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Man's effects on aquatic and riparian organisms in the canyons of Canyonlands and Arches National Parks and Natural Bridges National Monument

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Contract No. CA 1463-5-0001

Purchase Order No. Px-1200-0-C805

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30 April 1993

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EXECUTIVE SUMMARY

Small mammal, plant, and aquatic organism distributions or patterns of abundance were examined with respect to travel systems in three National Park Service Units in southern Utah from 1990 to 1992. At Canyonlands National Park we contrasted abundances or distribution patterns between a portion of Salt Creek Canyon containing a four wheel drive road, another portion lacking this road, and the road surface per se. The road appears to have strong negative effects on species in all three taxa. Some common xeric taxa appear to do better in the presence of the road. At Arches National Park we compared an area in Courthouse Wash that contained a hiking trail (also sometimes used by horses), to another area in this wash that has much less hiking use, and to the hiking trail per se. Although our sample sizes for this study are small, the trail appears to influence plant abundances and distributions. At Natural Bridges National Monument, small mammals, plants, and aquatic organisms all appear to be influenced by the hiking trail in White Canyon. Most species appear to be negatively effected.

Across all three National Park Service Units human use of travel systems appears to be at a level that effects species distributions and patterns of abundance. Most species, especially those typically found in the locally rare mesic habitats, tend to be negatively effected by use of the travel system. Many of the reductions in distribution or abundance are on the order of 200 percent. Management recommendations and a sampling protocol for the future are presented.

INTRODUCTION

Man has occupied the west in large numbers for less than one hundred years. Historically, human populations in deserts have been small, however, with advances in technology (deep water wells, air and surface transportation, and enhanced food transportation and storage) population sizes have gone up tremendously. In addition, the development of the National Park system has also brought additional human visitation pressures to bear on the desert southwest. Grazing has historically been the main human impact on desert areas in the lowland west (Busby 1979). With the large influx of humans into the desert system, other human effects are becoming important (Moss 1980, Knopf et al. 1988, Barinaga 1990, Vitt et al. 1990, Wake 1991, Scott and Seigel 1992).

Man influences wildlife in many ways. These effects can be direct, as through harvest (hunting, trapping, forestry practices), or indirect (effects of travel systems, effects of habitat fragmentation, removal of lands from wildlife usage <mining, agriculture, development of cities>). These effects can be either widespread (e.g., acid rain) or more localized (mining, forestry, agriculture). Many effects can be both. Agriculture, for example, will commonly have the local effect of removing habitat from wildlife, but may also have significant runoff effects well removed from the local area. Development has had a devastating effect on wildlife and wild places, with the result that these things are both relatively uncommon and localized in the western U.S.. In part as a consequence, there has been a tremendous increase in visitation to National Parks and other protected lands. Ironically, the increased interest in wild places may well be a major

threat to their very existence.

Increased interests in wild places has a multitude of effects on wildlife populations. Increased visitation inevitably leads to increased road development to the park, and usually to increases in support services and their attendant development on the margins of the parks. Both factors contribute to the fractionation and isolation of habitats conducive to wildlife populations. While suitable wildlife habitat usually surrounds a park at its creation, the ensuing development tends to make the extrapark habitat unsuitable to many types of wildlife. In addition, increased visitation usually leads to further development of travel systems (roads and trails) in the park itself. In part this latter development is an attempt merely to accommodate the influx (remove grid lock on the roads) and in part it may be an attempt to spread out the park visitors - either or both for the benefit of the wildlife or the visitors.

Use of trails and roads can influence wildlife in two ways. Sessile or slow species are subject to being squashed or harvested, either during construction of the travel system or later when it is being used. Plants and amphibians have probably been especially effected by this aspect of roads or trails. More mobile species, like birds or mammals, are more likely influenced by the disturbance associated with human use of trails or roads (Gilliam and Fraser 1987). The disturbance may increase time spent watching for "predators" including humans, at the cost of decreased time spent foraging. This can be an especially severe problem during the winter when organisms may need to feed almost constantly to survive (Ricklefs 1990). In the extreme, the disturbance may cause some man-shy species to entirely give up the habitat near the road. In cases like this, the road becomes a barrier

further fragmenting and subdividing wildlife populations in the park.

In this report we concentrate on these last types of human effects on wildlife. We examine the effect of man's travel systems in three canyons in National Parks or Monuments in southern Utah. We contrast wildlife populations above and below Bates Wilson Campground which marks the upper end of a four wheel drive road, to assess the effect of the road on wildlife populations in Canyonlands National Park. At Arches National Park we contrast wildlife populations in Courthouse Wash above and below the road crossing near "The Wall" to assess the effect on wildlife of heavy hiking trail and pack animal trail usage in the canyon bottom below the road crossing. Finally, at Natural Bridges National Monument we examined wildlife populations in White Canyon above and below Sipapu Bridge to assess the effect of heavy hiking trail use on wildlife populations. Our objectives with these comparisons is first to determine if wildlife populations differ in different areas of these canyons, and second to attempt to assess the influence of man's travel systems on these populations.

Over the last three years we have examined the distributions and abundances of four taxa across three National Park units. In 1990 and 1991 we looked at plants, small mammals, aquatic organisms, and birds in Canyonlands National Park. In 1990, 1991, and 1992 we examined plants, small mammals, aquatics, and birds in Natural Bridges National Monument. Finally, in 1992 we studied plants, and small mammals at Arches National Park.

We review our results for each site in a separate report for that site and include management recommendations for each Park Service unit. The sampling approach outlined in the Future Sampling Protocol section of the Arches National Park Report is applicable to all three sites.

ABSTRACT FOR CANYONLANDS NATIONAL PARK

In 1990 and 1991 we examined plants, small mammals, and aquatic organisms in Canyonlands National Park. Our approach was to look for differences in abundances or distributions of these taxa between subsets of a canyon with different patterns of human usage.

We compared the flora and fauna upstream and downstream of Bates Wilson Campground which is located at the upper end of a four-wheel drive road in Salt Creek Canyon. Plant surveys in 1990 (330 1 m sq plots) and 1991 (440 1 m sq plots) yielded very similar results, implying that our results probably hold over the whole canyon. Several plant species differed in coverage or in frequency of occurrence between the three treatments: the area containing the road, the area lacking the road, or the road surface per se. Total plant coverage was greater (146 % in 1990, 187 % in 1991) in the canyon bottom lacking the road relative to the canyon bottom containing the road. The canyon bottom containing the road did, however, have greater coverage than the road surface per se (293 % in 1990, 572 % in 1991). The road surface was largely devoid of vegetation.

Plant volumes were examined above each 1 m sq plot from the ground to a height of 0.5 m, from 0.5 - 1.0 m, from 1.0 - 3.0 m and above 3 m to see whether the vertical complexity of the habitat differed across our three treatments. In both years, canyon bottoms lacking the road had greater plant volume (at all four height increments) than the canyon bottom containing the road. Again, in both years canyon bottom containing the road had greater plant volumes (at all four heights) than the road surface per se. Our results imply that the canyon bottom lacking the road has greater structural

complexity and greater plant coverage than the canyon bottom containing the road, which is in turn more complex and denser than the road surface per se.

