REPORT TO THE CCNP ON ARTHROPOD SPECIES DIVERSITY IN THE BIG ROOM AND THE ENVIRONS

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1 Introduction

A study of species diversity in the Big Room and Left Hand Tunnel of Carlsbad Cavern was undertaken in 1988 by the authors to further study differences in species diversity that were noted previously by one of the authors (Northup 1988). By way of introduction, the literature on cave species diversity and previous findings concerning species diversity in Carlsbad Cavern will be reviewed by the authors.

1.1 Species Diversity in Cave Ecosystems

Species diversity and community structure have been extensively studied in cave ecosystems in the past (e.g. Culver 1970a, 1970b, 1971, 1973; Poulson

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1972, 1974, 1975, 1976; Poulson and Culver 1969). Community studies have concentrated on control of species diversity and abundance, the role of competition, and partitioning of the cave ecosystem into various microhabitats.

Poulson and Culver (1969) and Poulson (1972), using extensive pitfall trapping in Flint-Mammoth Cave, Kentucky, found that species diversity (as measured by the Shannon diversity index, H) is positively correlated with substrate diversity, and substrate organic and moisture content, and negatively with intensity of flooding in Flint Ridge, Kentucky. Further, these authors consider that increased food payoff and high risk (e.g. flooding that may make it too risky to continue foraging in a given food rich area) lead to dominance by time-efficient, opportunistic, short-lived species (which they termed "r+ species"). In contrast, low risk/low payoff food favors long-lived, resource efficient species, with no one species dominating. The latter situation should lead to high species diversity and evenness. Poulson (1972) further noted that "many species have a very high mobility and that there is a higher species diversity when food is scarce." Culver (1970a) emphasized the influence of regular flooding in explaining faunal differences among caves, but added his assertion that stochastic processes may account for a substantial portion of the unexplained variance.

Keith (1975), working in Murray Spring Cave, near Paoli, Indiana, found that factors affecting species diversity (H') included (1) outside temperature, (2) passage air relative humidity, (3) degree of flooding, (4) substrate moisture and organic content, (5) cave air temperature, and (6) cave morphology. In contrast to Poulson, Keith concluded that substrate organic content had the least effect. Keith also suggested that none of the cave organisms are food-limited. Differences in conclusions may be due to the different types of caves in which these researchers were working. Murray Spring Cave is a relatively short cave which floods frequently, in contrast to the Mammoth Flint Ridge system (where Poulson worked), which is over 350 miles in length and which floods to varying degrees. He noted that relatively large, mobile organisms (e.g. diplurans) were found at low densities, and were scattered evenly throughout the cave. Smaller, less mobile organisms (e.g. collembolans) occurred in high density patches with high organic content.

Northup's study (Northup 1988) of species diversity in Carlsbad Cavern was carried out in Bat Cave, Sand Passage, and Left Hand Tunnel. Hill's N_2 values of species diversity (alpha-diversity) (Hill 1973) were calculated from data collected for all three locations between December 1984 and October

1987. The results (Fig. 1) showed differences in species diversity between Left Hand Tunnel, and Bat Cave and Sand Passage. Overall, Left Hand Tunnel N_2 values were closer to one, while Sand Passage and Bat Cave had higher values, indicating relatively more even proportions of each species than in Left Hand Tunnel. Less variation was seen in the Left Hand Tunnel values than in the values for the other two sites. To investigate whether these results held up at a larger scale (ie the Big Room through part of Left Hand Tunnel), a series of transects were selected in these two areas. Details are given in the methods section.

1.2 Organism Systematics

The cavernicolous rhaphidophorids, *Ceuthophilus carlsbadensis* Caudell and *C. longipes* Caudell, which are the primary organisms found in the Big Room and Left Hand Tunnel, belong to the tribe Ceuthophilini (Hubbell 1977) in the family Rhaphidophoridae. The genus *Ceuthophilus* includes the majority of the species in North American Rhaphidophoridae, members of which were described by Hubbell (1936) as being wingless, somewhat cricket-like with rounded backs, secretive, nocturnal, and silent. Many are cavernicolous, and the rest either live in the forest floor debris or in burrows in deserts or grasslands. He listed more than 80 species, distributed from the Atlantic to the Pacific, and from Labrador and British Columbia to the state of Durango in Mexico. Keys are provided by Caudell (1916) and Hubbell (1936). The two species studied in this project were first described by Caudell (1924), who noted that they are not closely allied to any other. However, Hubbell (1936) described *C. carlsbadensis* Caudell as being related to *C. silvestris*, *C. cunicularis*, *C. umbratilis*, and *C. polingi*. He noted that *C. longipes* Caudell "...seems to be the only obligatory cavernicole of the group," and has the most troglophilic adaptations of the genus. It is also only known from Carlsbad Cavern (Hubbell 1936), while *C. carlsbadensis* Caudell is known from many caves in New Mexico and Texas.

Other organisms in the study include collembolans, centipedes, diplurans, and rhadine beetles. From Barr and Reddell (1967) these are probably *Thalkethops grallatrix* Crabill (the only centipede reported for Carlsbad), *Plusiocampa sp.* (dipluran reported from Carlsbad), *Folsomia candida* ? Willem or *Pseudosinella sexoculata* Schott (collembola reported from Carlsbad), and *Rhadine longicollis* Benedict.

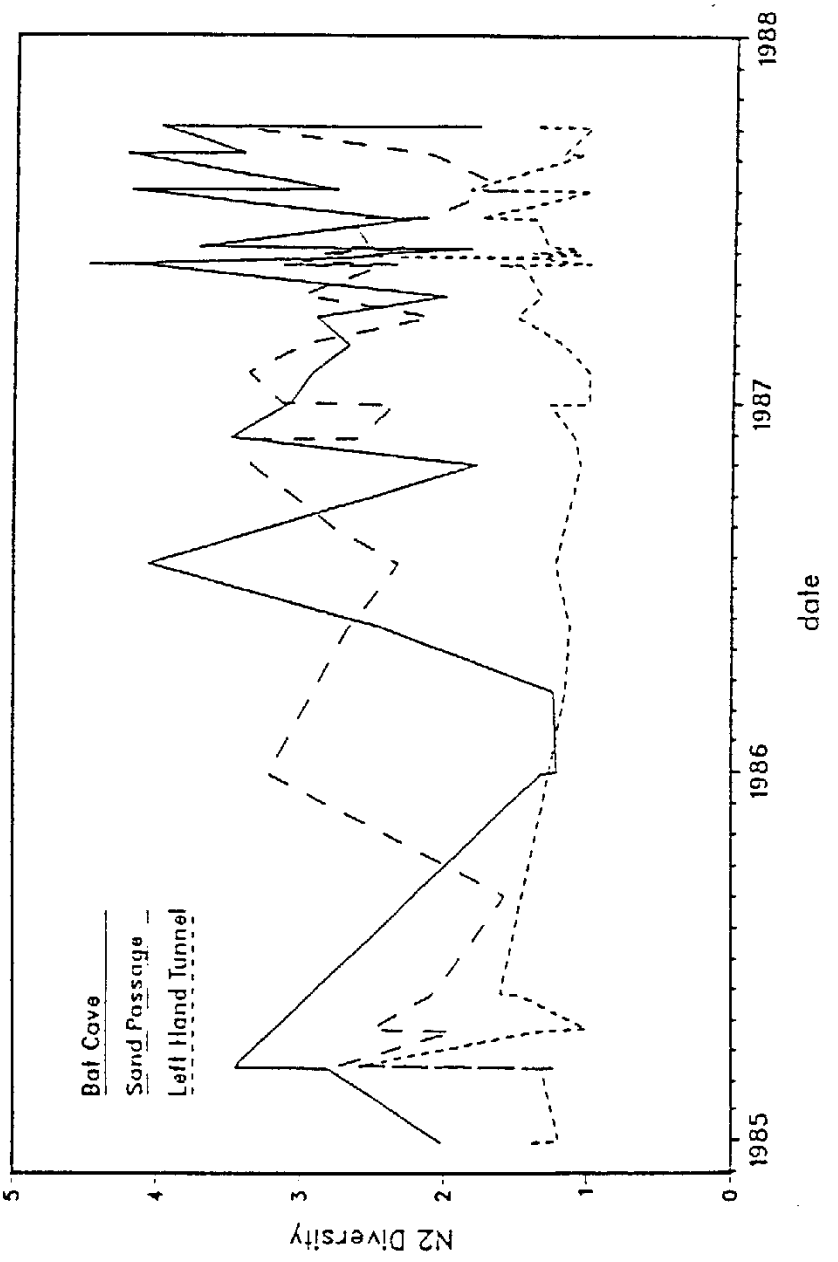

Figure 1: Species Diversity (Hill's N_2) for Carlsbad Cavern

2 Methods

2.1 Site Descriptions

2.1.1 Left Hand Tunnel

Representing an area of moderate food resources, Left Hand Tunnel is located 230m below the surface and is adjacent to the Carlsbad Cavern "Lunch Room." The two cavernicolous rhaphidophorid species co-occur there, but *C. carlsbadensis* Caudell clearly dominates. The area in which our traps were set is dry and food poor, but its proximity to the Lunch Room and various trash containers provided a reliable food source. Trash containers have been locked at night since the winter of 1984, and Cavern Supply trash is removed daily from the cave (R.C. Kerbo, personal communication 1987), but various park visitors drop small amounts of food in obscure places. During the day, light from the Lunch Room reaches Left Hand Tunnel; at night the lighting is decreased, but present. Temperatures in Left Hand Tunnel are higher than in other areas of Carlsbad Cavern, but are relatively constant. The trapping area in Left Hand Tunnel has a level, rocky floor with sides containing moderate amounts of crushed moonmilk that alternate with a few silt areas.

2.1.2 Big Room

Also representing an areas of moderate food resources, the Big Room is located at the same elevation as Left Hand Tunnel and parts of it are adjacent to the "Lunch Room." While a similar pattern of cavernicolous rhaphidophorid occurrence is seen, several species not previously censused in Left Hand Tunnel were observed. The Big Room offers a much greater variety of habitat types than are seen in the areas censused in Left Hand Tunnel. Areas vary from very dry old bat guano or gypsum to pools of water in flowstone areas. Thus, although there are many similarities in terms of temperature, food resources of human origin, and lighting, substantial difference occur in heterogeneity of habitat and visitation by humans.

2.2 Transect and Trap Site Selection

In the Big Room and Left Hand Tunnel, transects were selected to sample representative habitats at increasing distances from the Lunch Room and

from park visitor trails. Selection of transects was not done at random due to the delicate nature of some areas and unsuitability of some areas for trap setting due to their solid rock nature. Figs. 2, 3, and 4 show the locations of the traps and transects. Along the various transects, trap sites sampled the following kinds of microhabitats, of which the first three measures are qualitative, while the next two are quantitative:

- Vertical Heterogeneity (Low (< 0.5 feet), Medium (0.5 feet to 2.0 feet), and High (>2.0 feet))
- Soil Moisture Content (Dry, Dry Surrounded by Wet Areas, Damp, and Wet)
- Soil Type (Gypsum, Clay, Guano, Rubble, Silt, and Moonmilk)
- Distance from Trail
- Distance from Lunch Room
- Public vs Non-Public Areas

Selection of trap sites was accomplished by first evenly distributing sites within the habitats to establish a base location for each trap. Trap location was then perturbed in a random fashion along the transect by using coins to generate the random displacement. If the location was unsuitable for a trap, the trap location was moved left or right of the transect line until a suitable location for the trap could be located. This movement of trap location was limited by the length of the transect line within each habitat. Points were never moved more than half the distance between any two base locations within the habitat. Limitation left and right was limited to a maximum of 12 feet. Unsuitable locations were defined as those that either would have damaged delicate formations or in which it was impossible to dig a trap hole (eg flowstone).

2.3 Pitfall Trapping

Pitfall traps were set in the Big Room and Left Hand Tunnel beginning in February, 1988 and ending in September, 1988. Traps consisted of 16-oz Solo plastic cups with Solo "cozy" cup inserts. Traps were buried to their rims

