An analysis of effects of habitat structure on the ground beetle (Coleoptera: Carabidae) communities of two sites in eastern Massachusetts, USA

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Abstract

Changes in arthropod diversity are often at the center of ecological problems. Arthropods, due to their small size and different body structures, are more sensitive to environmental factors than vertebrates and must be studied separately. For this project two proximate but different sites in eastern Massachusetts were chosen: the Groton Forest located in the inland town of Groton and the Boston Harbor Islands National Recreation Area (BHI). Five habitat variables' effects on ground beetle (Coleoptera: Carabidae) diversity were studied in an attempt to observe how the habitat factors influenced the Carabidae community and to see how the beetle populations differed in the two areas. Four islands were chosen from the BHI, and I measured all the habitat factors at each of the plots, in which pitfall traps were set to capture ground beetles. The data showed that while the Carabidae diversity was richer on the Islands, the populations were more equitably distributed at the Groton site. In the two areas, three genera emerged as possible keystone genera and showed hints of competition. Results from this research were consistent with aspects of the theory of island biogeography and although further research is necessary, this research raises questions about the ecology of isolated ecosystems, how they respond to habitat alteration, and the ways in which different communities within one system affect each other.

Introduction

Overview

The global loss of biodiversity associated with habitat alteration is well-documented and of pressing concern. While the losses are frequently less publicized than those of other taxa, changes in arthropod diversity are often at the center of ecological problems. For instance, the eastern states of the United States have been suffering from the invasion of Asian Long-horned beetles which have been decimating populations of deciduous hardwood trees, in a manner similar to so many other changes to forest systems associated with alien species. Changes in the honeybee and other major pollinator communities may have economic repercussions and may make the conservation of flowering plants more difficult. Arthropods, because of their size and radically different body structures, are most likely affected in different ways by habitat factors than most vertebrates, and thus, in order to understand and preserve arthropod diversity, it is essential to study how various micro-scale factors affect arthropods.

Study Area

Two sites in eastern Massachusetts were selected for study. The Groton Forest located in the inland town of Groton, Massachusetts and the Boston Harbor Islands near Boston, Massachusetts are located within 70 km of each other and have similar forested communities. Despite their proximity to each other, there are significant factors which distinguish the two areas. The Boston Harbor Island habitats are isolated from the larger habitat areas on the mainland, may have perennially wetter conditions, and provide habitat types not found in the inland systems, including beach habitats and estuarine systems. This may affect ground beetle populations, as Petillon's research has suggested that salinity affects ground beetle diversity [1].The mainland Groton Forest habitats provide more abundant and diverse freshwater habitats, including wetlands and flowing water systems which are less abundant in island habitats. Comparing these two areas would allow a study of the theory of island biogeography, which states in part that isolated masses of land – not necessarily true islands – exhibit populations that are different from lands more connected to the mainland. [2, 3]

Natural History of Groups Studied

In comparing habitats, arthropods provide valuable data because of their importance to ecosystem functions [4]. They occupy all heterotrophic levels and thus have important roles in the nutrient flow of the environment [5]. Among the arthropods, the Coleoptera (beetles) represents the largest order, accounting for about 25% of all currently described species of animals [6]. Beetles have proven to be useful in assessing the environment and habitats not only because they are sensitive to environmental conditions but also because communities are comprised of diverse species of beetles, which provide a detailed view of ecological changes [7]. Ground beetles (Coleoptera: Carabidae) have been shown to be especially sensitive to small changes in habitat conditions and thus are useful indicators for studies regarding alterations to habitats [8]. Ground beetles are mainly predatory and omnivorous with developed trochanters on their hind legs that allow more rapid running in members of the family. Most species have well developed mandibles suited for hunting and killing other invertebrates, although most are omnivorous and will feed on carrion or plant matter [9].

Although the majority of species have fully developed wings capable of flight, adult ground beetles are rarely seen or captured in flight but are most commonly observed and collected on the ground or on plants [10]. Thus, the best trap to capture specimens of the Carabidae family is the pitfall trap, which relies on the movement of the beetles to collect the necessary specimens [11].

Habitat Variables

Of the numerous and various habitat factors that can affect Carabidae populations, five are of great significance: dominant plant type, ground coverage by rocks and logs, soil type, dominant litter type, and proximity to a body of water.

First, the structure and composition of the plant community would affect the populations of the herbivores in that area, which may, in turn, affect the population of the Carabidae that prey on those herbivores [12]. Thus, studying the types of plants present in the area could give insight into the predacious Carabidae populations in the studied zone.

Because Carabidae are ground-dwelling beetles with most adults spending a majority of their lives on, near, or under the ground surface, studying the soil and top litter type is imperative in researching ground beetle population and their habitats since it has been demonstrated that Carabidae respond to conditions in the soil and litter layers [13-15].

The amount of coverage from rocks and logs on the ground can also impact the Carabidae populations. Rocks and logs serve two purposes; they act as shelters from the environment for the beetles as well as a hiding spot from which the carnivorous Carabidae can hunt for prey [4]. Although it is feasible that logs and rocks present different types of shelter for the beetles, grouping the two together is reasonable for this general research.

The final factor to consider is the proximity of surface water to the pitfall trap site. Various studies have shown that moisture content in the soil affects the composition of ground beetle populations [1, 16, 17]. However, it is difficult to measure soil moisture on site because moisture measurements vary over time. Distance to water from the trap may provide a reasonable indicator of the moisture levels at the sites.

Community Structure and Island Biogeography

Although all four of the islands studied are less than ten miles from shore, it is still a significant distance for many terrestrial animals to cross. Thus, there are probably fewer small mammals and other vertebrates on the Islands, which would create different animal – and most likely, plant – communities in the two areas studied. With the smaller abundance of mammals on the Islands, it is also likely that there are fewer predators that prey on beetles, such as rodents and insectivores, which would greatly affect the population of ground beetles.

Purpose and Hypothesis

The main goal of this research is to evaluate environmental factors that are significant to Carabidae distributions, and to compare these factors in two geographically distinct areas.

Because the two areas' habitats are similar, at least in the five factors that I studied, I can group all the plots in both areas into six groups according to their habitat factors. Thus, each plot in the two areas can be labeled as one of six groups depending on its habitat structure. By doing this, I can observe the effects that the five habitat factors and their various combinations would have on the ground beetle populations in the two areas studied. I can also confirm whether the factors have similar effects in the two distinct areas.

The two areas do exhibit some differences as well. The relative isolation of the Islands has also contributed to the differences in community structures as compared to the Groton Forest. Thus, it is likely that the two areas would exhibit differences in the Carabidae population, with the Islands exhibiting a greater diversity of Carabidae due to the relative lack of natural predation and a different community structure because of disparities in biotic and abiotic factors.

Methods and Materials

Site Description

The four islands I chose are all a part of the Boston Harbor Islands National Recreation Area, which is made up of a series of islands and peninsulas within the Boston Harbor area. Of the numerous islands, I chose Thompson, Grape, Spectacle, and Bumpkin, as the four islands are similarly distanced from the shore, and are all connected by the same ferry which would reduce possible bias from isolation of the islands. All four islands are less than 10 km from the mainland (Figure 1).

Thompson Island (68.8 hectares) is the largest island of the ones sampled in this research. The island is highly developed with numerous camping sites and maintained trails and fields, as a result of heavy use since the Colonial times. The vegetation on the island consists of a mix of hardwoods, remnants of orchards, shrubs, open meadows, grass fields, and salt marsh grasses.