Data on coverages were collected on individual species (or species groups where identification was problematic). The results for species were then pooled into four ecological groups representing total grass coverage, total herb coverage, total shrub coverage, and total tree coverage. In both years, total grass coverage was greatest in the canyon bottom containing the road, lower in the canyon bottom lacking the road, and lowest in the road right of way per se. In both years, total herb coverage was greater in the canyon bottom with the road than the road right of way. In both years there was no difference in herb coverage between the canyon bottom with the road and the canyon bottom without the road. Total shrub coverage did not differ between canyon bottom lacking or containing the road in 1990, however, in 1991 canyon bottom lacking the road had greater total shrub coverage. The canyon bottom containing the road had greater total shrub coverage than the road right of way in both years. In both years, total tree coverage was greater in the canyon bottom lacking the road relative to the canyon bottom containing the road, which in turn had greater coverage than the road right of way per se. Results for individual species are too numerous to mention here, instead we summarize the overall patterns. In 1990, 14 species were abundant enough in samples to be analyzed. Of these 14, seven showed significant differences in coverage across canyon bottom containing or lacking the road. Four species had greater coverages in areas with the road, while three had greater coverages in areas lacking the road. In 1991, 24 species were encountered often enough to merit analysis. Of these 24, 8 species exhibited no pattern across the canyon bottoms with or without the

road, while eight had higher coverages in canyon bottom containing the road, and eight had higher coverages in areas that lacked the road. In 1990, 6 of 14 species examined had greater coverage in the canyon bottom containing the road relative to the road right of way per se. In 1991 7 of 24 species exhibited the same pattern.

Frequency of occurrence in the 1 m sq sample plots was compared across the three treatments for both the ecological plant groupings and for the individual species. In 1990, 7 of 11 species exhibited differences in frequency of occurrence in plots across the areas containing or lacking the road. Of these 7, 5 species were more frequently encountered in the area containing the road, while 2 were more frequently encountered in the area lacking the road. Twenty-one of 24 species examined showed differences in distributions in 1991. Ten species were more frequently encountered in canyon bottom without the road, while 11 were more frequently observed in canyon bottom containing the road. In 1990, 7 of 11 species were more commonly encountered in the canyon bottom containing the road relative to the road right of way per se. In 1991, 7 of 24 species exhibited the same pattern. In neither year were any species more frequently encountered in the road right of way relative to the canyon bottom containing the road.

In 1990, grasses were more abundant in the area containing the road, and trees were more abundant in the area that lacked the road. Shrubs and herbs were more abundant in the area next to the road relative to the road right of way per se. In 1991, trees, herbs, and shrubs were more frequently encountered in canyon bottom lacking the road relative to the canyon bottom containing the road. Grasses as a group were more frequently encountered in the canyon bottom containing the road relative to the canyon bottom lacking

the road. All types of ecological plant groupings, except herbs, were more frequently encountered in the canyon bottom containing the road relative to the road right of way per se.

Aquatic organisms were examined in three ways: comparisons of visual surveys, and frequency analyses of presence or absence in pools or in dip net sweeps. Results differed somewhat across these analyses, most likely reflecting our ability to sample different taxa with visual surveys or with nets. In 1990, whirligigs, horse hair worms, damselflies and notonectids were more commonly encountered or had higher densities in pools in the area lacking a road, whereas, toad tadpoles were more commonly encountered in sweeps in the area containing the road. Visual counts of number of individuals per species per pool revealed no differences in 1991 between pools located in an area containing a road or an area lacking a road. In contrast, in 1991, analysis of frequency of occurrence in pools revealed that hydrophilid larvae (beetles) occupied fewer pools in the canyon bottom lacking a road. Notonectids, brown damselflies, and snails were less frequently encountered in sweeps in pools in an area containing the road relative to an area lacking the road in 1991.

Experimental cages placed below road crossings collected and held significantly more sand than cages placed above the road crossing, implying that the road crossing was increasing sand flow in the stream, and increasing sand infiltration into the interstices in the rock cobble. This increased siltation may have serious negative consequences for aquatic organisms. Experimental cages that had their rock interstices packed with sand, contained fewer toad tadpoles, fewer damselfly larvae, fewer total species, and fewer total individuals relative to similar adjoining cages that did not

have their interstices packed with sand. Taken together these two sets of results offer a causal mechanism to explain why the road appears to influence the distribution and abundances of stream organisms in Salt Creek Canyon.

Small mammals were trapped at four grids in an area lacking a road and in four grids in an area containing a road in 1990. Eight new grids were trapped in these areas in 1991. In 1990, similar total numbers of mice were captured in both treatments. Reithrodontomys megalotis and Neotoma mexicana (harvest mice and Mexican woodrats) had lower densities in the area containing the road relative to the area lacking a road. In 1991, approximately 3 times as many small mammals were caught in the area lacking the road as in the area containing the road. Small mammals avoided traps in the road right of way in both years. Peromyscus crinitus (Canyon mice), P. maniculatus (Deer mice), Neotoma mexicana and N. cinereus (Bushy tailed woodrats) were more abundant in the canyon bottom lacking the road, while P. truei (Pinon mouse) was more abundant in the area containing the road.

Our results suggest that small mammals, aquatic organisms, and terrestrial plants experience the areas up and downstream of Bates Wilson Campground at Canyonlands National Park as markedly different environments. Some species have higher coverage or greater densities in the area near the road, others in the area lacking the road. The road right of way appears to be a harsh environment for plants, aquatic organisms and small mammals. The management implications of these results are discussed in detail.

INTRODUCTION

This project was designed to examine how a four-wheel drive road that ran up Salt Creek Canyon could influence the plants, or animals that live in this canyon. We are interested in both the direct effects of the road, and on effects of man's usage of this travel system that may extend beyond the road surface per se. Many of the species that we have examined do not have common names. We use common names where ever possible, and list all species that we encountered in Appendix 1. There we comment on species names, and on our degree of confidence in our identifications.

We contrasted the densities, or some measure of frequency of occurrence of our focal taxa between an area which contained a four wheel drive road (hereafter trt 2) to an area immediately upstream that lacked the road (trt 1). In addition, for our plant and small mammal trapping we were able to look at a third treatment type - the road surface per se (trt 3).

We have performed no manipulations and our comparisons always come from a single canyon. Thus our results could be peculiar to the particular canyon we studied, or our results could be due to undetected factors other than presence of the road. In our analyses we assume that any differences that we detect are due to the treatment effect (= presence of the road). We discuss the reasonableness of this assumption at the end of the report on our Canyonland studies.

STUDY AREA

Our study area was in Salt Creek Canyon at Canyonlands National Park.

We concentrated our efforts for approximately 5 km up and downstream of Bates Wilson Campground which is located at the upper end of a four-wheel drive road in Salt Creek Canyon. Aquatic surveys covered this whole 10 km stretch, while plants and small mammals were sampled at evenly spaced intervals across the 10 kms.