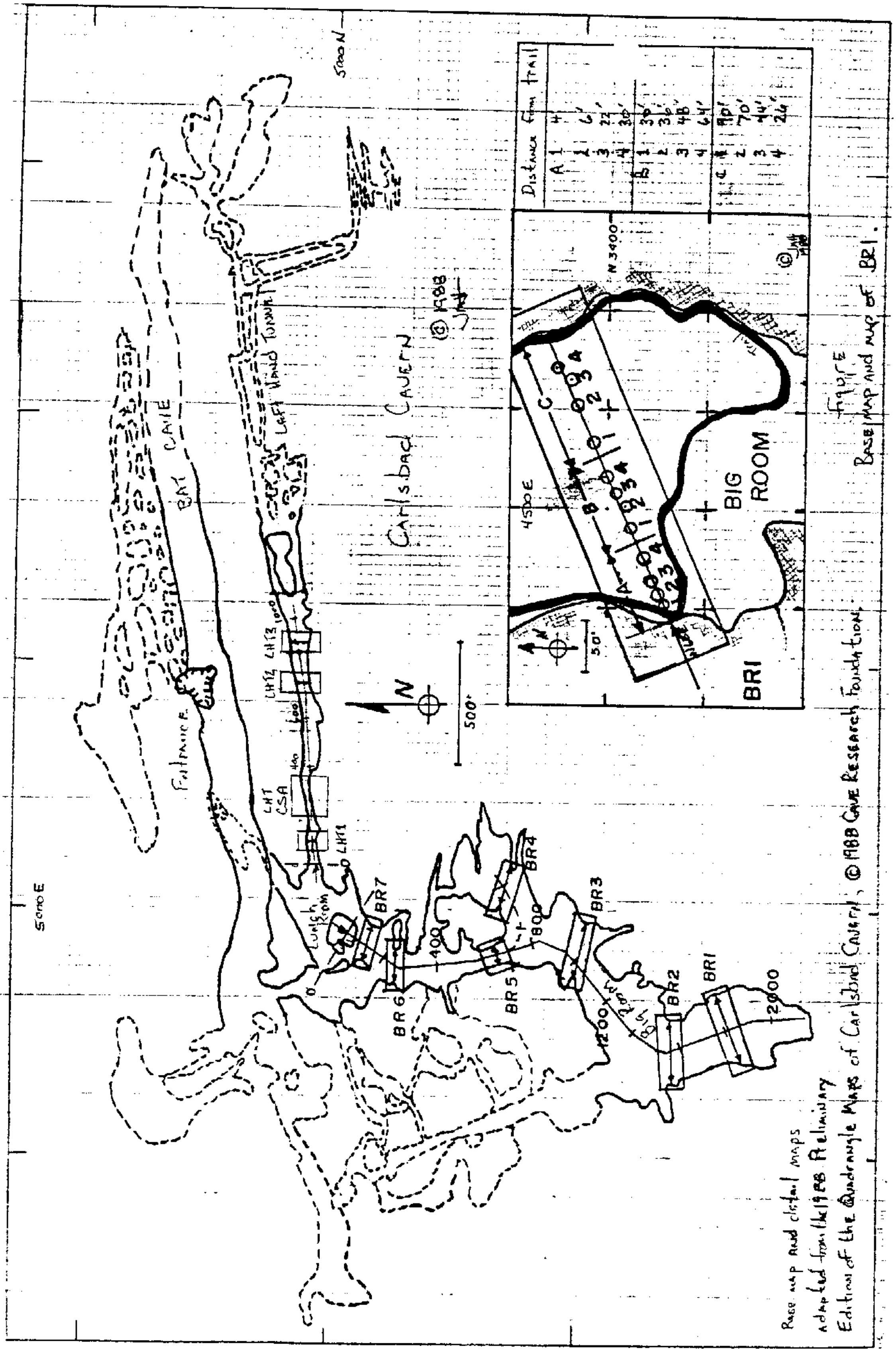

Figure 2: Location of Transects and Traps; BR1

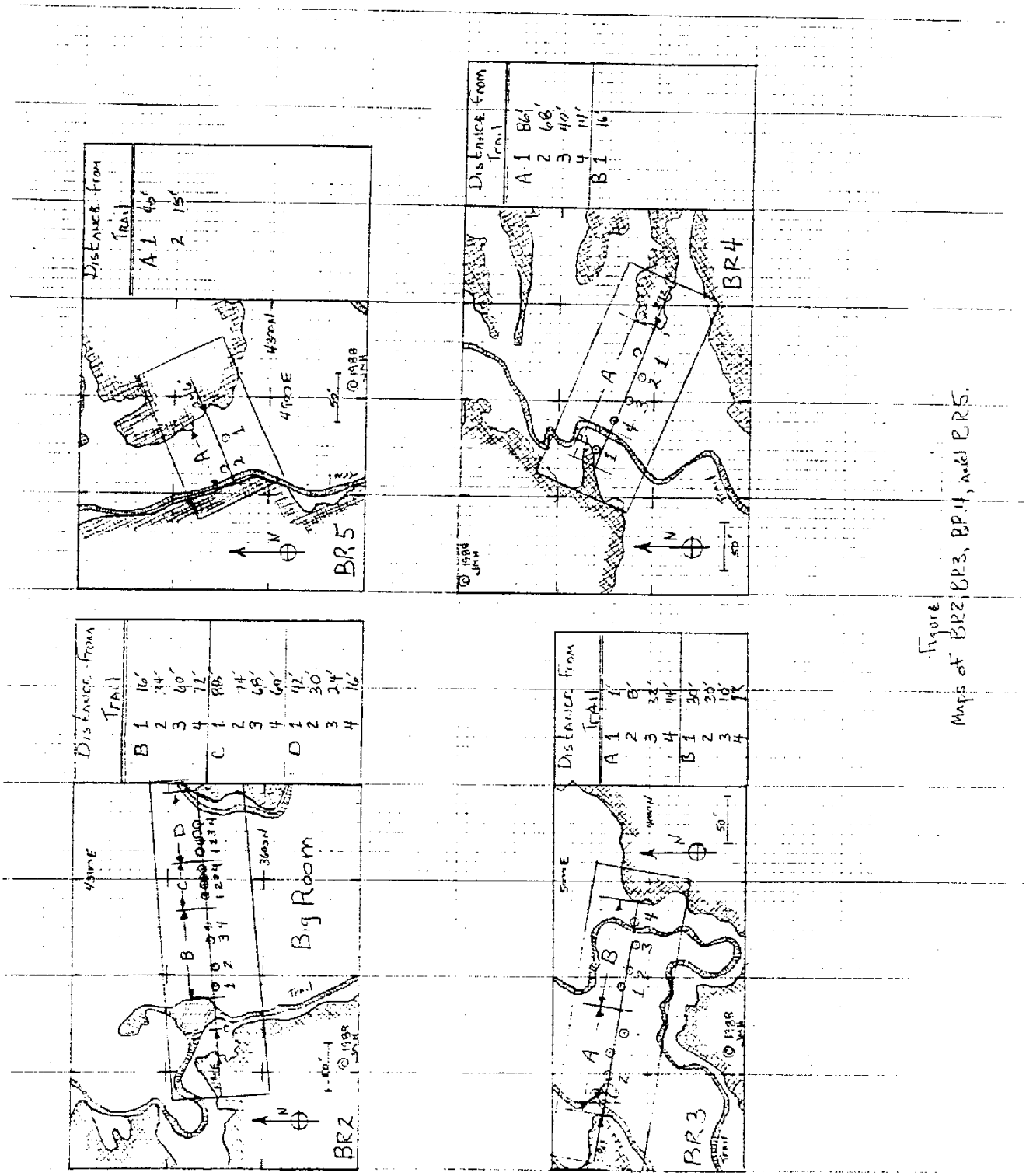

Figure 3: Location of Traps in BR2-5

Figure
Maps of BR6, BR7, LHT1, LHT2, LHT3, and LHT-CSA.

Figure 4: Location of Traps in BR6-8

in the substrate in the same location each time in all 73 trap locations. The interval between setting the traps and censusing the catch was approximately 24 hours and traps were censused two consecutive days.

Of the arthropods trapped, all adult and subadult rhaphidophorids, and all *Rhadine* beetles, were marked using a color scheme indicating transect location and censusing period. All organisms were counted and released, and all censusing was non-destructive.

2.4 Data Analysis

Data collected from these censusing trips was used to estimate alpha-diversity using Hill's N_2 index (Hill 1973), (the reciprocal of Simpson's Index), where

$$N_2 = \frac{1}{P_1^2 + P_2^2 + \ldots P_n^2}$$

P_1 and P_n are proportions of individuals of different species in a sample.

Raw data were entered into SAS[1] and S datasets, which was used to provide descriptive statistics of spatial and temporal species distribution. S was also used to provide boxplots of the data for examination for equal variances and outliers.

3 Results

3.1 Species Diversity

Hill's N_2 values of species diversity (alpha-diversity) were calculated from data collected for the Big Room and Left Hand Tunnel between February 1988 and September 1988. All observations in which species could be told apart were included in the analysis. The results of the Hill's N_2 are displayed in Fig. 5, which is calculated without any of the juveniles in which species could not be differentiated visually, and Fig. 6, which was calculated assuming the juveniles were *C. carlsbadensis*. This assumption was made on the basis that 97% of the identifiable cavernicolous rhaphidophorids were *C. carlsbadensis*. Overall, Left Hand Tunnel N_2 values remained closer to one, as was observed in Northup's previous study. The species diversity in Left

[1]SAS is the registered trademark of SAS Institute, Inc., Cary, North Carolina, USA.

Hand Tunnel was generally lower, but not by much, than in the Big Room, indicating that there is a slightly greater dominance by one species in Left Hand Tunnel. The peak in species diversity in the Big Room in April is due to the bulk of catch being either cavernicolous rhaphidophorids or diplurans, in relatively even numbers. Both species diversity plots display variance in the pattern seen, especially Fig. 5; however, less variation was seen in the Left Hand Tunnel values than in the values for the Big Room.

3.2 Species Abundance and Richness

Species richness was greater in the Big Room (number of species found equals eight) than in Left Hand Tunnel (number of species found equals six). Two of the six species found in Left Hand Tunnel, *C. conicaudus* and the black tenebrionid beetle, were observed from only one specimen. One of the eight species found in the Big Room, the centipede, was also observed from only one specimen. A plot of the overall numbers of different organisms for the entire study period for both locations is given in Fig. 7. Cavernicolous rhaphidophorids, particularly *C. carlsbadensis*, overwhelmingly predominate. A significant number of diplurans and collembolans were also observed.

Abundance patterns by date were also plotted and the results are presented in Fig. 8, which includes all organisms in both locations, in Fig. 9, which separates out the organisms caught in the Big Room traps, and in Fig. 10, which separates out the organisms caught in Left Hand Tunnel. Fig. 9 and Fig. 10 reveal lower total numbers of organisms in the Big Room than in Left Hand Tunnel. Except for the one sampling date in April, the numbers of organisms dropped off in the Big Room following the initial censusing in February.

3.3 Distance From Lunch Room

To investigate the possibility that organisms were aggregating around the Lunch Room, number of organisms found versus distance from the Lunch Room was plotted. Plots show the number of organisms per trap versus distance from Lunch Room where each point is labelled by its observation number. This method was used to reveal the large number of observations that would have been visually hidden otherwise. There are separate plots for the total number of organisms in the Big Room (Fig. 11), for the total

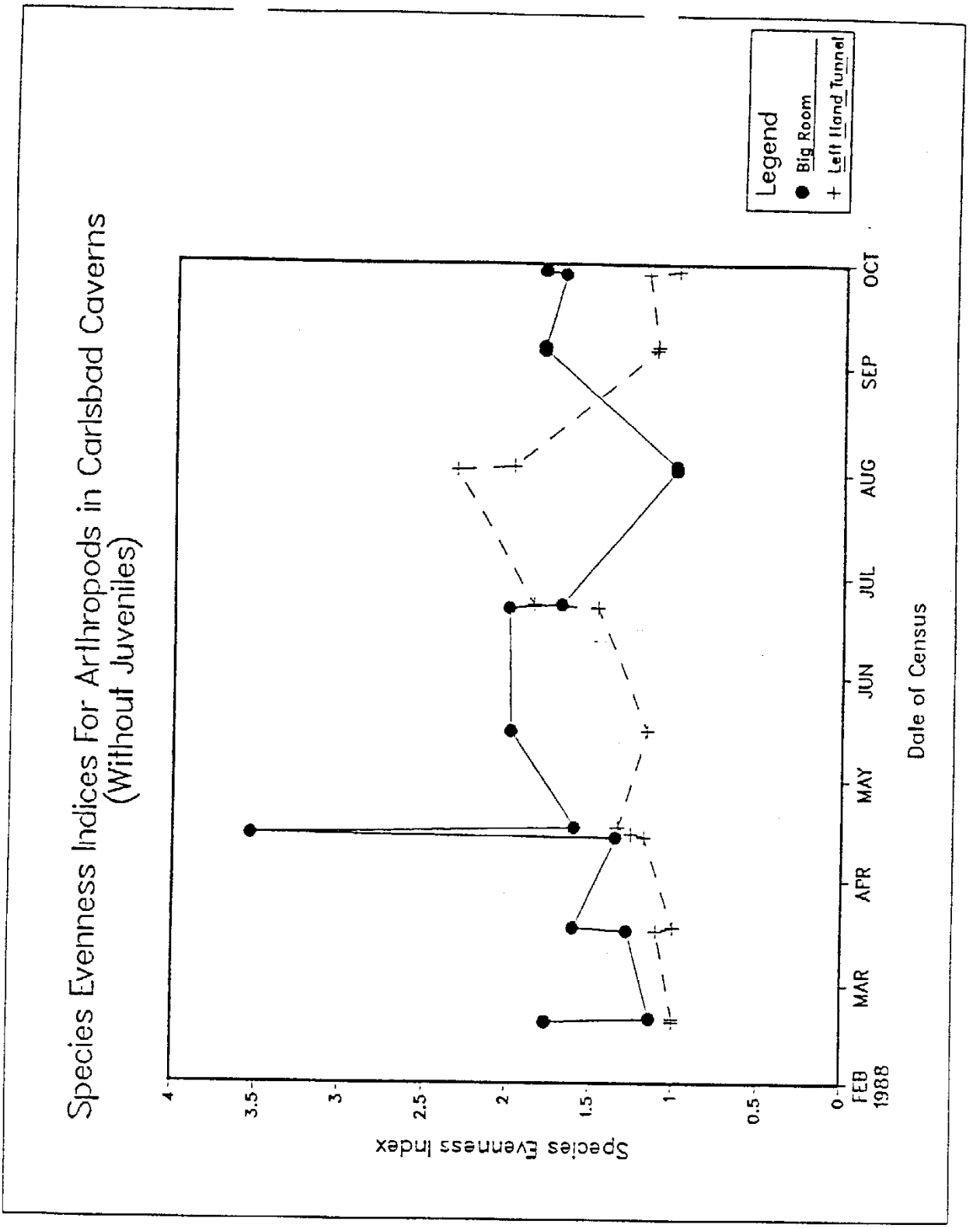

Figure 5: Species Diversity Indices for Arthropods in Big Room and LHT (Without Juveniles)