Bumpkin Island (25.1 hectares) was heavily farmed during the Colonial period and used as a camping ground as late as the Second World War. Trails are developed and well maintained, although not to the extent as is found on Thompson Island. The vegetation on Bumpkin Island consists mainly of early successional trees, shrubs, and vines that reflect the landscape's reversion from gardens and lawns in the early 1900's.

Grape Island (40.9 hectares) was farmed and grazed until the 1940's. It is the least developed of the four islands studied in this research. The vegetation on Grape Island consists of early successional trees and shrubs while salt-tolerant species dominate the marshy lowlands.

Spectacle Island (46.1 hectares) is different from the other three islands because it is a naturally formed island that was modified significantly by the waste materials from the Big Dig project. It is extremely highly developed and is most frequented by visitors. The vegetation is dominated by newly planted deciduous and coniferous trees, as well as grass in meadows. [18]

Figure 1. Boston Harbor Islands off the coast of eastern Massachusetts

The Groton Forest (Figure 2 and Figure 3) is a 410 hectare forest that was cleared in the 18th century for farming purposes and then abandoned after the American Civil War. After a period of heavy logging in the early 20th century, the forest was repopulated by a mix of pine, oak and other deciduous trees. Now, the forest would be characterized as a late successional forest with various levels of disturbance in some areas [19, 20].

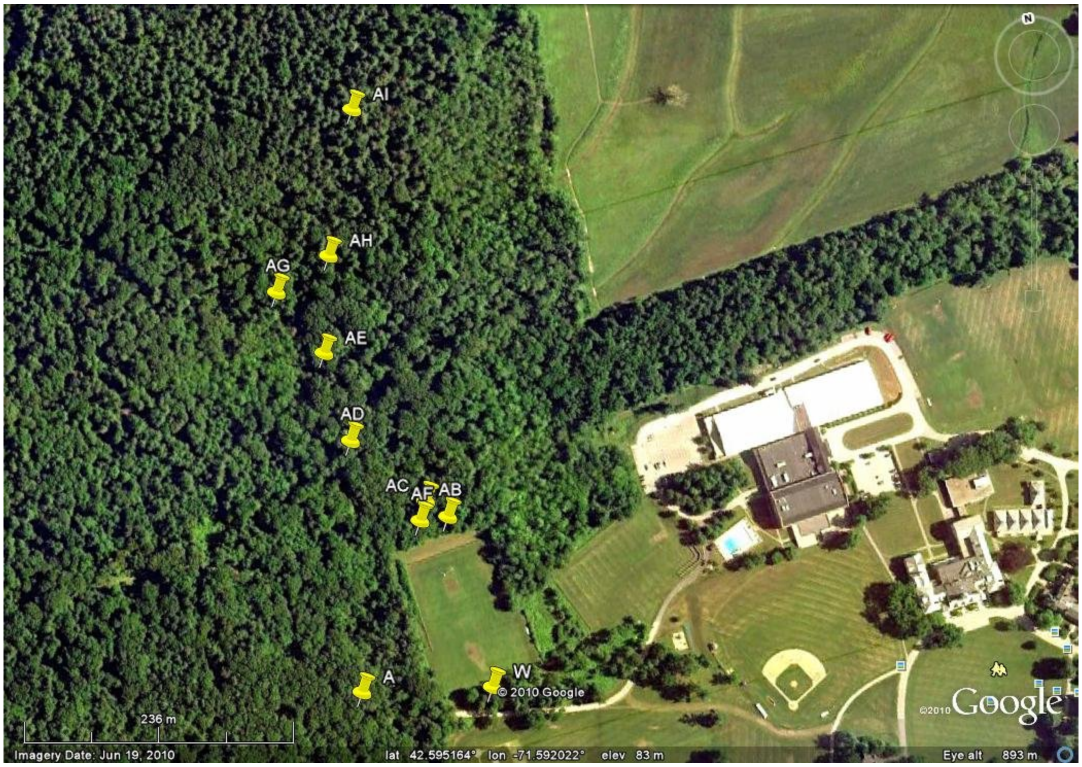

Figure 2. Groton School (North)

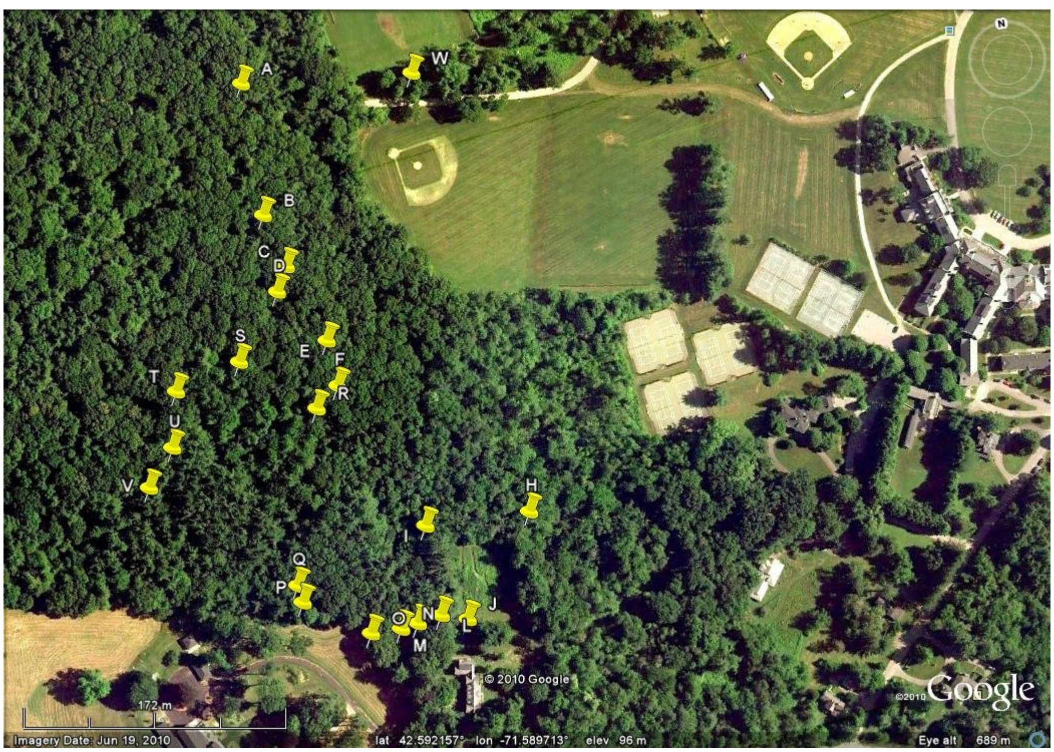

Figure 3. Groton School (South)

