It has a plastic transparent sheet to intercept flying beetles *(Figure 2)*. Once beetles get stopping, they drop into a funnel and the funnel lead them into a jar attaching with the funnel. The jars are filled with 70% ethanol to preserve beetles until the next collecting period. Pitfall traps are a cup filled with 70% ethanol buried in the ground, level with the soil surface (*Figure 3*). The collection interval was 2 weeks for both trap types and all beetles captured were stored in 70% ethanol immediately after retrieval.

Beetles were identified to family as were done by existing studies on saproxylic beetle diversity(Dillon & Dillon, 1972; Arnett et al., 2002; Arnett & Thomas, 2000). No attempt was made to identify the collection to species level as it would be impractical, if not impossible, for Coleoptera, the largest animal order on Earth, with more than 400,000 known species (Hammond, 1992). identification to family level is considered to be acceptable as well as are more practical for monitoring purposes (Ohsawa, 2010).

Forest Survey

The forest structure was described by the basal area and coarse wood debris (CWD) volume from each plot. The plots were a 13m radius circular area with a window and pitfall trap at the center (Lombardi et al., 2015). The basal area was calculated by diameter at breast height (DBH), and the CWD volume was calculated via cone trunk formula (Lombardi et al., 2012).

Data Analysis

Two-way ANOVA was used to test the differences of total abundance between study sites and trapping methods. Abundance was represented by individual of beetles caught per day in each plot with two trapping methods. Additionally, beetle’s diversity was represented and compared by the Shannon and the Simpson index from each plot. A simultaneous confidence interval for the Shannon and the Simpson index was tested between two locations and two trapping methods with a 95% confidence level. Cumulative family number curves were generated by rarefaction (package *Rarefy*). The cumulative family curves are based on individual number. Nonmetric multidimensional scaling (NMDS, package *vegan*) was used to visualize family composition in the two study sites and trapping methods. Moreover, the environmental vectors, basal area and CWD volume, were fit with family composition data by Envfit (*vegan*). It is to determine the influence of these factors on beetle's composition.

Results

A total of 2,253 individual beetles were sampled from 80 traps in the two study sites over the period from August 3rd – November 3rd, 2021 (92 days in total). The collection consists of 25 families of Coleoptera (*Table 1*). Some families are better represented than others, and the most abundant families were Bostrichidae (1,565 individuals), Scarabaeinae (132 individuals), and Silphidae (292 individuals). Those three families represented 88% of the individual sampled (*Figure 4*).

In order to account for some trap failures due to natural disasters or getting tipped over by forest animals, the average individuals caught per day was calculated to compare the two study sites and two trapping methods by a two-way ANOVA. There was no interaction between study sites and trapping methods ($F_{(1,76)} = 0.02$, $p = 0.881$), so trapping methods and study sites did not have the same effect on beetle abundance. And, significant differences were found between study sites and trapping methods for average number of individuals caught per day (p=0.03;

p=0.006, respectively; *Table 2*). More beetles were collected in Warbler Ridge than in Fox Ridge, and more beetles were collected using window traps than using pitfall traps (*Figure 5*).

Overall, Shannon-Wiener index showed significant differences between the study sites and between trapping methods, and Simpson index showed significant difference between the two sites only for beetles collected using window traps (*Table 3*). Fox Ridge State Park generally had higher diversity indices, except for Simpson index from pitfall trap data (*Figure 6*). Fox Ridge State Park's diversity indices, including both trapping methods were higher than Warbler Ridge overall, for both the Shannon and the Simpson index, but did not differ significantly (p = 0.201; p = 0.072). On the other hand, the windows traps had significant differences in both the Shannon and the Simpson index between sites, with higher diversity in Fox Ridge than in Warbler Ridge. Moreover, the pitfall trap data showed significant difference with the Shannon index but did not have statistically difference with the Simpson index. Pitfalls traps in Fox Ridge had higher Shannon index and lower Simpson index than Warbler Ridge. Last, rarefaction curves visualizing cumulative family richness based on number of individuals showed that Fox Ridge State Park had a steeper curve than Warbler Ridge (*Figure 7*)**.**

