Effects of Clear-cutting and White-tailed Deer Herbivory on Soil and Litter Arthropods at the Black Rock Forest, NY

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Abstract:

Due to the increased scrutiny placed on silvicultural and forest management practices, it has become increasingly important to understand the effects of these practices on ecosystem productivity and biological diversity. This study uses forest soil and litter arthropods, a diverse, abundant, and disturbance-sensitive group of organisms, to monitor the effects of clear-cutting and White-tailed deer herbivory on recovering sites in Black Rock Forest, NY, an experimental Oak-hardwood forest. By comparing plant species richness and arthropod abundance, species richness, and diversity of an undisturbed site with three 1987 clear-cuts that have been recovering under different conditions, I was able to evaluate site productivity and relative stability. This study revealed trends in plant species richness, arthropod species richness and arthropod abundance favoring the undisturbed site and the deer-exclusion 1987 clear-cut, suggesting that deer exclosures may help ecosystem productivity and species composition recover after clear-cutting. Furthermore, when compared to data looking at species richness in clear-cuts 11 to 100 years old in the same forest, I found that fencing reduced arthropod species richness recovery time by 10 years. My findings concerning the diversity of these sites were contrary to the aforementioned ecosystem trends. The greatest arthropod diversity was found in the 1987 clear-cut located on a hillside. Most likely this relatively high diversity can be attributed to the small number of individuals found at this site, causing a uniquely high degree of evenness. These findings imply that in order to ensure a productive recovery and increased species richness of both plants and

arthropods in clear-cut sites, it may be beneficial to exclude White-tailed deer from recovering areas during the early stages of colonization and succession.

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Introduction:

Increased criticism by environmentalists has caused forest ecologists to look more deeply into the effects of management on forest productivity and diversity (Burger & Zedaker 1993, Gupta & Malik 1996). Popular forest management practices, such as clear-cutting, have been called into question, so it has become increasingly important to understand their effects on biological diversity, ecological processes, ecosystem stability and long-term productivity. Human modification of these systems is the main cause of changes in ecosystem processes, and these changes in landscape also produce changes in species diversity and composition of that area (Chapin et al. 1997). It has been suggested that certain biotic changes may alter ecosystem processes sufficiently to alter the state of the world's ecosystems and the services they provide to humanity (Chapin et al. 1997).

The responsiveness of soil and litter arthropods to forest management practices makes them effective bioindicators. Furthermore, arthropods are diverse and taxonomically well known. For these reasons, a considerable volume of information concerning the effects of forestry on invertebrates in the boreal forest region has been amassed (Niemela 1997). In spite of this, published research on the effect of forest management practices on soil and litter arthropods in temperate forests is limited (Danoff-Burg & Bird 1997). Since community clear-cutting is one of the dominant methods of commercial forest management in the Northeastern U. S., it is important to look at the long-term effects of this type of management in an Oak-hardwood forest, one of the dominant forest types in this area. By investigating the responses of soil and litter arthropod communities to this type of management, this study endeavors to determine how these effects are manifested.

One implication of ecosystem complexity is that many factors may be involved in determining the patterns of forest succession and community development (Mladenoff & Stearns 1993). In this study, I concentrated my research on the effects of White-tailed deer (Odocoileus virginianus) populations on the richness of plant species as well as their correlative effects on the communities of soil and litter arthropods. Investigations of the effects of deer populations on forests with recovering clear-cut areas have revealed that clear-cutting increases browse available to deer, and this can lead to a significant increase in their population size (Brady 1994). Under conditions of densely populated deer communities, it has been observed that deer can be detrimental to plant re-growth (Alverson et al. 1988). It has been suggested that deer browsing may pose threats to plant and animal species more characteristic of late successional and mature forest ecosystems (Mladenoff & Stearns 1993). By studying the effects of deer populations on forest and litter arthropods, this study investigated the effect of White-tailed deer populations on the recovery of clear-cuts in the Hudson Highlands region of New York.

This study investigated the significance of the effect of deer herbivory on plant species richness under slightly different environmental conditions, the effects of decreased plant species richness on soil and litter arthropods in these different sites across a range of environmental conditions, and the variation in abundance, species richness, and diversity between various treatments.

Background

The Role of Soil and Litter Arthropods in Forest Ecosystems

Due to their involvement in many different processes, forest soil and litter arthropods are good indicators of how various systems in the environment are functioning. Soil and litter arthropods play an integral role in many ecosystem processes. They are key players in detrital cycling (interactions between organic material and microorganisms, decomposition), nutrient cycling (through involvement with the detrital system, and the mixing of nutrient and organic material through soil (Eijsackers 1994). Being key players in these systems makes forest floor invertebrates an important factor in "bottom-up" controls, and the change in species composition could alter resource availability as well as ecosystem structure and dynamics (Chapin 1997). As a result, difference in the organization and structure of the communities of these organisms may be an indication of changes in the nutrient cycle and productivity of their environment.

Soil and Litter Arthropods as Indicators of Disturbance and Recovery

Soil and litter arthropods have the potential to be good indicators of the condition of an ecosystem, its processes and the effect of environmental change (Hole 1982, McIver et al. 1990, Bohac and Fuchs 1991, Curry and Good 1992, Kopeszki 1992, Hogervost et al. 1993, Korg 1993, Hoekstra et al. 1995). The responsiveness of soil and litter arthropods to changes due to silvicultural practices has been noted (Huhta et al. 1967, Vlug & Borden 1973, Abbot et al. 1980, McIver et al. 1990, Salona & Iturrondobeitia 1993, Hoekstra et al. 1995). Soil and litter arthropods are strongly affected by environmental changes, such as availability and type of food sources and climate and moisture changes (Danoff-Burg & Bird 1997). These traits make these invertebrates useful in monitoring the effects of disturbance and other variables on a recovering ecosystem.

Diversity and Stability

The high diversity of soil and litter arthropods may have some affect on or be some indication of ecosystem stability (Danoff-Burg & Bird 1997). Although the long-standing hypothesis contends that increased diversity and complexity leads to increased stability (Elton 1958), the validity of this hypothesis has been called into question (Danoff-Burg & Bird 1997). The "complexity equals stability" hypothesis is supported by the assumption that simplifying ecosystem structure (i.e. by decreasing biological diversity) would increase this system's vulnerability to disturbance by lowering its resilience (Perry 1994). However, biological diversity results from such a great complexity of factors that no single process or theory can explain a this phenomenon (Huston 1994). Evidence for the functional role of biodiversity is not easily defined and the results obtained in one ecosystem are not necessarily directly applicable to another (Karieva 1996). This is in part due to the wide variety of interacting factors and processes that affect biological diversity. Among these particular site characteristics are climate, vegetation type, and local fauna, as well as the disturbance history of that site and the time elapsed from the most recent disturbance. It is important to investigate stability and productivity variation in recovering sites because these characteristics are important considerations for sustainability of production (Tilman et al. 1996).

The Effects of Clear-cutting on Biodiversity

The immediate effect of clear-cutting is the elimination of the existing communities, although some forest managers intersperse clear-cuts throughout the forest, creating a mosaic of young and old forest habitats. While the practice of clear-cutting may eliminate mature forest specialists from an area, and may eventually jeopardize more sensitive species, local invertebrate species richness (α-diversity) may increase as forest generalists persist and numerous open-habitat species appear (Niemela 1997). Another effect of the interspersion of these younger forest areas within an older forest is the potential threat to diversity by enabling the invasion of successional plant and animal species capable of interfering with species restricted to the older communities (Janzen 1983, 1985).

The Effects of Succession on Biodiversity

Ecological succession is the process an ecosystem progresses through, in a series of gradual stages of development and species replacement, from the time of disturbance until the achievement of a climax community. Clear-cutting modifies the environment, making it easier for shade-intolerant plants and exotic species to colonize the area. This is part of process called facilitation (Connell & Slatyer 1977).

Succession and Diversity in the Oak-Hardwood Forest

In an Oak-hardwood forest, the first six years of succession are characterized by the herbaceous stage (Huston 1994) and throughout this period diversity increases. This early stage is characterized by r-selected species; species that are good colonizers because of their high fecundity and excellent dispersal mechanisms but poor competitors in well established communities. The next 15-20 years are characterized by a period of dominance by highly productive species (Huston 1994). The time clear-cut sites in this study fall within this mid-successional period, approximately 11 years after clear-cut. Late successional stages that follow are characterized by a slowing down of the species replacement rate. These stages often exhibit a dropping off in species diversity as mid-successional species are out-competed by K-selected (longer lived, better competitors), late successional species. Although it has been suggested that along with forest succession, there is also a decreased diversity and species richness for arthropods (Coderre & Paquin 1997), this study had quite different findings. Perhaps this is an indication as to the severity of the affects of clear-cutting.

Clear-cutting and Edge Effects

Since the mid-1930s, the creation of clear-cuts has been the traditional means of increasing the populations of game species by creating these edge habitats (Alverson et al. 1988). The term "edge effect," which evolved at this time, was used to describe the resulting conditions: an increase in local diversity and abundance of plant and animal species found along the boundary between two habitat types (Alverson et al. 1988). In more recent years this term has become associated with increased predation and parasitism of vulnerable animals in edge area (Alverson et al. 1988) due to the noted microclimate changes including colonization by shade-intolerant and exotic plants as well as invasions by insects. Clear-cutting, as a silvicultural practice, yields comparable results.