METHODS

Plant Sampling

At Canyonlands we examined man's potential impact on the flora by looking at plant coverage in 1 m sq quadrats. In 1990, we examined the plants in four areas where a four-wheel-drive road went through the canyon bottom (here after referred to as a downstream site, or treatment 2), in four areas in the road per se (here after the road per se or treatment 3), and in four areas in a section lacking a road, immediately upstream of the roaded section (here after called the nonroaded section or treatment 1). The plant quadrats were located in grids. Upstream grids consisted of 50 1 m sq quadrats. These were located in 10 rows of 5 quadrats each, located perpendicular to the stream channel. The rows ran from the high water mark away from the stream for 25 m. Rows were located 50 m apart. Ten quadrats per grid were located in the area from 0 to 5 m from the high water mark, 10 from 6 to 10 m, 10 from 11 to 15 m, 10 from 16 to 20 m and 10 from 21 to 25 m. Thus within 500 m of canyon bottom we had 50 quadrats. The downstream grids were similar except that in addition to the 50 quadrats (representing treatment 2), we also had 10 quadrats placed in the road right of way (representing trt 3). These quadrats were added to the end of each of the 10 rows per grid. Each grid was located within a 600 m long bird transect. Thus the 8 plant grids were arranged along 4.8 km of canyon bottom. We

spread the quadrats out like this because the vegetation in Salt Creek was very heterogenous and we wanted to sample a broad area to capture this heterogeneity. Eight additional grids were sampled in 1991, four immediately upstream (trt 1) or four downstream (trts 2 and 3) of those sampled in 1990.

In each plant quadrat we recorded the total coverage for each species present. Finally, because the vertical complexity of the vegetation can influence the nature of the fauna that occupies an area (Yahner 1986, Knopf et al. 1988) we estimated the volume that the plant canopy occupied by estimating the percentage of volume occupied in a hypothetical cube extending in four layers above each 1 m sq quadrat (0 - 0.5 m, 0.5 - 1.0 m, 1.0 - 3.0 m, > 3.0 m).

For data analysis we first examined the frequency of occurrence of each species in quadrats. We deleted from consideration any species that did not occur in at least 10 percent of the quadrats for any one treatment. These species are relatively rare in our quadrats and thus our ability to compare their abundances is poor. In general we compared results across three treatments (trt 1 area without road, trt 2 area with road, trt 3 samples collected from the road per se). We used chi square tests to test for differences in frequency of occurrence of species, and nonparametric analysis of variance tests to test for differences in plant coverage. We also compared coverages between trt 1 and trt 2, and between trt 2 and trt 3. These are the most conservative comparisons possible. We subdivided the overall chi square tests to make the same comparisons among treatments for frequency of occurrence.

In addition to the data for individual species we also examined coverages for broad ecological plant groupings (trees, shrubs, grasses, and

herbs). We also pooled the coverages for these groups and tested for differences in total plant coverage across treatments. We used Kruskal-Wallis nonparametric analysis of variance tests to compare the volume the vegetation occupied in a hypothetical cube located at four heights above each plant quadrat. Volume occupied by plants was scored in one of four classes: 1 = 0 - 25%, 2 = 26 - 50%, 3 = 51 - 75%, 4 = 76 - 100%. Finally, in 1990, we also compared the number of species observed in each of our plant height zones with Kruskal-Wallis or Mann-Whitney U tests.

Small Mammal Sampling

In 1990, small mammals were live trapped at four grids in the canyon bottom containing a road (trt 2), and four grids in the canyon bottom upstream that lacked a road (trt 1). Each grid contained 70 traps arranged in 5 rows of 14 traps each. Each mammal grid was located within a plant grid. In the mammal grids along the roaded canyon bottom the central row of traps was run up the road surface. Each grid was trapped on 4 successive nights. In 1990, all eight grids were trapped over a 12 day period in September. In 1991, 8 additional grids located in the new plant grids were trapped. These grids were trapped over 17 days in late July and early August.

Our initial plan was to use mark-recapture techniques to estimate population sizes for the more abundant species. Trap mortality was high in 1990, causing mark-recapture estimators to yield sizeable underestimates of the actual number of individuals captured, consequently we have used the total number of individuals caught per species per grid as our best estimate

of population sizes in both years. We made comparisons of the total number of individuals of each species, the total number of species, and the total number of individuals caught, between treatments 1 and 2 with Mann-Whitney U or t tests. Finally, we used a chi square test to compare the frequency of trap usage of traps placed in the road per se to usage in traps in the grids that surrounded the road.

Bird Sampling

Birds were counted along 600-m long Emlen transects in 1990 (Emlen 1977). This work yielded estimates of bird densities that were just too small to allow comparisons. As a consequence we discontinued bird censuses in 1991, and will discuss the bird work no further in this report. Species observed over the course of the study are listed in Appendix 1.

Aquatic Animal Sampling

To sample aquatic animals we walked around the pools making visual counts of number of individuals per species. After this, we made 1 m long dip net sweeps through each pool and recorded number of individuals per sweep. Finally, we measured pool surface area and pool depth.

We analyzed the results for any species present in greater than 10 % of the samples. We compared the pool surface area, pool depth, number of species, number of individuals, or number of individuals per species observed in visual surveys in each pool between treatments with a t or Mann-Whitney U tests. We compared the frequency of occurrence of individual species in

pools or in net sweeps across treatments with chi square tests.

Cage experiments

In 1991, we placed 72, 30 x 30 cm wire screen enclosures into Salt Creek to ask how the road might influence sand movement in the stream, and stream use by aquatic organisms. To this end, we located four places where the four-wheel drive road crossed the stream and had water approximately 30 to 40 cm deep both above and below the road crossing. At these sites we loaded 12 cages with small rocks (2 - 8 cm in diameter) and placed them in 6 rows of two cages each in the water. Six cages were located above the road crossing and six below the crossing. In each row we chose a random cage and filled the interstices between the rock cobble with natural sand from the bank. Thus at these sites downstream of Bates Wilson Campground, we have sets of cages above and below the road crossing, and half of all cages contain sand (representing silted in areas) and half have nonsilted rock cobble. Above Bates Wilson campground (above the end of the road) we located four additional sites that had stream areas with water 30 to 40 cm deep and appeared similar to the downstream sites. At each of these areas we placed six cages, half with rock cobble only, half with rock cobble and sand.

The cages were placed in the stream on 17 May and removed on 2 June 1991. At that time we measured the quantity of sand present in each cage, and collected for later counting and identification all organisms that had colonized each cage. The effects of two variables were being examined in this experiment: amount of sand present between rocks, and location of the cage in the stream. We made comparisons of amount of sand in each cage at

the end of the experiment, the number of individuals of abundant species, the total number of individuals present and the total number of species present per cage. Our comparisons were made either between cage location (immediately above vs immediately below a road crossing vs above the upper end of the road) or between levels of sand (no sand added at the beginning vs rock interstices filled with sand at the beginning of the experiment). We used ANOVAs and contrast analysis (Rosenthal and Rosnow 1985), Kruskal-Wallis, or Mann-Whitney U tests to make these comparisons.