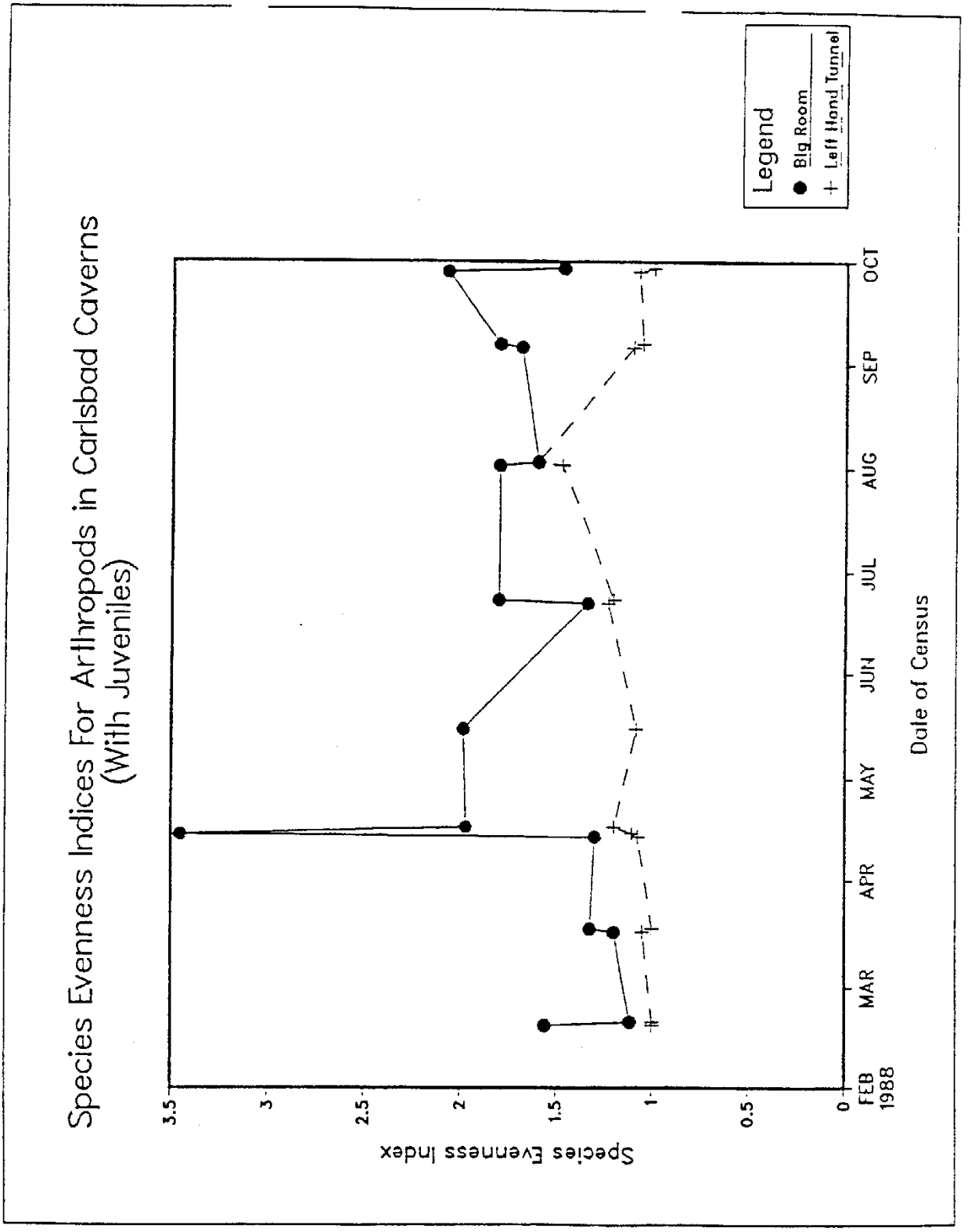

Figure 6: Species Diversity Indices for Arthropods in Big Room and LHT (With Juveniles)