The Effects of Clear-cutting on White-tailed Deer

Ongoing study at Black Rock Forest has shown that changes in the forest in the past century have directly affected the area's White-tailed deer population (Brady 1994). In this area, a young woodland will first become dominated by trees and shrubs, including berry bushes. The regenerating plants and berry crops provide more than the usual amount of deer forage, and over the past century, these recovering areas have enabled White-tailed deer populations to increase. In the 1960's and 1970's at Black Rock, this regenerating growth was supplemented by the acorn production of maturing oaks, providing even more food for the already highly dense deer populations (Brady 1994). In high population densities, such as in the situation described here, White-tailed deer populations have been found to be destructive of their environment, and are therefore important to monitor and control (Brady 1994).

The Effects of Mega-Herbivores on a Recovering Area

Many studies have investigated the effects that White-tailed deer populations have on recovering clear-cut areas. Deer browsing (or herbivory), in most cases, has a negative affect on vegetation (Belsky 1986, Allison 1990, Shelton & Inouye 1995). Several studies have found that declines in species richness and abundance of herbaceous and woody vegetation are directly attributable to browsing by White-tailed deer (Behrend et al. 1970, Warren 1991, McShea and Rappole 1992, Miller et al. 1992). White-tailed deer have such a profound influence that their browsing can affect the abundance and population structure of plant species and may even prevent regeneration in some species (Alverson et al. 1988). In a study looking at the affect of intensive deer browsing of canopy recruitment, Abrams and Orwig (1996) also came to the conclusion that the lack of tree recruitment and the present day lack of seedlings, saplings and shrubs in the understory is primarily to intense deer browsing.

Goals of This Study

In this study, I analyzed the effects of White-tailed deer herbivory and clear-cutting on soil and litter arthropod communities at the Black Rock Forest. I evaluated these effects by comparing plant species richness and species composition at four study sites and by comparing overall abundance, species richness, species composition, and diversity of forest and litter arthropods at the four sites. I compared sites by using the Jaccard and Sorenson Similarity Indices and calculated diversity by using the Shannon Diversity Index. Finally, these results were compared with arthropod species richness trends reported in an unpublished data set from a study done at Black Rock Forest on species richness in clear-cuts of various ages ranging from 11 to 100 years old.

Methods:

Black Rock Forest

The Black Rock Forest (appendix 1), located on the northwest side of the Hudson Highlands region of New York, was the study site for this project. Black Rock has mountainous terrain and a bedrock composed mainly of gneiss with a mantle of glacial till, granite (Brady 1994). This forest is composed of mainly oaks (74%) and associated hardwoods (Brady 1994). Of the oak trees, 60% are in the 6" - 12" diameter class, and these trees are mostly between 70 and 100 years of age (Brady 1994). Over the years, the forest has been exposed to a range of disturbances, including thinning, burning, and clear-cutting. Throughout its history, this forest has been used by scientists to expand our understanding of the ecology of this region (Maher 1996), and to this end portions of it have been systematically altered. Due to the way this forest has been researched and managed, detailed information on the way this land has been used over the past 100 years is readily available. These records, in addition to the long-term experimental research plots, made Black Rock Forest the ideal location for this study.

Treatments and Study Sites

For the purposes of comparison, four study sites were selected for this study (appendix 1): a three acre undisturbed plot (site 1) that has been left undisturbed for over 100 years and three one acre 1987 clear-cuts. Out of these three clear-cuts, one (site 3) was surrounded by a ten foot high fence immediately after clear-cutting. This fence is tall enough to exclude White-tail deer and prevent herbivory by them. Another plot (site 4) is located adjacent to site 3 and was left unaltered after the clear-cutting. Both of these sites are located in a heavily wooded, slightly marshy area in a little-disturbed portion of the forest. The final site for this study is located on a hillside along a main road (site 2), but was also left untouched after clear-cutting. These plots provide a means of examining both the effects of clear cutting as well as a means of isolating the effect of deer on a clear-cut site and the effects of the exclusion of deer from such sites.

Vegetation Assessment

For each of these sites, the species of plants growing in the plot and plants directly over or near the plot were recorded. Samples of leaves were taken from all plants and leaf litter and were recorded, collected, labeled and brought back to the lab for species verification.

Arthropod Collection Techniques

Sampling was done on September 20, 1997, before the first frost. Soil and litter arthropods were collected at ten sample points within each study site. Since each study site was relatively uniform in its characteristic, I used a random sampling method. Through each site a transect was established that ran perpendicularly away from the adjacent road. In each site, 10 samples were collected along the transect, each sample point located 10 meters away from the next. All litter and loose topsoil within a 25 by 50 centimeter frame was collected and placed in a plastic bag and labeled. Each sample was later sifted to remove coarse material. Data was extracted by placing the sifted material into berlese funnels and leaving them under a light source for one week. A canister filled with mineral oil was placed beneath each berlese funnel to collect arthropods and prevent them from escaping or decaying. After a week, each canister was removed from the funnels, and remaining litter was discarded. A Buchner funnel with filter paper on top was used to separate the arthropods from the mineral oil. The arthropods were then stored each sample in alcohol in a freezer for storage.

Arthropod Sorting

I conducted an initial taxonomic sort of the arthropods into seven categories: Pseudoscorpionida, Chilopoda, Diplopoda, Staphylinidae, Carabidae, Other Coleoptera, Formicidae. In addition, a sample containing a representative selection of other arthropods not accounted for in the aforementioned list of categories was collected. Each of these separated groups was then resorted to generic or species level by morphotype.

Between Site Analysis (β-diversity) For Vegetation Analysis

β-diversity is essentially a measure of how different (or similar) a range of habitats or samples are to each other in terms of species variety or abundance (Magurran 1988). To calculate this, I used two of the most widely used similarity indices: the Jaccard Index and the Sorenson Index. These indices are designed to equal 1 in the case of complete similarity and 0 in the case of complete dissimilarity. I chose to use these indices for the vegetation analysis because neither of them account for abundance. For the purposes of this study, I used these indices to compare similarity of species composition between the four study sites.

Between Site Analysis (β-diversity) For Arthropods

For further between-site analysis and comparison of arthropod diversity, I used the Shannon Index (Magurran 1988). This is one of the most commonly used indexes used for calculating β-diversity. I then used a t-test to compare significance of difference in arthropod species diversity between sites.

Limitations of the Methods

The accuracy of this study may have been thrown off by a couple of factors, including small study sites, small sample size, and misplaced materials. Due to the small size of the sample sites, leaves of plant species growing in the surrounding area may have contributed more to the composition of the leaf litter within these sites then they might have in larger sites. As a result, there were more plants accounted for in the vegetation analysis then were actually growing in the site, and this might have allowed a greater number of arthropod species to inhabit this area then would have otherwise been possible. While does not detract from the findings of this study, it most likely prevents me from extrapolating my results to a more large-scale example of clear-cutting.

The samples that I collected, for the most part, were composed of a relatively small number of individuals. Especially in the case of site 2 (the hillside clear-cut) this may have biased my diversity calculations. These and all my calculations might also have been thrown off by the occasional failure to properly label samples.

Results:

Vegetation Analysis

#1: Plant species richness

#2: Jaccard Similarity Index

#3: Sorenson Similarity Index

Analysis showed a notable range in plant species richness between the four sites. The mature forest site had the greatest species richness: a total of 16 species, while the unfenced clear-cut at the top of the hillside had the smallest species richness, with 9 species (fig. 1). The Jaccard and Sorenson Similarity Indexes revealed the composition of plant species were most similar at sites 3 and 4 (the two sites located in the swampy area) followed closely by sites 1 and 3 (the undisturbed site and the fenced site in the swampy area) (fig. 2, 3).

Arthropod Abundance Data

#4: Total abundance at each site

The overall arthropod abundance data I collected revealed a dramatic trend with regard to productivity. Both the undisturbed site (236 individuals) and the fenced site (302 individuals) showed markedly greater abundance than the other two 1987 clear-cuts (66 and 42 individuals) (fig. 4). How each individual taxon contributed to these results can be seen in figure #8.

Between Site Analysis (β-diversity)

#5: Arthropod species richness

#6: Jaccard Similarity Index

#7: Sorenson Similarity Index

#8: Arthropod species composition

#9: Shannon Diversity Index

Table 1: Shannon Diversity Index t-tests

The arthropod species richness data reflected trends almost identical to those present in the plant species richness data and the arthropod abundance data. The greatest number of arthropod species was 32, present at site 3 (the fenced clear-cut in the swampy area), followed by 25 at site 1 (the undisturbed site) (fig. 5). Both the Jaccard and the Sorenson Index revealed trends quite similar to those of the plant species similarities (fig. 2, 3). Like the vegetation species analysis using these two indices, arthropod species composition was most similar at sites 3 and 4 (the two sites in the swampy area) and sites 1 and 3 (the undisturbed site and the fenced site in the swampy area) (fig. 8, 9).

I charted the distribution of each taxon to determine to what degree each taxon was contributing to the total abundance in each site (fig. 8). This chart revealed interesting trends regarding which factors (environmental, time since disturbance, herbivory, etc.) were having the most significant impact on species composition. This chart revealed that the genera Carabidae was present mainly in the two swampy sites. Diplopoda were prevalent mainly in the three recovering clear-cut sites. Chilopoda, Other Coleoptera and Staphylinidae were most abundant in the undisturbed site, followed most closely by the fenced site in the swampy area, while the reverse was true for Pseudoscorpionida and Formicidae.