Multiple comparison and critical p values

Repeatedly we make comparisons of many species across treatments, to ask if there are treatment effects on individual species. A technical problem with this approach is that due to the large number of statistical tests we are at risk to rejecting the null hypothesis solely due to chance effects. This means that in some cases we could attribute observed differences to the presence of the road, when in fact the differences are really due to chance effects of sampling. In the typical biological application we set the critical p value at $p = 0.05$, which means that there is a 5 % probability that the results will be due to chance alone. The problem when making multiple comparisons is that we would expect to get some (statistically) significant results due to chance alone. For example if you compared the coverage of 100 plant species across two treatments at the $p = 0.05$ level, we would expect to see 5 (statistically) significant results due to chance effects alone. In the 1990 annual report we reviewed ways to handle this problem. For this final report we recommend the following way to interpret

the data. Use the p = 0.05 level to denote significance when looking for overall patterns across treatments (i.e., 11 of 24 species exhibited a pattern of difference across treatments), and use Bonferroni's adjustment when you want to look at (statistical) significance of results for individual species. To obtain the critical p value for testing significance using Bonferroni's adjustment you simply divide p = 0.05 by the number of tests you are making of a specific hypothesis. As an example if we contrast the coverage of 10 plant species across treatments 1 and 2 then the critical p value for each species becomes 0.05/10 = 0.005. Any species with a p value less than or equal to 0.005 could be regarded as demonstrating a significant effect of the treatment. Note that this is a conservative approach, that is, with this approach some species may be regarded as not exhibiting a significant difference across treatments when in fact that they do. We have indicated which comparisons should be regarded as statistically significant (following the Bonferroni procedure) in the tables accompanying the text.

RESULTS

Plant Sampling

1990

Thirty-five to 50 plant species were observed on each plant grid. In Appendix 1 we list each species with comments on our confidence of its identification. Most species were rarely encountered, some only in a vegetative state. Eleven species were abundant enough to merit analysis (Table 1, Fig. 1). Examination of the distributions of these species across

quadrats across treatments reveals that 10 of 11 of these species were not distributed evenly across treatments (Table 1, Fig. 1). Subdividing these chi square tests we see that there were differences in distributions across treatments 1 and 2 for 7 of 11 species. In a similar manner 7 of 8 times (three species were not abundant enough to meet the requirements of this analysis) there were differences in species distributions between treatments 2 and 3. Differences in plant distribution between the road surface per se and the canyon bottom containing the road were always in the direction of the road surface having fewer plants. Differences in plant distributions between the canyon bottom areas with or without roads went in both directions (Table 1, Fig. 1). Prickly pear cactus, Globe mallow, dropseed, Indian rice grass, and four wing saltbush were more frequently encountered in the canyon bottom with the road than in the canyon bottom lacking the road. Conversely, cottonwood and Tamarisk were more frequently encountered in the area lacking the road. The number of species found in the four vegetative height zones differed between treatments (Table 2), with the road right of way consistently containing the fewest species. Similarly, the total number of species per quadrat also differed between treatments (Table 2), with the road right of way containing the fewest species and canyon bottom containing or lacking the road not differing in number of species per quadrat.

Plant coverages were analyzed for 14 species. Coverages for individual species differed between treatments 7 of 14 times (Table 3, Fig. 2). Six species differed in coverages between treatments 1 and 2. Only three species differed in coverages between treatments 2 and 3. This low number may be a function of the relatively small sample size for treatment 3 (30 quadrats).

Coverages of various ecological plant groups commonly differed between

treatments (Table 4, Fig. 3). Total grass, total herbs, total shrub and total tree coverages all differed among treatments. Total grass coverage was higher in the area with the road, whereas total tree coverage was higher in the area lacking a road. Total herbs and total shrub coverage differed between the canyon bottom in the area with the road and the road surface area per se, with both having lower coverages in the road right of way. Total plant coverage also differed between all three treatments, treatment 1 and treatment 2, and between treatments 2 and 3 (Table 4, Fig. 3). Coverage was highest in treatment 1, next highest in treatment 2, and lowest in treatment 3. Total coverage almost always differed between treatments in the different plant height zones (Table 4, Fig. 3).

1991

Plant distribution in quadrats differed across treatments for 21 of 24 species examined (Table 5, Fig. 4). About half of these species were more frequently encountered in the area containing the road, the other half more frequently in the area lacking the road (Table 5, Fig. 4). Seven of 21 species were more commonly encountered in the area with the road relative to the road right of way per se (Table 5, Fig. 4). Plant volume was greatest (at all four height zones) in the canyon bottom lacking the road, next greatest in the canyon bottom containing the road, and lowest in the road right of way (Table 6).

Plant coverages were analyzed for 24 species in 1991. Of these 24, eight had greater coverage in the area containing the road (Oenothera pallida, Machaeranthera canescens, Hymenopappus filifolia, Sphaeraclea

grossulariaefolia, Muhlenbergia aspera, Distichlis spicata, Sporobolis spp, Stipa hymenoides), and eight greater coverage in the area lacking the road (Populus fremonti, Artemisia campestris, Salix exigua, S. lutea, Castilleja linariifolia, Melolotis alba, Clematis linqusticifolia, Agrostis alba; Table 7, Fig. 5). Seven of 24 species (Tamarix ramosissima, Chrysothamnus nauseosus, Castilleja, O. pallida, Muhlenbergia, Sporobolis, Stipa hymenoides) had greater coverages in the canyon bottom containing the road than in the road right of way per se. We believe that we correctly identified all individuals of Muhlenbergii and Distichlis, however, because they are quite similar, we also analyzed results for both species pooled into one category (see Table 5).

In 1991, total grass coverage was greatest in the canyon bottom containing the road, lower in the canyon bottom lacking the road, and lowest in the road right of way (Table 8, Fig. 6). Total tree coverage was greatest in the area lacking the road, next greatest in the area with the road, and lowest in the road right of way (Table 8, Fig. 6). Total herb coverage did not differ between canyon bottom lacking or containing the road, but canyon bottom containing the road did have greater herb coverage than the road right of way (Table 8, Fig. 6). Total shrub coverage was greater in the area lacking the road than in the area containing the road, and was greater in the area containing the road than in the road right of way per se. Total plant coverage was greater in the canyon bottom lacking the road than in the area with the road, which in turn had greater total coverage than the road right of way per se (Table 8, Fig. 6).

Small Mammal Sampling

1990

Five to seven species were captured on each grid (Table 9). There was no difference in the number of species per grid ($t = 1.6$, 6 d.f., $p = 0.17$) or the number of individuals caught per grid ($t = 0.7$, 6 d.f., $p = 0.49$) between the area containing the road and the area lacking a road. Most species were captured both in the traps near the road and in the traps in the road per se. Mexican wood rats and canyon mice were exceptions in that they were never caught in the road per se. Traps located in the road captured only 35 percent of the rodents that one would expect given their frequency in the trap grid (observed and expected values calculated per trap grid, $X2 = 21.4$, 3 d.f., $p < 0.001$).