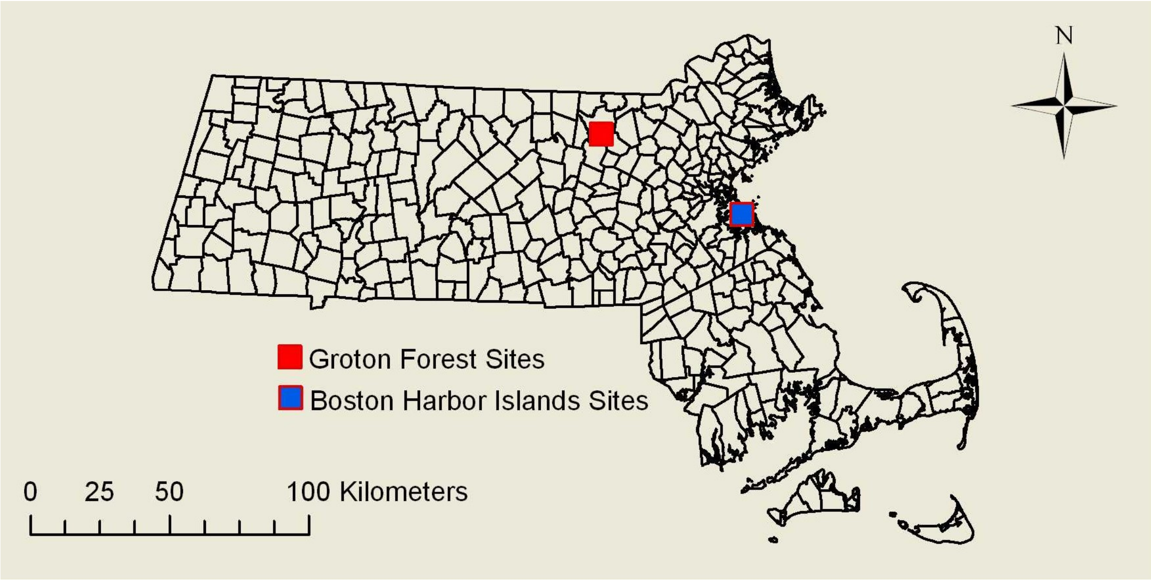

Figure 4. The two areas in relation to the state of Massachusetts, United States of America

Specimen Collection, Preservation, and Identification

I selected 19 plots on the Boston Harbor Islands and 29 plots in the Groton Forest to study. Most of the plots were located within 15 m from trails both for convenient access and as an attempt to reduce bias from different levels of human disturbance, as research has shown that simple disturbances, such as humans walking near a trap, can affect the number of specimens of crickets (Orthoptera: Grylloidea) caught and may affect the capture rate of other arthropods as well [21].

At each of the plots, I set a pitfall trap. For each trap, I used a plastic cup (9.0 cm diameter, 12.0 cm deep) that was buried underground with the rim even with the surface and contained antifreeze (propylene glycol) as preservatives. I also placed a red plastic dish at an angle above the cup to prevent water from entering the cup and diluting the content in case of rain. The traps were set at least 10 m apart and usually much farther, since 10 m has been suggested as the minimum distance that would avoid interference among traps [22]. The traps were checked weekly except in a few cases where the weather made it difficult. In both areas – on the Boston Harbor Islands and in the Groton forest – the traps were set and collected from May to October.

The specimens were either pinned or stored in vials as necessary. Pinned specimens were stored in storage drawers. For those stored in alcohol, the specimens collected on the Boston Harbor Islands were stored in 95% ethanol whereas the specimens collected in the Groton Forest were stored in 91% isopropyl alcohol.

Finally, the specimens were identified to genus using dichotomous keys in Torre-Bueno (1937) [23], Borror, Triplehorn, and Johnson (1989) [9], Downie and Arnett (1996) [24], Arnett and Thomas (2001) [13], and Marshall (2006) [6].

Habitat Survey

I collected the habitat data during the summer of 2010 either at the time the trap was set or in one of the later trips to collect the traps. Each of the plots were characterized using the five habitat characters (dominant plant type; dominant soil type; dominant top litter type; coverage by rocks and/or logs; and proximity of a body of water to the trap), some of which were used in S.A Lassau's research [4]. The first four factors were measured in a circular area of radius 3 m with the pitfall trap as the center, while the fifth factor was measured using a tape measure. Each habitat factor was divided into three categories in order to categorize each plot. Dominant plant type was divided into woody plants, non-woody vascular plants, or no dominance. Rock and log coverage was divided into less than 10%, between 10% and 25%, and over 25%. Dominant top litter type was divided into broad leaf litter, conical leaf litter, and other litter. Dominant soil type was divided into sand, clay, and gravel. Finally, proximity to nearest water body, either saltwater or freshwater, was divided into less than 5 m, between 5 and 15 m, and over 15 m. The 48 plots sampled in the two areas were all categorized into six habitat groups according to their habitat factor characterizations. Thus, all plots with same habitat characters were grouped together in their respective areas.

Results and Analysis

Overall

A total of 87 individual ground beetles and 8 genera were captured in the Groton Forest site at 29 plots during roughly 80 days of trapping from mid-May to mid-September. 2342 individuals from 30 genera were collected from the Boston Harbor Islands at 19 plots over a period of about 90 days of trapping from May to October. While the intensity of the effort was slightly greater on the Islands, captures per day were still significantly higher on the Islands than they were in the Groton Forest (approximately 1 for the Groton Forest and over 26 for the Boston Harbor Islands).

In order to compare the diversities of ground beetles in the two areas, two diversity measurements were used: generic richness (total number of genera) and Shannon-Weiner diversity (measurement of the balance in abundance among the genera present). Over its 29 plots, the Groton Forest area displayed a mean generic richness of 1.1 $\pm$ 0.20 (mean $\pm$ S.E) and mean Shannon-Weiner diversity of 1.0 $\pm$ 0.17 (mean $\pm$ S.E). Over its 19 plots, the Boston Harbor Islands area displayed a mean generic richness of 6.9 $\pm$ 0.50 (mean $\pm$ S.E) and mean Shannon-Weiner diversity of 3.7 $\pm$ 0.38 (mean $\pm$ S.E).

Habitat Variables and Diversity

Table 1 shows the effects of the habitat variables on the mean generic richness (mean $\pm$ S.E.) at the trapping locations and lists the most common genera collected at plots within each habitat factor. Plots on the Boston Harbor Islands displayed higher levels of generic richness under all habit variables. *Sphaeroderus* is clearly the dominant genus at Groton School.

Habitat Descriptor	Mean Generic Richness per Plot		Dominant Genera	
	Groton	*BHI	Groton	*BHI
Dominant Plant				
Woody Plants	1.0 ± 0.46 (8 plots)	6.5 ± 3.5 (2 plots)	*Sphaeroderus*	*Pterostichus*
Vascular Non-Woody	1.1 ± 0.24 (17 plots)	7.2 ± 0.50 (15 plots)	*Sphaeroderus*	*Amara*
No Dominance	1.5 ± 0.40 (4 plots)	5.5 ± 1.5 (2 plots)	*Bembidion*	*Apristus*
Rock/Log Coverage				
<10% of Area	0.9 ± 0.23 (10 plots)	7.1 ± 0.50 (10 plots)	*Sphaeroderus*	*Harpalus*
>10%, <25% of Area	1.4 ± 0.37 (10 plots)	7.3 ± 0.21 (6 plots)	*Sphaeroderus*	*Amara*
>25% of Area	1.1 ± 0.42 (9 plots)	5.7 ± 2.2 (3 plots)	*Sphaeroderus*	*Apristus*
Dominant Litter				
Broad Leaf	1.1 ± 0.22 (20 plots)	6.8 ± 0.95 (6 plots)	*Sphaeroderus*	*Pterostichus*
Conifer Leaf	0 (0 plots)	0 (0 plots)	**NA	**NA
Other Litter	1.3 ± 0.41 (9 plots)	7.0 ± 0.62 (13 plots)	*Sphaeroderus*	*Amara*
Dominant Soil				
Sand	2.00 (1 plot)	4.00 (1 plot)	*Bembidion*	*Apristus*
Clay	1.1 ± 0.20 (28 plots)	7.1 ± 0.50 (18 plots)	*Sphaeroderus*	*Amara*
Gravel	0 (0 plots)	0 (0 plots)	**NA	**NA
Proximity of Water				
<5 m from Trap	2.00 (1 plot)	4.00 (1 plot)	*Bembidion*	*Apristus*
>5 m, <15 m from Trap	0 (0 plots)	0 (0 plots)	**NA	**NA
>15 m from Trap	1.1 ± 0.20 (28 plots)	7.1 ± 0.50 (18 plots)	*Sphaeroderus*	*Amara*

Table 1. Ground beetle data at each habitat descriptor
(*BHI: Boston Harbor Islands, **NA: Not Applicable because there were no plots)

Table 2 compares the study sites as a whole. Plots dominated by non-woody plants supported more diverse ground beetle communities than plots with other types of plant cover. Plots with less coverage by logs and rocks supported a more diverse community on the BHI sites, with no large differences for the Groton Forest area. Finally, plots with broadleaf litter supported a less diverse community on the Islands, with no difference at Groton. Because only one trap at each area was set where the soil was sandy and there was a body of water within 5 m, the effects of the two variables were difficult to assess. The different numbers of sampled plots within each habitat descriptor also makes it problematic to determine the effects of the habitat factors on the ground beetle population.