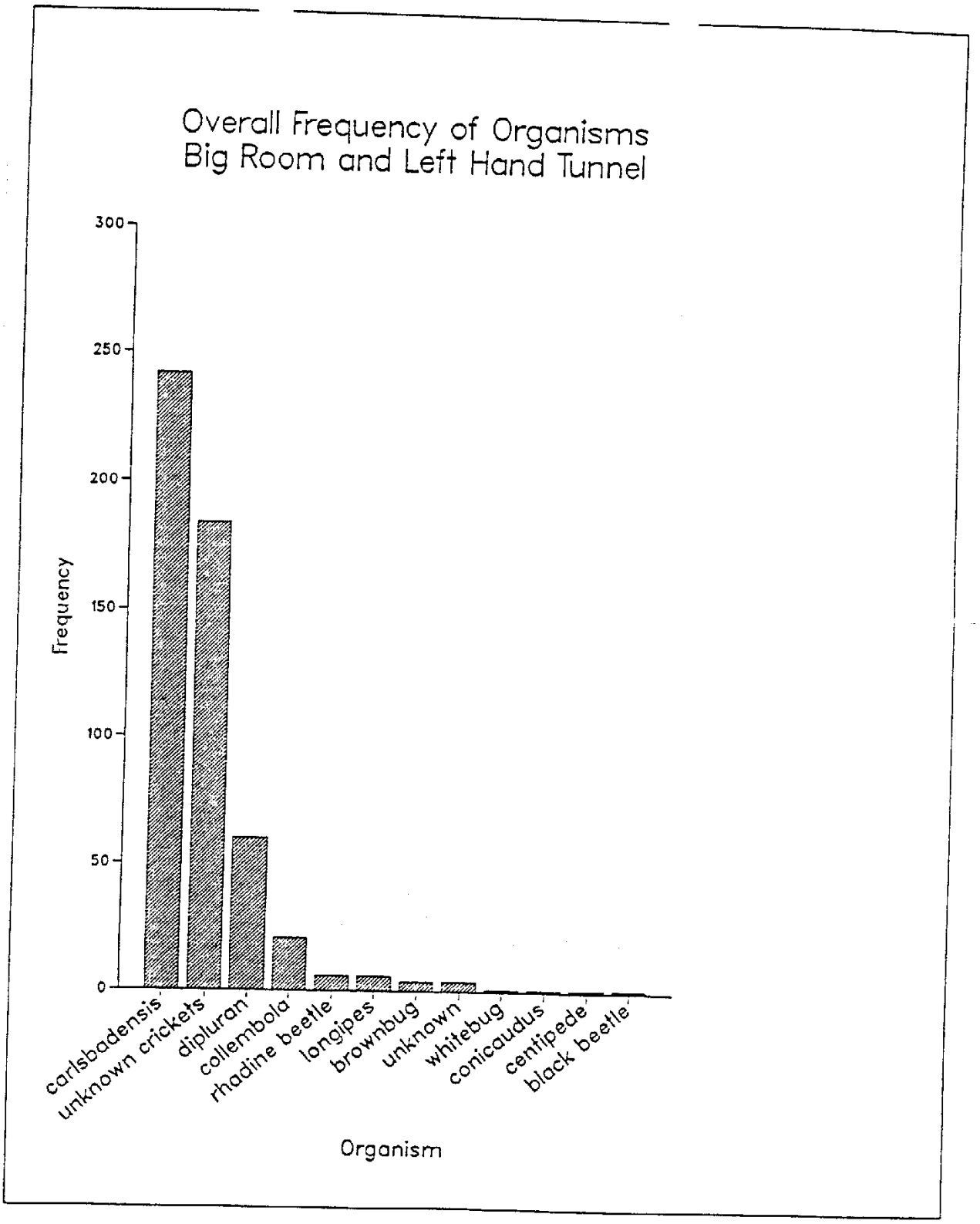

Figure 7: Number of Organisms for All Dates in the Big Room and Left Hand Tunnel

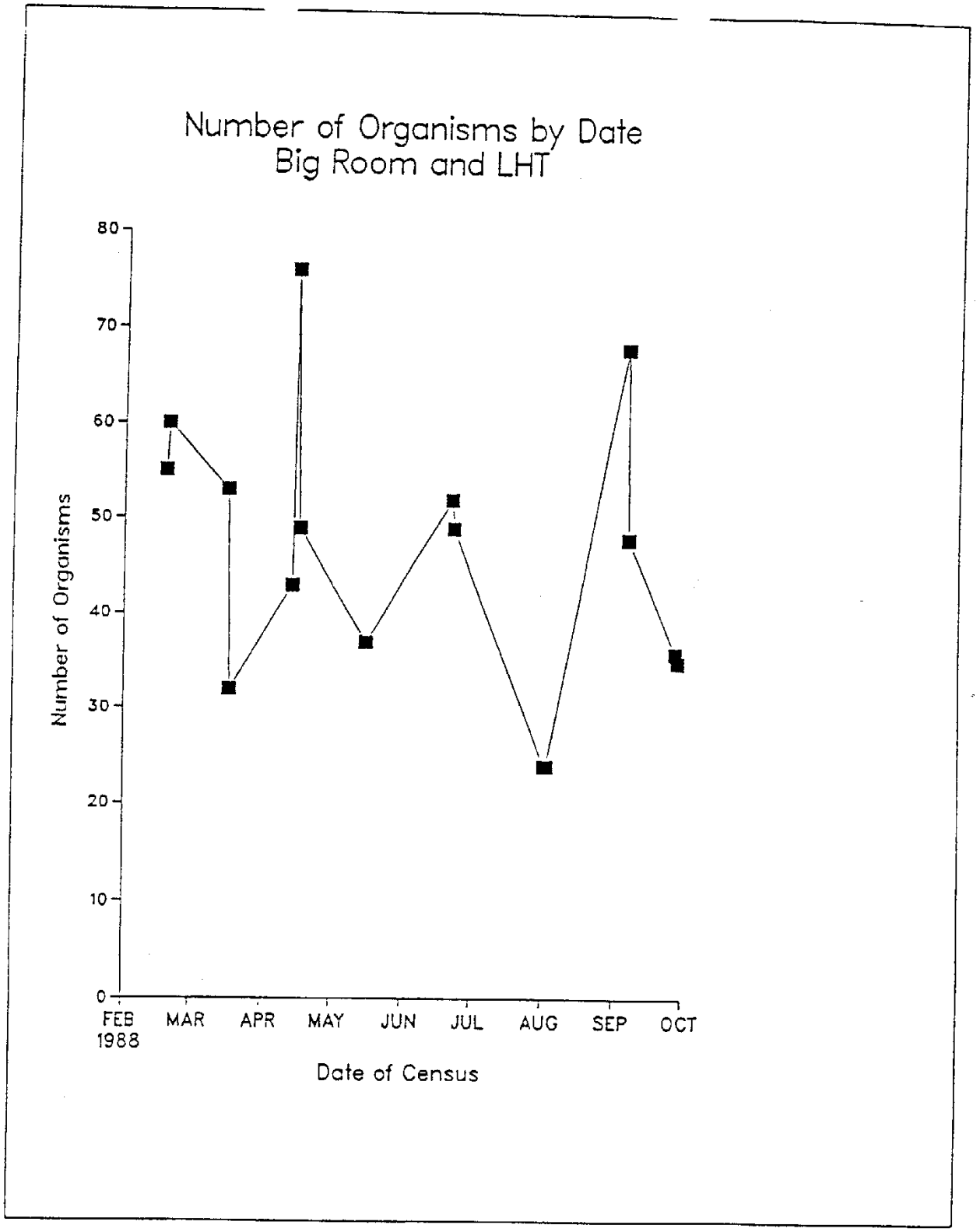

Figure 8: Number of Organisms by Date in the Big Room and Left Hand Tunnel

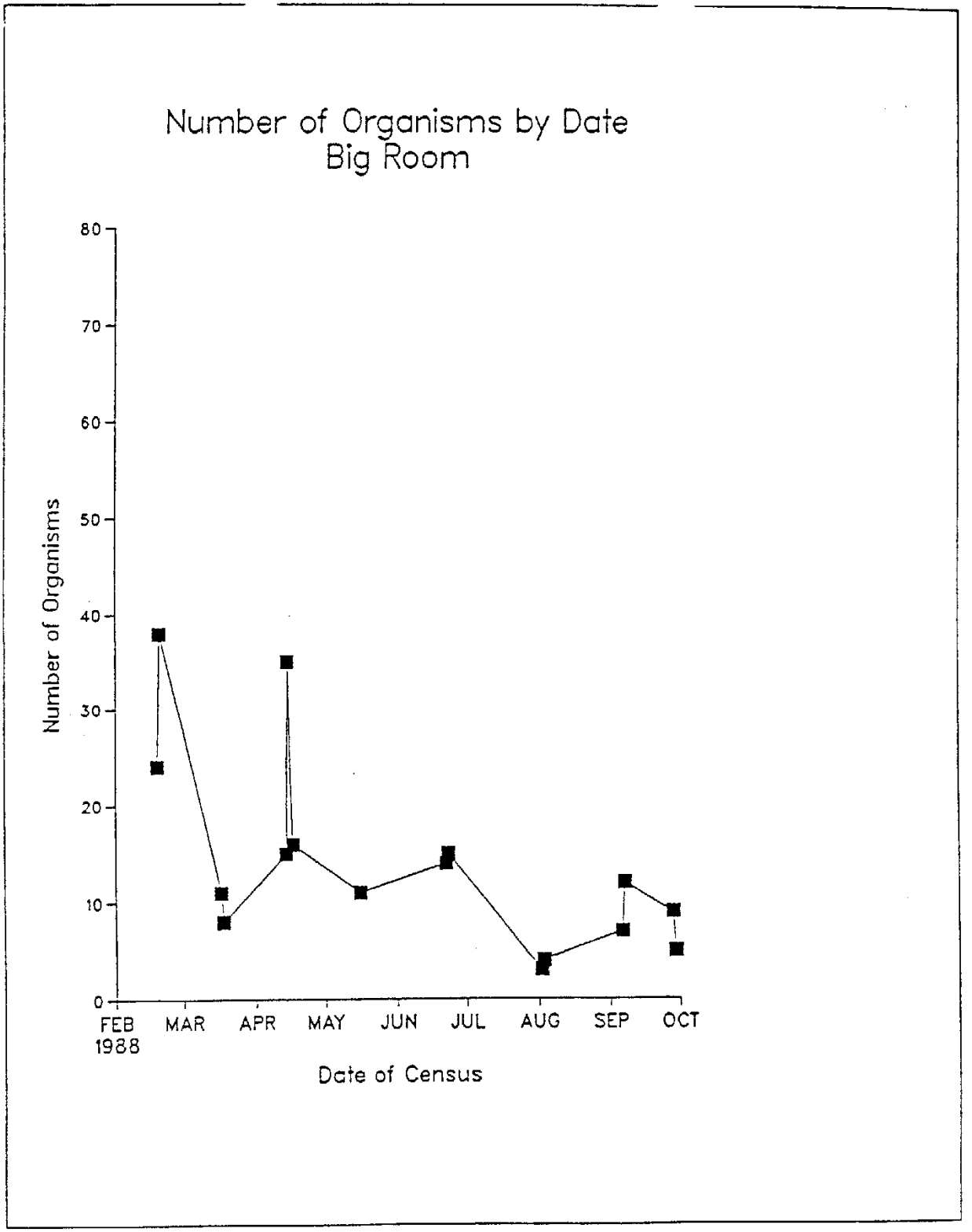

Figure 9: Number of Organisms by Date in the Big Room

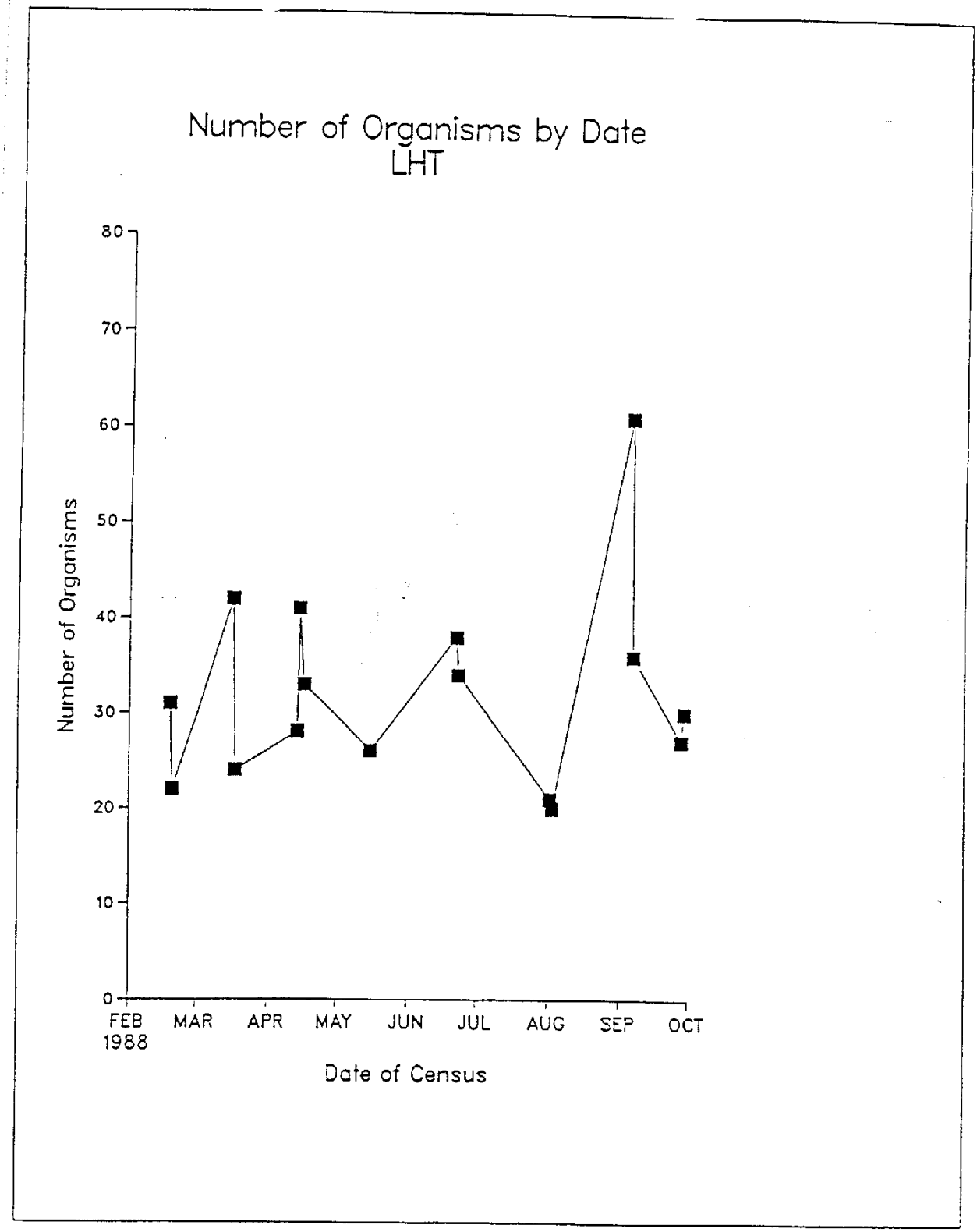

Figure 10: Number of Organisms by Date in Left Hand Tunnel

number of cavernicolous rhaphidophorids found in the Big Room (Fig. 12), the total number of collembolans found in the Big Room and Left Hand Tunnel (Fig. 13), and the total number of diplurans found in the Big Room and Left Hand Tunnel. (Fig. 14). The number of cavernicolous rhaphidophorids, diplurans, and collembolans, being the most numerous organisms found in the Big Room, were broken out to add detail to the picture. Finally, average number of organisms per trap for the entire study period was plotted against distance from Lunch Room (Fig. 15). This showed a stronger indication of clustering near the Lunch Room. Total number of organisms found in Left Hand Tunnel are presented in Fig. 16 and the L series traps are broken out for clarity purposes in Fig. 17.

An unsuccessful curve fitting attempt was made using the data from Fig. 11 and 16. The Big Room data especially does not seem to exhibit any clear pattern. The separate plot of cavernicolous rhaphidophorids found in the Big Room does exhibit a slight pattern of clustering of these organisms around the Lunch Room (Fig. 12). The plots of diplurans (Fig. 14) and collembolans (Fig. 13) in both locations, on the other hand, show no clustering around the Lunch Room.

The plots of the Left Hand Tunnel data (which consist mainly of cavernicolous rhaphidophorids), show a greater number of organisms than is found in the Big Room. Additionally, there appears to be some clustering of the cavernicolous rhaphidophorids near the Lunch Room, even when the greater number of traps set in this area is taken into consideration.

3.4 Distance From Trail

A plot of the number of organisms by the distance from trail in the Big Room, shows only a very slight tendency for organisms to cluster nearer to the trail (Fig. 18). To examine whether there were any differences among the most frequently seen organisms, plots of the number of cavernicolous rhaphidophorids (Fig. 19), collembolans (Fig. 20), and diplurans (Fig. 21) in the Big Room were done. All three of these plots show a slight tendency for organisms to cluster near the trails.

Left Hand Tunnel organisms (predominately cavernicolous rhaphidophorids) appear to cluster behind the gate (between 200 and 350 feet from the nearest trail) (ie the Lunch Room) and further back (ie 1000 feet) in an area that is believed to be an oviposition site (Fig. 22).

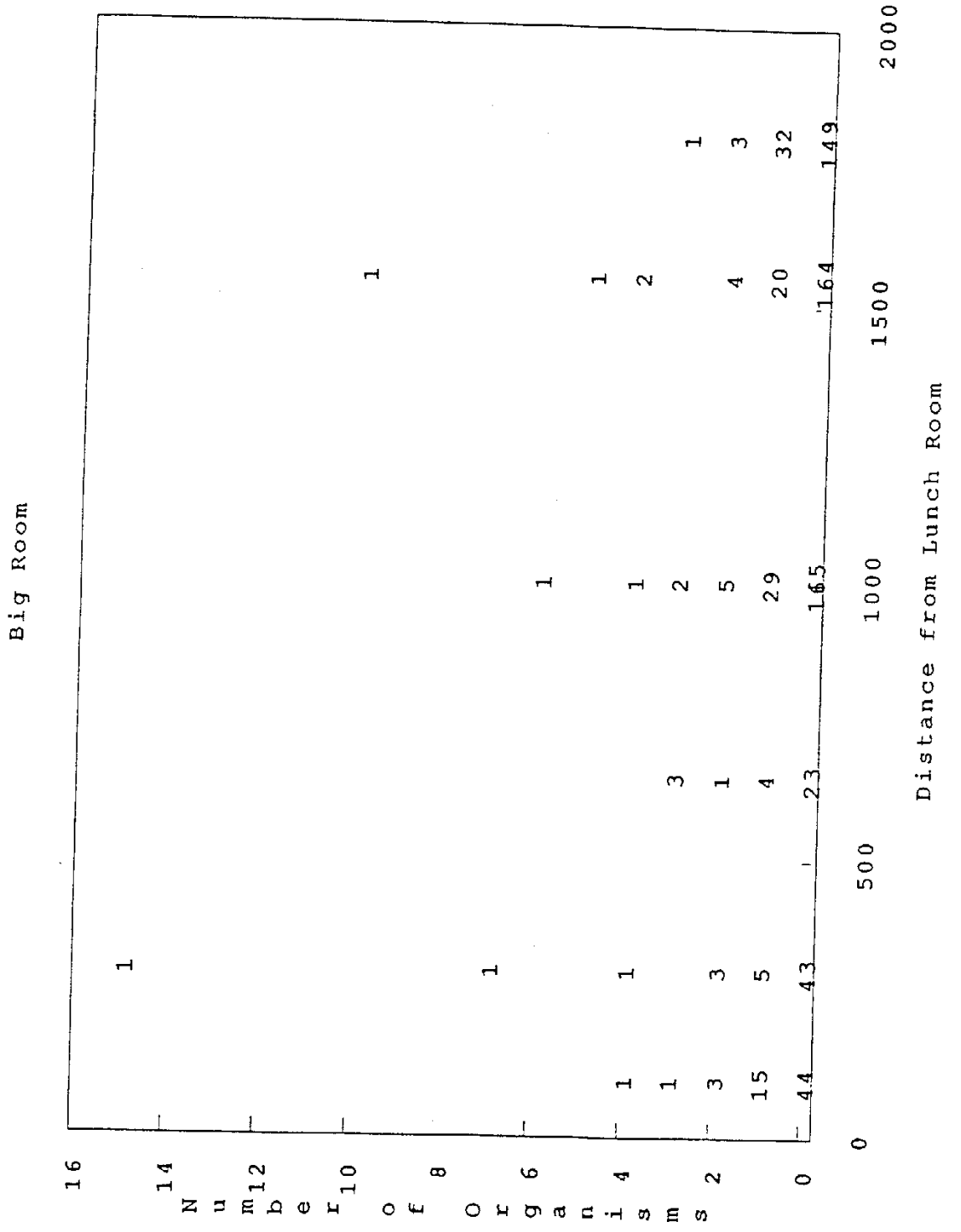

Figure 11: Total Number of Organisms by Distance from the Lunch Room in the Big Room

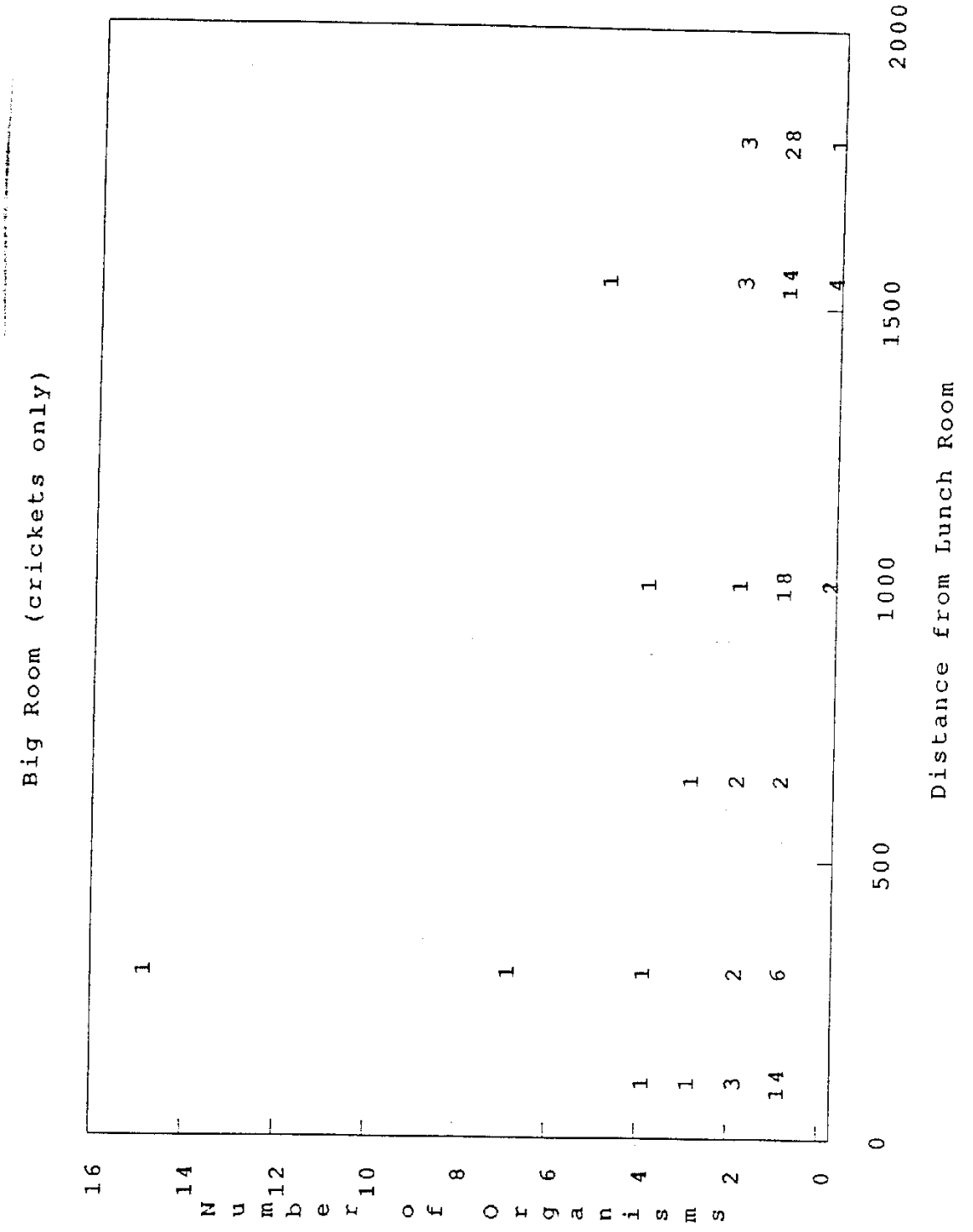

Figure 12: Number of Cavernicolous Rhaphidophorids by Distance from the Lunch Room in the Big Room