The results of the Shannon Diversity Index calculations (fig. 9) were not in accordance with the findings of these other measurements and tests. Using this index, I found site 2 (the hillside clear-cut) to have the greatest diversity (index number 2.2). Site 3 (the fenced clear-cutting the swampy area) followed closely behind (index number 2.1). Sites 1 and 4 (the undisturbed site and the unfenced site in the swampy area) had even lower species diversity (index numbers 1.8 and 1.6 respectively).

Discussion:

Approach to Analysis

Abundance and diversity are structurally and functionally significant ecosystem components. Changes in the abundance of species may affect the structure and function of an ecosystem. Changes in species diversity affect efficiency of resource use (Chapin 1997). Diversity is an emergent property that takes into account species richness and evenness. Species richness is the number of species living in a sample or species density when sample size is expressed in terms of area. Species evenness is the relative distribution of species among different types of organisms. By looking at these attributes of the ecosystem I can compare and contrast their productivity and efficiency.

Vegetation Analysis

At first glance, the four study sites looked markedly different in terms of plant species richness and evenness. The plant composition of both clear-cuts that were not fenced seemed relatively homogeneous. However, the results of the vegetation analysis revealed that, at least from the perspective of the soil and litter arthropods, this was not necessarily the case. Since the species I looked at in were soil and litter dwellers, I combined the plant species present in the leaf litter with those that I found growing in the site for the purposes of the vegetation analysis. This produced a surprisingly higher species list than I had originally expected. Due to perhaps the small scale of the sites (one acre in the case of the clear-cuts), the composition leaf litter seems to have been influenced by the plant species growing in the surrounding environment. The results of the vegetation species richness analysis (fig. 1) showed that sites 1 and 3 (the undisturbed site and the fenced site) had the same number of species (both had 16 species). Sites 2 and 4 (the two unfenced clear-cuts) had at least one third fewer species (9 and 10 respectively).

For the final analysis the Jaccard and Sorenson Similarity Index figures were calculated for comparisons of vegetation in all sites (fig. 2, 3). It seems that with these indices the location of the sites was highly influential in determining the degree to which these environments would be similar. For example, sites three and four (the two site in the swampy area) had the greatest similarity according to both indices, and these two sites are adjacent to each other. Sites two and four (the two unfenced clear-cuts) that are presumably under the most similar pressure by deer herbivory, were notably less similar. This may be attributed to the fact that they were also located in very different environments (a well-drained hillside and a swampy area respectively).

These results were further illustrated by the almost identical similarity figures between sites two and four (the two unfenced clear-cuts) and sites one (the undisturbed site) and three (the fenced site). While these figures provided us with some useful insights, it might have also been interesting if I had performed a different type of vegetation analysis, one that would have allowed us to take into account species evenness and distribution.

The Effects of Plant Species Richness on the Species Richness of Arthropods

By comparing figures #1 and #5, the potential connection between plant species richness and arthropod species richness becomes readily apparent. Both of these charts reveal very similar trends. For both plants and arthropods the undisturbed site (1) and the fenced site (3) had the greatest species richness. As stated earlier, in many cases, White-tailed deer browsing has been found to have a negative affect on plant species richness and abundance (Behrend et al. 1970, Warren 1991, McShea and Rappole 1992, Miller et al. 1992), and clearly this seems to be taking place at the Black Rock Forest as well. Studies have also shown that animals dependent on certain forest plant species may also be negatively affected by high density deer browsing (deCalesta 1994). These results seem to indicate that by lowering the number of plant species in the unfenced clear-cut sites, White-tailed deer are also eliminating the arthropods that utilize these plants, either by living on them or by preying on the arthropods that live on them.

Abundance and Productivity

The overall abundance data (fig. 4) reveals a distinct pattern similar to those of the plant and arthropod species richness trends. In terms of the effect of clear-cutting on ecosystem productivity, both the undisturbed site and the deer exclosure site had much larger populations of arthropods than the other two clear-cut sites. The undisturbed site had anywhere from three to six times as many individuals as either of the two unfenced clear-cut sites, and the fenced site had four to seven times as many individuals then the two unfenced clear-cuts. If this data is representative of the arthropod communities in these sites, then the implications are clear: fenced clear-cuts and undisturbed forest ecosystems are significantly more productive ecosystems than those that have been clear-cut and are then exposed to browsing by a high density White-tailed deer population.

Herbivory and Productivity

The two adjacent clear cut sites in the swampy area clearly reveal the affect of White-tailed deer herbivory on ecosystem productivity. Site 3 (the deer exclusion site) had four times the total number of individuals as site 4 (the unfenced site). Since site conditions (soil type, climate, etc.) were comparable for these two sites, it is evident that White-tailed deer browsing is having some affect on ecosystem productivity in this area. It is probable that deer herbivory has influenced site 4 in such a way that although the plant species composition is similar, there is less leaf litter, and therefore the resources available in this site are significantly impoverished compared to its neighboring site. White-tailed deer could cause this result through their effects on vegetation, such as inhibition of tree recruitment (Abrams & Orwig 1996) or plant reproduction.

The results of this study are consistent with the results of many other researchers investigating the relationships between deer browsing and animal populations. For example, several studies have found that silvicultural practices yielding forest fragmentation and the elimination of mature forest characteristics causes songbird populations to decline (deCalesta 1994). In a review article, Niemela (1997) also sites several cases in boreal forest areas where forest fragmentation has caused the elimination of specialist species unique to mature forest ecosystems.

The abundance data for sites 1 and 3 reveals another interesting trend. The overall abundance is greater in the deer-exclusion site than in the undisturbed forest. A possible explanation for this is that these clear-cut sites are providing more forage for the deer populations in this area (Johnson et al. 1995). This increased forage results in burgeoning deer populations by increasing their destructiveness both inside the clear-cut sites and in the surrounding forest. The productivity results for sites one and three support this hypothesis.

Another possible explanation for the abundance trends of sites 1 and 3 requires a closer look at the arthropod and plant species richness data, and at these data in terms of overall forest trends.

Herbivory and Species Richness

The trend of arthropod species richness is almost identical to that of arthropod abundance (fig. 4, 5). The number of arthropod species was greatest in site 3 (the fenced site in the swampy area) followed by site 1 (the undisturbed site). The greatest species richness occurs in the clear-cut from which deer have been eliminated; therefore, according to previous findings about the negative effects of White-tailed deer on plant species diversity and tree recruitment, it follows logically that in an environment from which these pressures have been eliminated, arthropod species richness should flourish. Although the undisturbed site has been subjected to the pressures of a high density deer population, this site has had longer to develop, and is therefore capable of supporting more species that are specific to a more mature forest ecosystem.

Trends of Recovery of Species Richness at the Black Rock Forest

On the same day that the data for this study was collected, data was also collected at sites that had been clear-cut at 11, 11, 25, 68, and 100 years ago (appendix 2). Since the average age of the mature oaks at Black Rock Forest is between 70 and 100 years old, the data collected from the site that was clear-cut

100 years ago may be viewed as representative of the most mature forest areas at Black Rock. Looking at the trends in the development of species richness over time, it appears as if in this forest, species richness peaks around 25 years after clear-cutting. (There is, however, a huge gap in this record, which means that species richness may continue increasing after 25 years). By 68 years, the species richness has begun to decline and 100 years after clear-cutting species richness continues to decline.

The clear-cut sites used in this study were all done about 11 years ago, and indeed both sites 2 and 4 (the two unfenced clear-cuts) have species richness quite close to those recorded in appendix two. Site three (the fenced clear-cut), however, has much greater species richness and in fact seems much more comparable to the species richness of the 25 year old clear-cut. This means that by fencing a clear-cut, it may be possible to significantly reduce the time necessary for the recuperation of species richness.

Taxonomic Distribution of Abundance

The taxonomic distribution of arthropod abundance reveals to a certain extent which arthropod genera are influenced by what external factors (environmental, time since disturbance, herbivory, etc.) From figure #8, it is possible to extrapolate certain site and taxon characteristics. For example, the genera Carabidae was present almost exclusively in the two swampy sites, thereby revealing that this genera is most strongly influenced by climatic conditions and soil moisture. Diplopoda were prevalent mainly in the three recovering clear-cut sites, implying that this type of arthropod peaks in the earlier successional stages. Certain other types of arthropods seemed to favor mature forest conditions, such as the Chilopoda, other Coleoptera and Staphylinidae, which were most abundant in the undisturbed site. The fenced site had the second largest populations of Staphylinidae and other Coleoptera, which may mean that this site is closer than the other two clear-cut sites to attaining the species composition of a mature forest community.

Again sites 3 and 4 (the two sites in the swampy area) are strong evidence for the negative effects of deer herbivory on the arthropod community. Although sites 3 and 4 have similarly proportioned species compositions, site 3 has a markedly higher species abundance. Supposing that the only difference between these two sites is the fence, these results are therefore strong evidence of the effect of high density deer populations.

Arthropod β-Diversity

The results of the Shannon Diversity Index calculations (table 1, fig. #9) surprisingly did not correspond with the findings of the other measurements and tests I used to compare these study sites. Using this index, I found that site 2 (the hillside clear-cut) has the greatest arthropod species diversity (index number 2.2). This directly contradicts Huston's (1994) assertion that diversity increases with increased productivity. One possible explanation for these unexpected results might be that in some situations local invertebrate species richness may increase as forest generalists persist and numerous open-habitat species appear (Niemela 1997). Another possible explanation is that the number of individual arthropods collected in this site was quite low (42 individuals), which means that the evenness of these specie would have been uniquely high among the study sites. Since diversity as a measurement is a synthesis of species richness and evenness, this high degree of evenness must have contributed a great deal to this finding. Site 3 (the fenced clear-cutting the swampy area) followed closely behind (index number 2.1), and this finding was probably most strongly influenced by the high number of species found at this site (32 species).