Habitat Descriptor	Total Number of Genera Collected	
	Groton	*BHI
Dominant Plant		
Woody Plants	4 (8 plots)	11 (2 plots)
Vascular Non-Woody	6 (17 plots)	26 (15 plots)
No Dominance	5(4 plots)	11 (2 plots)
Rock/Log Coverage		
<10% of Area	4 (10 plots)	24 (10 plots)
>10%, <25% of Area	6 (10 plots)	17 (6 plots)
>25% of Area	5 (9 plots)	14 (3 plots)
Dominant Litter		
Broad Leaf	7 (20 plots)	16 (6 plots)
Other Litter	7 (9 plots)	23 (13 plots)
Dominant Soil		
Sand	2 (1 plot)	4 (1 plot)
Clay	7 (28 plots)	29 (18 plots)
Proximity of Water		
<5 m from Trap	2 (1 plot)	4 (1 plot)
>15 m from Trap	7 (18 plots)	29 (18 plots)

Table 2. Total number of genera collected within each habitat descriptor
(*BHI: Boston Harbor Islands)

Table 3 shows the six habitat groups that characterize all plots, along with the number of plots in each group in the two areas studied.

Group Code	Group Explanation	Number of Plots (*BHI)	Number of Plots (Groton)
1	Woody plants, more than 25% rock cover, broadleaf litter, clay, water more than 15 m away	2	8
2	Vascular non-woody plants, less than 10% rock cover, broadleaf litter, clay, water more than 15 m away	3	9
3	Vascular non-woody plants, less than 10% rock cover, other litter, clay, water more than 15 m away	7	1
4	Vascular non-woody plants, 10% to 25% rock cover, other litter, clay, water more than 15 m away	5	7
5	No dominant plant, 10% to 25% rock cover, broadleaf litter, clay, water more than 15 m away	1	3
6	No dominant plant, more than 25% rock cover, other litter, sand, water less than 5 m away	1	1

Table 3. Number of plots with each combination of habitat factors
on the Boston Harbor Islands and at Groton.
(*BHI: Boston Harbor Islands)

Figure 5 shows the average number of genera per plot for each habitat group shown in Tables 3. For the data, the total numbers of genera found in plots of each habitat group were divided by the numbers of plots in order to reduce the bias from uneven number of plots in each habitat group. While the Boston Harbor Islands plots exhibit a much greater average generic richness than the plots on Groton Forest do, Group 3 exhibits the lowest diversity in both areas while Group 5 has the highest diversity on the Islands and the second highest at Groton. This again suggests the positive effects of broadleaf litter on generic richness of the Carabidae family.

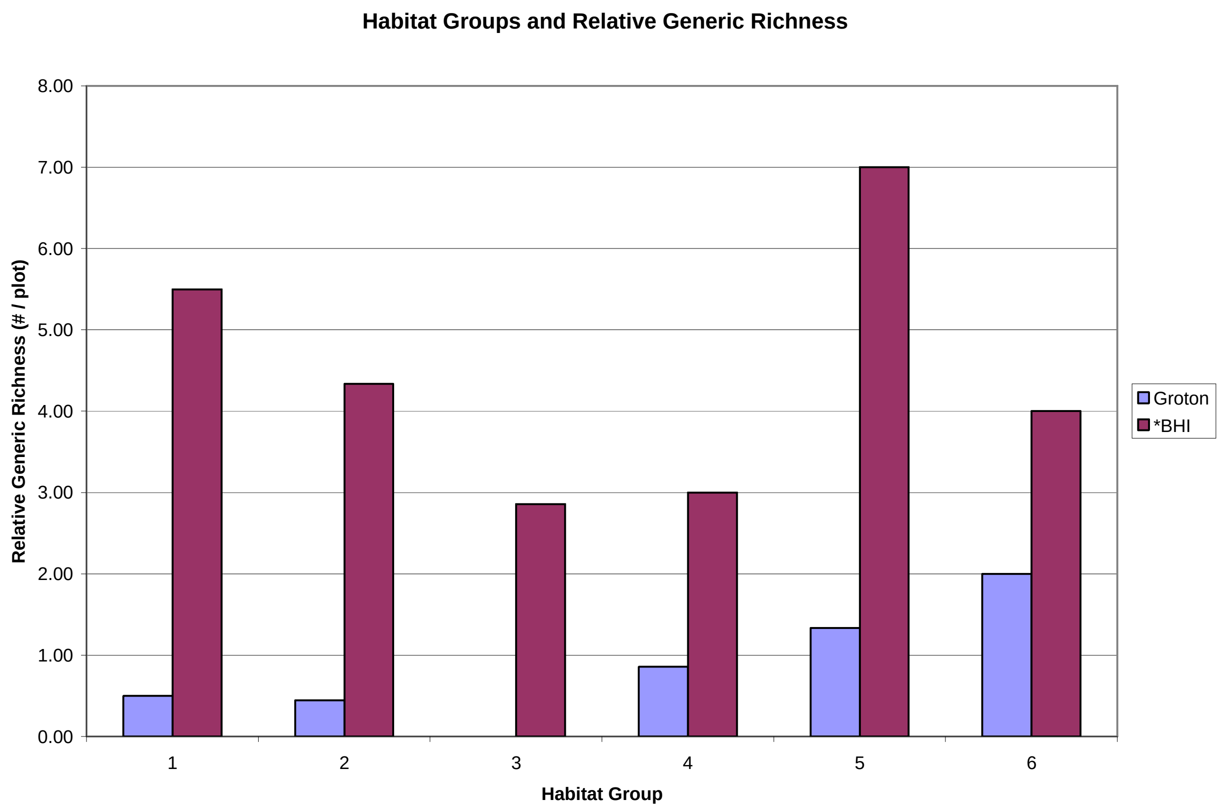

Figure 5. The six habitat groups and the relative generic richness in each group on the Boston Harbor Islands and in the Groton Forest
(*BHI: Boston Harbor Islands)

Keystone Genera in Studied Areas

The abundance of three genera, *Carabus* on both the Islands and at Groton, *Harpalus* on the Islands, and *Sphaeroderus* at Groton, showed possible correlations with generic richness and Shannon-Weiner diversity, suggesting that those genera may affect the populations of other ground beetles in the area. As this is one factor among many affecting these populations, the correlations proved to be somewhat weak.

Figure 6 suggests that the abundance of beetles in the genus *Carabus* has a possible negative correlation with both the generic richness and the Shannon-Weiner diversity, more notably on the Boston Harbor Islands. Although not statistically significant, this pattern suggests that *Carabus* beetles reduce diversity in their communities.