Species composition significantly varied among trapping methods (Permanova, $p <$ 0.001, $F_{1,70}$, stress = 0.08) (*Table 4*). The NMDS plot showed species composition patterns based on different trapping methods, with window trap loaded close to y-axis and pitfall trap loaded further to y-axis (*Figure 8*). It did show a strong pattern that different trapping methods on beetle's composition. Window traps tend to catch more beetles from families of Bostrichidae, and Curculionidae, and so on, while pitfall traps caught most of beetles from families of Nitidulidae, Scarabaeinae, and Silphidae (*Table 1*). In addition, several families, Chrysomelidae, Cryptophagidae, Curculionidae, Latridiidae, and Nitidulidae were obviously much better represented in Fox Ridge than in Warbler Ridge (*Table 1*).

The test of fits over environmental vectors did not find significant correlations on basal area or CWD between the two sites (*Table 4)*.

Discussion

We had varying degrees of success with different beetle families between the two trapping methods. This would allow the selection of the best method of beetle sampling depending on the goals of a project. Increased sampling intensity, both in terms of number of collected specimens and increased sampling area often results in more species, especially those that are relatively common. The cumulative family curves increase steeply first then leveled off while they cover most of the families in the area. In other words, choosing an efficient sampling method may save time, because it has higher possibility to sample more taxa. In this project, sampling with window traps were much more efficient than with pitfall traps (*Table 2; Figure 5*). In addition to be more efficient, window traps are also easier to set up and do not get tipped over by wildlife as often as compared to pitfall traps. However, the NMDS result showed that different trapping methods tended to be more successful for collecting different families of beetles. Therefore, the use of multiple trapping methods may be more desirable may provide a more accurate pictures of beetle diversity in the study area.

Fox Ridge State Park had higher diversity overall, excepting pitfall traps in the Shannon index which were lower than Warbler Ridge Conservation Area. And, for pitfall traps the Simpson index was not statistically significant. The Shannon index is an informatic theory statistic index. Both richness and evenness are affecting the index. Since the window traps caught more beetles in Warbler Ridge Conservation Area, its Shannon index should be higher. Some of families had high uneven number in pitfall traps, so the Shannon index gave them more weight, such as Scarabaeinae and Silphidae. In contrast, the Simpson index is a dominance index. Instead of evenness having much influence on the index, the common or dominant species increase the index significantly.

Diversity indices may compare species diversity in study sites, but it largely ignores the rare species or families at n the same time. During this project, some uncommon families were found that only had 1 individual each. Thus, cumulative family can provide us an objective visual curve to compare with multiple sites in the same time, based on sample number. This measure captures both location level diversity (alpha) and species turnover across locations (beta) to provide an estimate of forest wide diversity (gamma). Fox Ridge State Park had lower catch rate than Warbler Ridge Conservation Area, but it had a steeper family cumulative curve (*Figure 5*). The Fox Ridge cumulative family curve raises steeper than the Warbler Ridge curve. 23 families were found in Fox Ridge State Park, and 21 families were found in Warbler Ridge Conservation Area. In Fox Ridge State Park, we only collected 834 individuals and reached 23 families. On the other hand, only 21 families presented in 1,419 individuals from Warbler Ridge Conservation Area. Fox Ridge had relative high performance in beetle diversity, although Warbler Conservation Area caught more beetles average. The reason that Fox Ridge had lower catching rate was not clear at this moment yet. It might relate to the sampling locations in each study sites.

There are at least 131 beetle families in North America (Arnett et al., 2002; Arnett & Thomas, 2000).. As one of the most diverse taxa, beetle species number is varied in families. Number of species in a family can range from a few species to thousands in North America. For example, there are only 2 species in Passalidae in United States (Schuster, 1983, 1994); there are over 2,000 species in Carabidae (Arnett, 1968). And, we are still finding new species each year. Hence, if a place has more families than others, it has potentially higher species diversity.