Conclusion:

It is apparent that clear-cutting has a significant impact on the productivity and species richness of soil and litter arthropods of Northeastern Oak-hardwood forest. This study demonstrates the significance of these impacts as well as the apparently adverse affects of White-tailed deer herbivory on the species richness of vegetation, the abundance and species richness of soil and litter arthropods, and on the productivity of a recovering ecosystem. This study did not, however, reveal a predictable impact of clear-cutting and deer herbivory on arthropod species diversity. However, most of these findings are in accordance with the findings of similar studies in other areas that have found that increased deer densities work against the preservation of natural diversity (Alverson et al. 1988).

How these findings should be applied depends on what a forest is being managed for. If a forest is being managed for increased productivity and species richness, then clearly fencing after clear-cutting could be a useful management technique, allowing productivity and species richness to recover faster and with greater vigor than an unfenced site. However, if a forest is being managed for increased diversity, then the contributions that fencing after clear-cutting will make towards management efforts are not as clearly defined.

Recommendations:

The results of this study suggest that by excluding White-tailed deer from a recovering clear-cut, it is possible to allow species richness and productivity to increase at an accelerate rate. Although the results of the diversity tests did not provide expected data, this should not be seen as detrimental to the rest of the findings of this study, but rather this should perhaps reflect on the complexity of issues that must be accounted for in ecosystem evaluation. Therefore, in order to manage for increased ecosystem productivity and for recovery of species richness and community composition, the construction of deer exclosures around clear-cuts for the first stages of succession in areas that are subjected to deer pressure may be beneficial.

Additionally, it has been noted that there is a need for the White-tailed deer populations at Black Rock Forest to be monitored on a continual basis, as attempts are being made to keep deer populations within the forest's carrying capacity (Brady 1994). The environmental impacts of these species are currently being watched and controlled at Black Rock Forest, and as our study has shown, soil and litter arthropods do reflect the presence and effects of this species. I therefore propose that through a more extensive data collecting structure, (monitoring more sites that exclude deer in different terrain), soil and litter arthropods should be used as one means of keeping tabs on the effects that the Black Rock Forest White-tailed deer populations are having on this particular ecosystem.

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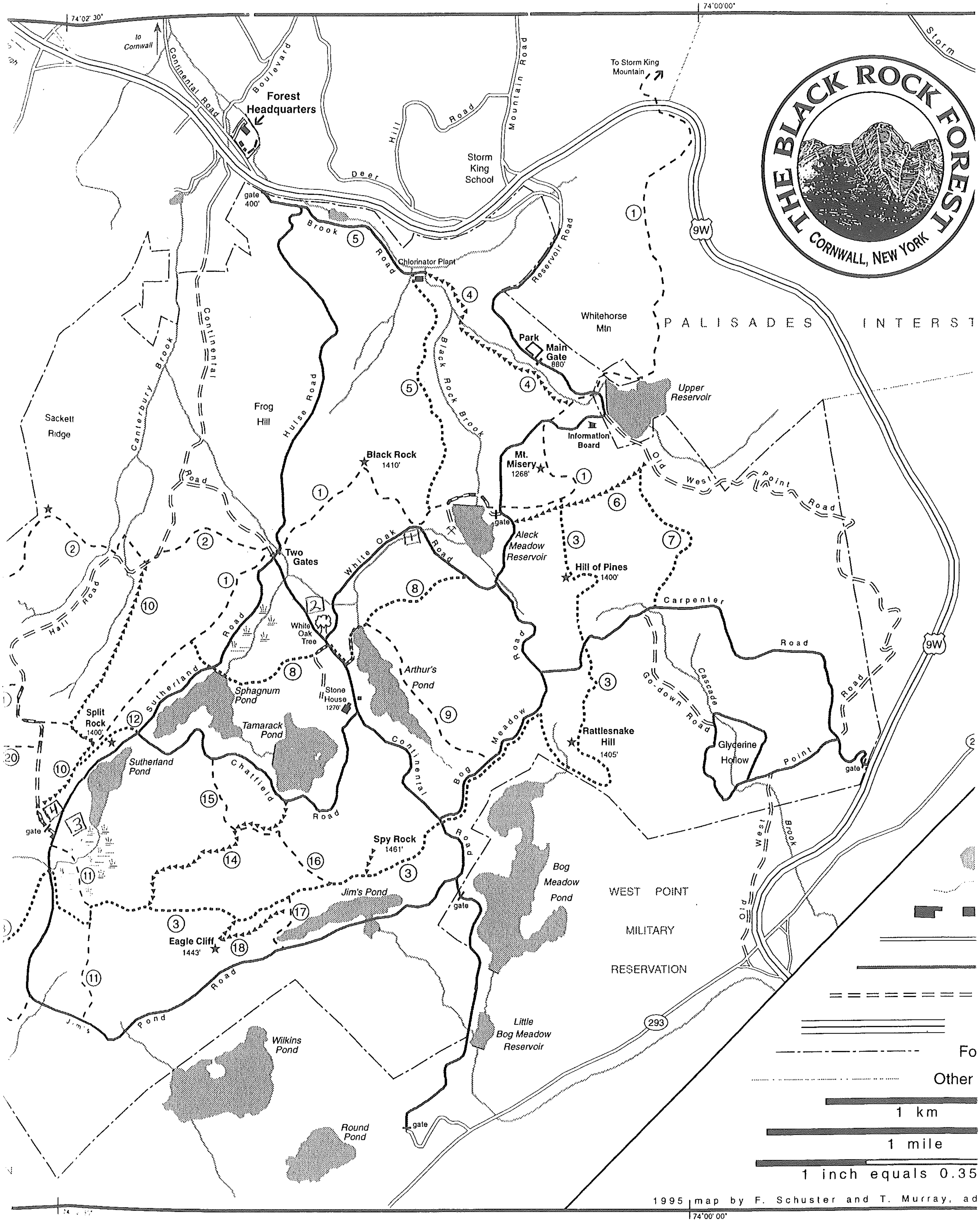
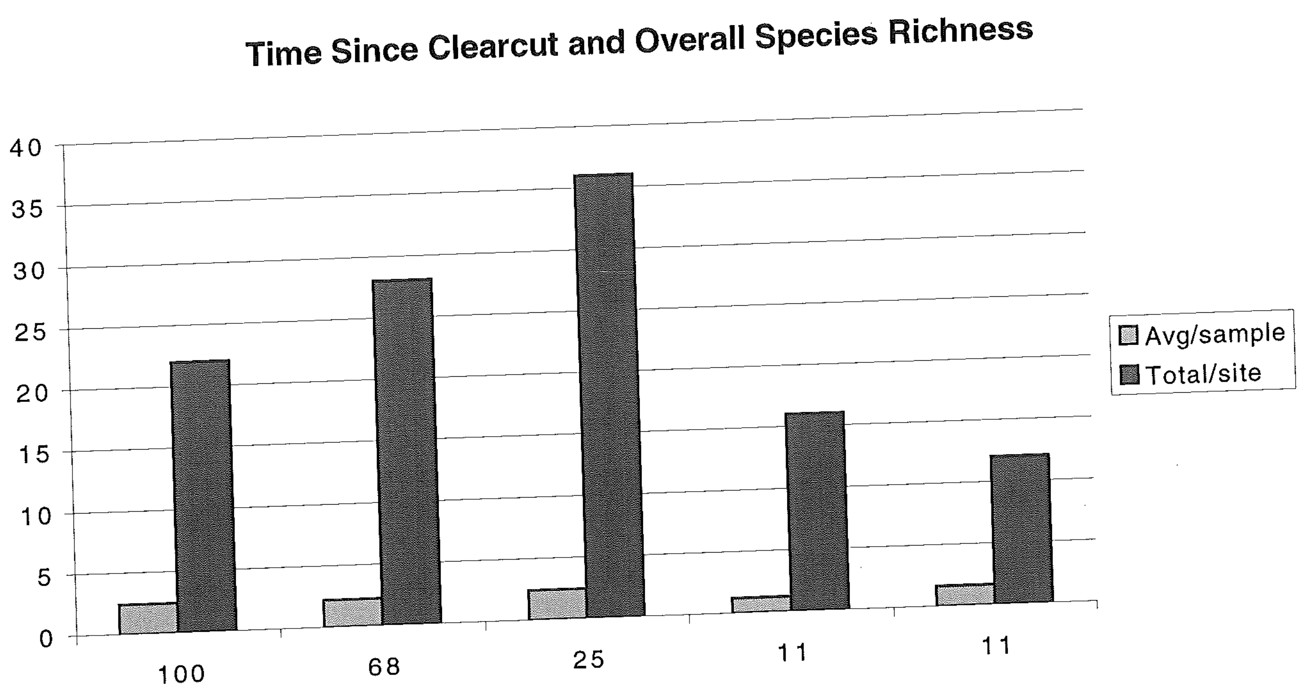
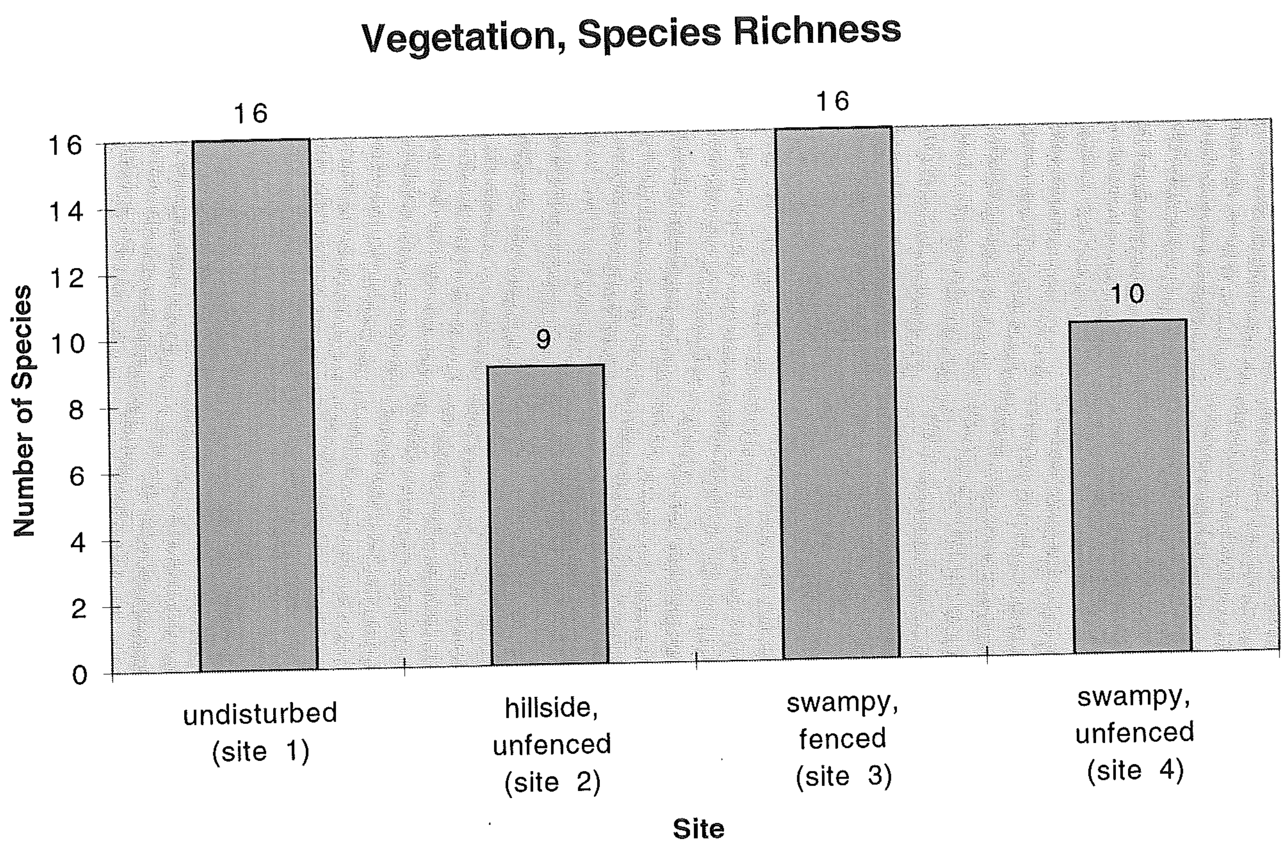