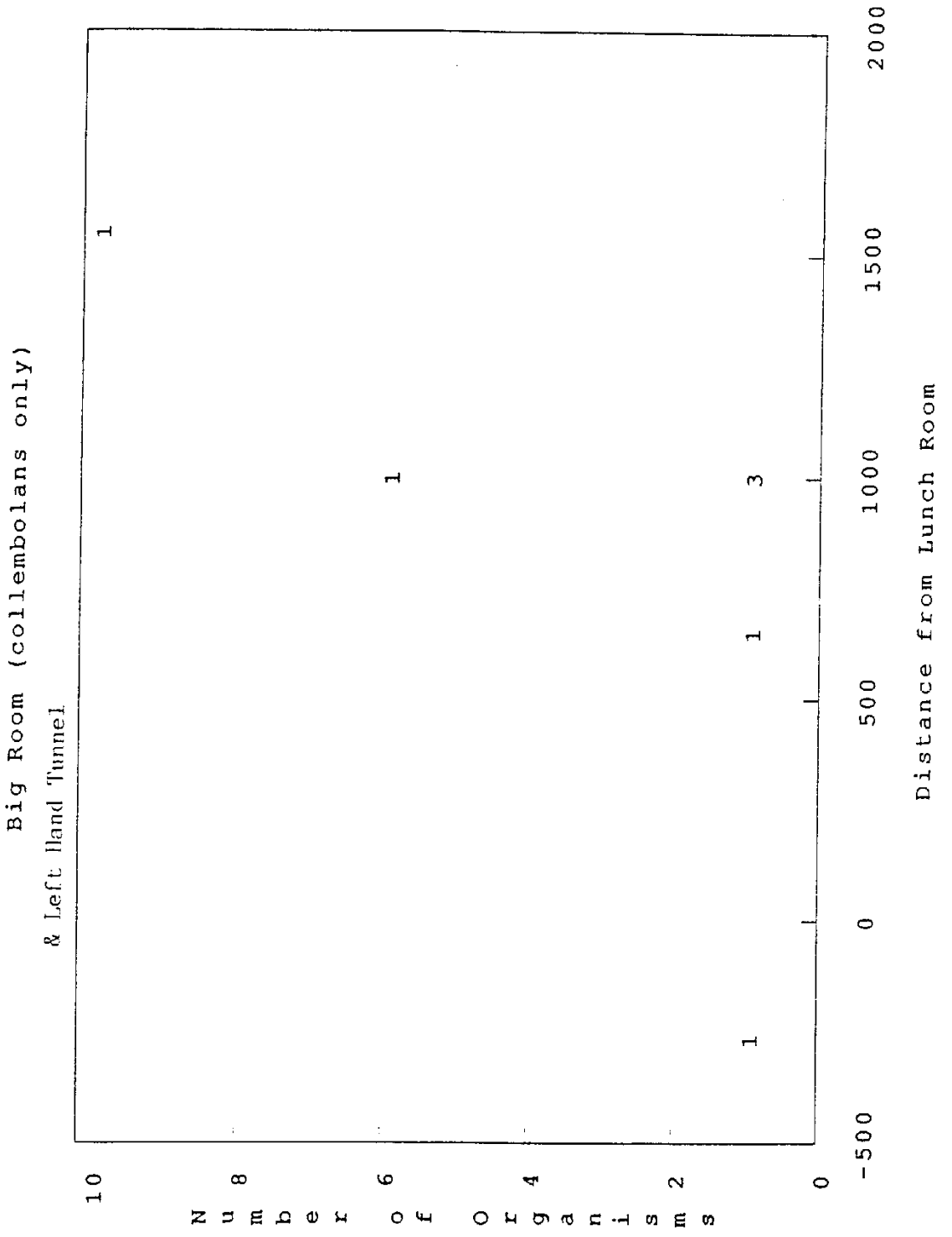

Figure 13: Number of Collembolans by Distance from the Lunch Room in the Big Room and Left Hand Tunnel

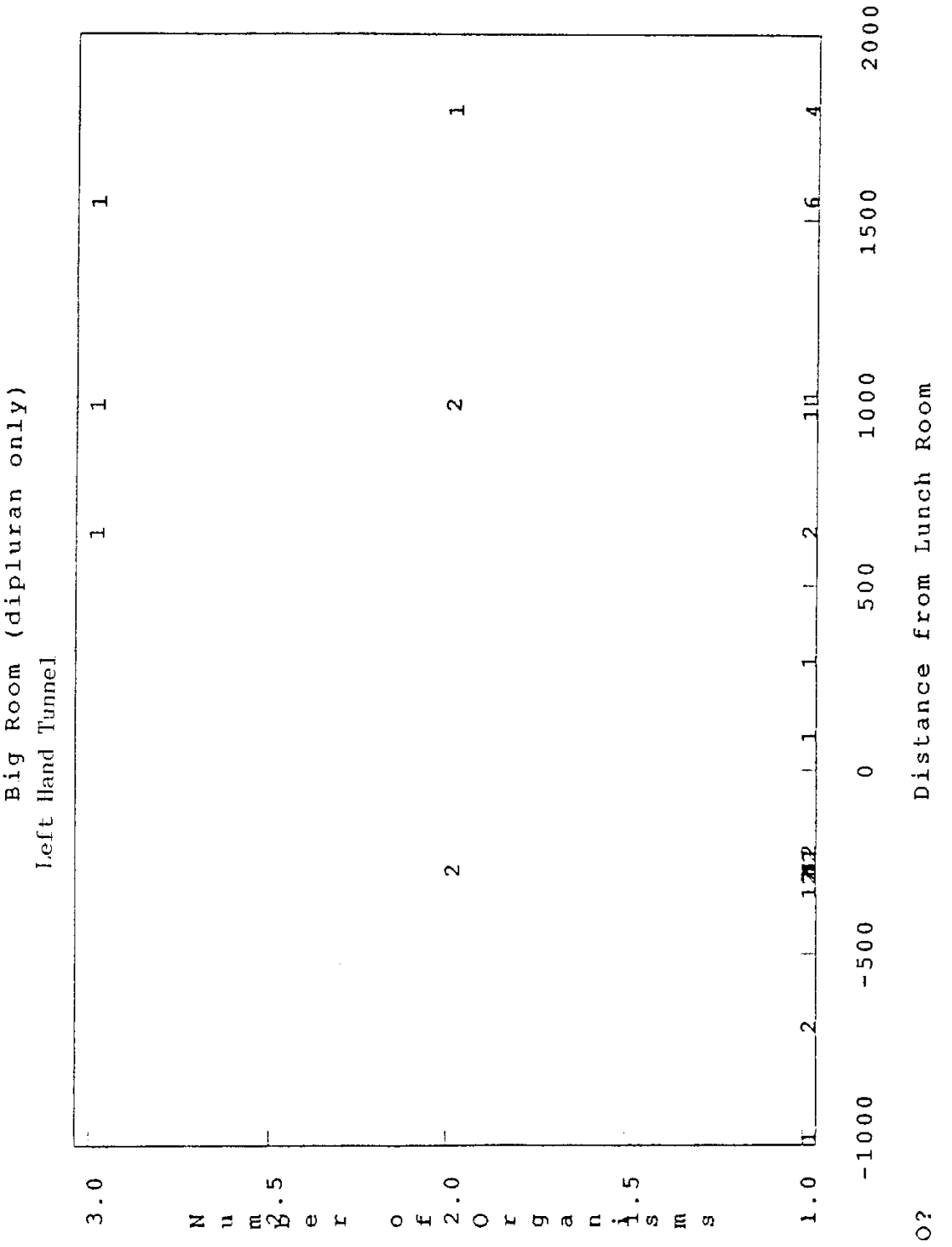

Figure 14: Number of Diplurans by Distance from the Lunch Room in the Big Room and Left Hand Tunnel

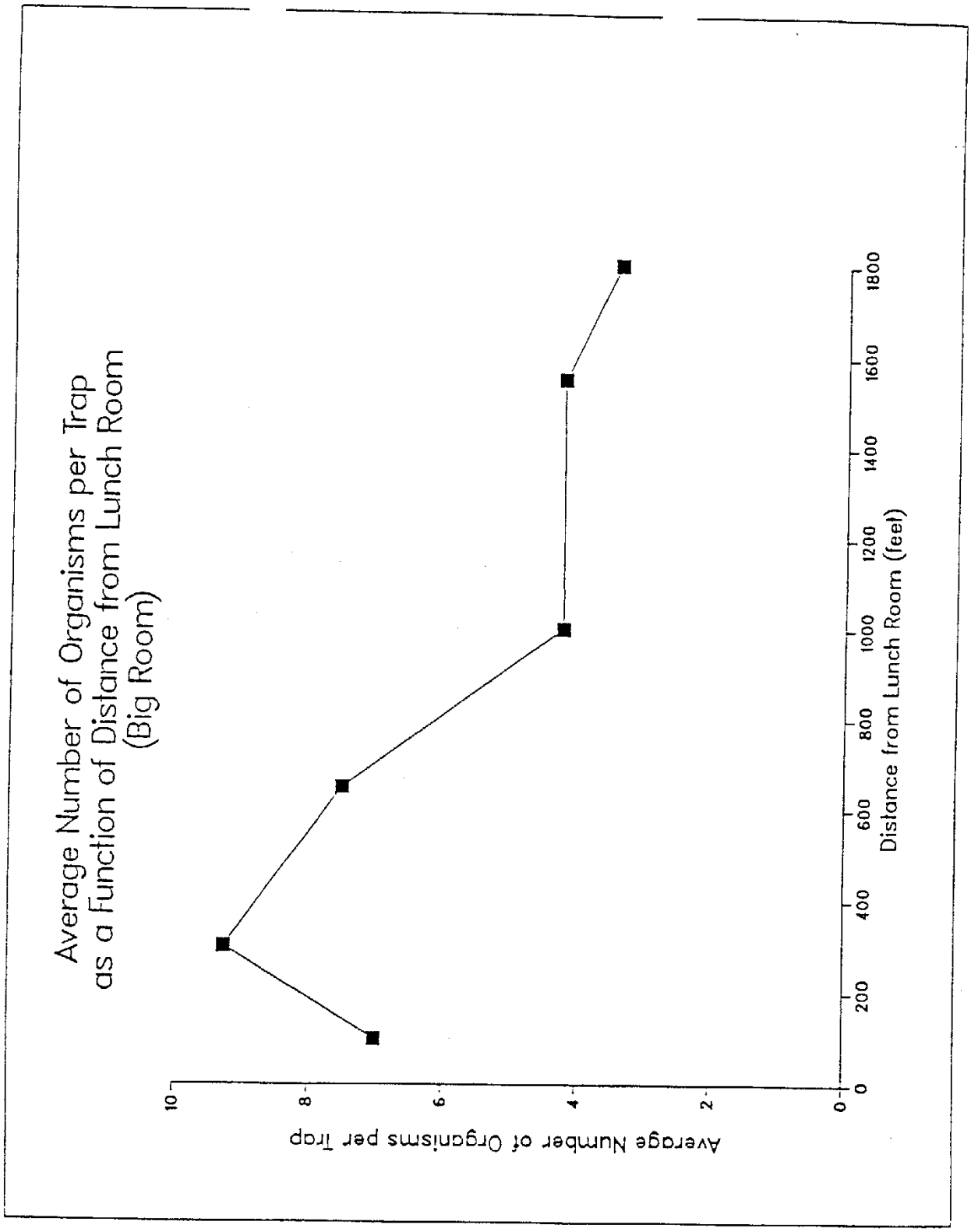

Figure 15: Average Number of Organisms per Trap by Distance from the Lunch Room in the Big Room