The Non-metric Multi-dimensional Scaling (NMDS) plot not only showed distinct beetle family composition resulted from the two trapping methods, but also between the two study sites (*Figure 8)*. Nonetheless, we were not able to identify the environmental factors that might contribute to the differences in beetle family diversity between the two study sites. This might be due to the fact that the Fox Ridge State Park is much bigger, has more preserved region than Warbler Ridge Conservation Area, and have been preserved for a much longer time.

Conclusion

The results of this project are consistent with the previous studies about higher saproxylic beetle diversity associating with superior forest management, but this research includes all families in Coleoptera. Although the exact factors involved in beetle family diversity were not identified in the present study, the data from the study did show that the forest with bigger area and longer historical preservation tended to have higher beetle diversity and performance. Continued monitoring of beetle diversity and comparing parameters of forests may give us more understandings to explain the mechanisms between beetle diversity and forest structure. Therefore, it would be of great interest if the project could be developed as a long-term project for monitoring the changes of biodiversity of certain interest taxonomic groups, such beetles, and various environmental factors, such as forest volume and CWD. Information on species distribution can also be used to monitor climate change and invasive species, such as emerald ash borer (*Agrilus planipennis*)that has been found in Illinois since 2006 and caused significant damages in trees (Hawthorne & Kimberly, 2006).

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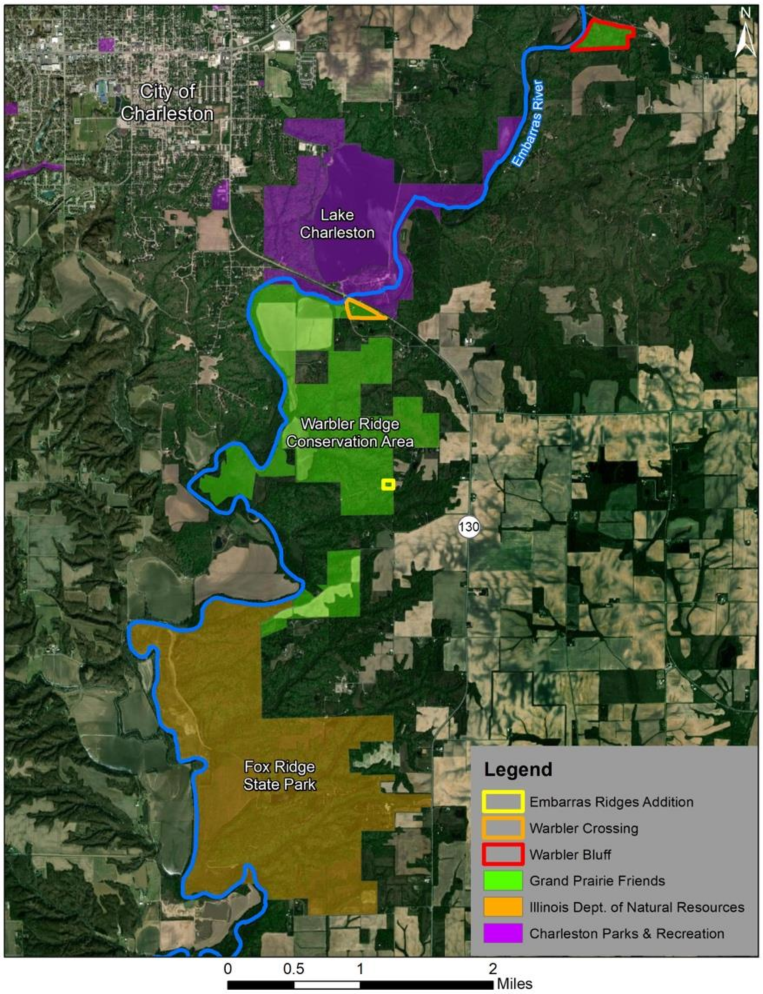

Figure 1. The area of two study sites: Warbler Ridge Conservation Area and Fox Ridge State Park.

Figure 2. Window trap. Window traps are a flight interception trap. It has a plastic transparency sheet attaching to a funnel than a jar. When fly beetles hit the plastic sheet, they will drop into the funnel which lead them into the jar.

Figure 3. Pitfall trap. Pitfall traps target crawling beetles. It is a plastic cup buried in the ground, level with the soil surface. When beetles are traveling, they might have chances to drop into cups.