THE BLACK ROCK FOREST
CORNWALL, NEW YORK
74°02' 30"
74°00'00"
to Cornwall
Forest Headquarters
Continental Road
Boulevard
Hill Road
Mountain Road
Deer
Storm King School
To Storm King Mountain
Storm
9W
gate 400'
Brook Road
Chlorinator Plant
Reservoir Road
Whitehorse Mtn
PALISADES INTERST
Park
Main Gate 880'
Upper Reservoir
Information Board
Black Rock Brook
Continental
Canterbury Brook
Sackett Ridge
Frog Hill
Hulse Road
Black Rock 1410'
Mt. Misery 1268'
Old West Point Road
Aleck Meadow Reservoir
gate
Hill of Pines 1400'
Two Gates
White Oak Road
Hall Road
Road
White Oak Tree
Carpenter Road
Sutherland Road
Sphagnum Pond
Stone House 1270'
Arthur's Pond
Tamarack Pond
Go-down Road
Cascade
Glycerine Hollow
Rattlesnake Hill 1405'
Split Rock 1400'
Sutherland Pond
Chatfield Road
Continental Road
Bog Meadow Road
Point
gate
Spy Rock 1461'
Jim's Pond
Bog Meadow Pond
WEST POINT MILITARY RESERVATION
Old West Point
Brook
Eagle Cliff 1443'
Jim's Pond Road
293
Wilkins Pond
Little Bog Meadow Reservoir
Round Pond
Fo
Other
1 km
1 mile
1 inch equals 0.35
1995 map by F. Schuster and T. Murray, ad
74°00'00"

Appendix 2.



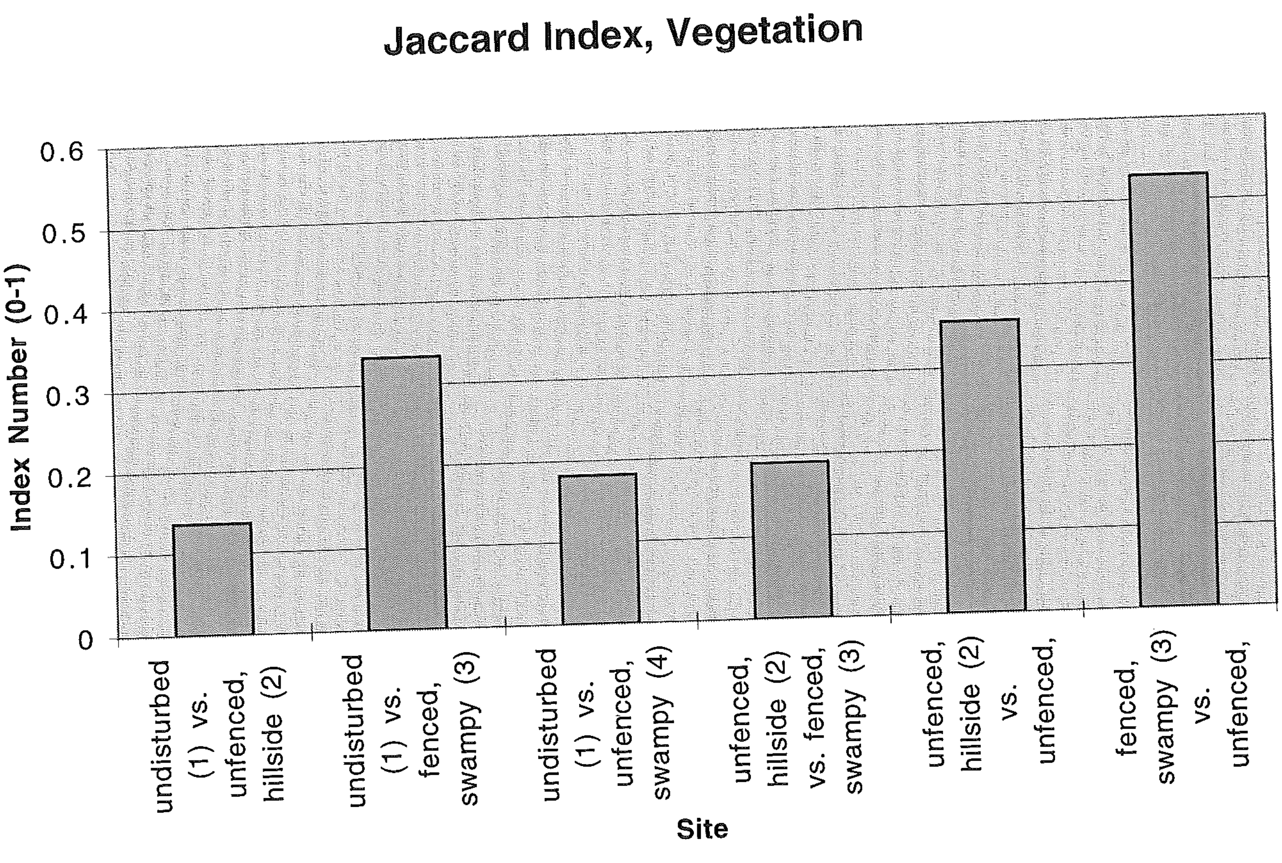
Time Since Clearcut and Overall Species Richness
40
35
30
25
20
15
10
5
0
100
68
25
11
11
Avg/sample
Total/site