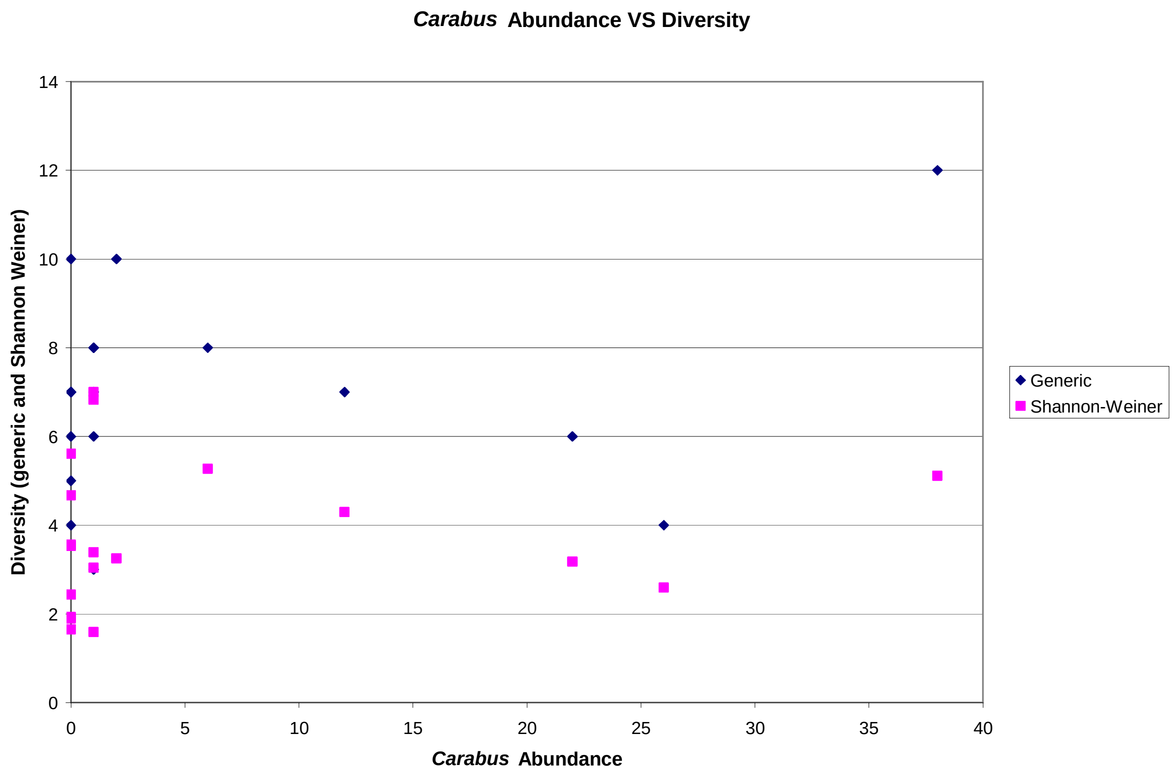

Figure 6. The relationship of *Carabus* density to generic richness and Shannon-Weiner diversity on Boston Harbor Island plots

The abundance of *Carabus* was further related to combinations of habitat variables as shown in Table 4. Group 3 habitats had the highest density (mean ± S.E) as well as the highest relative density of *Carabus* beetles. Relative density was calculated by taking the percentage of *Carabus* beetles among all ground beetles captured at the plots. The genus was most abundant in plots characterized by non-woody plants and less than 10% rock and log coverage.

Group Code	Group Explanation	*Carabus* density (individuals per plot)	*Carabus* relative density (%)
1	Woody plants, more than 25% rock cover, broadleaf litter, clay, water more than 15 m away	0.50 ± 0.50	1.20
2	Vascular non-woody plants, less than 10% rock cover, broadleaf litter, clay, water more than 15 m away	2.3 ± 1.9	4.22
3	Vascular non-woody plants, less than 10% rock cover, other litter, clay, water more than 15 m away	13 ± 6.0	6.88
4	Vascular non-woody plants, 10% to 25% rock cover, other litter, clay, water more than 15 m away	3.0 ± 2.3	2.43
5	No dominant plant, 10% to 25% rock cover, broadleaf litter, clay, water more than 15 m away	0	0
6	No dominant plant, more than 25% rock cover, other litter, sand, water less than 5 m away	0	0

Table 4. The effect of habitat variable combinations on the abundance of *Carabus* on Boston Harbor Island plots

Figure 7 suggests that there is a negative correlation between the coverage from rocks and logs of a plot and the *Carabus* abundance within that plot. Although not statistically significant, this pattern suggests that increased coverage by rocks and logs reduce *Carabus* abundance.

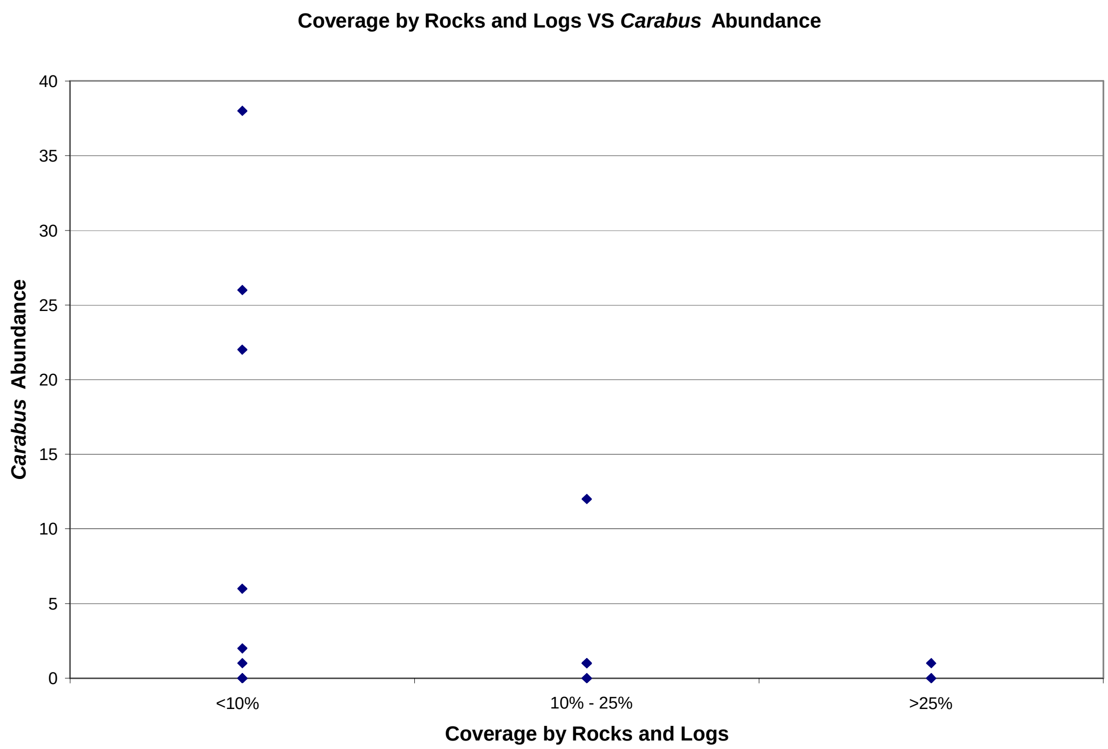

Figure 7. The relationship of rock and log coverage to *Carabus* abundance on the Boston Harbor Islands

Figure 8 suggests that the abundance of beetles in the genus *Harpalus* does not affect Shannon-Weiner diversity but may have a positive correlation with generic richness on the Boston Harbor Islands. Although not statistically significant, this pattern suggests that *Harpalus* beetles possibly increase diversity in their communities.

