

**Surveying Herpetofaunal Diversity Using Artificial Refugia:
A Comparison of Coverboard Designs**

BIO409- Internship in Biological Sciences

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ABSTRACT

The enigmatic habits of reptiles and amphibians often make them difficult to detect. Efficient, yet effective sampling methods are required for monitoring due to the substantial contributions of herpetofauna to ecological communities. Unfortunately, little is known about herpetofauna other than species lists amassed from random or outdated observations. The use of coverboards presents a feasible method for natural resource managers or persons with limited training.

The first objective of this study was to test two aspects of coverboard design, board size and board spacing above the substrate, in an effort to determine the number of species of herpetofauna and their relative abundances that utilize particular designs. The encounter rate under large coverboards was greater, but per unit area, small boards had a higher encounter rate. Shannon estimates of biodiversity were calculated and large boards had greater diversity estimates than small boards.

The second objective was to quantify hydric and thermal microclimates beneath boards in an effort to correlate conditions created by manipulations of board design with the types of herpetofauna that were detected. Large boards created drier and warmer conditions than small boards. Certain classes of herpetofauna have particular temperature and moisture requirements, so the conditions created by the different board types should attract specific assemblages of herpetofauna. Large boards attracted a greater proportion of reptiles than small boards, while small boards attracted a greater proportion of amphibians than small boards. This demonstrates that careful attention must be paid to coverboard characteristics to achieve desired results.

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INTRODUCTION

Heightened awareness of amphibian and reptilian population decline (Zappalorti and Reinert, 1994) has established the need for effective monitoring programs. Because the roles amphibians and reptiles play in ecosystems are quite notable (Seigel and Simons, 1995) and they are relatively sedentary making them good indicators of local conditions, herpetofaunal populations can be very sensitive indicators of environmental change (Grant et al., 1992). However, these creatures are quite elusive, making it difficult to detect the presence or absence of certain species. Hence, there is a pressing need to develop and test reliable, yet cost effective censusing techniques.

Several common herpetofaunal sampling techniques that have been used in the past, at numerous different study sites, have produced various results. A common practice involves the use of drift fences in conjunction with pitfall traps or funnel traps. These methods may lead to a large number of encounters and a broad range of species, however initial setup is labor intensive and once set, traps must be checked frequently (Fitch, 1992). Additionally, trapping may sometimes lead to injury or predation because the animals are detained (Fitch, 1992). General herpetological collecting is a more painstaking method that includes overturning and replacing ground cover, time-constrained hand-collecting, nighttime road-surveys and other various means (Seigel and Doody, 1996). These techniques are generally the most effective for inventory purposes, both in terms of species richness and abundance. However, a major problem with hand-collecting is that the results are largely influenced by the ability of the collector (Seigel and Doody, 1996).

Another concern is that natural habitat is often left in a disturbed state by disrupting forest litter and turning or breaking existing logs (DeGraaf and Yamasaki, 1992).

A less intrusive method, the use of coverboards, has produced successful results (Grant et al., 1992 and Fitch, 1992) without disturbing habitat or individuals (DeGraaf and Yamasaki, 1992). The most common procedures involve placing between 50 and several hundred boards along transects or in arrays in the habitats to be surveyed. Coverboards of several different types of material have been used, including plywood and galvanized roofing tin (Grant et al., 1992). The boards are generally placed in pairs (Seigel and Doody, 1996 and Grant et al., 1992) or triplets (DeGraaf and Yamasaki, 1992) at each station along a transect. Seigel and Doody (1996) recommend using at least 20 boards per array with coverboards spaced at least 10 m apart. Different studies have used various board sizes, some were 100 cm long x 20 cm wide x 2.5 cm thick (DeGraaf and Yamasaki, 1992) while others were 133 cm long x 66 cm wide x 1 cm thick (Seigel and Doody, 1996). Coverboards are placed flat on the substrate to act as shelters for reptiles and amphibians. They are turned as often as every day (Seigel and Doody, 1996) to as seldom as once per week (DeGraaf and Yamasaki, 1992) to check for the presence of herpetofauna. The leaf litter beneath each board is sometimes gently raked (Seigel and Doody, 1996) and replaced to detect hidden individuals.

Not all coverboards produce the same results. Variations in coverboard design have created different microhabitats that are more suitable for certain types of herpetofauna. For example, in South Carolina encounters beneath galvanized roofing tin coverboards were dominated by lizards, while the majority of encounters beneath wood

coverboards were salamanders (Grant et al., 1992). Further, litter was significantly wetter beneath wood coverboards than tin coverboards and litter was significantly cooler beneath wood than tin (Grant et al., 1992), hence other factors in coverboard design may also influence microclimates.

The first objective of this study was to test two aspects of coverboard design, board size and board spacing above the substrate, in an effort to determine the number of species of herpetofauna and their relative abundances that utilize particular designs. The second objective of the study was to quantify hydric and thermal microclimates beneath boards in an effort to correlate conditions created by manipulations of board design with the types of herpetofauna that were detected.

A suite of physiological attributes adapt a particular species to survival under specific environmental conditions (Duellman and Trueb, 1986). Microhabitat differences were quantified in order to indicate the particular manner by which interactions between temperature, moisture, and coverboard type influence herpetofaunal encounter rates. Coverboard size was expected to have some influence on microclimates, consequently attracting different types of amphibians and reptiles. Additionally, large boards were expected to create more space for larger bodied animals like snakes and small boards were predicted to be more suitable for small animals like salamanders. Spacers were placed on the underside of coverboards in an effort to increase accessibility and to create more space for movement. The spacers were also predicted to influence microclimates and create a gradient of conditions from the high to low end of the board..

METHODS

Study Area

Valley Forge National Historical Park (VFNHP) is located 20 km northwest of Philadelphia, Pennsylvania, on the border of Chester and Montgomery Counties. VFNHP is a 1192 ha tract of land and one mile of Valley Creek and three miles of the Schuylkill River run through the park. VFNHP consists of approximately equal amounts of forest and meadow habitat. The park is bordered by industrial, commercial, and residential development, and three major highways lie to the north, east, and south, respectively. Regional temperatures average 0 C in winter and 23 C in summer with extremes of -27 C to 44 C. Mean annual precipitation is 117 cm, and mean annual snowfall is 76 cm. Between 170 and 200 days per year are frost-free. Soils are typically deep, well to moderately drained silt-loams (Cypher et al., 1985).

The actual study site, located on Mt. Misery, is bordered on the east by Valley Creek, on the north and west by moderate-density residential development, and on the south by meadows and a secondary road. The study site is 88.2 ha and mature mixed hardwood forest predominates (Cypher et al., 1985). Hardwood stands contained northern red oak (*Quercus rubra*), sassafras (*Sassafras albidum*), yellow poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and chestnut oak (*Quercus prinus*). Shrubs were primarily maple leaf viburnum (*Viburnum acerifolium*) and mountain laurel (*Kalmia latifolia*, Cypher et al., 1985 and Yahner et al., 1995). There is generally a lack of understory vegetation due to excessive deer browse. Located within the study site was a small seep wetland feeding a stream, and also an intermittent stream.

Study Design

Preparation. Coverboards were placed along five 762.2 m transects (Fig. 1). The transects were established randomly using a numbered grid overlaid on a topographical map. They were selected from potential transects located in two sites on Mt. Misery by using a random numbers table. Site A consisted of three transects extending eastward from the western park boundary parallel to the northern park border. They were spaced 30.5 m and 91.5 m apart respectively. The other two transects, making up site B, extended north from the easternmost point of the first three transects where the park boundary takes a turn north. These transects were placed 30.5 m apart. Elevation was approximately consistent along each transect and all transects fell within an elevational range of 73 to 134 m. The transects were all located within the same habitat type. Ten sampling stations were placed evenly along each transect, with four boards at each station for a total of 200 coverboards. Steep slopes were avoided when establishing stations.

There were four coverboards at each station with a distance of 0.5 m between each board (Fig. 2). Two different sized boards were placed at each station: the large coverboards measured 120.0 cm long $\times$ 60.0 cm wide $\times$ 0.9 cm thick and were made of CDX pine plywood, and the small boards of pine measured 105.0 cm long $\times$ 17.5 cm wide $\times$ 1.9 cm thick. One of the two large boards at each site had three 3.75 cm long $\times$ 3.75 cm wide $\times$ 1.9 cm thick spacers affixed to the underside of the board to support one edge of the board 3.75 cm above the substrate. The spacers were evenly spaced along one edge of the 120 cm length of the board. One of the two small boards at each site had a spacer of the same dimensions placed on its underside along the 17.5 cm edge. All

spacers were fastened with roofing nails. The remaining two boards at each station, one of each size, were set flat on the ground with no spacers.

The small coverboards were weathered for 14 months, each lying flat on a soil/leaf litter substrate in a forested habitat. The large coverboards were weathered for one week on a gravel substrate in an open area exposed to full sunlight. The coverboards were then placed on the ground in their respective positions and left undisturbed for two weeks before surveying. As coverboards were placed, any large rocks (>2.5 cm) or branches (>2.5 cm in diameter) were removed from the ground where they were to be placed.

Microclimate sampling protocol. Three times during the course of the study (August 20, September 9, and September 23) hydric microclimates beneath coverboards were quantified by obtaining soil samples of the O horizon and the top layer of the A horizon. The samples were collected with a scoopula into a labeled preweighed vial (vial, label, and lid were weighed). The vial and cap were reweighed each time after cleaning out the old sample. All samples were approximately the same size (0.84-10.99 g, wet mass) and were taken from roughly the center of where the board lay. Each sample was taken from the surface of the O horizon to 1 cm below the surface of the A horizon. Samples were collected from under all four board types at two stations along each transect (20% of the total number of stations). The stations sampled were chosen using a random numbers table. In each of three sampling periods, a total of 40 samples were collected and processed from the same 40 boards. For each of the sampling periods and each station that was sampled, two control samples, one in the sun and one in the shade, were

collected from the same portion of exposed ground each time. The control soil samples were collected in the same manner as the coverboard samples.

Once samples had been collected, they were weighed the same day (including vial, lid, and soil). The mass of the vial and the lid were subtracted to obtain a wet soil mass. The vials were then placed in a drying oven with their lids removed for a period of five days. The dry soil mass was then obtained by weighing the sample in the vial and subtracting the mass of the vial. This was repeated one day later to be sure that masses had stabilized and all moisture had been extracted. To calculate the moisture mass the dry soil mass was subtracted from the wet soil mass. The moisture mass was divided by the wet soil mass (Grant et al., 1992) and multiplied by 100% to determine percent moisture.

To quantify thermal microclimates beneath coverboards, temperature was recorded from under all four board types at the same stations from which soil samples were taken. No control samples were taken because there was no analog. A standard mercury thermometer measuring 30 cm with a range of -20 to 110°C was used to measure temperatures. The thermometer was inserted under the edge of the board so that the bulb extended to the center. The thermometer was left in the same position for at least two minutes to allow the temperature reading to stabilize (see Appendix B).

Canopy cover was recorded at the same ten stations using a spherical densiometer. Readings were taken facing north, south, east, and west and averaged to obtain percent canopy cover.

Coverboard sampling protocol. Surveys were conducted from July 3 through September 28, and boards were turned two times per week or every three to four days.

While turning each board, the leaf litter beneath it was gently moved aside with a small plastic rake to detect any concealed individuals. The litter was returned to its original location before replacing the board. Upon encounter each individual's snout to vent length (SVL) and any distinguishing characteristics were recorded to help identify repeat encounters. Additional data taken upon encounter included air temperature (taken at 2 m in the shade), substrate moisture (dry, moist, or wet; Brower and von Ende, 1990), litter depth (cm), substrate/litter type (soil, leaf litter, rock, or any combination of the three), and an ocular estimate of percent canopy cover (see Appendix A).

Statistical analyses. Analyses were accomplished using Statistica for the Macintosh (StatSoft, Inc., 1994). Soil moistures were analyzed using an ANOVA on squareroot transformed data. A post hoc Newman-Keuls Test was used to test for differences between specific pairs of board types. Thermal microclimates were analyzed using an ANOVA on natural logarithm transformed data. The transformations were used to improve homoscedasticity of the data. Frequency counts of herpetofaunal encounters were analyzed using a Log-Linear Model (LLM). For ANOVA, sampling period (1=August 20, 2=September 9, 3=September 23), site (A=transects A, B, C; B=transects D, E), transect (A, B, C, D, E), board size (L=large, S=small), spacing (C=cleated, NC=no-cleat), and board type (LC=large cleated, SC=small cleated, LNC=large non-cleated, SNC=small non-cleated, and control if applicable) were used as treatment factors. In LLM analyses, period (1, 2, 3, 4, 5, with five censuses per period) transect, size, and cleat were used as treatment factors.

RESULTS

Microclimates beneath coverboards

Hydric. Mean percent moistures over the three sampling periods were 38.0%, 43.9%, and 51.9%, respectively. There were highly significant differences among sampling periods (Table 1) with the driest litter conditions in the first census and increasing moisture over the next two censuses (Fig. 3). Further, there was a highly significant interaction (Table 1) between the effects of census and board type because the control samples had an uncharacteristically low mean percent moisture that did not follow the general pattern of the other two censuses (Fig. 3). Additionally, the first sampling period shows higher moisture beneath large cleated boards and the last two censuses show higher moistures beneath large non-cleated boards (Fig. 3).

Mean percent soil moisture beneath large boards and small boards was 33.3% and 52.8%, respectively. Litter beneath large boards was highly significantly drier than under small boards (Table 2, Fig. 4). There were highly significant differences among board types including the control (Table 1). Both large cleated boards and large non-cleated boards had highly significantly drier litter conditions than small cleated boards, small non-cleated boards, and the control (Table 3, Fig. 4). There was a trend for higher moistures under small non-cleated boards than the control samples (Table 3, Fig. 4). Mean percent soil moistures for cleated boards and non-cleated boards were 41.7% and 44.4%, respectively and did not differ significantly (Table 2).