Table 1.Individual counts by family level with two trapping methods in two study sites. Several of the families (in bold) were obviously much better represented in Fox Ridge than in Warbler Ridge.

Study Site	Fox Ridge			Warbler Ridge		
Family/Trap type	W[1]	P[2]	W+P	W	P	W+P
Bostrichidae	602	6	608	944	13	957
Carabidae	4	23	27	2	14	16
Chrysomelidae	**4**	**0**	**4**	**1**	**0**	**1**
Cryptophagidae	**13**	**1**	**14**	**5**	**2**	**7**
Curculionidae	**7**	**6**	**13**	**4**	**1**	**5**
Cupedidae	1	1	2	1	0	1
Dermestidae	1	0	1	1	1	2
Elateridae	4	0	4	4	0	4
Erotylidae	1	0	1	1	0	1
Geotrupidae	0	3	3	0	4	4
Histeridae	0	1	1	1	0	1
Laemophloeidae	1	0	1	0	0	0
Latridiidae	**15**	**0**	**15**	**1**	**1**	**2**
Leiodidae	6	1	7	2	4	6
Meloidae	0	3	3	0	0	0
Mordellidae	0	0	0	1	0	1
Mycetophagidae	0	0	0	2	0	2
Nitidulidae	**11**	**8**	**19**	**2**	**7**	**9**
Rhipiceridae	1	0	2	0	0	0
Scarabaeidae	0	17	17	1	114	115
Silphidae	1	62	63	0	229	229
Staphylinidae	0	18	18	2	35	37
Tenebrionidae	2	9	11	1	17	18
Trogidae	0	1	1	0	0	0
Trogossitidae	0	0	0	1	0	1
Subtotals	674	160		977	442	
Site Totals	834			1,419		
Grand total			2,253			

([1]Window trap, [2]Pitfall trap).