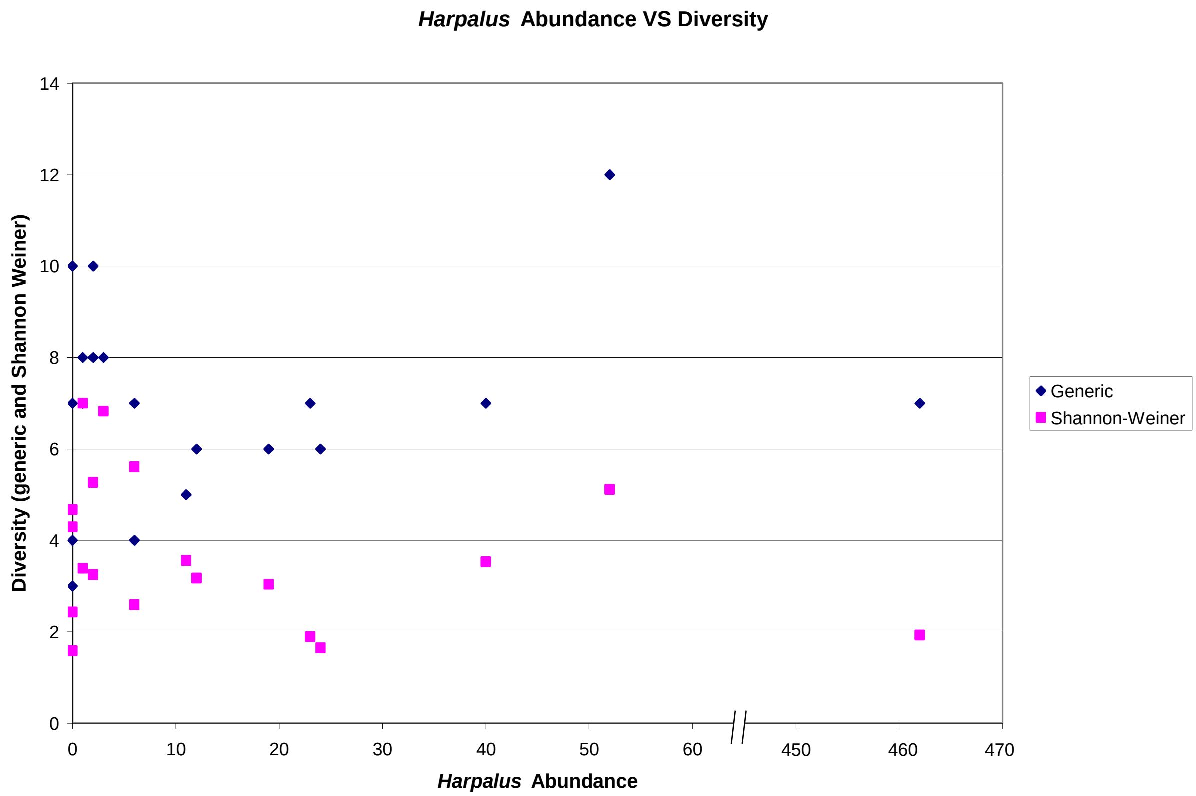

Figure 8. The relationship of *Harpalus* density to generic richness and Shannon-Weiner diversity on Boston Harbor Island plots

The abundance of *Harpalus* was further related to combinations of habitat variables as shown in Table 5. Group 3 habitats, dominated by non-woody plants, had the highest mean density (mean ± S.E) as well as the second highest relative density of *Harpalus* beetles. This suggests that both *Harpalus* and *Carabus* beetles prefer habitat group 3.

Group Code	Group Explanation	*Harpalus* density (individuals per plot)	*Harpalus* relative density (%)
1	Woody plants, more than 25% rock cover, broadleaf litter, clay, water more than 15m away	0	0
2	Vascular non-woody plants, less than 10% rock cover, broadleaf litter, clay, water more than 15m away	9.0 ± 5.1	16.3
3	Vascular non-woody plants, less than 10% rock cover, other litter, clay, water more than 15m away	81 ± 64	44.5
4	Vascular non-woody plants, 10% to 25% rock cover, other litter, clay, water more than 15m away	5.6 ± 4.4	4.54
5	No dominant plant, 10% to 25% rock cover, broadleaf litter, clay, water more than 15m away	40	47.1
6	No dominant plant, more than 25% rock cover, other litter, sand, water less than 5m away	0	0

Table 5. The effect of habitat variable combinations on the abundance of *Harpalus* on Boston Harbor Island Plots

Figure 9 suggests that there is a negative correlation between the coverage from rocks and logs of a plot and the *Harpalus* abundance within that plot. Although not statistically significant, this pattern suggests that increased coverage by rocks and logs reduce *Harpalus* diversity.

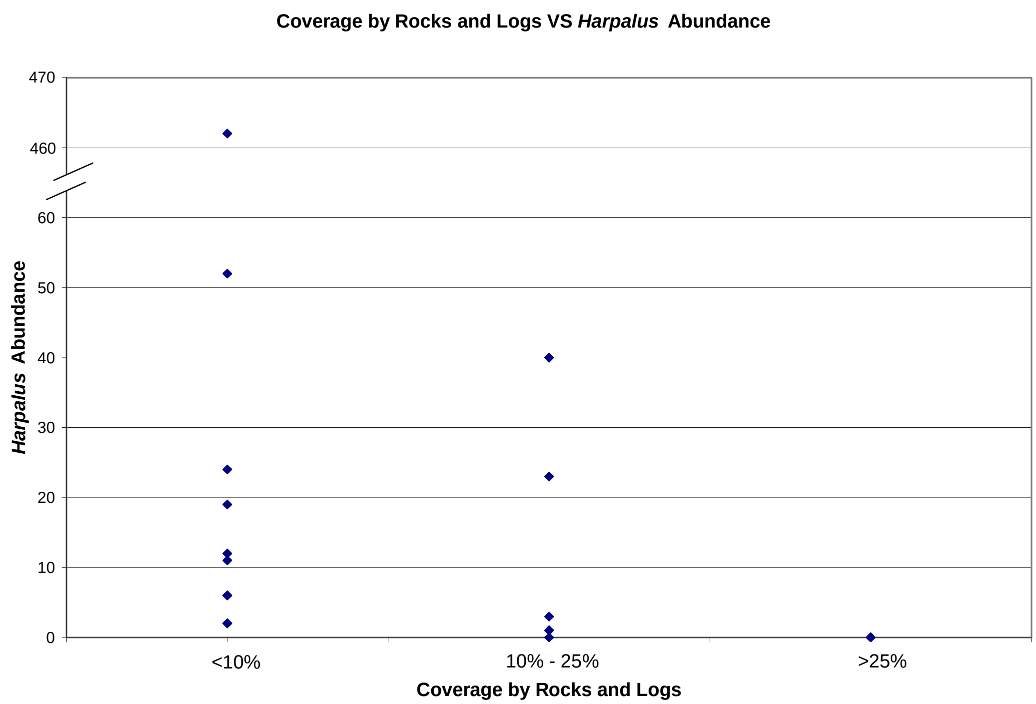

Figure 9. The relationship of rock and log coverage to *Harpalus* abundance on the Boston Harbor Islands

Figure 10 displays the population densities of *Carabus* and *Harpalus* in all nineteen plots on the Boston Harbor Islands. Of the seventeen plots on the Islands in which at least one of the two genera were captured, nine were inhabited by both genera. Of those nine, three exhibited the same abundance, three exhibited higher *Harpalus* populations, and three exhibited higher *Carabus* populations. With the exception of plot 12 in the graph, one genus dominates over the other in the plots in which there is a difference in population. The abundance of beetles of each genus is generally higher in plots where they exist by themselves (i.e. plots 9, 10, 14, 15, and 18).