The total number of individuals per species that were caught did not differ between treatments 1 and 2 for most species (Table 9). Western harvest mice and Mexican wood rats were notable exceptions; both were much more abundant in the area lacking a road.

1991

Five to seven species were captured in each grid. Approximately three times as many mice were caught per grid in the area lacking a road relative to the area containing a road (Table 10). All species except Peromyscus truei (pinon mouse) were captured in the road. Traps located in the road were avoided by small mammals as these traps accounted of only 4.95% of captures (5/101 mice) but represented 20% of the traps that were set (chi

square = 15.9, 1 d.f., $p < 0.001$). The total number of individuals caught per species differed between trap grids located in canyon bottom containing or lacking the road for five of the ten species examined (Table 10).

Aquatic Animal Sampling

1990

Two aquatic surveys were performed at Canyonlands. The first, in June included only a visual survey, the second in July included both a visual and sweep net sampling. Fifteen species were observed in June while only 11 appeared in our samples in July. Three species were amphibians (toad tadpoles, Woodhouse's toad juveniles or adults, red spotted toad juveniles, and Great Basin spadefoot toad tadpoles); most of the remaining species were insects. In the June sample there was a surprisingly high density of predatory insects in the pools. Snails were also sometimes very abundant.

Visual survey results:

Seven species were present in greater than 10 percent of the pools in June and thus subjected to analysis. Of these seven, only damselfly larval densities approached statistical significance (Table 11). Chi square analyses of distribution patterns across pools revealed that while whirligigs were more frequently observed in pools in an area lacking a road relative to the area with the road ($X2 = 4.5$, 1 d.f, $p < 0.05$) there were no detectable differences for Horse hair worms ($X2 = 0.041$, 1 d.f., $p > 0.90$), beetles ($X2 = 0.008$, 1 d.f., $p > 0.90$) or toad tadpoles ($X2 = 0.041$, 1 d.f., $p > 0.90$).

Pool depth data were not recorded for this data set and thus could not be compared across treatments. Neither pool surface area, number of species observed per pool, and number of individuals observed per pool, differed between treatments (Table 11).

In July, 8 species were abundant enough for analysis of number of individuals per species observed in the pools. Of these eight, only horse hair worms differed in abundance between pools (Table 12). Chi square analyses revealed that there were no detectable differences in species distributions across pools in the two treatments (whirligigs $X2 = 0.62$, 1 d.f., $p > 0.90$; snails $X2 = 1.89$, 1 d.f., $p > 0.25$; toad tadpoles $X2 = 0.10$, 1 d.f., $p > 0.90$). There were no differences in pool depth, pool surface area or number of individuals seen per pool; there were, however, more species seen in pools in the area lacking a road relative to the area containing a road (Table 12).

Sweep survey results:

Sweep surveys were performed only for the July sampling period. Relative abundances per sweep were compared across treatments for six species. Damselfly larvae were more abundant in the area lacking the road relative to the area containing the road (Table 13), all other species exhibited no pattern. Chi square tests revealed that several species did differ in the relative frequency of occurrences in sweeps across treatments (notonectids $X2 = 10.62$, 1 d.f., $p < 0.001$; damselflies $X2 = 9.97$, 1 d.f., $p < 0.001$; toad tadpoles $X2 = 4.17$, 1 d.f., $p < 0.05$; whirligigs $X2 = 0.17$, 1 d.f., $p > 0.90$; water striders $X2 = 1.23$, 1 d.f., $p > 0.50$). Toad tadpoles were more frequently encountered in sweeps in pools where the road was

present, while damselflies and notonectids were more prevalent in pools in the area lacking the road. The number of species captured in the sweeps did not differ between treatment 1 (3.2 + 0.5) and treatment 2 (2.8 + 0.3; $t = 0.81$, $p = 0.42$).

1991

Aquatic organisms were sampled in 15 pools in the area containing the road, and in 15 pools in an area lacking the road. This was a relatively dry year and the pools were widely scattered in mid July when the sample was collected. None of the five species examined for the visual survey differed in abundance across the two treatments (Table 14). Further, neither total number of individuals per pool, or total number of species per pool differed between the two treatments. Hydrophild larvae (a predacious beetle larvae) were found more frequently in pools in the area with the road relative to the area lacking the road (Table 15). Notonectids, brown damselfly larvae, and snails were more frequently encountered in sweeps in the area lacking the road relative to the area containing the road (Table 16).

Cage results

Sand levels varied across locations ($F = 4.29$, 2, 66 d.f., $p = 0.018$) and across sand-level treatments ($F = 16.4$, 1, 66 d.f., $p < 0.0001$, Table 17, Fig. 7). Sand levels in cages below the road crossings were considerably higher than sand levels from cages above the road crossing, ($F = 6.26$, 1, 66 d.f., $p = 0.015$) implying that the road crossing was increasing downstream

sand flow and filling the interstices in the rock cobble. Interestingly, sand volumes in cages above the end of the road were indistinguishable from sand volumes in cages above road crossings ($F = 0.12$, 1, 66 d.f., $p = 0.915$).

Presence of sand in the rock interstices had strong effects on colonization of the cages. Cages that received added sand at the beginning of the experiment had fewer toad tadpoles (0.14 + 0.008 vs 0.95 + 0.34), fewer damselfly larvae (0.03 + 0.03 vs 0.31 + 0.13), fewer total individuals (0.39 + 0.16 vs 1.92 + 0.40), and fewer species (0.33 + 0.13 vs 1.06 + 0.17) relative to cages that did not receive added sand at the beginning of the experiment (Table 17). Location of the cage also had an effect on colonization. Damselfly larvae were more likely to colonize cages upstream of the road crossing (0.29 + 0.14) than below it (0.0 + 0.0, Table 17).

Computer disks

We have included copies of the systat data files on computer disks. In addition we have included a paper copy and a disk file copy of "tcont" which is a table of contents for the computer disk files. "Tcont" is attached as Appendix 4 at the end of the report.

DISCUSSION AND CONCLUSIONS

Plants were relatively easy to sample, and large sample sizes could be accumulated over a reasonable amount of time. Our plant samples appear to be

repeatable from year to year. Plants are fixed in space and thus susceptible to man's effects all year. These factors suggest plants are an ideal group for our study. Our results are pretty consistent from 1990 to 1991. The major difference in 1991 was an increase in total coverage and an increase in shrub coverage. Much of the 1991 sample in trt 1 came from areas with dense willow stands which contributed greatly to these patterns. These areas are common in the area above the four wheel drive road.