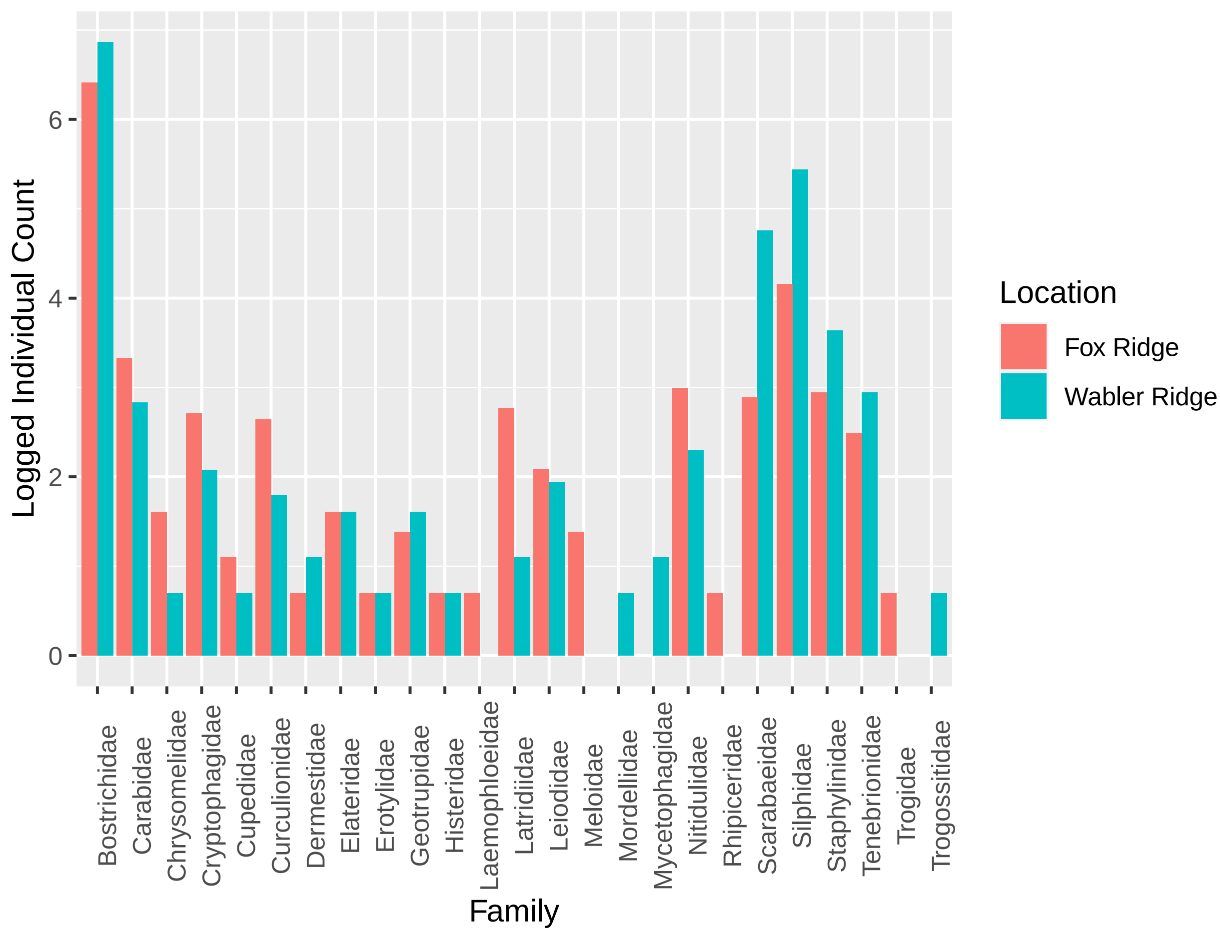

Figure 4.The logged average caught number per days in each family from two study sites.

Table 2. Analysis of Variance table comparing the effect of different trapping methods (window trap and pitfall trap) and study sites (Fox Ridge State Park and Warbler Ridge Conservation Area) on average individual caught per day.

	Df	Sum of Square	Mean Square	F	*p*
Location	1	0.0480	0.0480	4.8280	0.0310*
Trapping	1	0.0786	0.0780	7.8750	0.0063**
Location × Trapping	1	0.0002	0.0002	0.0220	0.8810
Error	76	0.7580	0.0090		

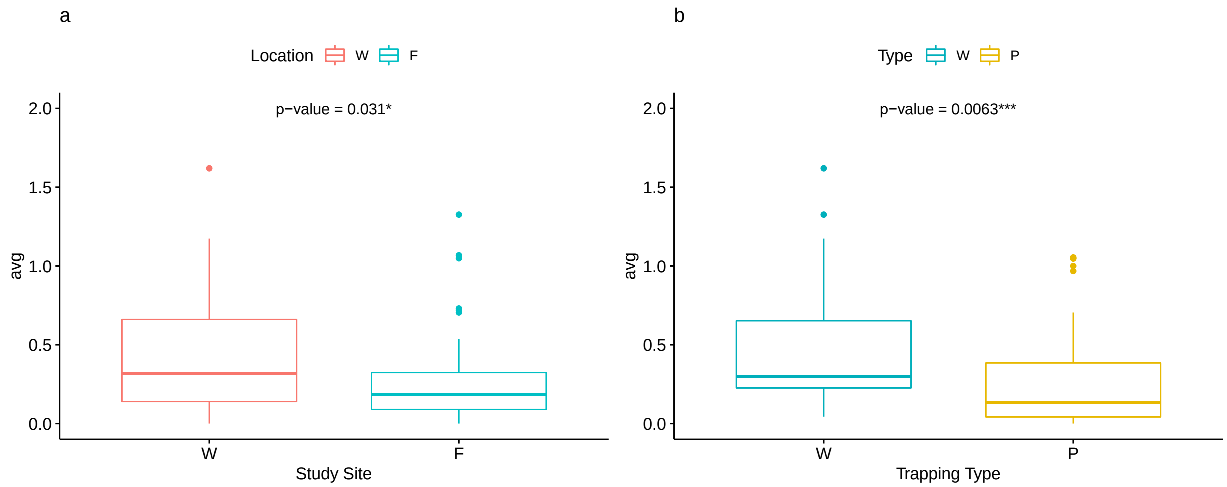

Figure 5. Boxplot of a) average individual caught per day in two study sites, F = Fox Ridge State Park; W = Warbler Ridge Conservation Area, b) trapping methods, W = window trap; P = pitfall trap.