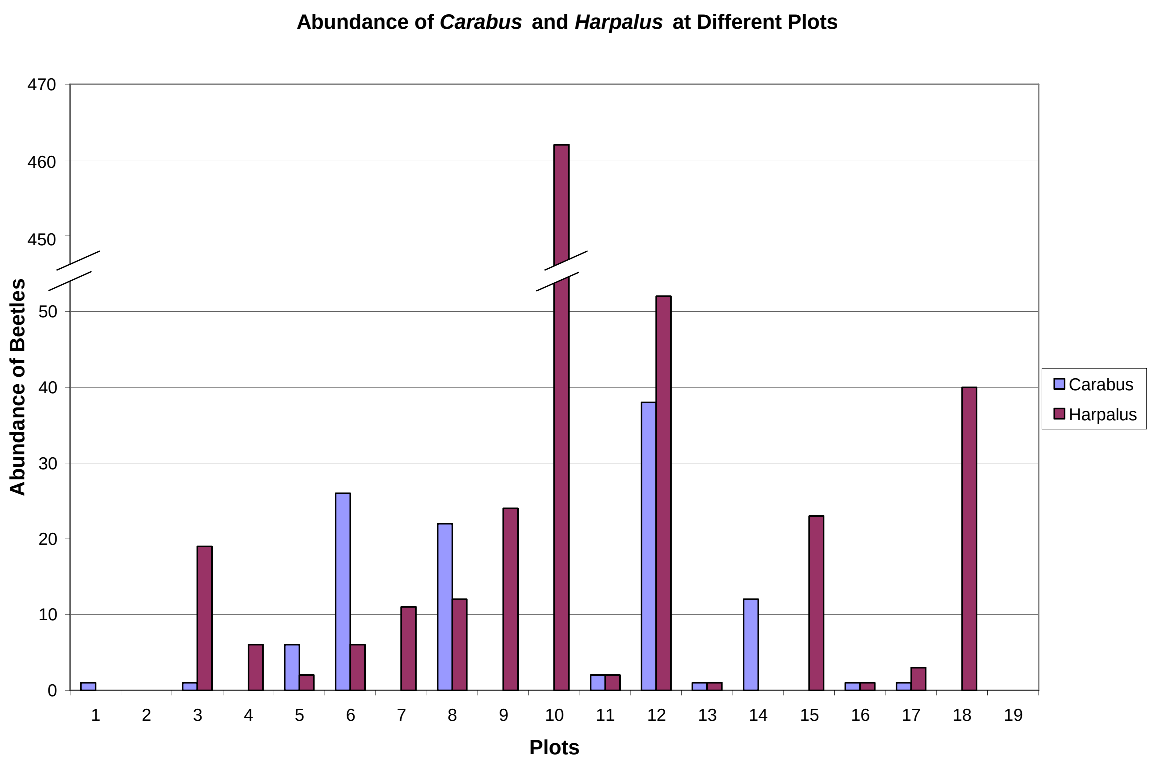

Figure 10. The comparison of abundance of *Harpalus* and *Carabus* densities on Boston Harbor Island plots

Figure 11 suggests that the abundance of beetles in the genus *Sphaeroderus* does not affect the generic richness of the plots, but there may be a negative correlation between the abundance of *Sphaeroderus* and Shannon-Weiner diversity in the Groton Forest in plots with more than just the *Sphaeroderus*. Although not statistically significant, this pattern suggests that *Sphaeroderus* beetles reduce diversity in their communities.

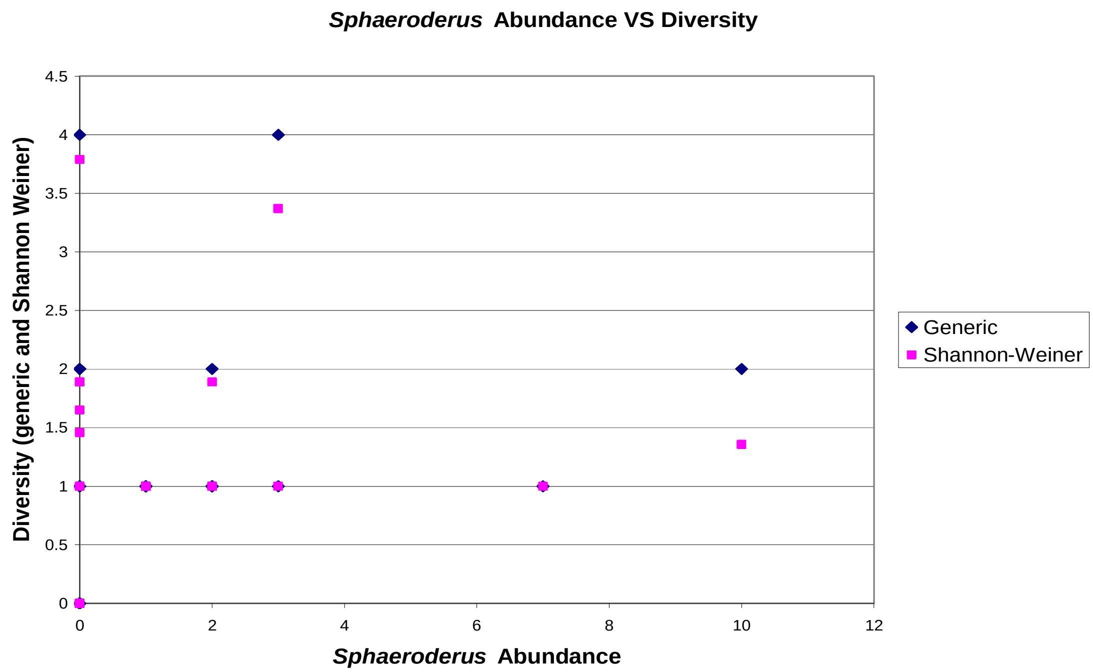

Figure 11. The relationship of *Sphaeroderus* density to generic richness and Shannon-Weiner diversity on Groton Forest plots

The abundance of *Sphaeroderus* in the Groton Forest was further related to combinations of habitat variables as shown in Table 6. Unlike *Carabus* and *Harpalus* beetles, *Sphaeroderus* beetles do not seem to favor one type of habitat specifically over another, although none were captured in Group 3 and Group 5 habitats.

Group Code	Group Explanation	*Sphaeroderus* density (individuals per plot)	*Sphaeroderus* relative density (%)
1	Woody plants, more than 25% rock cover, broadleaf litter, clay, water more than 15m away	1.6 $\pm$ 0.86	61.9
2	Vascular non-woody plants, less than 10% rock cover, broadleaf litter, clay, water more than 15m away	1.6 $\pm$ 1.1	38.9
3	Vascular non-woody plants, less than 10% rock cover, other litter, clay, water more than 15m away	0	0
4	Vascular non-woody plants, 10% to 25% rock cover, other litter, clay, water more than 15m away	1.1 $\pm$ 0.46	44.4
5	No dominant plant, 10% to 25% rock cover, broadleaf litter, clay, water more than 15m away	0	0
6	No dominant plant, more than 25% rock cover, other litter, sand, water less than 5m away	2	33.3

Table 6. The effect of habitat variable combinations on the abundance of *Sphaeroderus* on Groton Forest plots

Discussion

Habitat Factors and Their Effects on Carabidae Diversity

Carabidae diversity seems to be related to both abiotic environmental factors and the interactions among the various genera. As shown in Figure 5, Habitat Group 3 had the lowest mean generic richness in both areas studied and Group 5 had the highest generic richness for the Islands and the second highest for Groton. This suggests that habitat factors may have the same or similar effects in areas that are in completely different ecosystems, such as the Islands and Groton.