Thermal. There were highly significant differences among sampling periods (Table 4) with a much lower mean temperature of 15.6 C in the third sampling period than the first two that both had a mean of 23.1 C (Fig. 5). Further, there was a highly significant difference in temperatures at the two sites on Mt. Misery (Table 4) with a mean of 20.3 C at site A and 21.0 C at site B.

The mean temperature under large boards was highly significantly warmer than the mean temperature under small boards at 20.8 C and 20.4 C, respectively (Table 4, Fig. 6). Although cleated boards had a slightly warmer mean temperature of 20.7 C than non-cleated boards, 20.5 C (Fig. 6), the difference was not significant (Table 4). There was also a trend for an inexplicable interaction that occurred between sampling period, site, size, and cleat (Table 4).

Encounter rates

Coverboards were checked 25 times between July 3 and September 28, 1996. A total of 174 reptiles and amphibians of seven different species were encountered (Table 5). For all censuses combined, each board yielded 0.87 reptiles or amphibians. A total of 5000 board checks were made, with an average encounter rate of 3.48% or about three to four reptiles or amphibians per 100 coverboards (Fig. 7). However, between July 3 and September 16, the average encounter rate was only 0.9% or about 1 reptile or amphibian per 100 coverboards (Fig. 7). Up to that date the maximum number of encounters in one census was only four. Between September 16 and 28 the average encounter rate increased to 22.2% or about 22 reptiles or amphibians per 100 boards (Fig. 7). The maximum number of encounters in this period was 59 in one census.

A comparison between large and small boards (Fig. 8) showed that for all species combined, large boards had an average encounter rate of 4.8% or about four to five reptiles or amphibians per 100 large boards, while small boards had an encounter rate of only 2.2% or about two encounters per 100 small boards. However, if surface area of the coverboards was taken into account (Fig. 9), one large board was equal to 3.91 small boards. When multiplied by this factor, small boards yielded an encounter rate of 8.6% or approximately eight to nine encounters per 100 small boards.

Species most commonly encountered

Eastern redback salamander. Redback salamanders, *Plethodon cinereus*, made up 79.3% of all encounters, but were only recorded in the first census and the last four censuses. There was a highly significant difference among sampling periods (Table 6) with more *P. cinereus* encounters in period five than any other. There was highly significant variation in frequency of encounter among transects (Table 7). This variation among transects was also significant for frequency of encounter among board sizes and spacings (Table 6, Fig. 10). A significant interaction between the effects of transect and cleatedness occurred in which non-cleated boards had a greater frequency of encounter along three of the transects, while the other two transects had a greater number of encounters under cleated boards (Table 7, Fig. 11).

Large boards had 90 encounters or almost twice the number of *P. cinereus* found under small boards which had only 48 encounters (Fig. 12 and 13). This difference in encounter rate under large and small boards was highly significant (Table 7) and did not vary across transects (Fig. 12). In addition, a significant interaction occurred between the

effects of size and cleatedness (Table 7). Large non-cleated boards had a higher frequency of encounter than large non-cleated boards, and small non-cleated boards had a higher frequency of encounter than small cleated boards (Fig. 12).

American toad and northern ringneck snake. The American toad, *Bufo americanus*, (N=13) and the Ringneck snake, *Diadophis punctatus*, (N=17) had an apparent preference for large coverboards. Toads were found under large boards 76.9% of the times encountered (Fig. 14). This difference in encounter rate between sizes was not significant, however there was a trend in preference for large boards (Table 8). Ringneck snakes were found under large boards 94.1% of the times encountered (Fig. 15) and this preference for large boards was highly significant (Table 9).

Herpetofaunal diversity

A widely used index of species diversity, the Shannon index, H' (Grant et al., 1992 and Brower and non Ende, 1990) was used to estimate herpetofaunal diversity. Overall, herpetofaunal biodiversity was quite low ($H'=0.33$) and there was a total of seven species for all board types combined (Fig. 16). Large boards had higher diversity ($H'=0.35$, N=5), than small boards ($H'=0.23$, N=5, Fig. 17) but the same number of species was found with both. Uncleated boards had higher diversity estimates ($H'=0.32$, N=6) and one more species than cleated boards ($H'=0.31$, N=5, Fig. 17). When comparing the combined effects of size and cleatedness (Fig. 18), large cleated boards had the highest diversity ($H'=0.28$) and the greatest number of species (N=5). Large uncleated boards were next

($H'=0.27$, $N=4$), followed by small unclefted boards ($H'=0.18$, $N=4$), and finally, small clefted boards ($H'=0.13$, $N=3$) with the lowest diversity.

DISCUSSION

A comparison of several coverboard designs evaluated the microhabitats they produced and their relative efficiencies at surveying herpetofaunal diversity. Differences in encounter rate were associated with variation in almost all aspects of the study design-- sampling period, transect location, coverboard size, and hydric and thermal microclimates beneath coverboards. Different encounter rates and species compositions among small and large boards reflected microclimatic preferences of different classes of herpetofauna. The preferred microclimatic conditions of amphibians are dictated primarily by moisture conditions (Duellman and Trueb, 1986). Whereas, the most substantial physical factor in the ecology of reptiles is temperature (Heatwole, 1976). Reptiles inhabiting temperate regions must carefully select microhabitats and microclimates to regulate their body temperature (Spellerberg, 1982). Variations in litter water content result in different degrees of evaporative cooling and different (coverboard) substances absorb, conduct and lose heat at different rates (Heatwole, 1976).

Microclimates beneath coverboards

Hydric. Differences in hydric conditions between large and small boards (Fig. 4) were presumably due to higher temperatures beneath large boards and differences in edge to area ratios of the two board sizes. Warmer temperatures beneath large boards would have a tendency to increase evaporation and drive soil moisture further underground. The

edge to area ratio of small boards was much greater than that of large boards, which would allow a greater amount of moisture to reach the center of small boards. In the case of large boards, assuming that moisture was only able penetrate a given amount from each edge, the central region of the board would be left considerably drier and hence warmer than the edges.

The similarity in hydric conditions between the small boards and the control further supports the rationale behind edge to area effects. The litter beneath small boards was so similar to the exposed surrounding litter that it must have received at least the same amount of moisture from precipitation. Litter moisture under small non-cleated boards was somewhat higher than the control, most likely because non-cleated boards trapped moisture and prevented evaporation, while the litter under small cleated boards was more exposed due to the spacer.

Edge to area effects were also supported by the frequent observation of small moist patches of litter beneath the edges of large boards, although the interior portion of the litter was much drier. Moisture of the litter beneath small boards was generally more homogeneous than conditions beneath large boards (Lutcher, *personal observation*).

Differences in hydric conditions may also be partially attributable to the difference in thicknesses of the large boards and small boards. Large boards were 0.9 cm thick and small boards were 1.9 cm thick. Fellers and Drost (1994) reported that in a comparison of boards of different thicknesses, 5 cm thick wood tended to retain moisture more effectively and provide a more stable thermal environment throughout the year than 0.5 cm thick wood, however 10 cm thick wood was not appreciably different from 5 cm thick

wood. Presumably, a difference of 1 cm in thickness between large and small boards should not have impacted hydric conditions nearly as much as the combination of temperature and edge-to-area effects previously mentioned. However, future efforts should investigate the effects of small differences in board thickness.

Other factors that may have caused moisture differences between large and small boards were board materials and the length of time that boards were weathered. Small boards were weathered approximately 14 months longer than large boards. This longer period presumably allowed the small boards time to absorb more moisture than the large boards. Therefore, small boards would have been more effective at buffering changes in hydric conditions. Small boards were made of solid pine and large boards of CDX pine plywood. This may also have contributed to differences in moistures beneath small and large boards. Fellers and Drost (1994) reported that plywood worked fairly well during cooler times of the year, but that wood was better at retaining moisture throughout the rest of the year. However, their comparison was between plywood and wood boards of different thicknesses (the wood boards were thicker than the plywood boards).

Conditions created by different board materials and varied amounts of time weathering should be investigated more thoroughly.

Differences in hydric conditions among sampling periods probably occurred due to seasonal climatic conditions. Moisture increased gradually between the first and last censuses (Fig. 3). The highest litter moisture in the third census coincided with the lowest temperatures beneath boards. Such a large decrease in temperature would reduce evaporation considerably resulting in higher litter moisture. A less noticeable increase in

moisture occurred between censuses one and two, where temperature differences were marginal.

The interaction between the effects of census and board type appears to be due to differences between the first census and the other two censuses (Fig. 3). An uncharacteristically low litter moisture in the control for the first census does not follow the general pattern of the other two censuses. This may reflect the lag time for moisture to reach the litter beneath coverboards after a rain event, whereas the control would get wet immediately. In the same manner, the control would dry faster than the litter beneath coverboards which would tend to retain moisture. A reversal also occurred in the first census between large cleated boards and large non-cleated boards; the last two censuses show higher moistures beneath large non-cleated boards and the first shows higher moisture beneath large cleated boards.

The best explanation for the insignificant difference in moisture among cleated and non-cleated boards is the rocky, uneven terrain of the study site. Small rocks and debris tended to create a natural spacing effect under all board types (R. Schroeder, *personal communication*). The 3.75 cm cleats were probably too small to achieve spacing significantly different from the background level in this type of habitat. On level terrain with less debris to interfere, or possibly with larger cleats, the spacers might create more noticeable differences. Another problem was slight irregular warping in large boards due to their greater size and lower structural stability.

Thermal. Differences in thermal conditions between large and small coverboards (Fig. 6) are most likely due to differences in surface area, thickness, and hydric conditions

beneath them. A board with greater surface area would intercept more solar radiation and have higher thermal conductivity, causing a proportionally larger increase in the temperature of the litter beneath it. The difference in thicknesses of the two board sizes would also have an effect on thermal microclimates. The large boards were thinner than the small boards and consequently thermal conduction would be greater in large boards. Small boards were also wetter than large boards and increased moisture would have a buffering effect to temperature changes due to increased insulation under small boards.

Temperature differences among censuses (Fig. 5) occurred due to normal seasonal climate changes and the difference between sites A and B was most likely a result of slightly different orientations to the sun. Board spacing again had no significant effect on microclimate, however, cleated boards of both sizes were slightly warmer. This was probably due to greater exposure to ambient air temperatures, rather than direct contact with the cooler ground.

Encounter rates

The large differences in encounter rates over different intervals of the study (Fig. 7) suggested the importance of the sampling period in which data is collected. Different classes of herpetofauna were present at various times throughout the sampling period, influencing the overall encounter rate.

The higher encounter rate for large boards (Fig. 8) was probably due to per capita size availability. However, the encounter rate per unit area (Fig. 9) is a much more useful measure of the cost effectiveness of each board type if only lumber prices are taken into

account. Per unit area, small boards had an encounter rate that was more than twice that of large boards.

Relationships between coverboard utilization and species composition are apparent to some extent. Amphibians commonly prefer diurnal retreats with higher moisture than surrounding areas (Duellman and Trueb, 1986). Small coverboards were significantly wetter than large boards, hence, amphibians should have preferred small boards. Small boards yielded 54 amphibians of four different species, whereas, large boards produced 102 amphibians of only three different species. If size difference is accounted for, small boards produced more than twice the number of amphibians as large boards. Two amphibian species, the northern dusky salamander (*Desmognathus fuscus*) and the northern red salamander (*Pseudotriton ruber*), were found exclusively under small boards. One amphibian species, the pickerel frog (*Rana palustris*) was found exclusively under large boards. The results, for the most part, supported the assumption that amphibians would have a preference for small boards, though the two species found exclusively under small boards were only encountered once and twice, respectively, and the species found exclusively under large boards was only encountered twice.

The 18 reptiles encountered were under large boards 94.4% of the time. Even taking into account the difference in board size and calculating the number of reptiles per unit area, they were still encountered under large boards 77.6% of the time. This most likely reflects their preference for warmer temperatures and lower moisture.

Large boards also offer more cover for reptiles with larger body sizes than amphibians. The average ringneck snake encountered had a snout-vent length of 24.9 cm,

while the width of small coverboards was only 17.5 cm. Small boards would not allow as much movement or provide as much of a thermal gradient as large boards.

The only turtle encountered beneath a coverboard was the eastern box turtle (*Terrapene carolina*). It was found under a large cleated board, probably the only board type under which it was able to fit. The cleat helped provide a space just barely large enough for access (Lutcher, *personal observation*). Artificial refugia are generally considered unsuitable for turtles and to date I am not aware of any prior mention of coverboard use by turtles. This encounter indicates that with further development of the coverboard spacer, a coverboard design that is suitable for use by turtles might be possible.

Another factor that may have influenced encounter rates was coverboard age. The small boards were weathered longer than the large boards, therefore they may have been more similar to a decaying log and hence, more attractive to herpetofauna. However, the mechanisms by which herpetofauna detect differences between old and new coverboards are unknown. It could be related to leaching of volatile chemicals from the coverboards or may be associated with colonization of microscopic soil organisms beneath the boards before they become suitable microhabitats (Grant et al., 1992). In the case of the latter, age would have no effect because all boards were placed in their respective locations at the same time. Grant et al. (1992) determined that from their limited results, age had no effect on encounter rate after only a few months. The large increase in encounter rate after about two months (Fig. 7) may, to some extent, support this conclusion. The

influence of coverboard age should be more carefully examined to determine its precise effects on microclimates.

Species most commonly encountered

American toad and northern ringneck snake. B. americanus and D. punctatus had relatively small sample sizes, hence their statistical power was somewhat limited. However, they are worth mention due to their apparent preference for large boards (Figs. 14 and 15).

The reason ringneck snakes were so commonly encountered under large boards was probably due to the temperature and size preferences mentioned earlier. The American toad was also found more commonly under large boards probably due to its adaptations to drier conditions combined with a possible preference for greater moving space. *Bufo* species have a granular venter that enables greater water absorption from the substrate by providing greater surface area for uptake (Duellman and Trueb, 1986). This could explain the reason they did not require the higher moisture of the small boards and probably based their preference on size or microtopography rather than hydric conditions. Toads were often observed sitting in small depressions under the boards (Lutcher, *personal observation*). Large boards offered more heterogeneous microtopography than small boards because of the greater amount of surface that they covered.