In desert systems, streams are typically associated with more mesic types of vegetation, but these species typically occupy a very narrow band along the stream, usually less than 10 m wide. Farther than this from the stream we return to natural desert vegetation typical of that geographic region. In the Salt Creek Area the desert vegetation is dominated by shrubs: big sagebrush, 4-winged saltbush, rubber rabbit brush, and grasses: Indian rice grass, dropseed, and needle and thread grass. The more mesic plants associated with the stream are trees: cottonwood and tamarix, herbs: white clover, sedges, and horsetails, and shrubs: primarily willows. Our subjective impression (we have no measurements of width of the riparian zone) is that this zone is very narrow and commonly broken in the area along the road, while it is very wide (in places over 100 m wide) and forms a continuous linear band in the canyon bottom above the road. Our data do reveal that the area lacking the road has greater coverage and grater plant volumes at all height zones examined (Tables 2,4,6,8).

We examined plant coverage and frequency of occurrence of plants in the 1 m sq quadrats. Both of these metrics are measures of the abundance or prevalence of species in an area. Two important points come from these analyses. The first is that the plants treat the three treatments as

different environments. All species for which differences were observed had lower coverages or lower frequencies of occurrence in the road right of way. This suggests that the road is having a negative effect on plants. This is not surprising, and is probably due to direct physical damage, and shading due to dust accumulation on leaf surfaces. Across years, about half of the species did better in the area with the road and the other half did better in the area lacking the road, again suggesting that these species experience the treatments as different. The second important point to draw from these results is that species that do better in the area lacking the road tend to be more mesic species, while those that do better in the area containing the road tend to be typical desert species (Tables 1,3,5,7). This has important management implications, in that it implies that the four-wheel drive road is favoring desert species at the expense of the more mesic species. Our subjective impression is that the mesic species are locally rare in the Canyonlands area relative to the typical desert species. This means that while the road favors some and disfavors other species, its most important effect appears to be to restrict the more mesic species, a locally rare resource.

The results of the aquatic surveys shift more from sampling date to sampling date than those for the other taxa we have examined. This probably reflects the seasonal nature of many of these species which have aquatic larvae but terrestrial adults. There are, however, some overall patterns to species distributions. We again used both counts and frequency analyses to give us estimates of abundance. Notonectids, whirligigs, damselflies, horse hair worms, and snails were more abundant in the pools in the canyon bottom lacking a road, whereas toad tadpoles and hydrophilid beetle larvae were more

abundant in pools in the area containing the road. We would speculate that disturbance by vehicles may be important to the notonectids and whirligigs which live and feed on the pool surface. Increased siltation associated with the road (see results of cage experiment) may explain the distribution of snails. Horse hair worms are parasites of large ungulates (most likely mule deer in this area) and we would speculate that deer distribution may explain their bias towards the nonroaded area.

The most striking results from our aquatic work is that the aquatic organisms see the areas above and along the four-wheel drive road as different environments. It appears that somehow the road changes the characteristic of the stream environment. Our cage experiment suggests that one aspect of this change may relate to increased sand flow and greater sand infiltration in the rock cobble interstices.

The distribution of small mammals across treatments suggests that these taxa experience the treatments as different environments. Similar to the plant results, it appears that more mesic (or at least locally rarer) species do better in the absence of the road, whereas species typical of the desert do better in the presence of the road.

Direct examination of the effect of the road indicates that rodents avoid the road per se. It is well documented that small mammals avoid open areas and this probably accounts for the low capture rate of traps placed in the road right of way.

Management Implications for Canyonlands

A strong case can be made that plants, aquatic organisms and small

mammals experience the areas above and below Bates Wilson Campground as markedly different environments. The differences in their distributions also will make the environments above and below Bates Wilson Campground very different for taxa that feed on these species. It is also clear for both plants and the small mammals that species that do better in the environment above Bates Wilson are species that are uncommon in the greater Canyonlands area. Species that do better below Bates Wilson tend to be typical desert species and tend to be widespread in the greater Canyonlands area. From these results it follows that the area above Bates Wilson should receive special management consideration and should be protected to some degree. At a minimum this means that there be no extension of the road into this area. At the other extreme it may mean that management actions like closing or shortening the four-wheel drive road might be employed to further isolate the area above Bates Wilson.

Whether the differences above and below Bates Wilson are due to the road is difficult to ascertain. The fact that we examined only one canyon and that the road was present before our study began means that we cannot definitively assign the cause of differences in distributions of species to the road. On the other hand, the sharp changes in the nature of flora and fauna in association with the end of the road, and the lack of obvious biological causes to this change, strongly imply that the road may play a major role. Our cage experiment also implicates the road as an important factor, at least with respect to the aquatic species. The reduced capture rate of small mammals in traps placed in the road, and the low plant coverage values in the road argue that the road can have negative effects on these taxa.

Isolated pockets or refugia of the mesic habitat common above Bates Wilson, can be found along the stream all the way down to Peek-a-boo Campground. Whether this mesic habitat was once continuous down to Peek-a-boo, and whether the road has made it intermittent will never be known. Closing the four-wheel drive road at Peek-a-boo or at the junction of Horse Collar Canyon could potentially allow the mesic habitat to spread downstream to this point. Closure at this point would also greatly reduce travel into the area above Bates Wilson Campground.

Management decisions with respect to road closure must weigh both the impact of the road on the flora and fauna, and the impact of closure on lost recreational opportunities. As biologists, we can speak with authority on the issue of the impact of the road, we will also offer our opinion on the recreational opportunities in Salt Creek Canyon.

The area above Bates Wilson is locally unique and a rare environment in the greater Canyonlands area, which we believe the Park Service should be working to protect and expand. We can say that there is evidence that the road has a negative effect on small mammals, plants, and aquatic animals. Remnants of this mesic habitat are isolated along the road between Peek-a-boo and Bates Wilson Campgrounds. This distribution is consistent with the interpretation that the road has led to the fragmentation of the mesic habitat between the two campgrounds. This argues that road closure above Peek-a-boo should be given serious consideration. Below Peek-a-boo Campground the volume of sand in the stream channel appears to be so great that effects of road usage are likely to be wiped out by sand scouring (at least in the stream channel itself).

From a recreational perspective, Salt Creek Canyon offers four types of

recreation that would be affected by road closure. The first is isolation from civilization. Road closure would contribute to this end and thus has a positive effect with respect to this goal. Three negative effects would arise: loss of an area to go four-wheeling, loss of a remote area that can be reached by car, and loss of access to arches (in particular Angel Arch). Our opinion is that access to better areas to four-wheel, access to extensive remote areas by car, and access to arches is widespread in Canyonlands and in the greater Canyonlands area. Thus while road closure would entail recreational loses to the general public, we believe that these can easily be made up. On the other hand, the potential damage of the road and loss of this isolated mesic habitat will be very difficult if not impossible to replace.

From having talked to the public on our trips up Salt Creek Canyon, it is very clear that the typical Canyonlands visitor considers Peek-a-boo Campground to be a very remote site, which requires serious four-wheel drive challenges to reach. Terminating the road at Peek-a-boo Campground is an option that we would recommend to you.