Figure #1



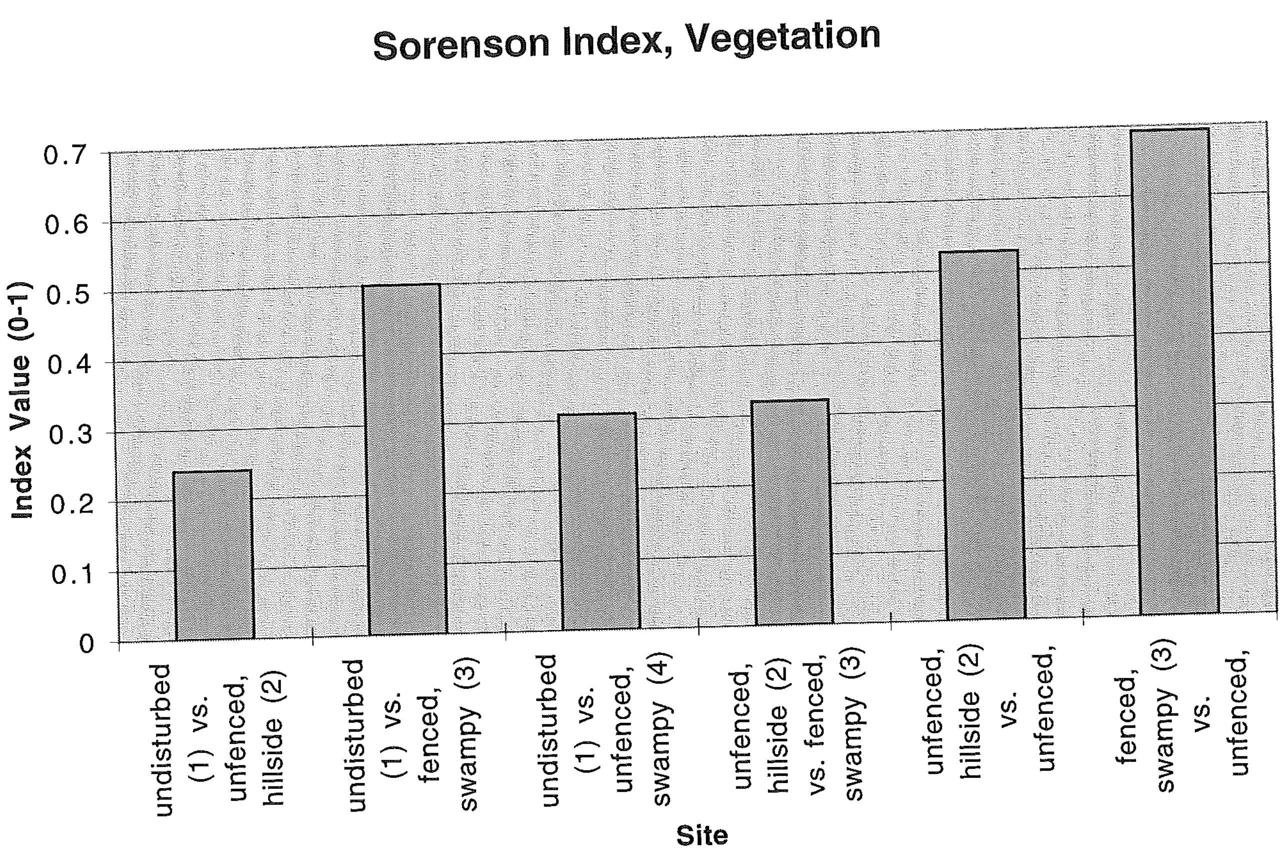
Vegetation, Species Richness
16
9
16
10
16
14
12
10
8
6
4
2
0
Number of Species
undisturbed (site 1)
hillside, unfenced (site 2)
swampy, fenced (site 3)
swampy, unfenced (site 4)
Site

Figure #2



Jaccard Index, Vegetation
Index Number (0-1)
0.6
0.5
0.4
0.3
0.2
0.1
0
undisturbed (1) vs. unfenced, hillside (2)
undisturbed (1) vs. fenced, swampy (3)
undisturbed (1) vs. unfenced, swampy (4)
unfenced, hillside (2) vs. fenced, swampy (3)
unfenced, hillside (2) vs. unfenced,
fenced, swampy (3) vs. unfenced,
Site

Figure #3



Sorenson Index, Vegetation
Index Value (0-1)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
undisturbed (1) vs. unfenced, hillside (2)
undisturbed (1) vs. fenced, swampy (3)
undisturbed (1) vs. unfenced, swampy (4)
unfenced, hillside (2) vs. fenced, swampy (3)
unfenced, hillside (2) vs. unfenced,
fenced, swampy (3) vs. unfenced,
Site

Figure #4

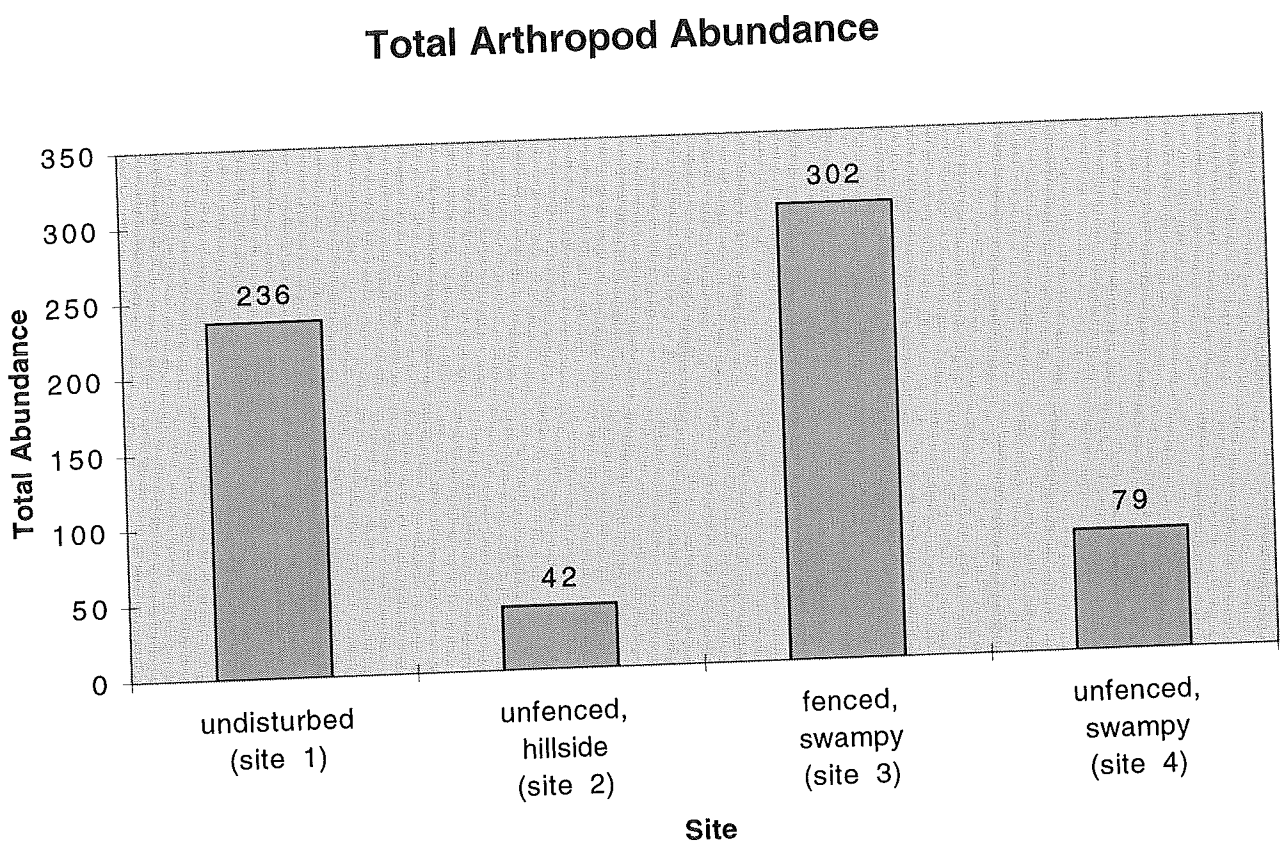
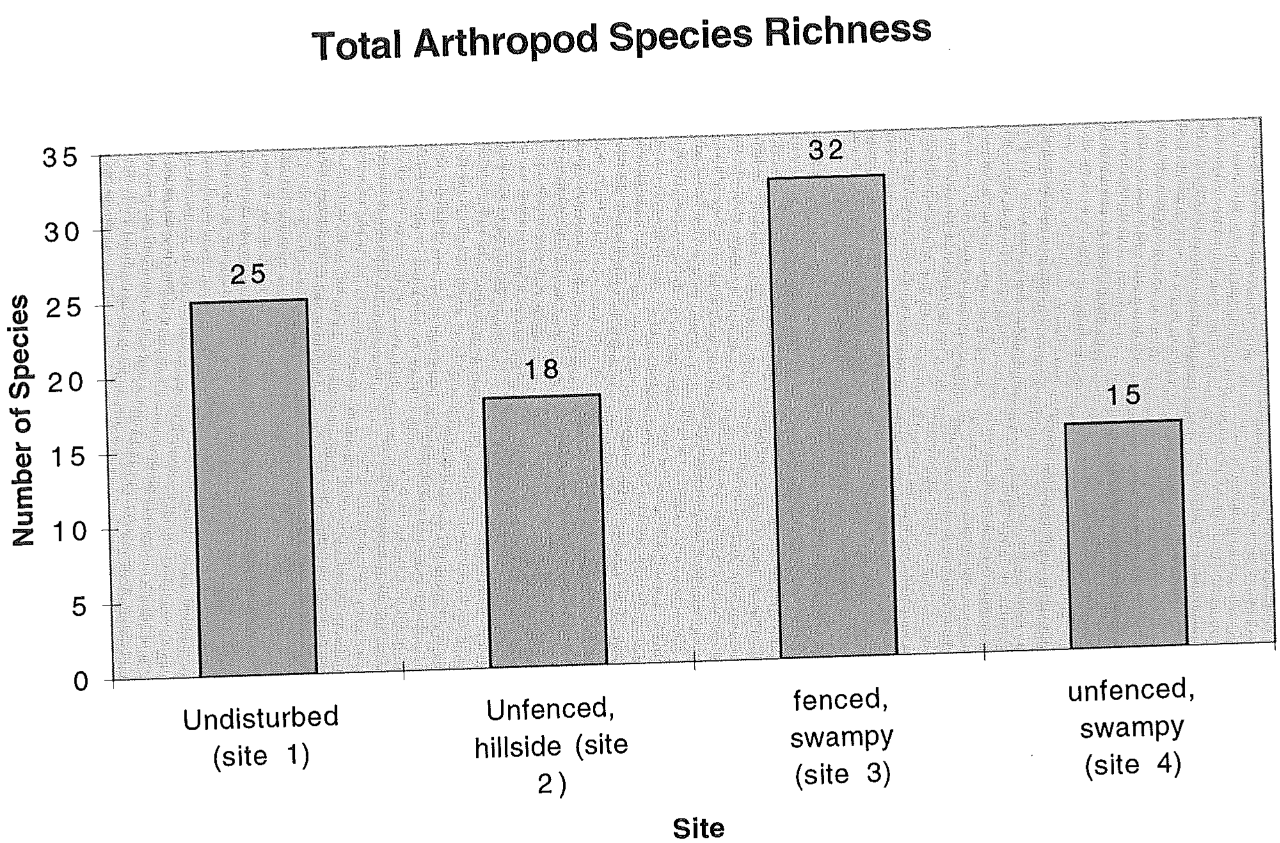