The eastern redback salamander. P. cinereus, is the most ubiquitous salamander throughout the majority of its range (Conant and Collins, 1991). In deciduous forests of the United States densities can exceed 2 individuals per square meter and their annual

production of biomass is greater than that of either small mammals or birds (DeGraaf and Yamasaki, 1992). This is presumably the reason that a great majority of the encounters consisted of *P. cinereus*. The large increase in redback salamander encounter rates between September 16 and 28 was due largely to vertical seasonal movement patterns. *P. cinereus* has problems maintaining a positive energy budget at summer temperatures because their assimilation efficiency is inversely related to ambient temperatures. To avoid this problem they take refuge at lower temperatures below ground (Hairston, 1987), explaining their absence in the warmer summer months. Their emergence coincided with a drop in temperatures and an increase in litter moisture beneath boards between the second and third sampling periods (Figs. 3 and 5).

For *P. cinereus* encounters, the interaction between transect, size, and clearedness probably occurred because of variations in topography that led to differences in soil moisture conditions among different board types (Fig. 10). The differences among transects (Figs. 10 and 11) were also probably due to variations in topography or moisture at different elevations. Additionally, some transects may have had more suitable salamander habitat than others, due to proximity to other wet areas, abundance of decaying logs, or higher prey density.

The greater encounter rate under large boards (Figs. 12 and 13) was presumably due to a larger amount of surface area available to each individual. Experimental studies have revealed that *P. cinereus* exhibit territoriality among conspecifics. "Dear enemy" behavior was also established in which familiar neighboring salamanders recognized each other by pheromones, and mutual boundaries were generally respected to conserve energy.

However, when unfamiliar salamanders were introduced, threats or even aggressive biting were observed more frequently (Hairston, 1987). This may suggest that only a certain number of individuals per unit area will take refuge beneath coverboards. The large boards would allow more salamanders because of their greater surface area, but more desirable moisture conditions were probably the cause of the higher encounter rate per unit area beneath small boards.

The variation in encounter rate among cleated and non-cleated boards over different transects (Fig. 11) again indicates the inadequacy of cleats to create a standard spacing effect. The interaction between size and cleatedness related to *P. cinereus* encounters was probably due to differences in cleat positioning. The large boards had three spacers placed along one edge and the small boards had one spacer at its end. This difference combined with irregular warping in some of the large boards may have created an inconsistent spacing between the board and the substrate. Taking these factors into consideration, the cleats on large and small boards were probably not achieving the same spacing effect, hence encounter rates varied.

Herpetofaunal diversity

The Shannon Index assumes that no individual may be counted more than once in any of the calculations. Each unique individual should be identified to obtain accurate estimates of diversity (Grant et al., 1992). Species like *P. cinereus* have relatively small home ranges ranging from 10.8 m² on average for males to 19.9 m² on average for females (Duellman and Trueb, 1986). Each coverboard station was approximately 4.9 m², thus individuals encountered under boards presumably did not stray very far from them. None

of the animals in this study were marked, so a significant number of them were probably repeat encounters. This would cause bias toward species that were repeatedly encountered under the same board and would result in underestimates of diversity (Grant et al., 1992). Grant et al. (1992) reported that when only unique individuals were recorded, diversity estimates were approximately 20% higher. To obtain more accurate estimates of diversity, all individuals should be marked to identify repeat encounters. It is difficult to estimate diversity accurately. However, comparisons of Shannon indices and number of species represented among coverboard types may still provide some insight to their relative efficiencies at surveying herpetofaunal diversity.

The highest diversity was associated with large boards (Fig. 17) most likely because of their more heterogeneous microclimates. Moisture gradients were typically greater beneath large boards with wet, moist and dry litter conditions sometimes represented under a single board, however small boards were usually either moist, wet, or occasionally, dry (Lutcher, *personal observation*). Temperature gradients under large boards were also probably greater due to their larger surface area. Various portions of large boards would sometimes receive differing degrees of solar radiation depending on the canopy directly above them, whereas small boards were more limited because of their size. Greater variations in microtopography under large boards also created ideal retreats for species with different body sizes. The more noticeable variation in overall microhabitat conditions under large boards, including hygrothermal gradients and microtopography, probably provided suitable refuge for a greater diversity of reptiles and amphibians.

The same number of different species was encountered beneath large and small boards, but the taxa represented were different. Small boards were better suited to amphibians and large boards were suitable for both reptiles and amphibians.

Non-cleated boards had slightly higher diversity estimates than cleated boards (Fig. 17) because the small cleated boards did so poorly, skewing the combined index for cleated boards. Non-cleated boards detected the greatest number of different species. This was because of the less common salamander species, the Northern Red salamander, *Pseudotriton ruber*, and the Northern Dusky salamander, *Desmognathus fuscus*, that were present only under non-cleated boards.

Of the individual board treatments, diversity and number of species represented was greatest with large cleated boards (Fig. 18). This is due in part to the eastern box turtle found under a large cleated board. This again supports the idea that the cleat may provide more space for animals with larger body sizes. The lower diversity estimates among small cleated and small non-cleated boards were probably due to their restricted ranges of microhabitat variation.

Implications

Microclimatic differences among coverboard types can lead to significant variation in encounter rates. Thus, coverboard design and habitat selection should be carefully considered to target specific organisms. If the greatest diversity is desired, large coverboards are recommended because they had a 65% greater Shannon diversity index than small coverboards. More specifically, large cleated coverboards are recommended because they had the highest Shannon diversity index and detected the greatest number of

species. The only combination of coverboard treatments that would have detected all seven species was large cleated and small-non-cleated boards. If only encounter rate is considered, or salamanders are the target organisms, then small boards are far more cost effective than large boards. At this stage, conclusions can not be made about spacing, but it is possible that with further development, they may achieve the desired effect of providing easier access and more space for larger herpetofauna like turtles and large snakes. Presumably, the success of any coverboard design is largely dependent upon the habitat type to be surveyed. In the initial inventorying stages, a variety of coverboard types should be applied to determine the most effective long-term monitoring scheme.

Future studies should seek to improve and standardize coverboard techniques, and to examine new designs. Many other manipulations of coverboard design are possible (coverboard material, artificial substrate, increased interception of solar radiation or precipitation, and microtopography) and each factor must be investigated thoroughly to determine the precise mechanisms of microclimate modification.

A global approach to biodiversity management includes the need for efficient methods of inventory and monitoring. Coverboards are an inherently proficient monitoring technique for detecting herpetofaunal declines because the number of coverboards is constant, so the sampling effort remains the same over time. This method is relatively easy to implement and can be maintained by resource managers at reasonable costs and with comparatively lower time investments. The coverboard technique is highly recommended to aid in detecting human disturbance and environmental change.

TABLES

Table 1. 3-way ANOVA of period (1, 2, 3), site (A, B), board type (LC, SC, SNC, LNC, Control) for soil moisture beneath coverboards.

Variable	F values	P-value (rounded)	Significance
period	$F_{2,120}=24.39$	0.0000	**
site	$F_{1,120}=1.90$	0.1710	
board type	$F_{4,120}=30.60$	0.0000	**
period * site	$F_{2,120}=0.08$	0.9267	
period * board type	$F_{8,120}=3.57$	0.0010	**
site * board type	$F_{4,120}=1.01$	0.4038	
period * site * board type	$F_{8,120}=0.30$	0.9634	

** = highly significant

* = significant

T = trend

Table 2. 3-way ANOVA of period (1, 2, 3), size (L, S), cleat (C, NC) for soil moisture beneath coverboards.

Variable	F values	P-value (rounded)	Significance
period	$F_{2,108}=10.33$	0.0001	**
size	$F_{1,108}=96.20$	0.0000	**
cleat	$F_{1,108}=1.63$	0.2043	
period * size	$F_{2,108}=0.30$	0.7420	
period * cleat	$F_{2,108}=0.07$	0.9285	
size * cleat	$F_{1,108}=1.23$	0.2690	
period * size * cleat	$F_{2,108}=0.41$	0.6678	

** = highly significant

* = significant

T = trend

Table 3. Newman-Keuls Test of main effect: board type (LC, SC, SNC, LNC, Control) for soil moisture beneath coverboards.

Variable	SC	SNC	LNC	Control
LC	0.0000 **	0.0000 **	0.8983	0.0000 **
SC		0.1570	0.0000 **	0.9652
SNC			0.0000 **	0.0726 T
LNC				0.0000 **

** = highly significant

* = significant

T = trend

Table 4. 4-way ANOVA of period (1, 2, 3), site (A, B), size (L, S), cleat (C, NC) for temperature beneath boards.

Variable	F values	P-value (rounded)	Significance
period	$F_{2,96}=1191.88$	0.0000	**
site	$F_{1,96}=20.94$	0.0000	**
size	$F_{1,96}=7.76$	0.0064	**
cleat	$F_{1,96}=1.56$	0.2147	
period * site	$F_{2,96}=4.35$	0.0155	*
period * size	$F_{2,96}=0.92$	0.4016	
site * size	$F_{1,96}=1.88$	0.1731	
period * cleat	$F_{2,96}=0.06$	0.9415	
site * cleat	$F_{1,96}=0.15$	0.6977	
size * cleat	$F_{1,96}=0.34$	0.5635	
period * site * size	$F_{2,96}=0.31$	0.7365	
period * site * cleat	$F_{2,96}=2.10$	0.1277	
period * size * cleat	$F_{2,96}=0.25$	0.7783	
site * size * cleat	$F_{1,96}=2.28$	0.1340	
period * site * size * cleat	$F_{2,96}=2.46$	0.0910	T

** = highly significant

* = significant

T = trend

Table 5. Species list from 174 encounters of herpetofauna beneath coverboards (July 3 to September 28, 1996).

Taxa	Species	Common Name	# Encountered
Salamanders: N = 141			
	<i>Plethodon cinereus</i>	Redback salamander	138
	<i>Pseudotriton ruber</i>	Northern red salamander	2
	<i>Desmognathus fuscus</i>	Northern dusky salamander	1
Anurans: N = 15			
	<i>Bufo americanus</i>	American toad	13
	<i>Rana palustris</i>	Pickerel frog	2
Snakes: N = 17			
	<i>Diadophis punctatus</i>	Ringneck snake	17
Turtles: N = 1			
	<i>Terrapene carolina</i>	Eastern box turtle	1

Table 6. 4-way Log Linear Model of period (1-5), transect (A-E), size (L, S), cleat (C, NC) for encounters of the eastern redback salamander, *Plethodon cinereus* (N=138).

Variable	P-value (rounded)	Significance
period	0.0000	**
transect	0.0032	**
size	0.0008	**
cleat	0.2651	
period * transect	0.8278	
period * size	0.3285	
period * cleat	0.7770	
transect * size	0.3979	
transect * cleat	0.0277	*
size * cleat	0.0320	*
period * transect * size	0.7855	
period * transect * cleat	0.9816	
period * size * cleat	0.5225	
transect * size * cleat	0.0122	*

** = highly significant

* = significant

T = trend

Table 7. 3-way Log Linear Model of transect (A-E), size (L, S), cleat (C, NC) for encounters of the eastern redback salamander, *Plethodon cinereus* (N=138).

Variable	P-value (rounded)	Significance
transect	0.0020	**
size	0.0005	**
cleat	0.2495	
transect * size	0.3807	
transect * cleat	0.0194	*
size * cleat	0.0242	*

** = highly significant

* = significant

T = trend

Table 8. 2-way Log Linear Model of size (L, S), cleat (C, NC) for encounters of the American toad, *Bufo americanus* (N=13).

Variable	P-value (rounded)	Significance
size	0.0653	T
cleat	0.7962	

** = highly significant

* = significant

T = trend

Table 9. 2-way Log Linear Model of size (L, S), cleat (C, NC) for encounters of the northern ringneck snake, *Diadophis punctatus edwardsi* (N=17).