ABSTRACT FOR ARCHES NATIONAL PARK

Preliminary sampling at Arches National Park reveals that some plant species experience the canyon bottoms containing or lacking the trail as markedly different environments. There also is some suggestion that deer mice and mice in general may also regard these environments as different. Six of nine of the common plant species differed in coverage between canyon bottom containing the trail, canyon bottom lacking the trail or the trail right of way per se. One species had greater coverage in the area lacking the trail, while two had greater coverage in the canyon bottom with the trail. The most typical difference among treatments was for coverages to be smaller in the trail right of way relative to the adjoining canyon bottom. Five of nine species differed in frequency of occurrence across treatments. Two species were more commonly encountered in the canyon bottom with the trail, and two in the canyon bottom lacking the trail. Three of nine were more commonly encountered in the canyon bottom containing the trail relative to the adjoining treatment in the trail right of way.

Analyses of coverages across broad ecological plant groupings (all grasses, all herbs, all shrubs, all trees, all plants) yielded patterns similar to that seen for individual species. Total plant coverages were roughly similar in the canyon bottom containing or lacking the trail, while total plant coverage in the trail right of way was 200 % less. Shrub coverage was greatest in quadrats in the canyon bottom lacking the trail. Shrub coverage, herb coverage, and coverage for all plants combined was reduced in the trail right of way relative to the canyon bottom containing the trail. Herbs, shrubs, and all plants combined were not distributed

equally across the three treatments. Herbs were more commonly encountered in the area lacking the trail. Herbs, shrubs, and all plants combined were more common in the canyon bottom containing the trail relative to the trail right of way per se. Examination of confidence intervals for mark-recapture estimates suggests that deer mice and all mice (pooled) may be more abundant in the area lacking the trail relative to the canyon bottom containing the trail. Mice appeared to be avoiding the open area of the trail.

STUDY AREA

Our study area was immediately upstream and downstream of the paved road crossing White Canyon near "The Wall". Plants were sampled for approximately 1 km up and downstream of the bridge. Small mammals were sampled in two trap grids, one located immediately below the bridge, the other 800 m above the bridge.

METHODS

We examined plant and small mammal populations in Courthouse Wash in October 1992. There was very little water in the wash and aquatic organisms were too uncommon to merit examination at that time. Species encountered at the site are listed in Appendix 2.

Plant sampling

Plant characteristics were examined in 250 - 1 m sq plots. These plots were arranged such that 100 plots were present in the canyon bottom above the bridge (= trt 1, area with low trail usage), 100 plots were in the canyon bottom below the bridge (= trt 2, area receiving heavy trail usage by hikers and some pack animal use), and 50 plots in the trail right of way per se (= trt 3). Plots were arranged in rows which ran perpendicular to the stream channel. Each row contained 5 plots and was located 50 m from the next row. All plant quadrats were located within 2 km of the bridge over Courthouse Wash. Within each row in trts 1 and 2 the plots were arranged as follows: 1 plot located from 1 - 5 m from the high water mark, 1 plot from 6 - 10 m, 1 plot 11 - 15 m, 1 plot 16 - 20 m, and 1 plot 21 - 25 m above the high water mark. Exact location of each plot was varied systematically within each 5 m

range, and was predetermined before the investigators arrived on site. Plots for trt 3 were centered on the most actively used hiking trail (trails braid along the canyon bottom with several typically present in any area), and located every 25 m. The bridge over Courthouse wash (near "The Wall") was used as the starting point for upstream and downstream row locations.

Once located in space, a 1 m sq grid with one hundred 10 cm x 10 cm subdivisions was placed over the plot, and plant coverages measured in cm sq for each plant species. This data was then summarized in each plot to obtain the following data for analysis: total grass coverage; total herb coverage; total shrub coverage; total tree coverage; total plant coverage; number of grass species; number of herb species; number of shrub species; number of tree species; number of plant species; and the number of plots occupied by grasses, herbs, shrubs, trees, and all plants. Finally, all species that occurred in at least 10 % of the plots of at least one of the treatments (species that could be regarded as relatively common) were analyzed for coverage, or frequency of occurrence in plots.

For most of these groupings, the most typical observation per plot was 0 (none of this grouping was observed in this particular plot). This means that the data sets tended to be bimodal (one peak in observations at 0 and another peak at a positive integer). This causes problems for parametric analyses so we analyzed the coverage or count results using nonparametric tests (Kruskal-Wallis Analysis of Variance tests, and Mann-Whitney U tests), to overcome this problem. We used chi square tests to compare the frequency of occurrence for various ecological plant groups or species, across treatments. We made the overall comparison across the three treatments to ask if plant characteristics differed between canyon bottom receiving light

use (Trt 1), canyon bottom receiving heavy use (Trt 2), or the trail right of way per se (Trt 3). We followed this test with two way comparisons between the canyon bottom receiving (Trt 2) or lacking (Trt 1) heavy use, or between the canyon bottom receiving heavy use (Trt 2) and trail right of way per se (Trt 3).

Small mammal sampling

We set 100 traps in each of two trap grids at Arches National Park. The traps were arranged in 5 rows located 7 m apart. Within each row 20 traps were arranged 10 m apart. Each trap grid thus covered an area of approximately 28 x 190 m, or 0.53 ha. One grid was located approximately 1 km above the bridge that crosses Courthouse Wash near "The Wall", while the other was located immediately below this bridge. Traps were baited with rolled oats, and opened just before dark. Traps were checked at first light, and sprung. Ant activity was low, bait removal was minimal, and all traps maintained large amounts of bait. Each captured mouse was identified, had a fish fingerling tag placed in its ear, and was released.

We contrasted the number of mice caught between the two trap grids using chi square tests. We compared the number of each species for common species, and the total number of mice caught. Finally, for the downstream grid we used a chi square test to determine if mice were avoiding the trail right of way, comparing the number of mice caught in the row located in the trail to the four rows located out of the trail. We also used a chi square test to contrast trap success of the traps in the streamside Juncus habitat to the brushy upland habitat adjacent to it.

RESULTS AND DISCUSSION

Plant sampling

Twenty nine species were observed in the 100 plant samples collected above the bridge, 29 species were observed in the 100 plant samples below the bridge in Courthouse wash, and 16 species were observed in the 50 samples collected in the trail right of way. However, only 9 species were present in at least 10 % of the 1 m sq plots (for at least one treatment), and treated with a statistical analysis. Species of all taxa encountered during sampling at Arches are listed in Appendix 2.

Six of nine species exhibited statistically significant differences in plant coverage (at $p < 0.05$ level) across the three treatments (Table 18). Of these nine, only Salix (willows), Tamarix (Tamarisk), and Equisetum (horsetails) exhibited statistically significant differences in coverage across treatments following the Bonferroni procedure (Fig 8.). One of nine species had greater coverage in the canyon bottom lacking the trail, while 2 of 9 species had greater coverages in the canyon bottom containing the trail (Table 18., Fig. 8, $p < 0.05$). Horsetail coverage was greater in the canyon bottom with the trail, while tamarisk coverage was greater in the canyon bottom lacking the trail (Fig. 8, Table 18. Bonferroni procedure). Four of nine species had greater coverage in the canyon bottom with the trail than in the trail right of way, while no species had greater coverage in the trail right of way ($p < 0.05$, Table 18,). Willow coverages in the canyon bottom containing the trail were higher than willow coverages in the trail right of way (Fig. 8., Table 18, Bonferroni procedure).