Of the individual habitat factors, dominant plant type, rock and log coverage, and dominant litter type emerge as possibly important factors in this research. Figure 7 and Figure 9 show that single habitat factors may affect certain genera of ground beetles. However, more in-depth research is needed to determine whether this is caused by different levels of tolerance among different genera or by competitive interactions.

Carabidae Diversity in the Two Areas and Possible Explanations for Differences

The data shows that the Islands have a higher mean generic richness (6.9 $\pm$ 0.50, mean $\pm$ S.E) but that the Groton campus has a higher mean Shannon-Weiner diversity to mean generic richness ratio (0.92). This shows that while the Islands support a larger number of genera of ground beetles, the Groton Forest exhibits more evenly distributed populations, as ratio of the mean Shannon-Weiner diversity to the mean generic richness is a measurement of population balance.

The greater abundance of the genus *Carabus* on the Islands may be a contributing factor to the less evenly distributed populations in the area. The data from the Islands show a possible negative correlation between the abundance of *Carabus* and diversity, both generic richness and Shannon-Weiner diversity. All species of the genus *Carabus* are carnivorous and of the beetles captured on both the Islands and in the Groton forest, the *Carabus* beetles are by far the largest Carabidae by size [25, 26]. Previous research have suggested that competition exists between different species of ground beetles [27]. It is possible that their large size gives *Carabus* an advantage, allowing them to outcompete the other beetles and thus reduce the diversity in the area.

The data from the Boston Harbor Islands also suggest that *Harpalus* beetles may compete with *Carabus* beetles and in turn, increase the overall diversity of the plots when the two genera are able to coexist with each other. Figure 10 shows that in three of the nine plots in which the two genera coexist, the populations of both genera were lower than in other plots. In the six other plots in which they coexist, one genus seems to dominate over the other one. Finally, in six plots in which only *Harpalus* were captured, the population of *Harpalus* was higher than in most plots where both genera were found. Thus, it is possible that *Harpalus* beetles suppress the *Carabus* population and contribute to increasing the overall diversity in those plots. While *Harpalus* was the second most numerous genus captured on the Islands, it was only the fourth most populous at Groton. The Groton *Harpalus* population might not have been large enough to compete against the *Carabus* and to increase overall diversity of the ecosystem.

Proximity to civilization and disturbance by humans may also play a role in regulating the Carabidae populations. Previous research has shown that *Carabus* beetles prefer mown lawns and thus may be synanthropic and that other Carabidae may similarly rely on human disturbance [28]. One of the pitfall sites at Groton (Pit-O) illustrated the *Carabus* beetles' preference for maintained fields. During the first five weeks of study, the field was undisturbed and only two *Carabus* were caught in that period. At the end of the sixth week during which the field was mowed, I captured nine *Carabus* in the pitfall trap suggesting that the disturbance attracted the *Carabus* beetle. The four islands studied are highly developed as tourist attractions with maintained trails, whereas the Groton Forest is, for the most part, less affected by persistent human disturbance which may be a contributing factor to the larger population of some genera of Carabidae on the Islands.

Finally, the possibly smaller population of natural predators of ground beetles on the Islands may be a contributing factor to the Islands' higher Carabidae diversity. The distance from the four islands to the mainland, while less than 10 km, may be a significant distance for many small, predatory mammals to cross. In the Groton Forest, there are many natural predators, the most significant one being the Northern Short-tailed Shrews (*Blarina brevicauda*). The shrews are voracious eaters and prey mainly on invertebrates, primarily beetles [29]. The shrews, along with other predators, maintain the beetle populations at Groton at levels of abundance lower than those in less predator rich environments. Predators such as the *B. brevicauda* seemed to be either lacking or scarce on the Islands; while over a dozen shrews were caught in the pitfall traps at Groton, none were caught on the four islands studied. This may contribute to the existence of larger population of beetles on the Islands compared to Groton, and to the dominance of fewer genera of beetles as the superior competitors flourish and are able to control a large share of the habitat resources.

Other Observations

The relative isolation of the Islands may cause differences in the prey populations for many of the Carabidae in the two areas studied. As Table 1 shows, the most dominant genus in the Groton Forest is *Sphaeroderus*, commonly known as the slug-eating beetles. Terrestrial slugs and snails are most likely more abundant in the mainland forest than they are on the isolated Islands, which may allow *Sphaeroderus* population to outcompete other beetles, as suggested in Figure 11. On the Islands, Figure 6 suggests that *Carabus* beetles reduce both the generic richness and Shannon-Weiner diversity in the community. It is possible that *Sphaeroderus* and *Carabus* serve similar functions in their respective habitats as the dominant competitors for resources.

Bias

For this research, the habitat factors were categorized very generally into three categories, but more specificity could have been useful in better understanding the effects of various factors on ground beetle populations. Studying the beetle species rather than genus may have altered the results as well, as it is possible that species within the same genus do not all act similarly. Temperature could have been an important explanatory factor as well, and the Islands would have been generally cooler due to the ocean, but the temperature at the plots was not measured for this research. Bias could also have occurred from the use of pitfall traps in this research. Traps should have been set randomly but instead, they were set closer to the trails where it was easy to access them. Furthermore, pitfall traps, by nature of their capturing methods, tend to favor arthropods that are active and are on the ground. Pitfall traps also favor larger specimens not only because collected specimens are separated visually by the collector but also because larger individuals are more likely to ignore the rim of the plastic cups that may protrude out of the ground and fall into the trap. Also, I sampled an unequal number of plots in each habitat group, which could have biased the data in spite of my efforts to reduce such bias by averaging some of the data. Moreover, the four islands, although they are similarly distanced from the mainland and are connected with each other by a ferry system, might display differences in beetle communities compared to each other, but this was not studied in this research. Finally, predation by other animals may have been significant, but was not studied for this research.

Conclusion

This research allowed the comparison of two distinct areas through the Carabidae populations in each area as well as the habitat factors that affected these beetles. The results of the study were consistent with the theory of island biogeography. The data also supported my prediction that the five habitat factors I studied would have similar effects on the Carabidae population in the two distinguished areas. The Carabidae population was also far more diverse on the Islands. Finally, the dominant genera in each area were different. In fact, the two genera were only captured in their respective areas: *Amara* on the Islands and *Sphaeroderus* at Groton.

Future research could focus on the competition for resources among species or genera of Carabidae, which were only hinted at between *Carabus* and *Harpalus* beetles on the Islands in this research. Exclusion studies by removing certain genera, such as *Carabus*, from plots may reveal more information.

Focusing on islands or other isolated landmasses may prove especially valuable in studying beetle populations in the future because, as we can speculate from the comparison of the mainland Groton Forest to the four isolated islands studied, differences in predator and prey abundance that stems from the isolation of islands may be important to beetle diversity.

In a broader sense, this study raises questions about the ecology of isolated and disturbed systems, how they respond to habitat alterations and about the complexity of the ecological impacts to these communities.

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