Total Arthropod Abundance
Total Abundance
350
300
250
200
150
100
50
0
236
42
302
79
undisturbed (site 1)
unfenced, hillside (site 2)
fenced, swampy (site 3)
unfenced, swampy (site 4)
Site

Figure #5



Total Arthropod Species Richness
35
30
25
20
15
10
5
0
Number of Species
25
18
32
15
Undisturbed (site 1)
Unfenced, hillside (site 2)
fenced, swampy (site 3)
unfenced, swampy (site 4)
Site

Figure #6

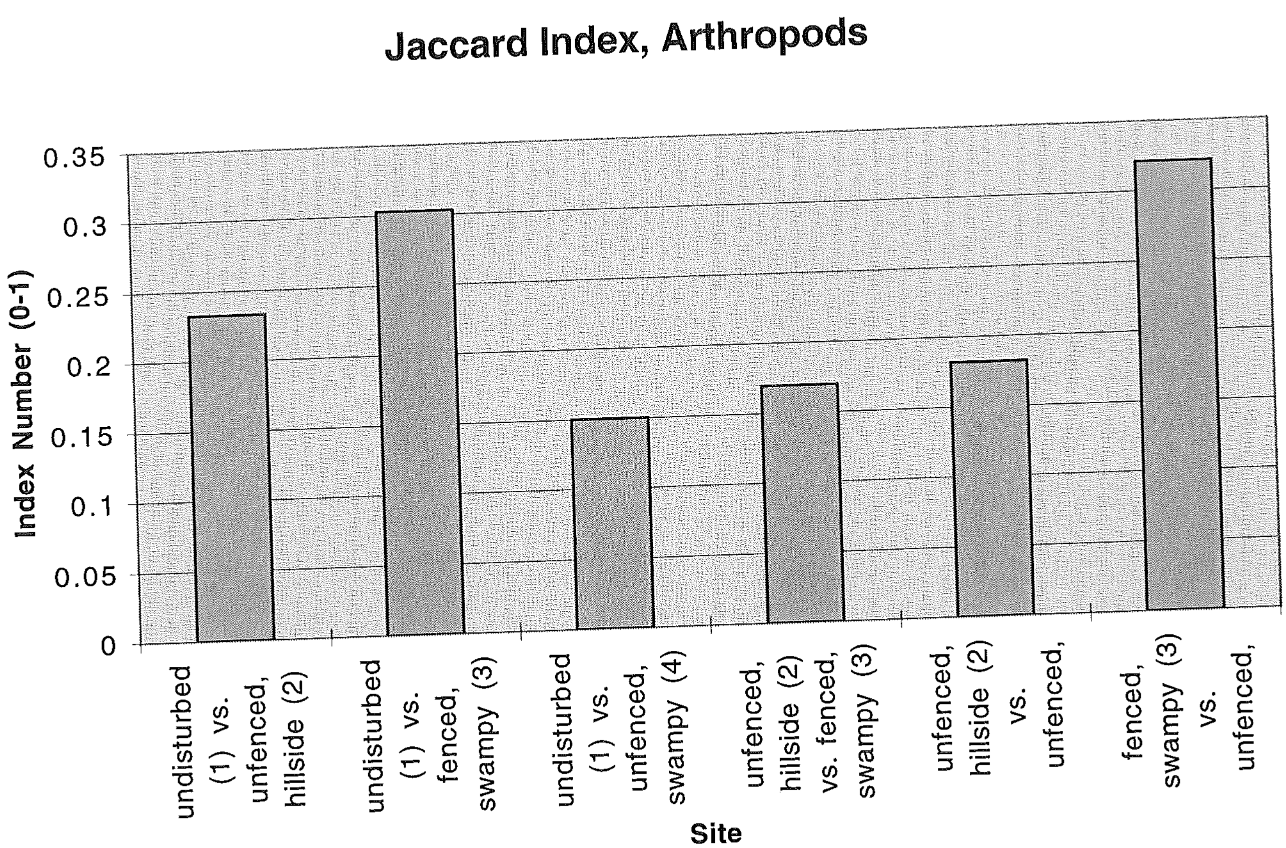

Jaccard Index, Arthropods
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Index Number (0-1)
undisturbed (1) vs. unfenced, hillside (2)
undisturbed (1) vs. fenced, swampy (3)
undisturbed (1) vs. unfenced, swampy (4)
unfenced, hillside (2) vs. fenced, swampy (3)
unfenced, hillside (2) vs. unfenced,
fenced, swampy (3) vs. unfenced,
Site