Table 3. The simultaneous confidence interval investigating 95% confident interval of the Shannon and the Simpson index in all traps in two study sites and two trapping methods in different study sites.

	Shannon	Simpson
	p	
Study Site	0.201	0.072
Window Trap	0.018 *	0.015 *
Pitfall Trap	0.004 **	0.074

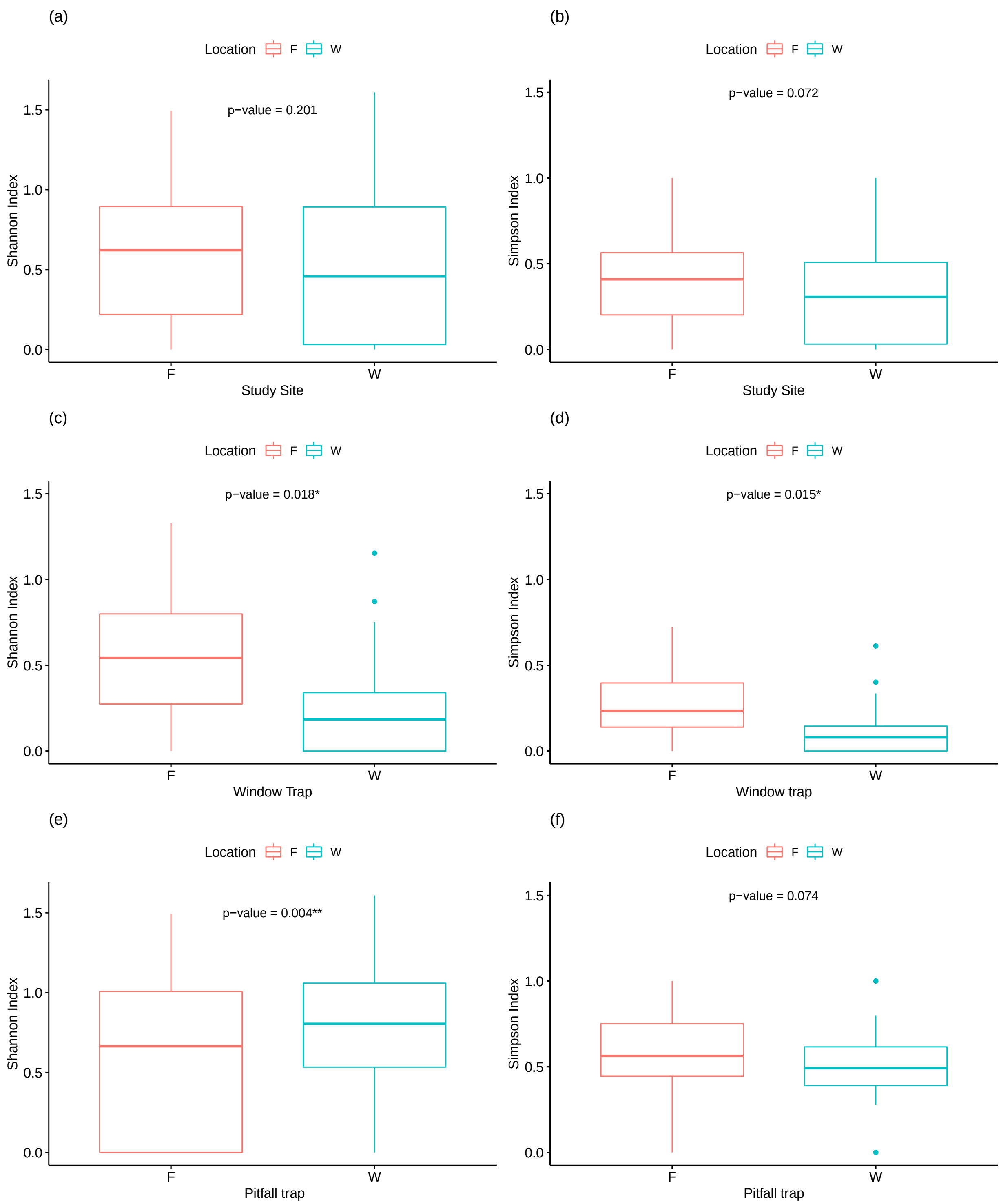

Figure 6. Boxplot of the Shannon and Simpson index between study sites, F = Fox Ridge State Park; W = Warbler Ridge Conservation Area. (a) the Shannon index between two study side by all traps (b) the Simpson index between two study sides by all traps (c) the Shannon between study sides by window traps (d) the Simpson index between two study side by window traps (e) the Shannon index between study sides by pitfall traps (f) the Simpson index between study sites by pitfall traps