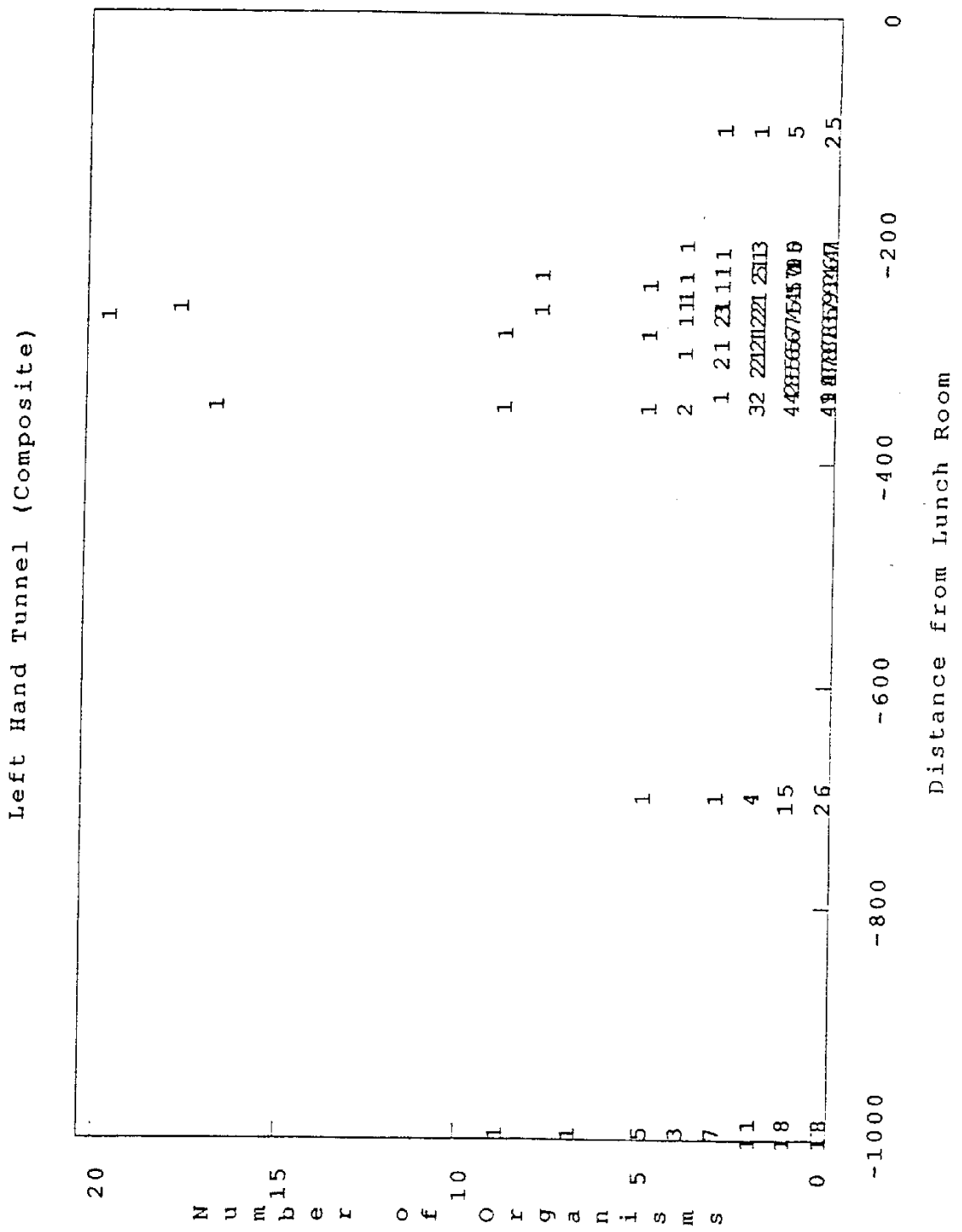

Figure 16: Number of Organisms by Distance from the Lunch Room in Left Hand Tunnel

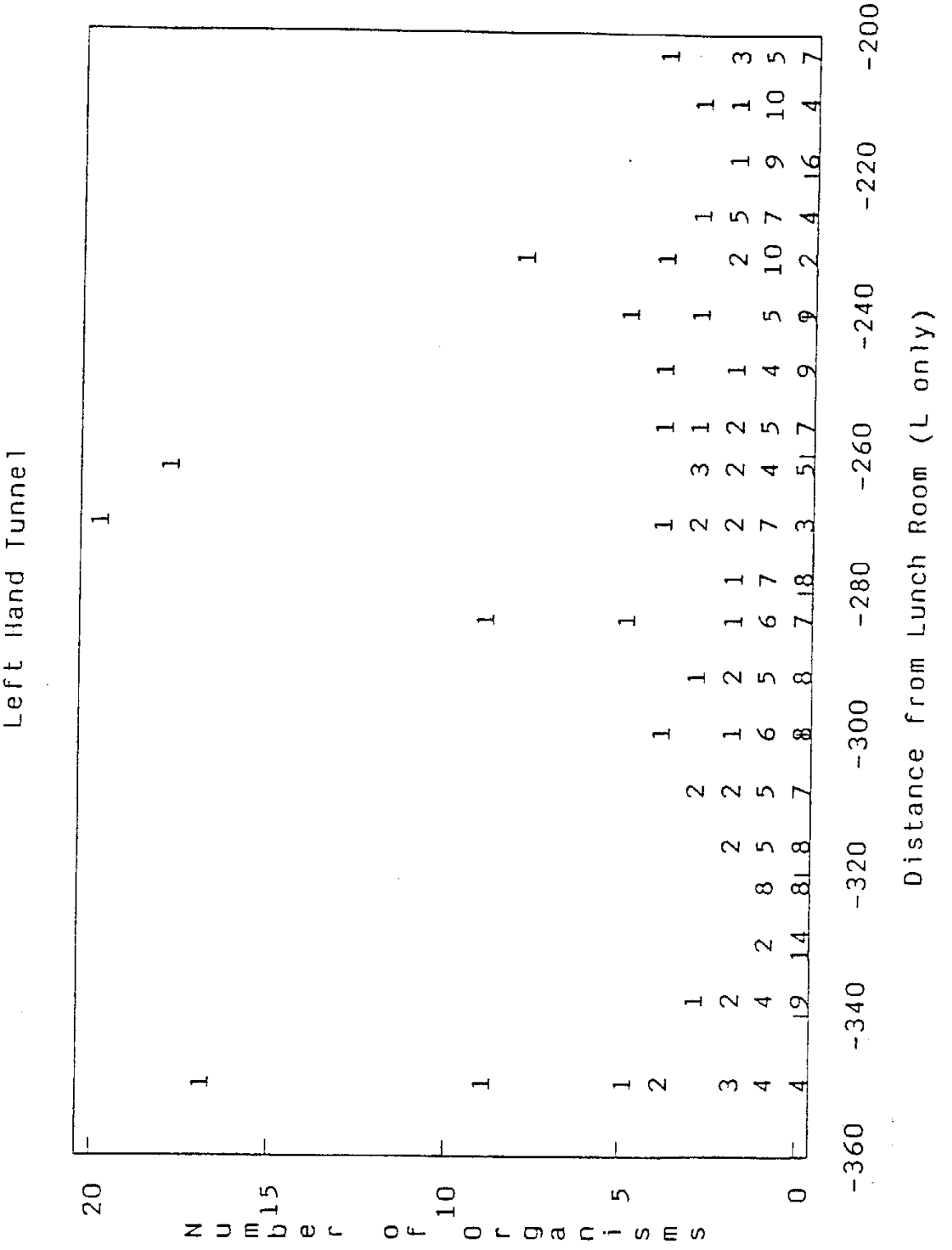

Figure 17: Number of Organisms by Distance from the Lunch Room in the L Series Traps in Left Hand Tunnel

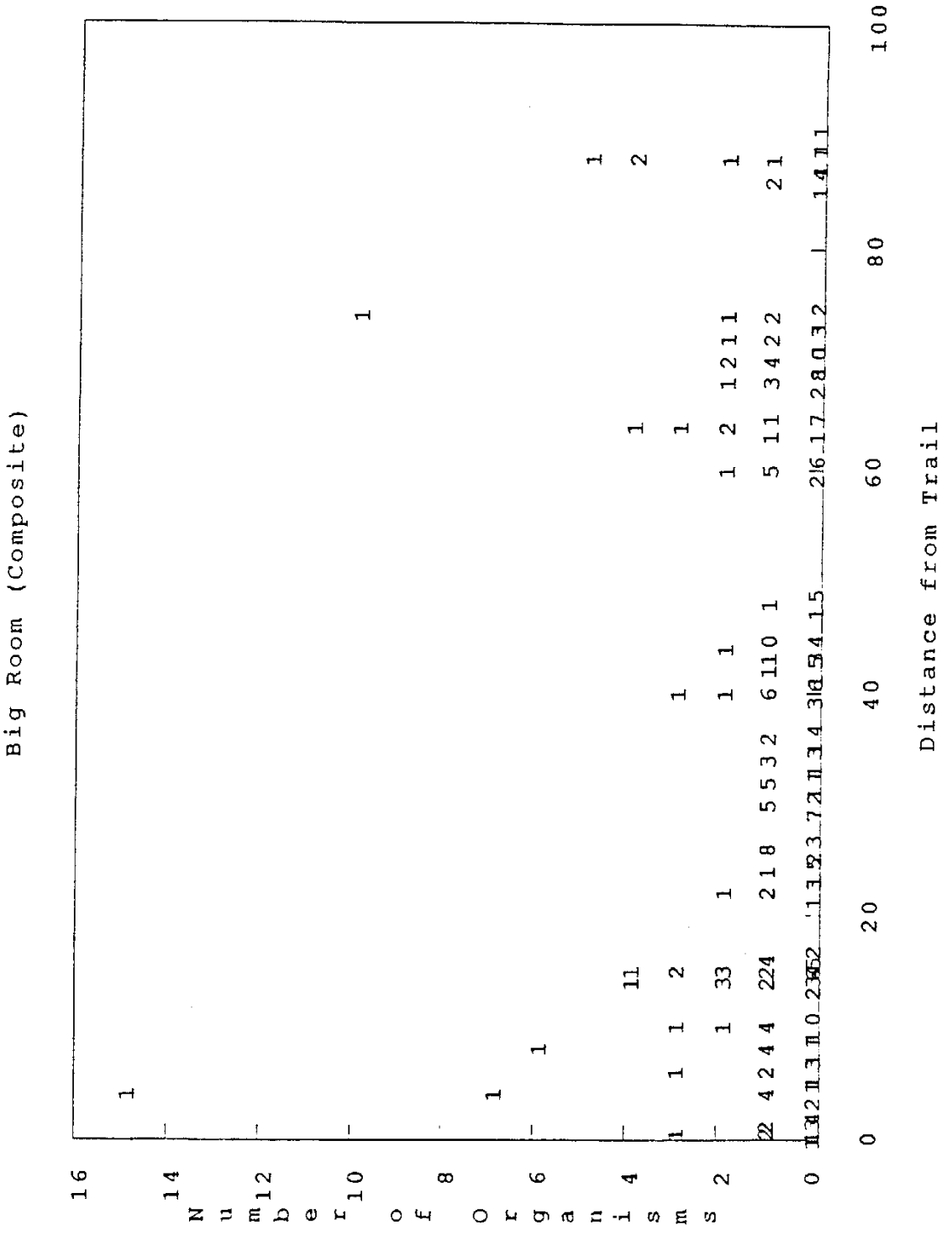

Figure 18: Number of Organisms by Distance from the Trail in the Big Room

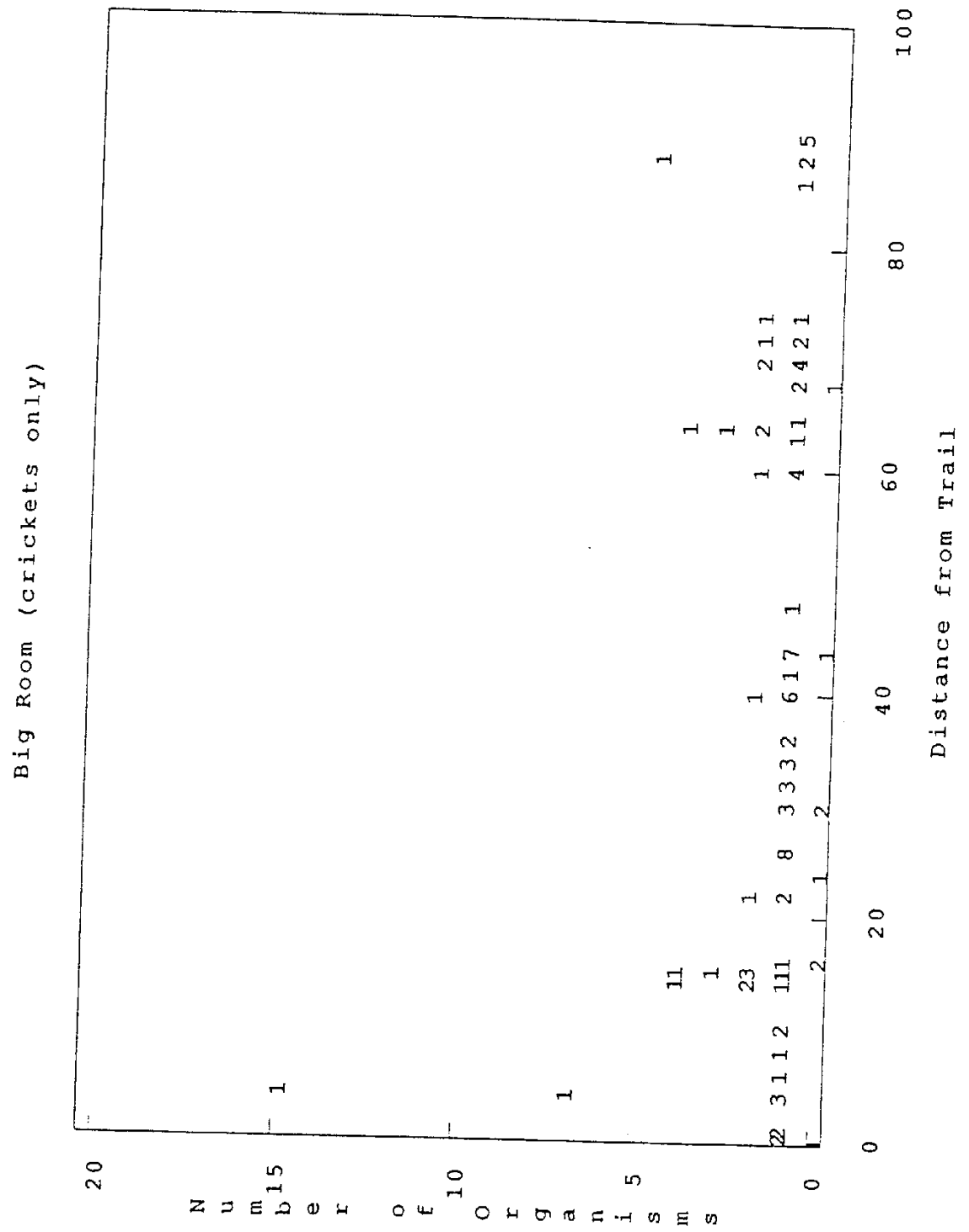

Figure 19: Number of Cavernicolous Rhaphidophorids by Distance from the Trail in the Big Room