Figure #7

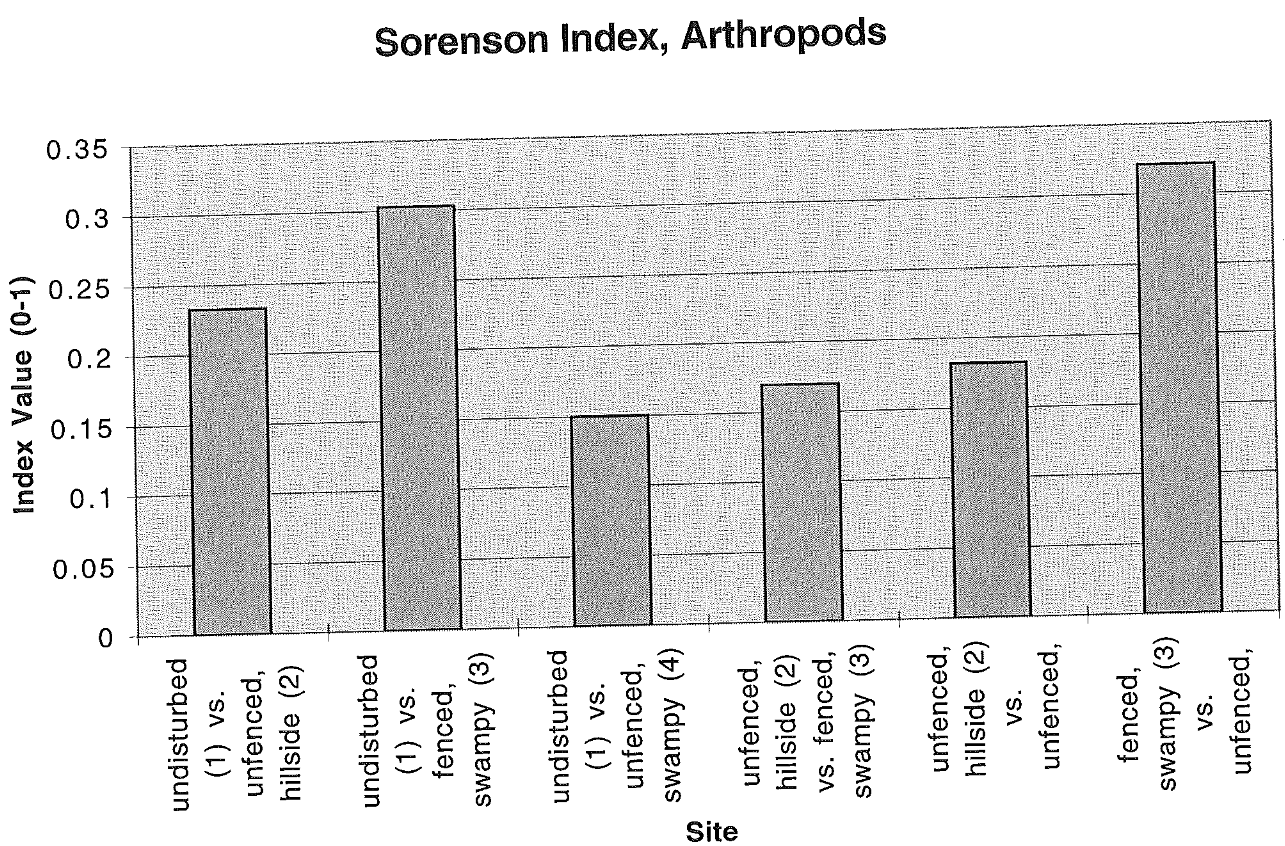
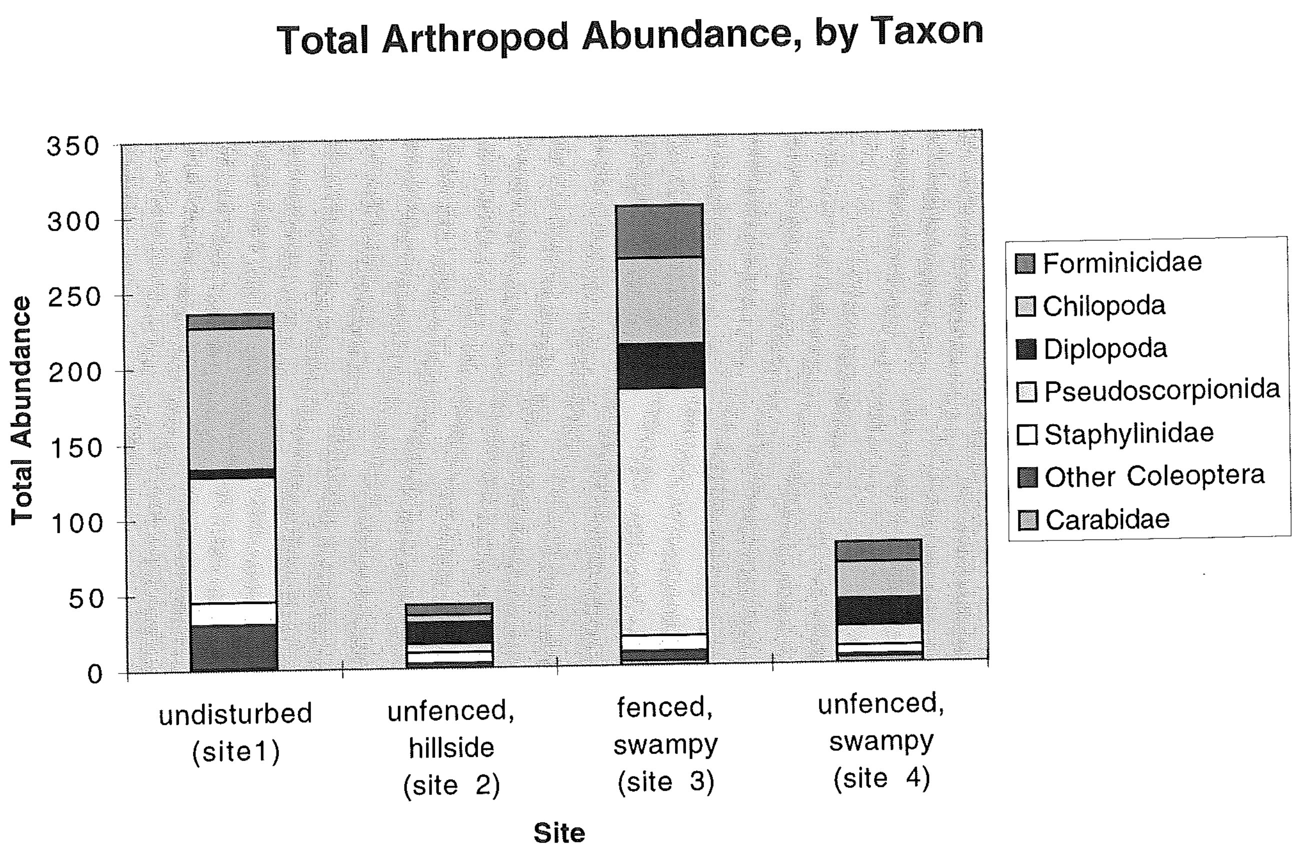
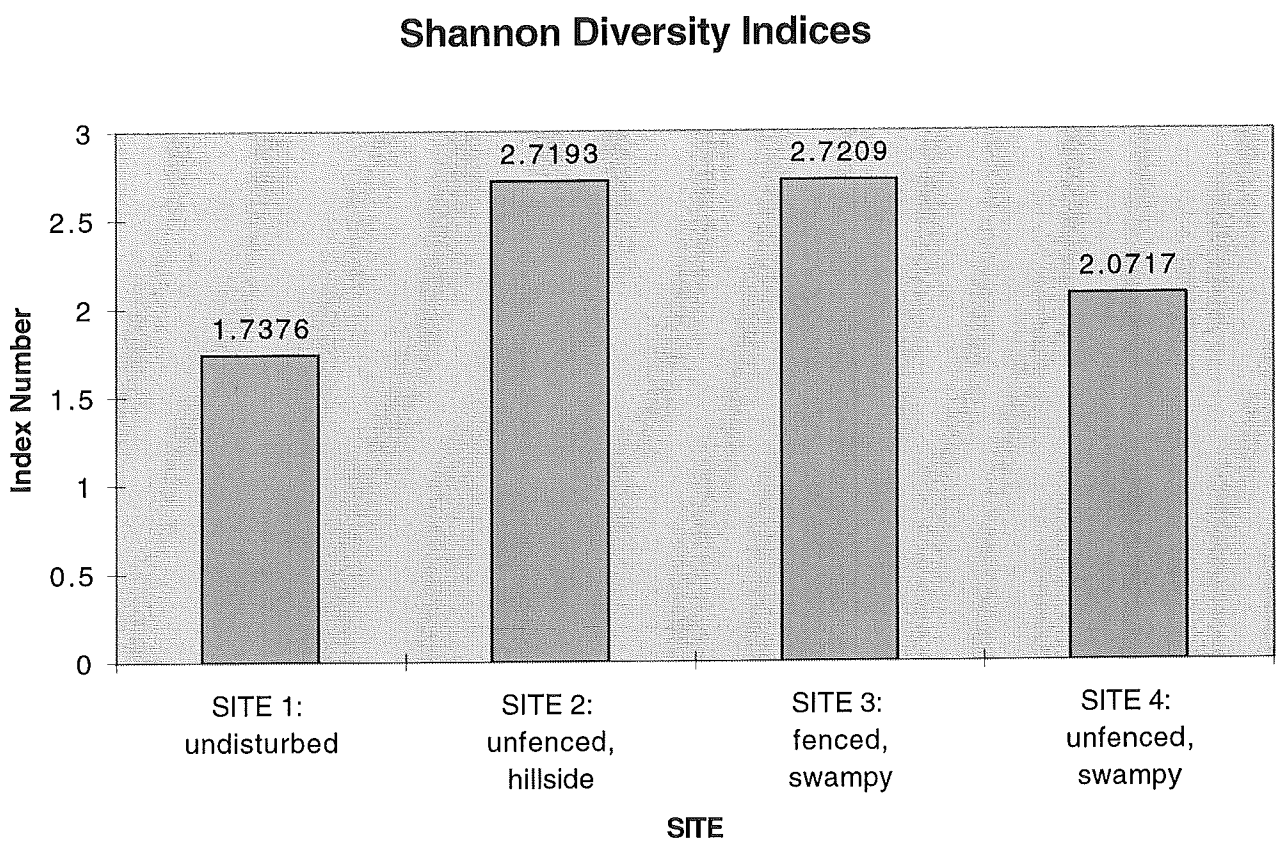

Sorenson Index, Arthropods
Index Value (0-1)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
undisturbed (1) vs. unfenced, hillside (2)
undisturbed (1) vs. fenced, swampy (3)
undisturbed (1) vs. unfenced, swampy (4)
unfenced, hillside (2) vs. fenced, swampy (3)
unfenced, hillside (2) vs. unfenced,
fenced, swampy (3) vs. unfenced,
Site

Figure #8



Total Arthropod Abundance, by Taxon
Total Abundance
350
300
250
200
150
100
50
0
undisturbed (site1)
unfenced, hillside (site 2)
fenced, swampy (site 3)
unfenced, swampy (site 4)
Site
Forminicidae
Chilopoda
Diplopoda
Pseudoscorpionida
Staphylinidae
Other Coleoptera
Carabidae

Figure #9



Shannon Diversity Indices
Index Number
3
2.5
2
1.5
1
0.5
0
2.7193
2.7209
2.0717
1.7376
SITE 1: undisturbed
SITE 2: unfenced, hillside
SITE 3: fenced, swampy
SITE 4: unfenced, swampy
SITE

Shannon Diversity t-test, Table 1

SITE 1	SITE 2	
H'= 1.7376	H'= 2.7193	**DOF = 110.6554988**
Var (H')= 0.00739	Var (H')= 0.0107	**t = 7.298935193**
N= 236	N= 42	**p= 4.80703E-11**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity

SITE 1	SITE 3	
H'= 1.7685	H'= 2.7209	**DOF = 261.6404401**
Var (H')= 0.00739	Var (H')= 0.0004	**t = 10.79072582**
N= 236	N= 302	**p= 1.09124E-22**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity

SITE 1	SITE 4	
H'= 1.7685	H'= 2.0717	**DOF = 171.7180406**
Var (H')= 0.00739	Var (H')= 0.01353	**t = 2.096275492**
N= 236	N= 79	**p= 0.037529602**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity

SITE 3	SITE 4	
H'= 2.7209	H'= 2.0717	**DOF = 83.72100768**
Var (H')= 0.0004	Var (H')= 0.01353	**t = 5.500509929**
N= 302	N= 79	**p= 4.10136E-07**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity

Shannon Diversity t-test, Table 1

SITE 2	SITE 4	
H'= 2.7193	H'= 2.0717	**DOF = 116.4132592**
Var (H')= 0.0107	Var (H')= 0.01353	**t = 4.160352536**
N= 42	N= 79	**p= 6.12294E-05**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity

SITE 2	SITE 3	
H'= 2.7193	H'= 2.7209	**DOF = 45.1900991**
Var (H')= 0.0107	Var (H')= 0.0004	**t = 0.015186528**
N= 42	N= 302	**p= 0.987950502**

If $t_{calc} > t_{tab}$ at p=0.05 level reject H_0 that 2 sites have same diversity