Variable	P-value (rounded)	Significance
size	0.0002	**
cleat	0.4904	

** = highly significant

* = significant

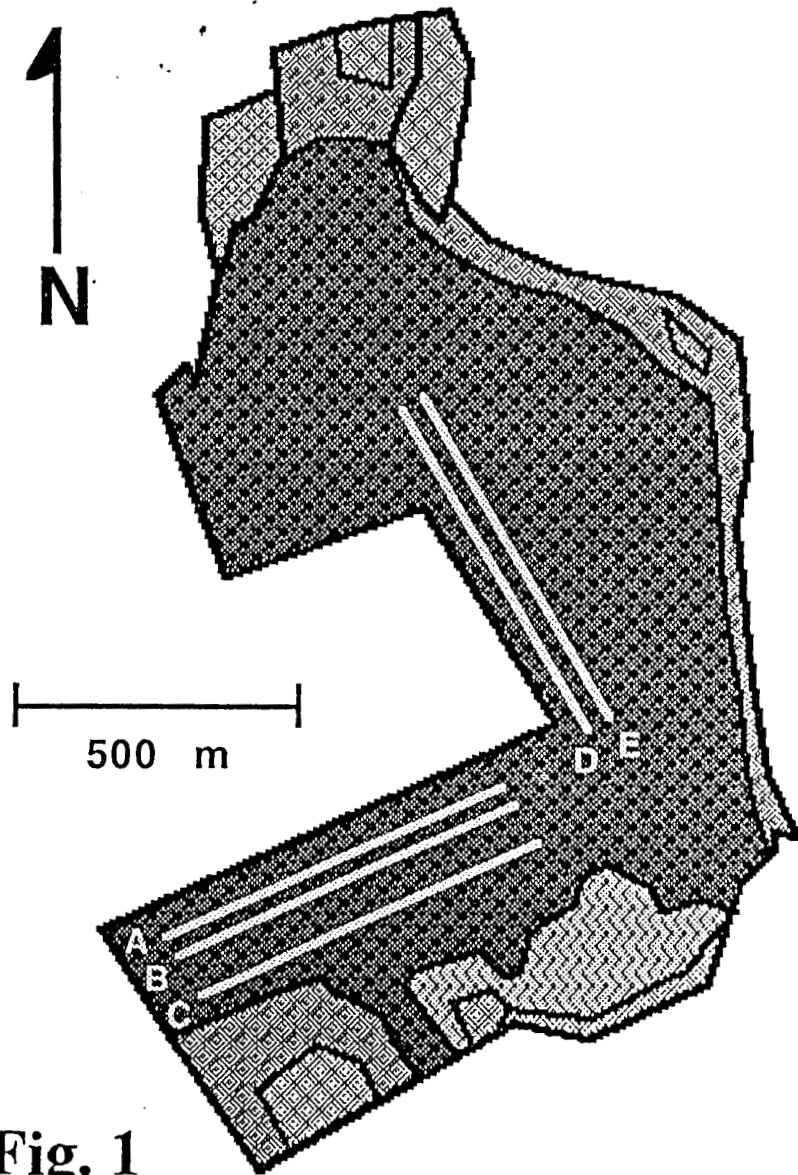
T = trend

FIGURES

1. Map of the study site, Mt. Misery, showing habitat types and transects (indicated by letters).
2. Diagram of a coverboard station indicating cleat positioning, direction of transects, and distance between boards.
3. Average soil moisture beneath the four coverboard types and the control for each sampling period indicating moisture differences among sampling periods.
4. Average soil moisture beneath the four coverboard types and the control for all sampling periods combined indicating moisture differences between coverboard types.
5. Average temperature beneath the four coverboard types for each sampling period indicating temperature differences among sampling periods.
6. Average temperature beneath the four coverboard types for all sampling periods combined indicating temperature differences between coverboard types.
7. Number of individuals encountered in each coverboard survey with all coverboard types and all species included, indicating changes in encounter rate over time.
8. Number of individuals encountered under large boards versus small boards with all species included indicating differences in encounter rate between coverboard sizes.
9. Number of individuals encountered under large boards versus small boards with size differences accounted for by multiplying the number of encounters under small coverboards by 3.91, the number of small boards per large board.
10. Number of eastern redback salamander, *P. cinereus*, encounters beneath the four coverboard types along all transects illustrating differences in encounter rates among coverboard types and different transects.
11. Number of eastern redback salamander, *P. cinereus*, encounters beneath cleated versus non-cleated coverboards along all transects illustrating differences in encounter rates among cleated and non-cleated coverboards along different transects.
12. Number of eastern redback salamander, *P. cinereus*, encounters beneath the four coverboard types illustrating differences in encounter rates between different coverboard sizes and spacings and also showing a greater number of encounters under large coverboards than small coverboards.

13. Number of eastern redback salamander, *P. cinereus*, encounters beneath large versus small coverboards along different transects showing a greater number of encounters beneath large coverboards than small coverboards along all transects.
14. Number of American toad, *Bufo americanus*, encounters beneath the four coverboard types showing a greater number of encounters beneath large coverboards than small coverboards.
15. Number of northern ringneck snake, *Diadophis punctatus*, encounters beneath the four coverboard types showing a greater number of encounters beneath large coverboards than small coverboards.
16. Pie diagram of all herpetofauna encountered beneath the four coverboard types showing the percentage of the total number of individuals encountered that each species accounted for. The overall Shannon diversity index for all coverboard types combined is indicated.
17. Shannon diversity indices for large versus small versus cleated versus non-cleated coverboards indicating differences in diversity among board characteristics.
18. Shannon diversity indices for each coverboard type indicating differences in diversity among the four coverboard types.

Mount Misery
Valley Forge
National Historical Park



-  Mature Forest
-  Hayed Fields
-  Old Field Without Stems
-  Old Field With Stems
-  Maintained Fields