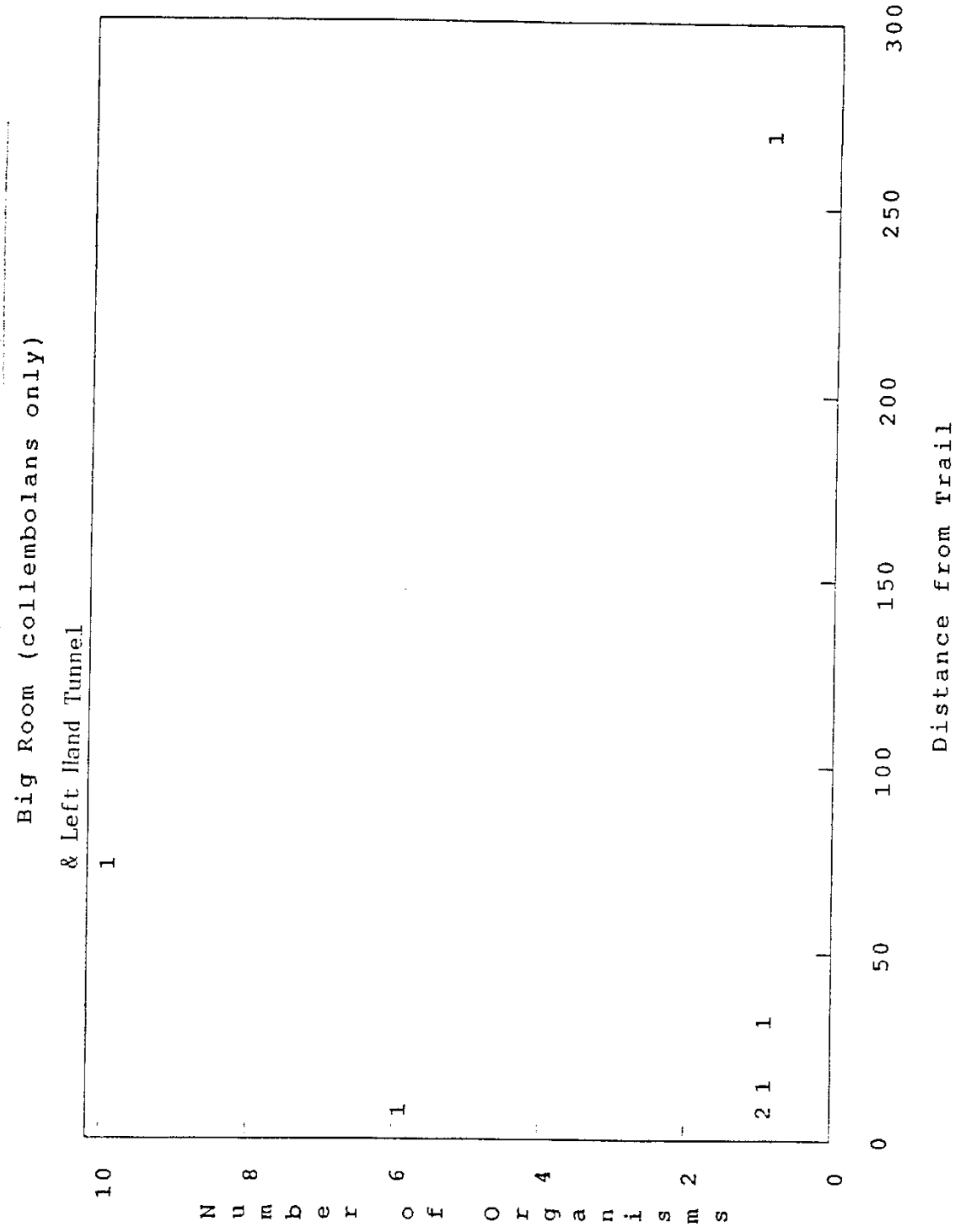

Figure 20: Number of Collembolans by Distance from the Trail in the Big Room and Left Hand Tunnel

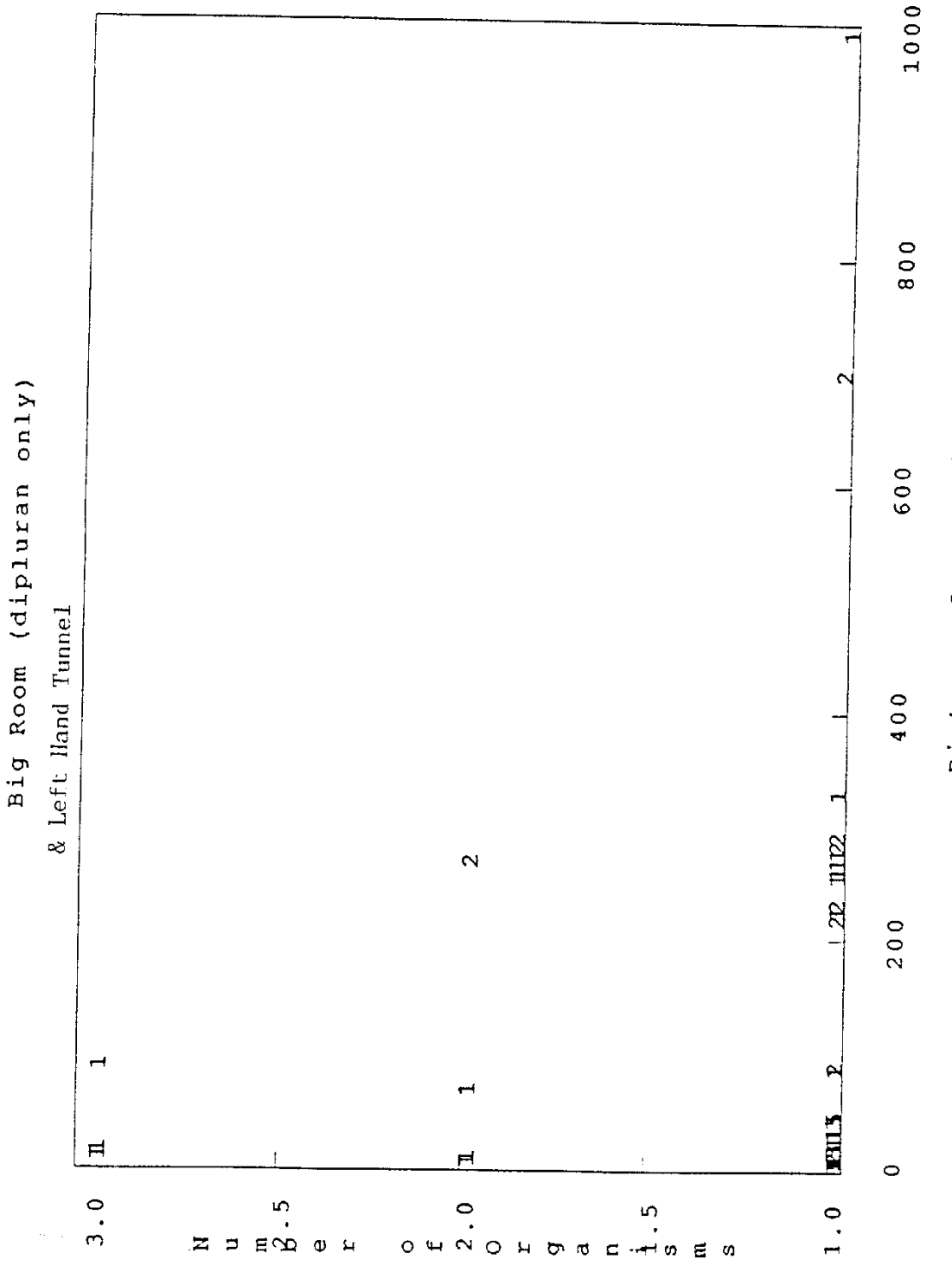

Figure 21: Number of Diplurans by Distance from the Trail in the Big Room and Left Hand Tunnel

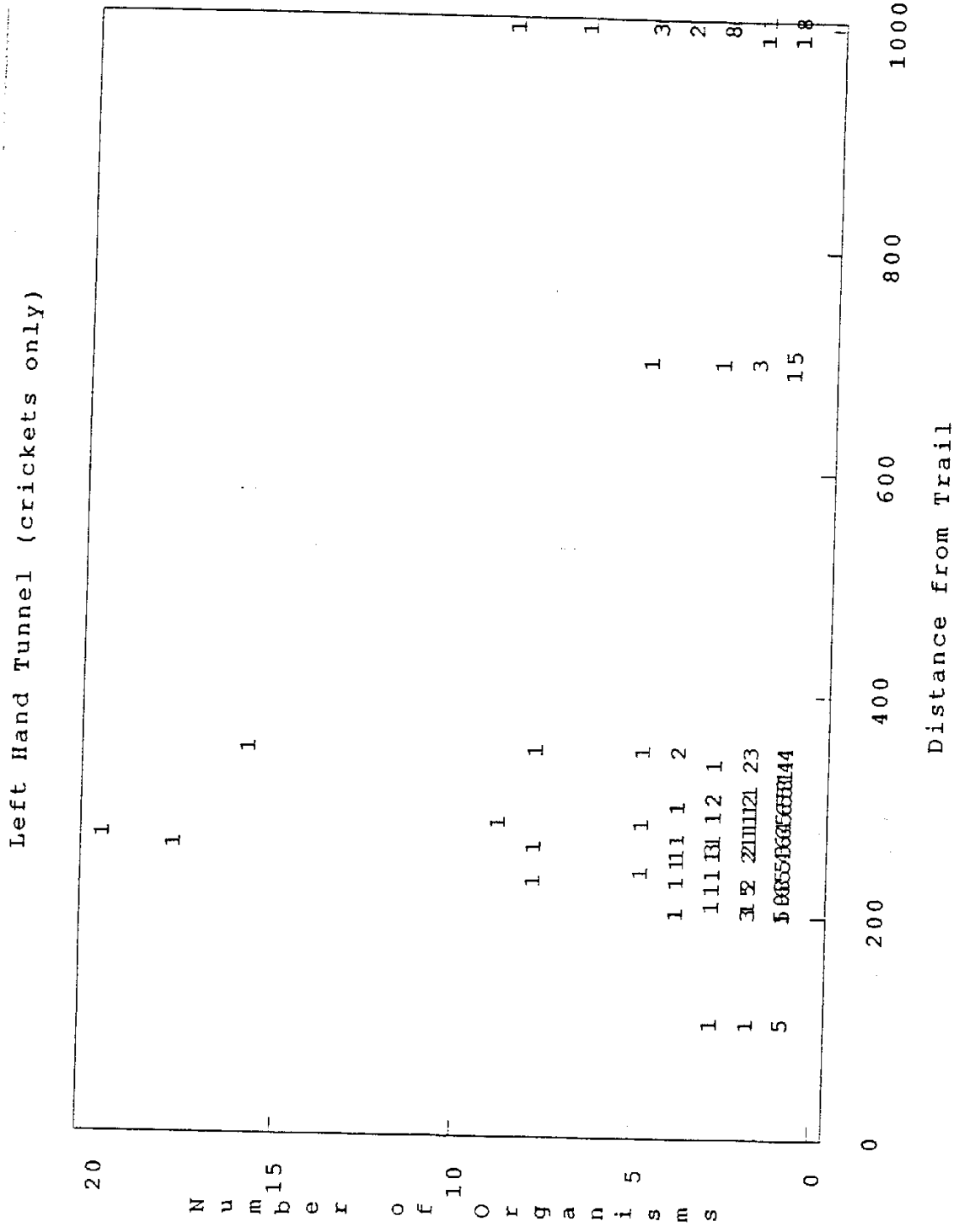

Figure 22: Number of Organisms by Distance from the Trail in the Left Hand Tunnel , Cavernicolous Rhaphidophorids only

3.5 Soil Substrate

To investigate the differences in organism abundance patterns among the differing types of soil substrates, a plot was constructed of the average number of organisms caught in traps of each substrate type. This plot (Fig. 23) shows greater average number of organisms in moonmilk, rubble, and silt. The clay average is misleading because of the low number (N=2) of traps set in clay.

3.6 Vertical Heterogeneity

The Big Room, especially, and to a lesser extent, Left Hand Tunnel, contain a variety of habitats in terms of the amount of vertical heterogeneity. The relationship between average number of organisms per trap and increasing vertical heterogeneity (low, moderate, high) is a fairly linear one, with a higher average number of organisms being observed with increasing vertical heterogeneity (Fig. 24).

3.7 Soil Moisture

Because the number of traps set in areas of damp, wet, or dry areas surrounded by pools (wdry) was small, this plot (Fig. 25) can only provide a preliminary indication of relative abundances. The highest average number of organisms per trap was found in the dry area traps.