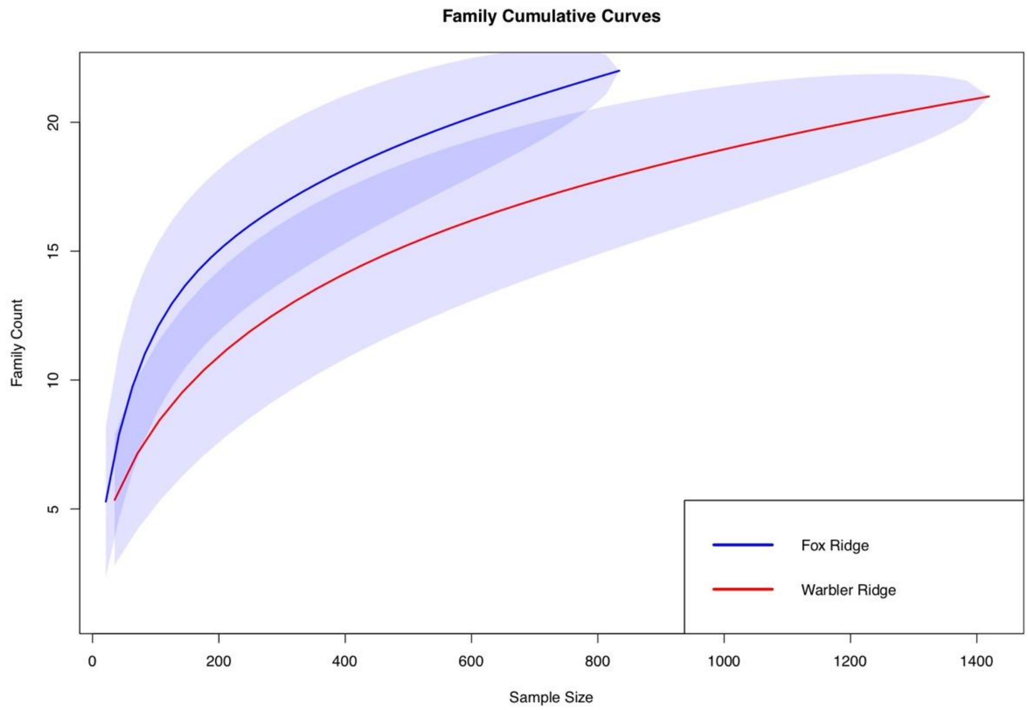

Figure 7. Family Cumulative Curves with 95% confident interval. As the number of collected beetle specimens accumulated, the family count increased more steeply at Fox Ridge than at Warbler Ridge.

Table 4. Permanova table comparing species composition between trapping methods and study sites.

	Df	Sums of Square	Mean Squares	F	*p*
Trapping	1	7.44	7.449	30.76	0.001 ***
Location	1	0.525	0.525	2.168	0.053
Trapping x Location	1	0.556	0.556	2.29	0.038 *
Error	70	16.953	0.242		

Table 5 Envfit for PERMANOVA table. Envfit test showed that basal area and CWD volume did not have significant effect on beetle's composition and only trapping methods did have effect statistically.