Fig. 1

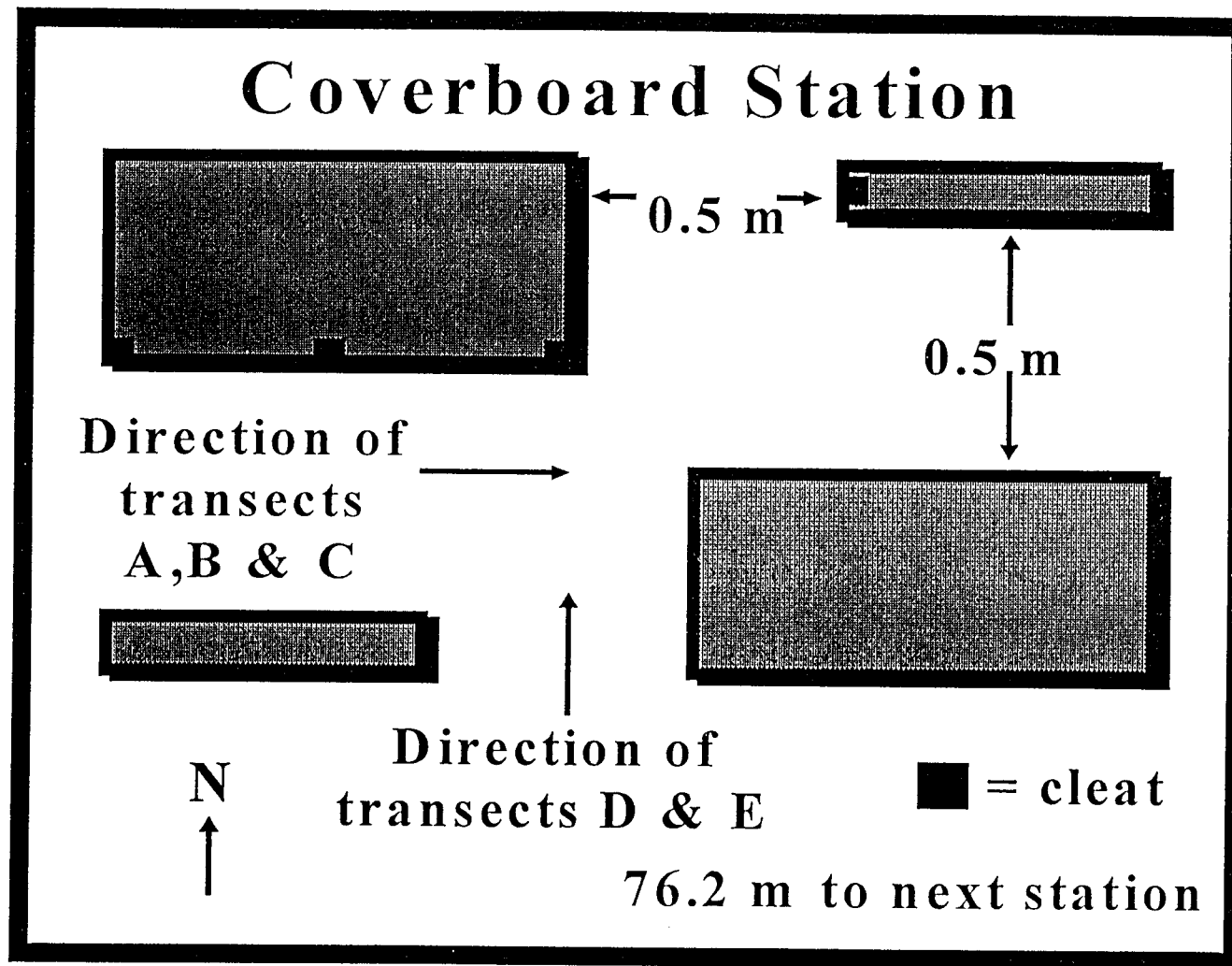


Fig. 2

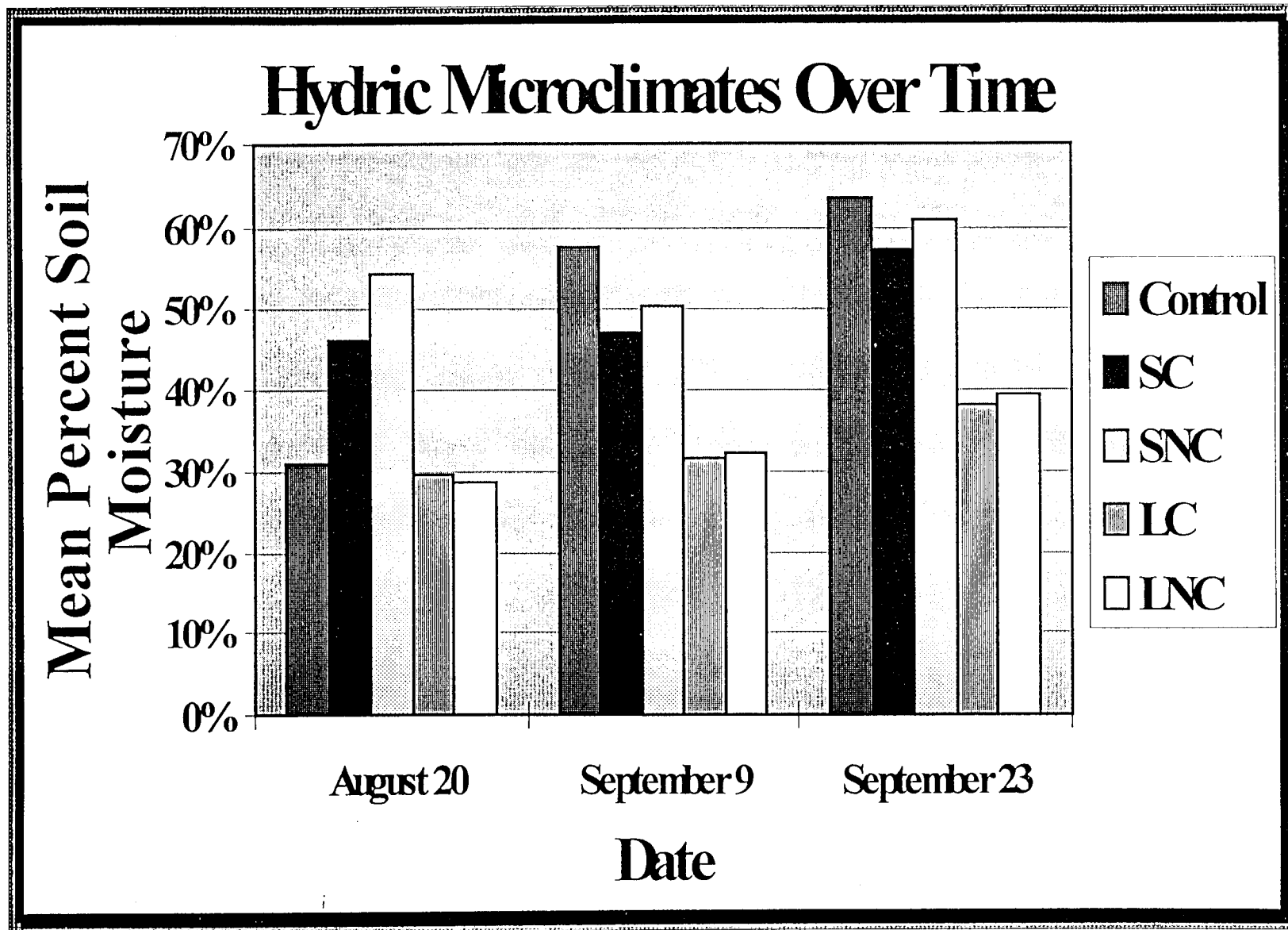


Fig. 3

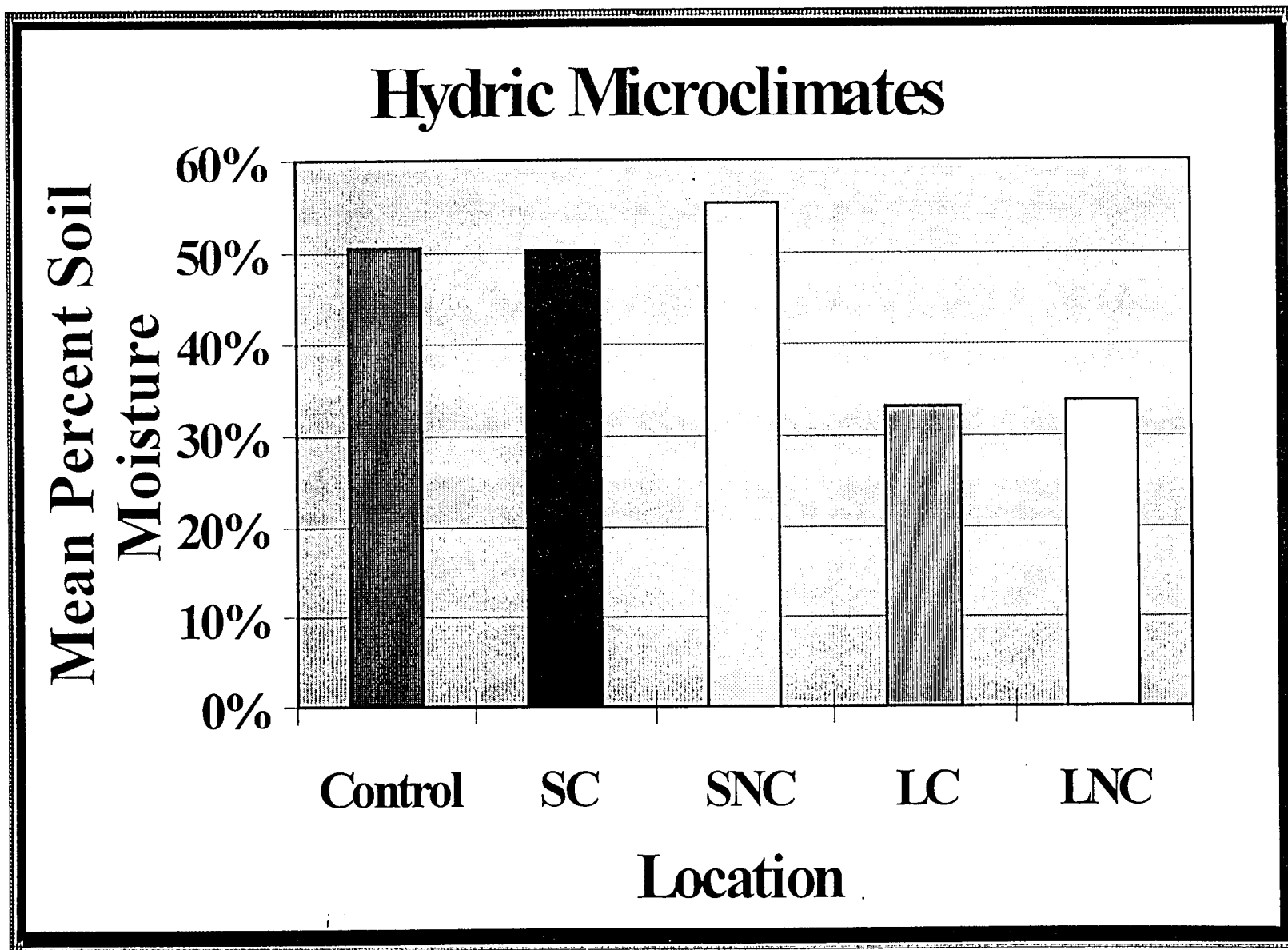


Fig. 4

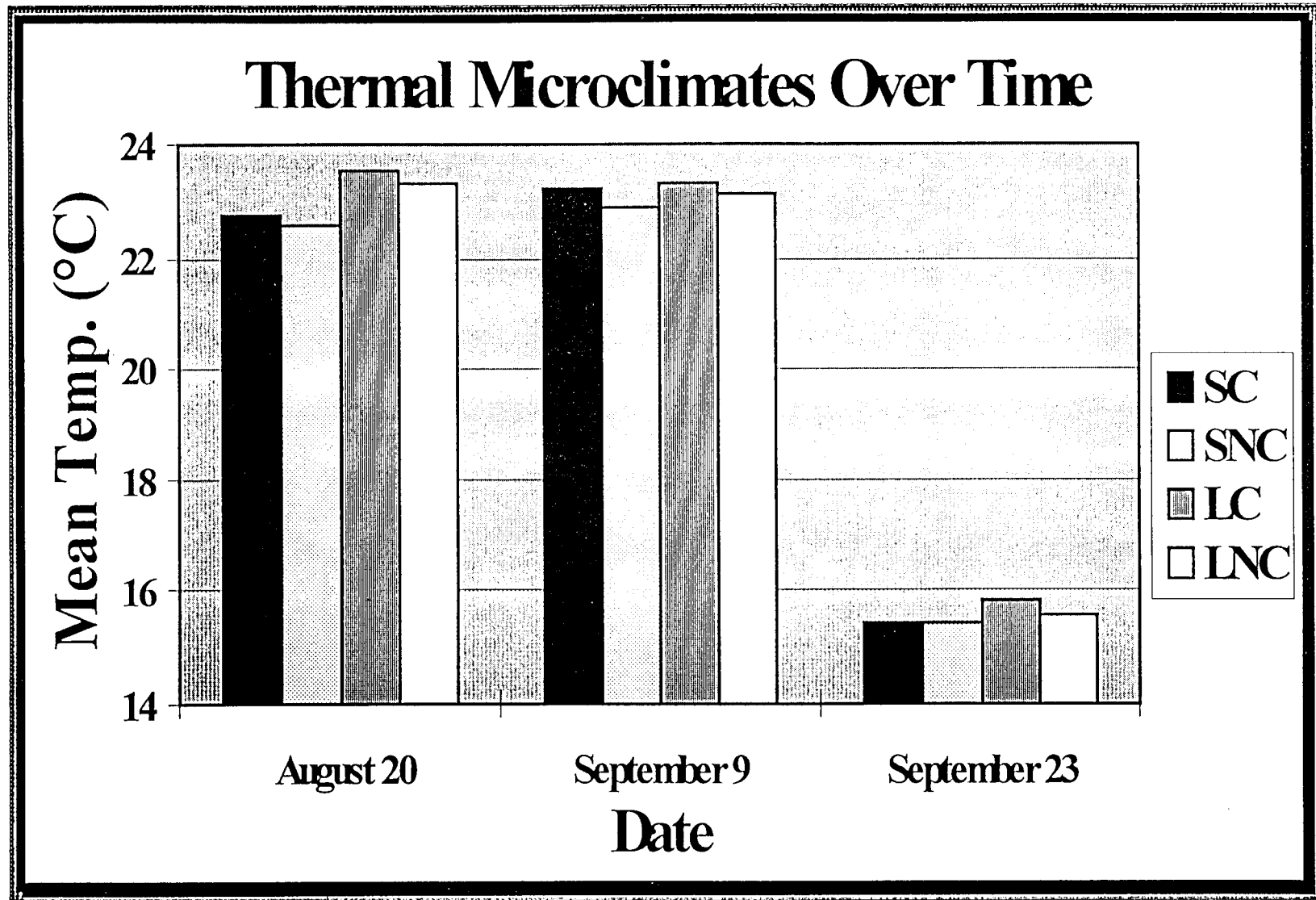


Fig. 5

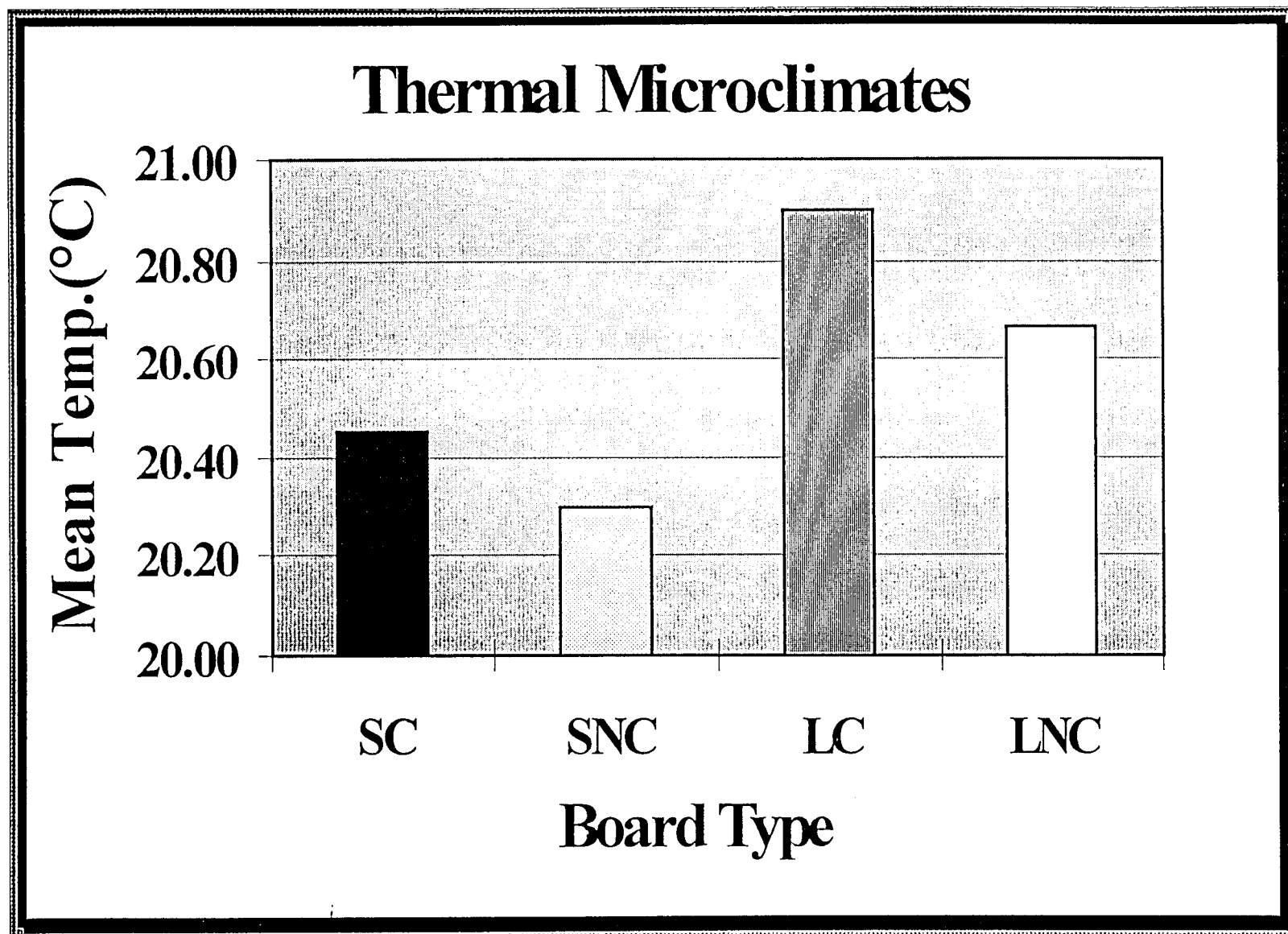


Fig. 6

Encounters Over Time- All Species

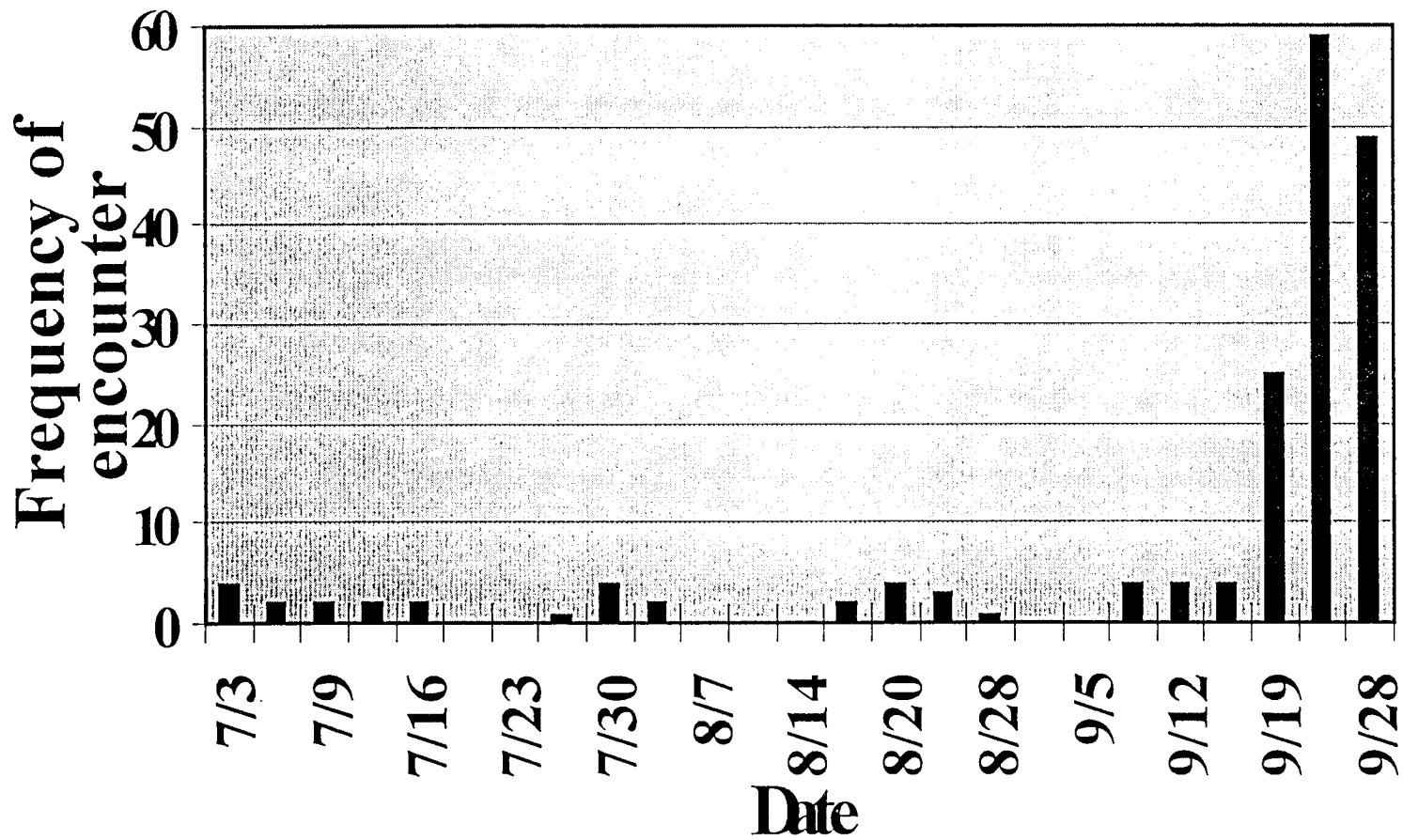


Fig. 7

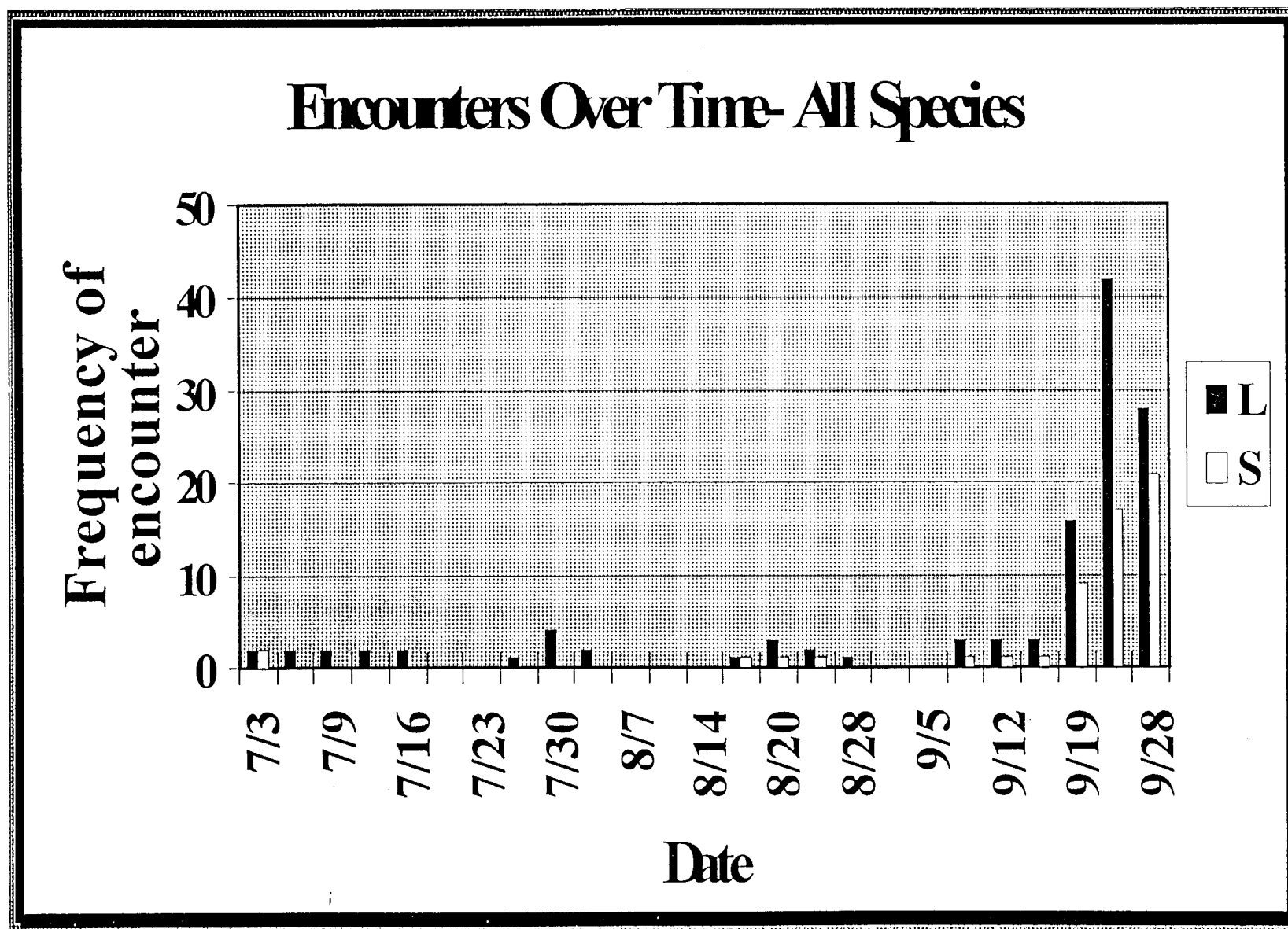


Fig. 8

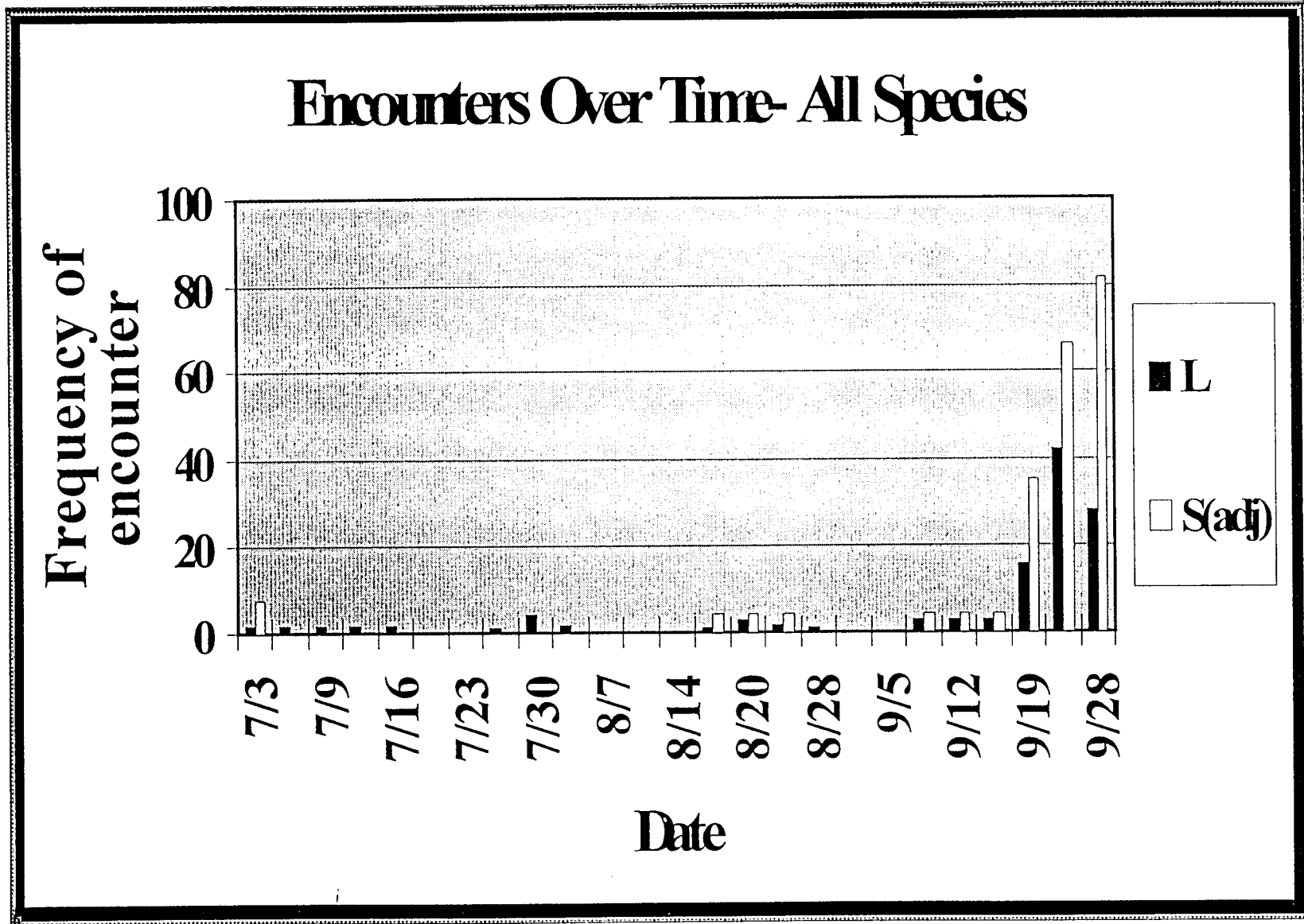