4 Discussion

4.1 Critique of Methods

Ideally, not just the traps, but the transects should have been set in a random manner. This was not done due to the need to avoid certain delicate areas and the need to place transects in areas in which it was possible to dig trap holes. Another possible criticism of this project was the change in personnel during the study period. To minimize the impact of change in personnel, flags were set at each trap location identifying the particular trap to be set in that location, and descriptions of trap locations were provided to personnel. Additionally, new personnel were either trained by Northup or by John Roth, a biologist park ranger familiar with the fauna in Carlsbad Cavern. A last

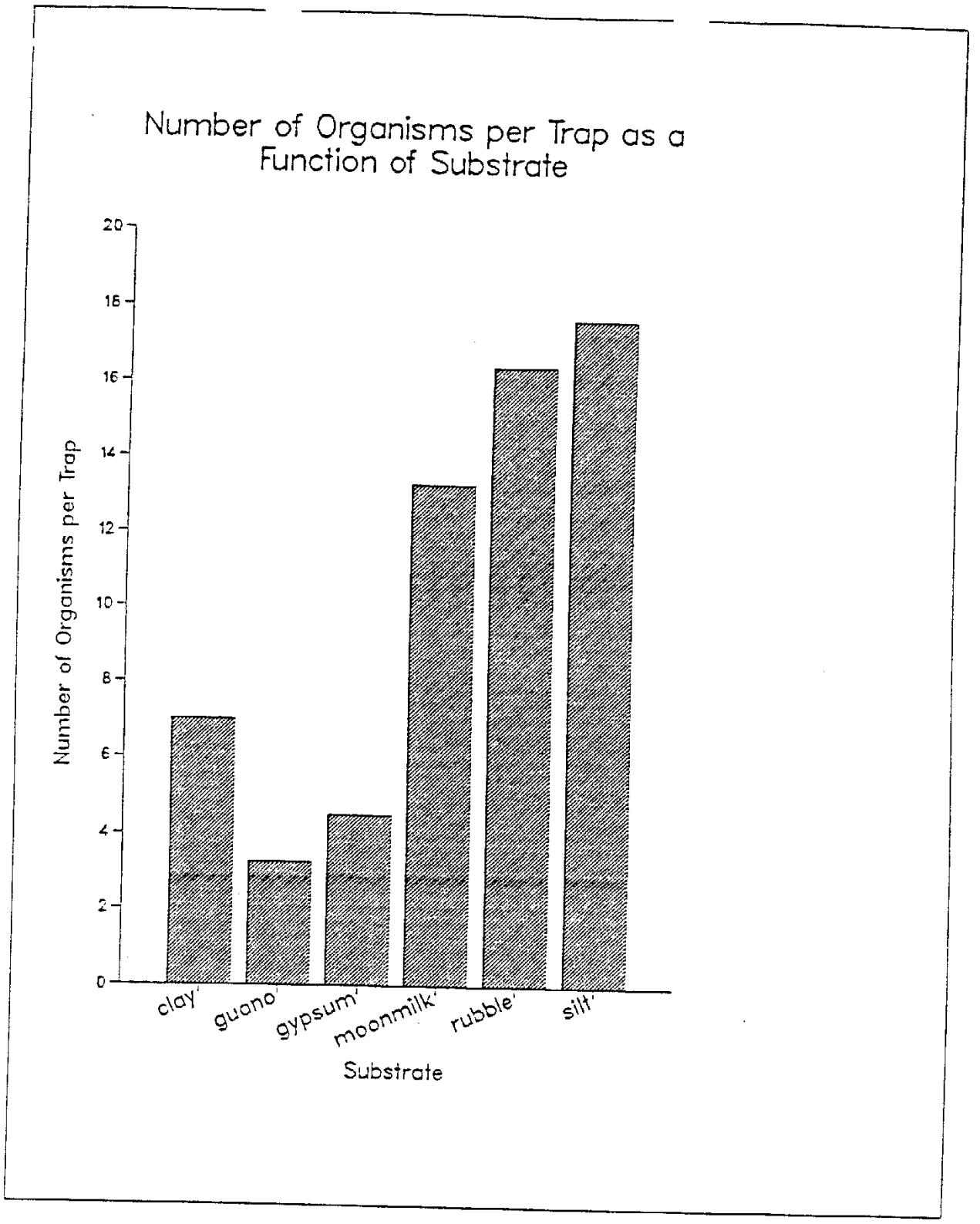

Figure 23: Average Number of Organisms Per Trap in Different Substrates

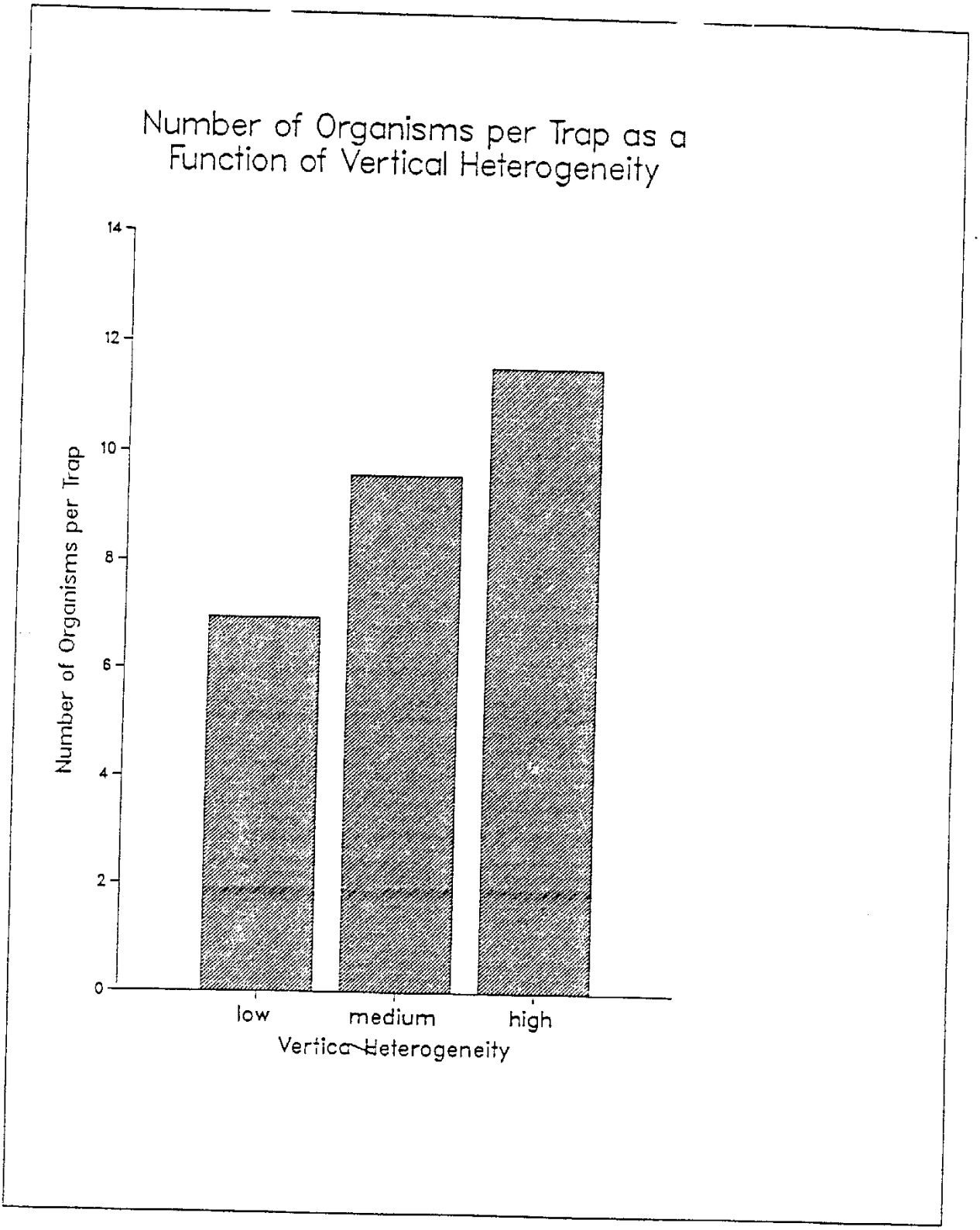

Figure 24: Average Number of Organisms Per Trap as a Function of Increasing Vertical Heterogeneity

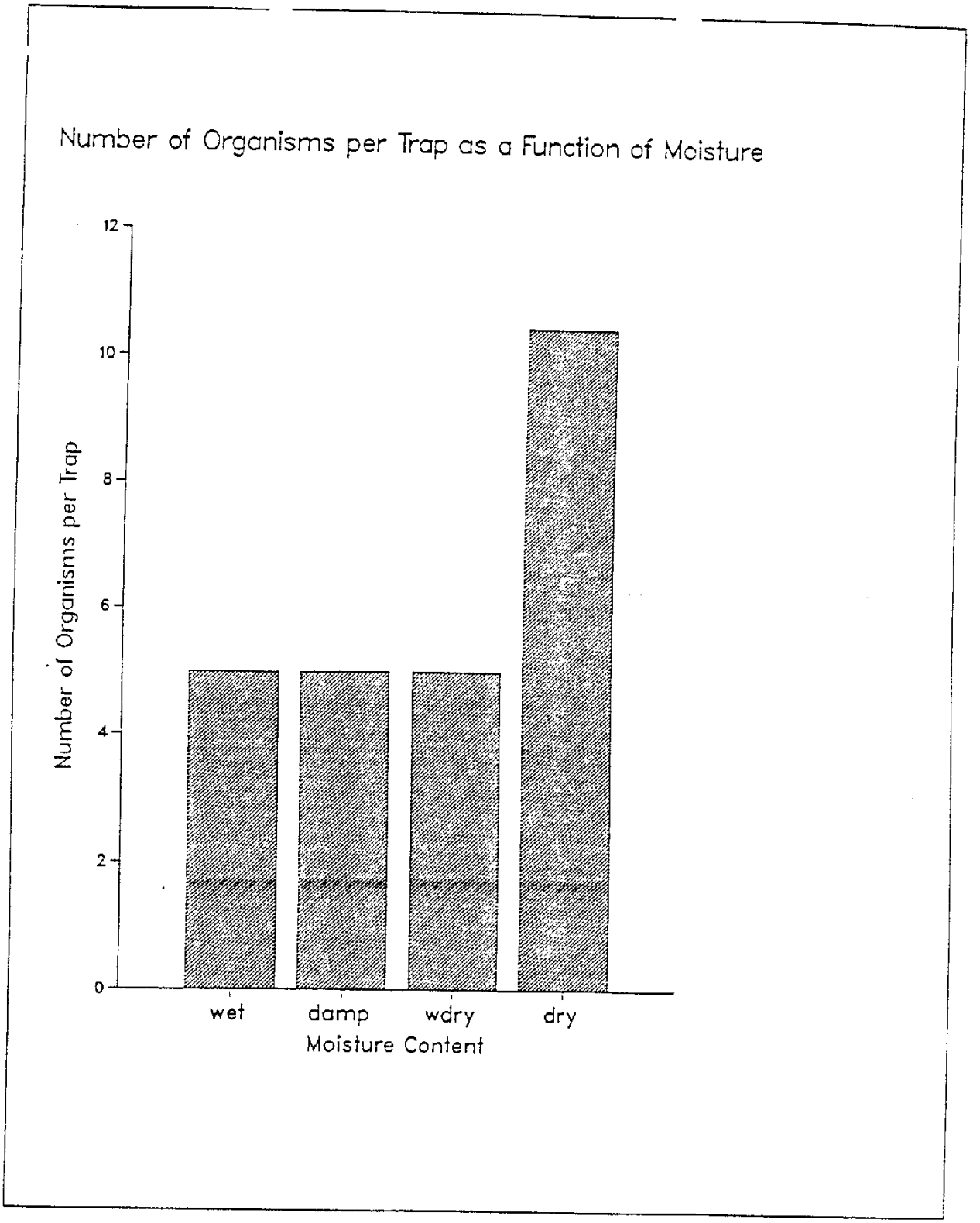

Figure 25: Average Number of Organisms Per Trap in Habitats of Different Moisture

area of concern is the considerable variance that is seen in some of the data which indicates the possibility that our sampling methods did not capture as complete a picture as desired. While pitfall traps are a good and traditional method for examining distribution and abundance patterns of surface active macroarthropods, they have limitations.

4.2 Species Diversity and Richness

The investigation of species diversity at the greater scale of the Big Room and Left Hand Tunnel, showed a similar pattern of generally low species diversity in Left Hand Tunnel as was found in Northup's previous study from 1984 to 1987. Species diversity values for the Big Room were slightly higher. Thus, there is some confirmation that this area, for whatever reason, is different in terms of species diversity than Sand Passage and Bat Cave, which had higher species diversity values. This difference is due to the numerical dominance by *C. carlsbadensis* in the Big Room and Left Hand Tunnel. The species diversity findings in Carlsbad Cavern do not support Poulson's suggestion that high diversity values are associated with food-poor habitats (Poulson 1972), as the Big Room and Left Hand Tunnel are food rich as compared to Sand Passage.

Species richness, which is often tied to the productivity of the area, is greater in the Big Room than in Left Hand Tunnel, and is intermediate between Sand Passage (which is the same as Left Hand Tunnel) and Bat Cave. It is also known that the amount of sampling effort/area is associated with species richness, with increasing species richness with sampling effort/area. Thus, it is possible that with additional traps and/or censuses, we might find additional species. It does appear though, that the Big Room is richer in terms of the absolute number of species found there. To quantify whether this is associated with productivity (food resources) of the area, a variety of additional investigations would be needed, such as organic content analysis, measuring how much food is dropped by park visitors and not cleaned up, etc. Additionally, other sampling methods than traps, might reveal additional species, especially microarthropods. Because of the limitations of time and personnel, these were not done as part of this study.

4.3 Species Abundance

Two trends seem at least somewhat evident from the data: (1) there is some clustering, especially among cavernicolous rhaphidophorids, near the Lunch Room. (2) there are greater numbers of organisms in Left Hand Tunnel than in the Big Room. Whether this relationship, which is not a dramatic one in terms of distance from the Lunch Room in the Big Room, is a cause and effect phenomenon cannot be determined from data such as that gathered in this study. Determination, such as it can be accomplished, of cause and effect requires experimentation. While it is evident that organisms are clustering in non-public areas, it is possible that there are other factors which we may not have considered. Another concern is the effect of the trail resurfacing that was done is March 1988 and covered approximately 1500 feet of trail in the Big Room. Exactly what effect that had on abundance patterns is not known, but it seems likely from the drop in numbers that it had an effect. Additionally, one of the rangers noted sweeping up "cricket bodies" after the resurfacing. One last concern is the possibility of stochastic effects due to the great mobility of the cavernicolous rhaphidophorids especially.

4.4 Possible Further Investigations

To further investigate the impact of human activity on cave fauna, it would be worthwhile to examine other caves of similar depth to look at the penetration by various species to different depths. It would also be useful to look at species abundance patterns in other non-commercial caves at a similar depth as the Lunch Room. Additionally, some experimentation would be useful, such as provisioning non-public areas, prohibiting food entirely, etc.

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