		R^2	*P*
Vectors	L	0.0010	0.969
	CWD	0.0343	0.281
Factors	Type	0.5022	0.001***
	Location	0.0238	0.177

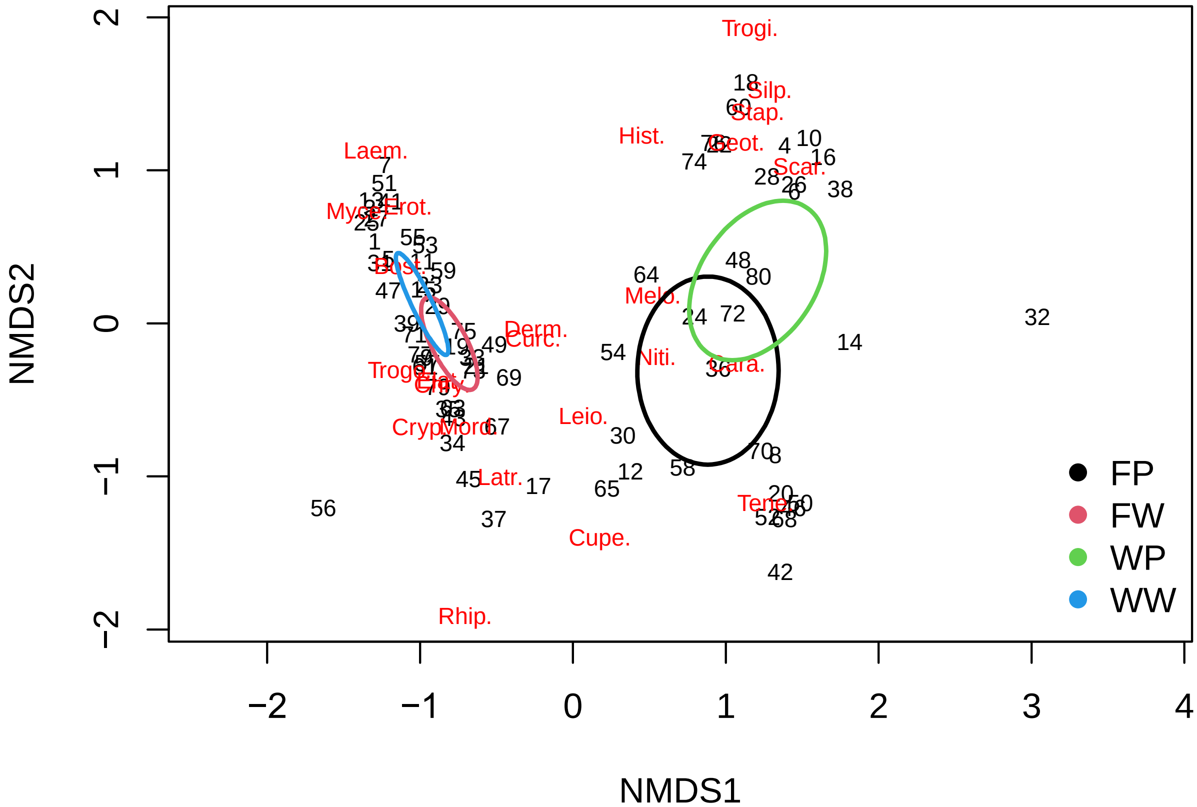

Figure 8 NMDS plot. The four groups represent trapping methods in two sites. Details for abbreviation in table 6. WW: Warbler Ridge's window traps, FW: Fox Ridge's window traps, WP: Warbler Ridge's pitfall traps, and FP: Fox Ridge's pitfall traps. Abbreviations of Beetle families: Bost - Bostrichidae, Cara - Carabidae, Chry - Chrysomelidae, Cryp - Cryptophagidae, Cupe - Cupedidae, Curc - Curculionidae, Derm - Dermestidae, Elat - Elateridae, Erot - Erotylidae, Geot - Geotrupidae, Hist - Histeridae, Laem - Laemophloeidae, Latr - Latridiidae, Leio - Leiodidae, Mord - Mordellidae, Niti - Nitidulidae, Myce - Mycetophagidae, Melo - Meloidae, Rhip - Rhipiceridae, Scar - Scarabaeinae, Stap - Staphylinidae, Silp - Silphidae, Tene - Tenebrionidae, Trogi - Trogidae, Trogo - Trogossitidae.

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