Fig. 9

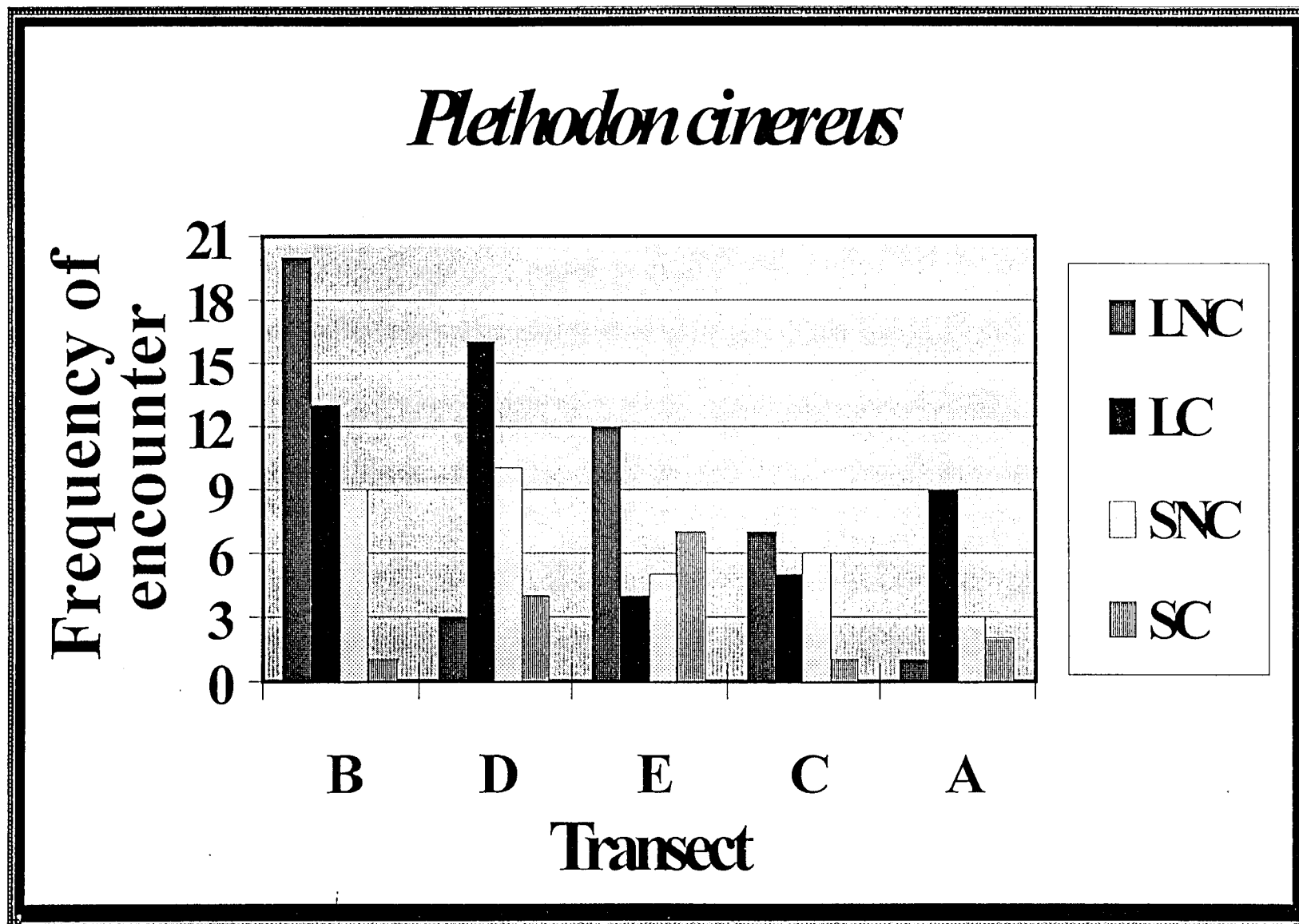


Fig. 10

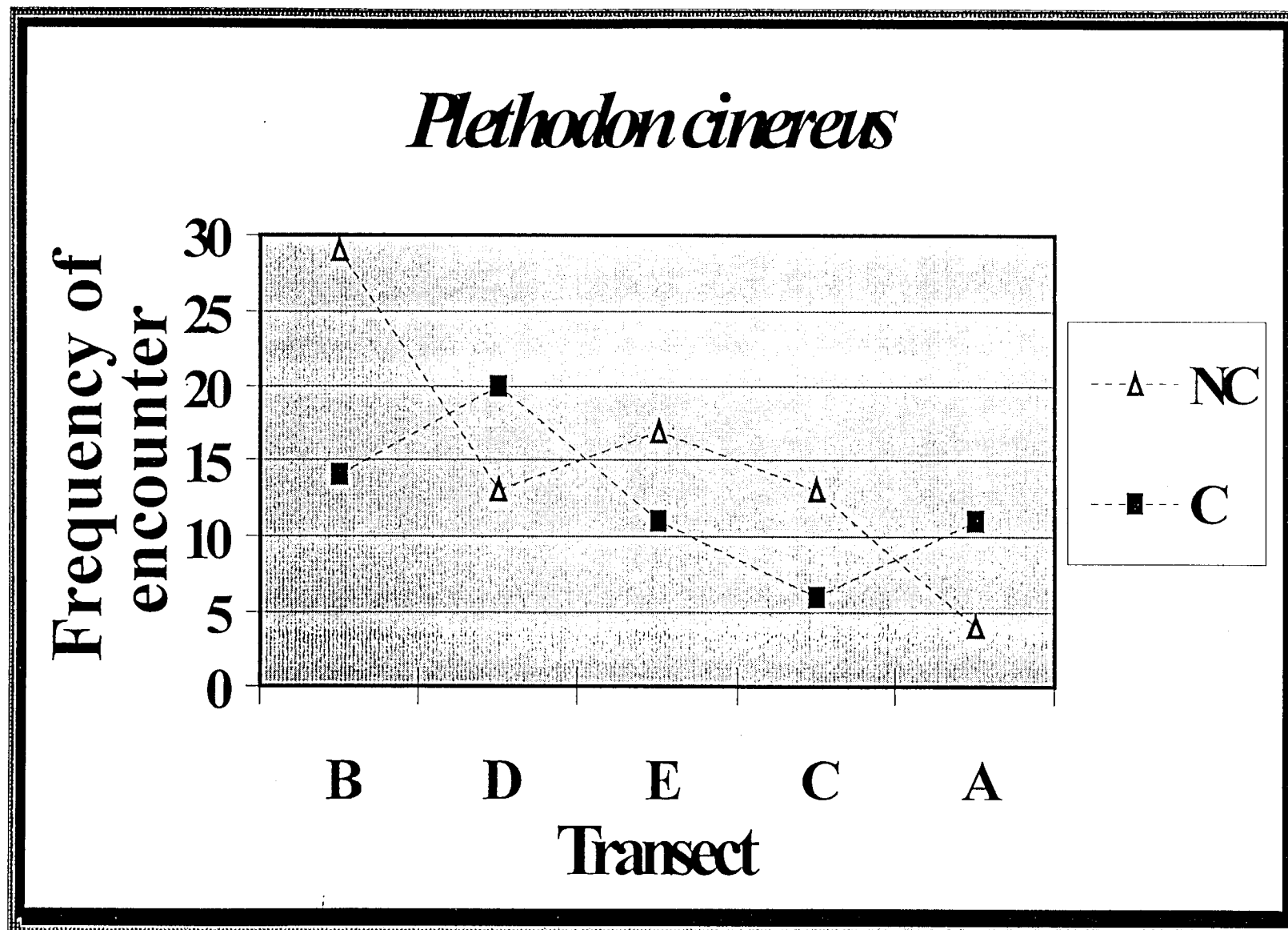


Fig. 11

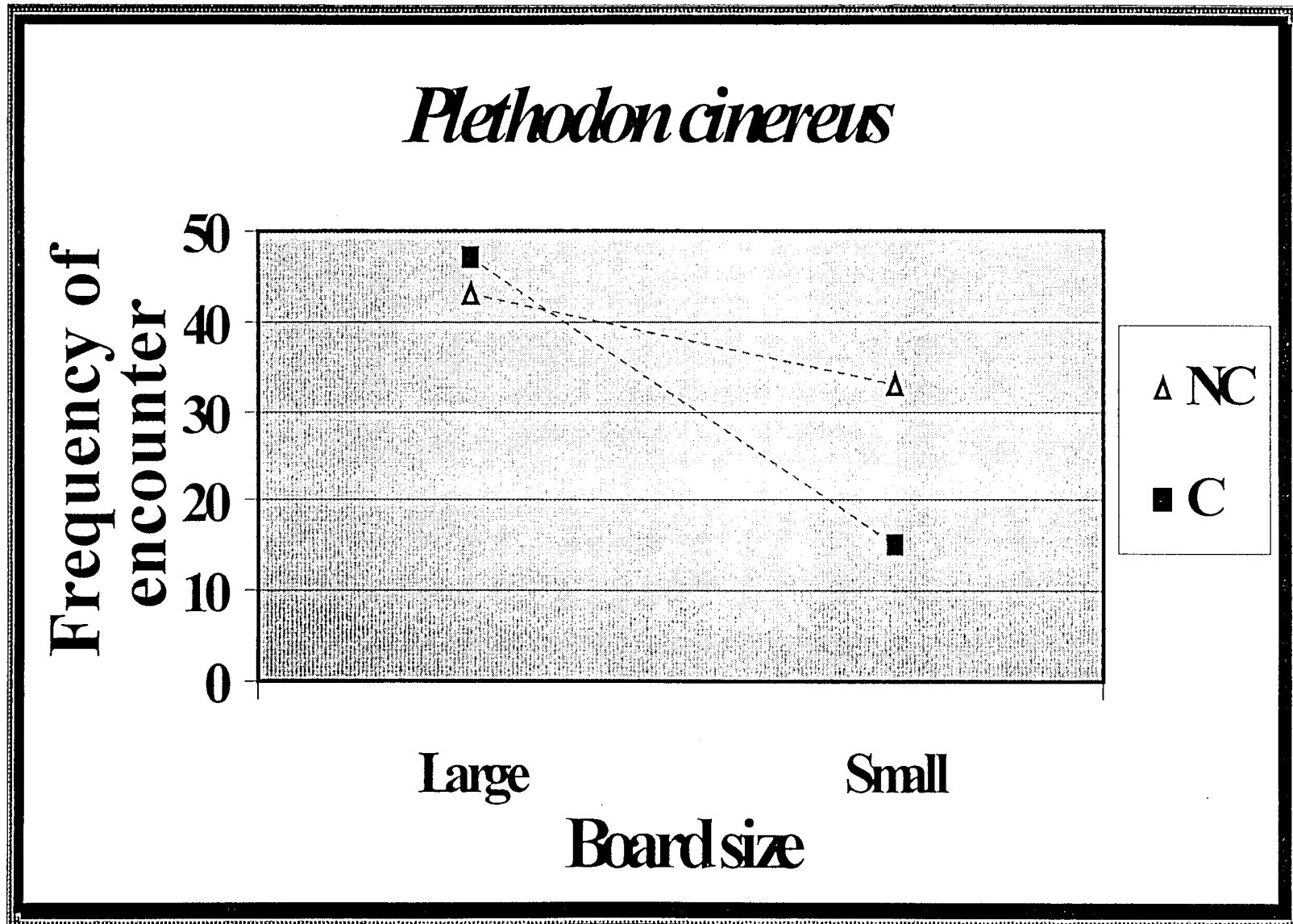


Fig. 12

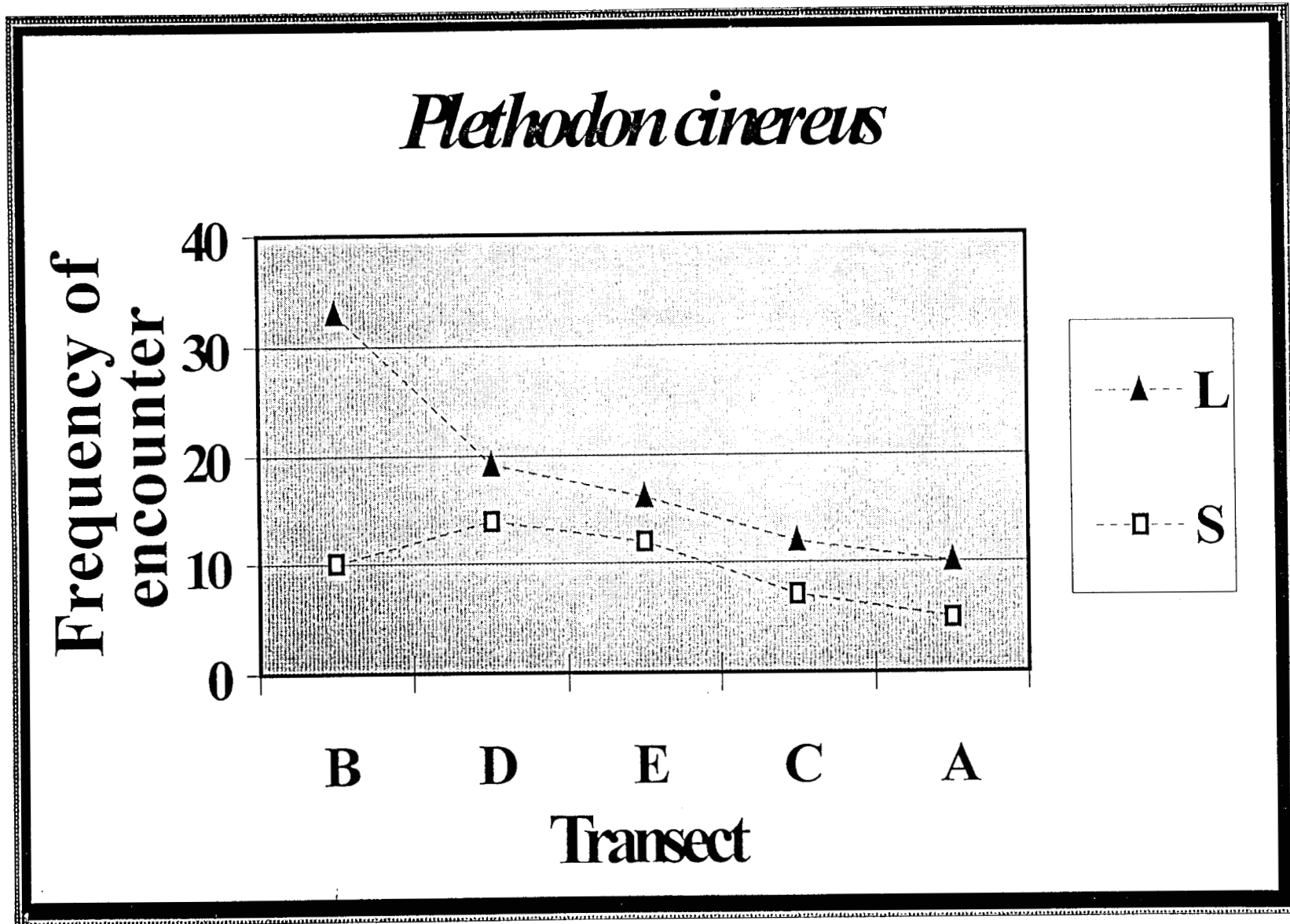


Fig. 13

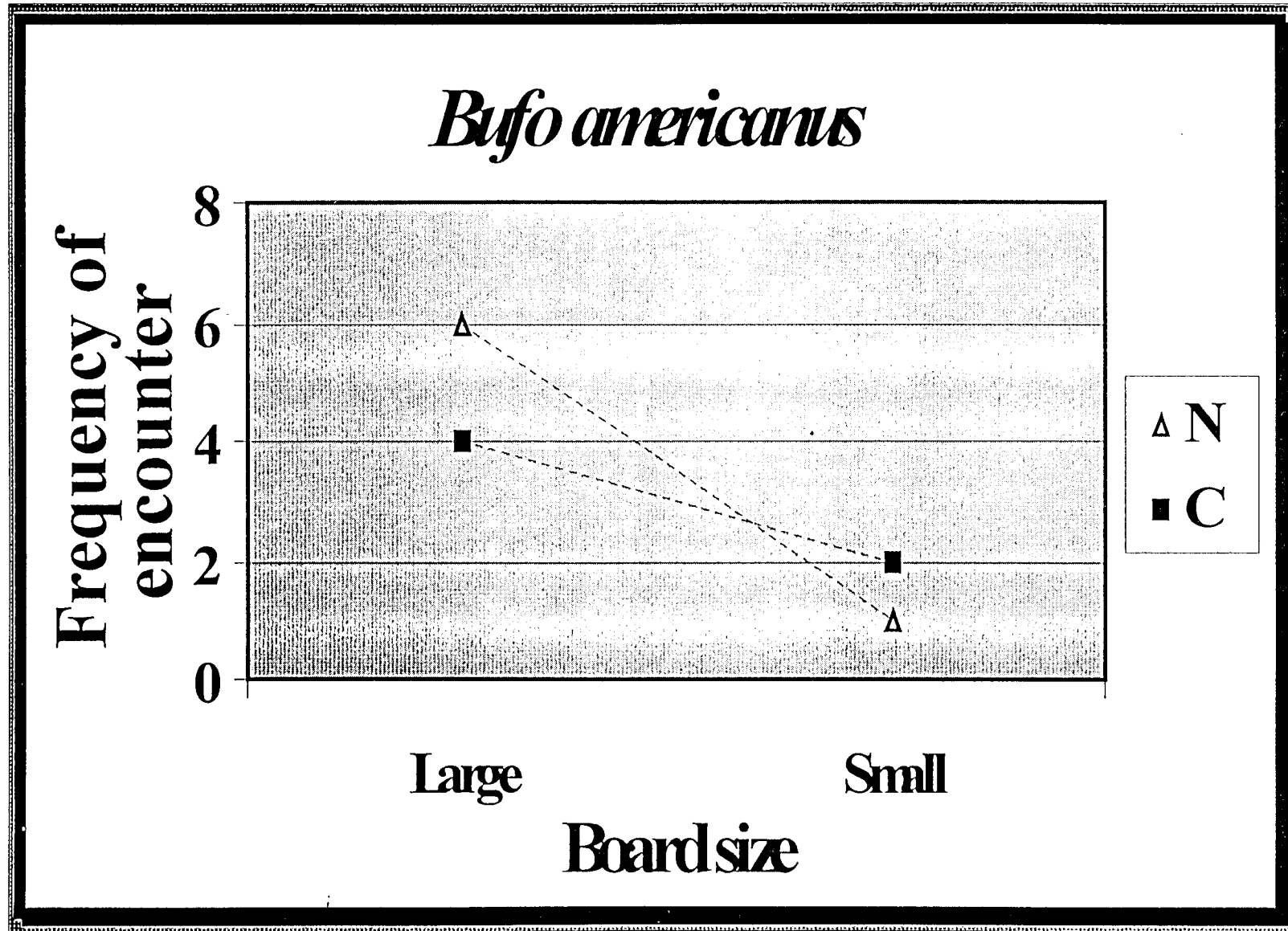


Fig. 14

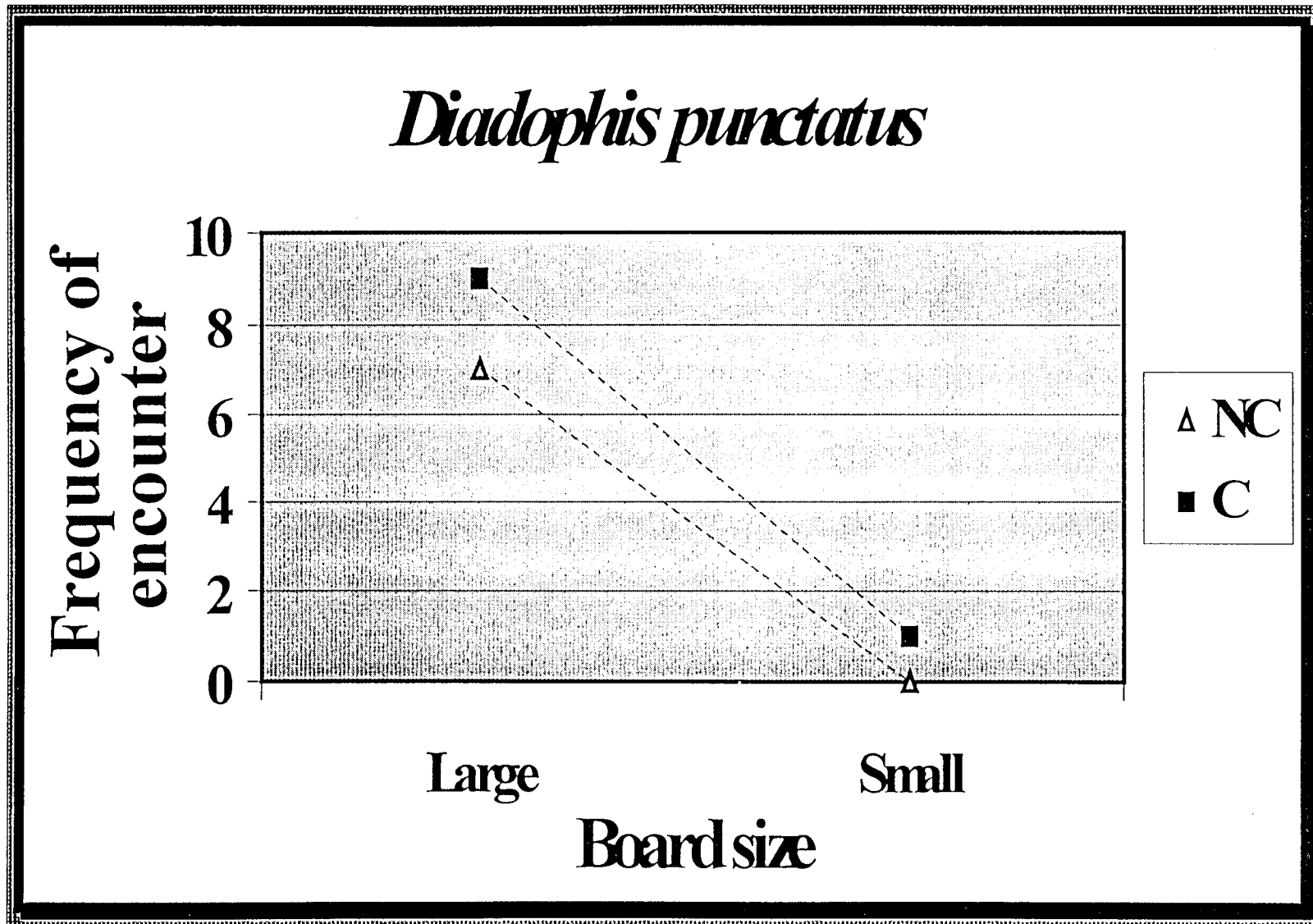


Fig. 15

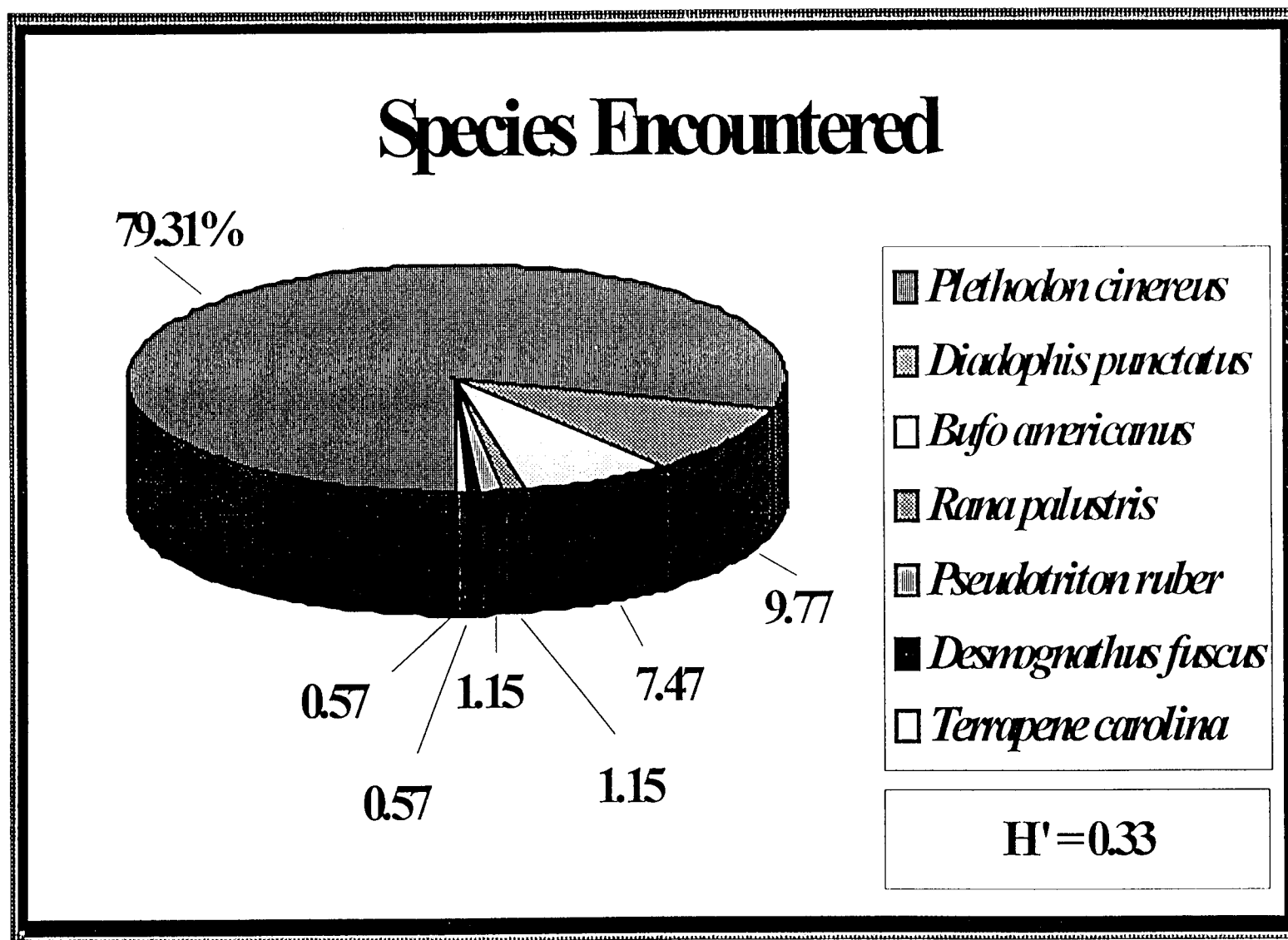


Fig. 16

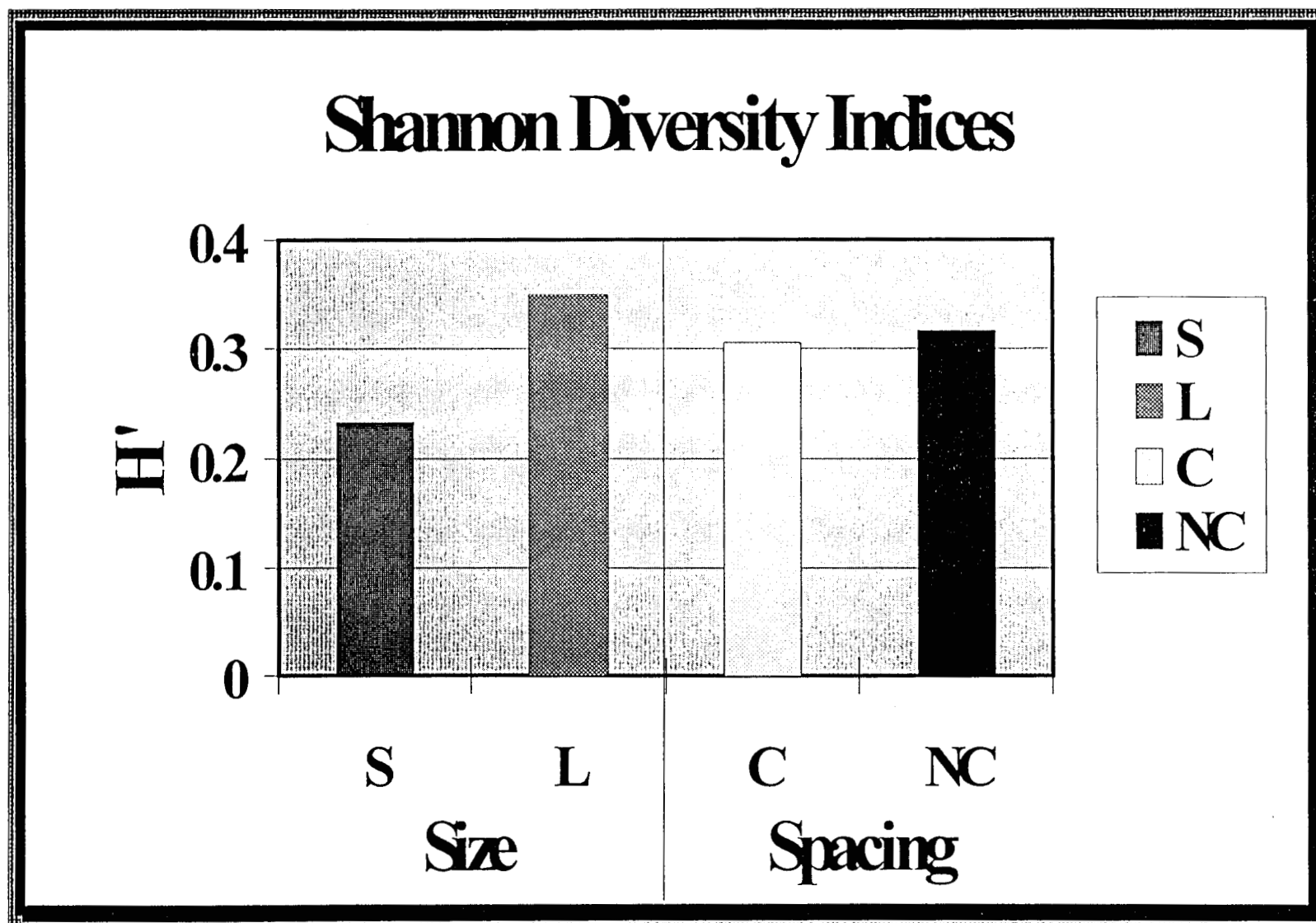


Fig. 17

Shannon Diversity Indices

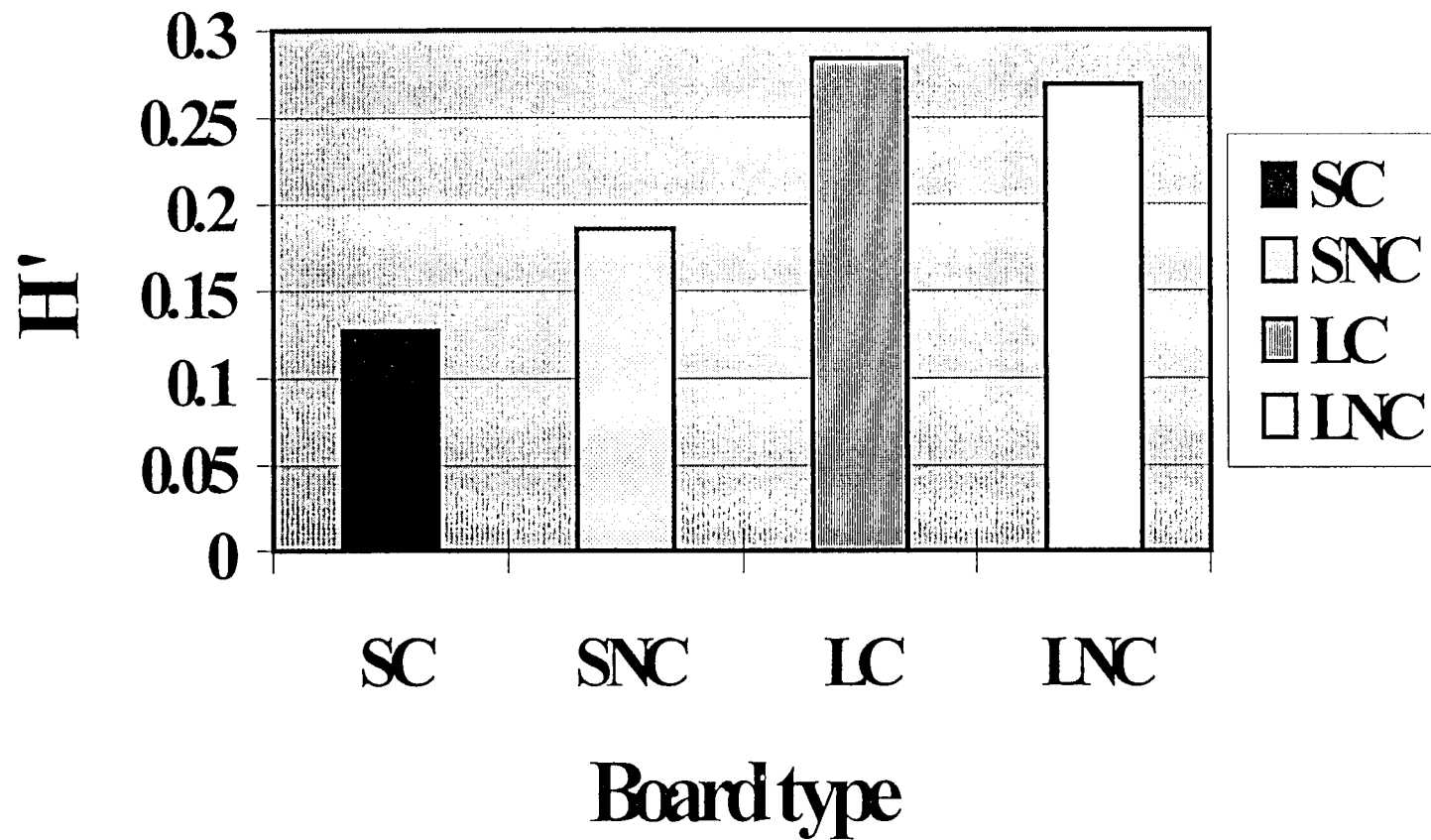


Fig. 18

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APPENDIX A. Data sheet for coverboard surveys.

Herpetofauna Data Sheet

Date:

Conditions:

Collectors:

Time of census:

[illegible]

Trans= transect

Depth= litter/soil depth

SVL= snout-vent length

Moisture= dry, moist, or wet

Substrate= type of litter/substrate

Temp(F)= air temperature

APPENDIX B. Data sheet for microclimate sampling.

Coverboard Soil Moisture Data Sheet

Date:

Time:

Conditions:

Station	Site	Size	Cleat	C Mass	V Mass	V + C + WS	V + DS	WS Mass	DS Mass	Mois. Mass	% Mois.	Temp (C)

C= cap

DS= dry soil

V= vial

Temp (C)= beneath board

WS= wet soil

Control

Transect	Position	C Mass	V Mass	V + C + WS	V + DS	WS Mass	DS Mass	Mois. Mass	% Mois.	Temp (C)

C= capDS= dry soil

V= vialTemp (C)= beneath board

WS= wet soilPosition= sun or shade