Five of nine species exhibited statistically significant differences in frequency of occurrence across treatments ($p < 0.05$, Table 19, Figure 9.). Melolotus alba (white clover), willows, and Tamarisk all differed in frequency of occurrence across the three treatments (Fig 9., Table 19, Bonferroni procedure). Two of nine species were more frequently encountered in the canyon bottom lacking the trail, while two of nine were more frequently encountered in the canyon bottom containing the trail (Table 19. $p < 0.05$, Fig. 9.). Horsetails were more often encountered in the area containing the trail then in the canyon bottom lacking the trail (Fig 9, Table 19, Bonferroni procedure). Three of nine species were more commonly encountered in the canyon bottom containing the trail relative to the trail right of way per se, whereas no species were more common in the trail right of way per se (Table 19, Fig. 9., $p < 0.05$). No species met the Bonferroni procedures criterion for statistical significance for comparisons between treatments 2 and 3.

Patterns in plant coverages across broad ecological plant groupings were more similar to what one would expect to see if the trail was having a negative effect on the flora. Plants were subdivided into four ecological plant groupings: trees, shrubs, grasses, and herbs, and also pooled into total plants for analysis. Three of five of the comparisons across the three treatments (= four plant groupings and total plants) were significant (Table 20, Fig. 10 at the $p < 0.05$ level). Total herb coverage, total shrub coverage and total plant coverage also met the Bonferroni criterion for significance. Shrub coverage was higher on the plot lacking the trail than on the plot containing the trial (at the $p < 0.05$ level), but not when following the Bonferroni procedure. No groups were more abundant on the plot

containing the trail. Herb, shrub, and total plant coverages were all more abundant in the plot containing the trail relative to the trail right of way per se following either the regular or the Bonferroni procedure (Table 20, Fig. 10). Coverages of none of the ecological grouping were greater in the trail right of way per se.

There were significant differences in number of species observed per 1 m sq plot across all three treatments for herb, shrub, and total plant species, following either the regular or Bonferroni rules (Table 21, Fig. 11). Total number of herb species /1 m sq plot was greater in the area lacking the trail relative to the area containing the trail following the regular rules, but not following the Bonferroni procedure (Table 21, Fig. 11). There were more shrub and total plant species in the area containing the trail relative to the trail right of way per se following either the regular or the Bonferroni procedure (Table 21, Fig. 11). Herbs were more abundant in the area containing the trail relative to the trail surface per se (Table 21, Fig. 11), but only following the regular rules and not the Bonferroni procedure.

Total herbs, total shrubs, and total plant groupings differed in frequency of occurrence across the three treatments, following either the regular $p < 0.05$ level, or the Bonferroni procedure (Table 22, Fig. 12). Only total herbs differed in frequency of occurrence across treatments 1 and 2, being more abundant in the area lacking the hiking trail following the regular, but not the Bonferroni procedure (Table 22, Fig. 12). Total herbs were more commonly encountered in the area containing the trail relative to the trail right of way per se (only at the regular $p < 0.05$ level, Table 22. Fig. 12). Total shrubs and total plants were more commonly encountered in the area containing the trail than the trail right of way per se (following

both the regular and Bonferroni procedures, Table 22, Fig. 12).

It is clear from the plant analyses that some plants treat the three treatments as different environments. Whether these differences are due to the trail per se is not clear. If one looks at plant coverages for the ecological plant groupings (Table 20), the major differences that jump out are the marked reductions in coverage in the trail right of way. This implies that the trail is negatively affecting plant coverage, apparently reducing it to about one third of that observed in the other two treatments.

Small mammal sampling

Seven mouse species and a weasel were captured in the 100 trap grid in the area containing the heavily used hiking trail, while. six mouse species were caught in the area lacking the trail (Table 23). Petersen mark-recapture estimates were quite similar to the total count of number of small mammals actually caught. Because only two grids were trapped there are no multiple estimates from which we could obtain a estimate of variation, and thus no statistical tests are possible. We contrast the 95 % confidence intervals for the deer mouse and all mice combined as these two groupings had high densities. We caution (Menkens and Anderson 1988) that these confidence intervals are only hypothetical and may differ considerably from the underlying values. Simple inspection of the data suggest that there might be more deer mice and more total mice in the area lacking the trail. Further study of this possibility would appear to be worthwhile.

Twenty of the 100 downstream traps (20%) were located in the trail right of way. These traps accounted for only 8 of the 81 captures (9.9%), a

proportion far short of their expected contribution (chi-square = 8.7, 1 d.f., $p < 0.01$). Small mammals appear to be avoiding the open area in the trail. The trail was located in a Juncus dominated habitat that contained the first two rows of traps (40 traps) in the downstream area. Trap success of traps in the more bushy habitat (60 of 240 = 25%) was much higher than that in the more open Juncus habitat (21 of 160 = 13%, chi-square = 12.9, 1 d.f., $p < 0.001$), suggesting that the open Juncus habitat is not good mouse habitat. This latter effect may explain much of reduction of trap success in the trail, as trap success in the trail (8 of 80 trap nights = 10%) was not much different from that in the Juncus habitat but not in the trail (13 of 80 = 16.3%, chi-square = 1.38, 1 d.f., $p > 0.10$). These results imply that both the trail and Juncus habitat may be detrimental to mouse populations. Juncus habitat was about twice as abundant in the canyon bottom below the road relative to that above the road. This difference was marginally nonsignificant, and would merit watching in a more extensive examination of the canyon bottom.

MANAGEMENT IMPLICATIONS

Our investigation at Arches National Park examined only a small portion of the park, and took place near the bridge over Courthouse wash near "the Wall". This is at the upper end of the heavily hiked section of this canyon, and probably receives lesser usage than the downstream end of the canyon. In spite of this, we still observed significant differences in plant coverages and distributions across treatments. The small mammal sampling effort was even smaller than that for plants, yet it still yielded some

evidence that the three treatments were experienced differently by small mammals. Taken as a whole our work at Arches suggests that the trail may have negative consequences on the plants and animals in Courthouse Wash. Our work was probably too localized and small to draw inferences on the true magnitudes of this effect. Our recommendation for Arches is that more study is merited, and that this should be spread more widely over the canyon bottom. Based on our sampling effort at the three study sites we would recommend the sampling procedure discussed below. This approach is simple, repeatable by different investigators, and does not require advanced botanical, zoological, or statistical skills to carry out.

FUTURE SAMPLING PROTOCOL

Our research suggests that presence of a road or trail typically leads to lowered plant coverage, and an increase in bare ground. Some species do better in the road or trail while others do worse. While 50 plant species can be expected to be encountered in any of these areas, only a few, usually 10 to 15 are abundant enough to be quantitatively sampled. Further we have demonstrated that broad ecological plant groupings also vary across treatments. This suggests that these broad groupings are also useful monitoring tools. In the procedure we outline below either or both individual species (those discussed in our reports) or ecological plant groups could be monitored. The procedure is designed to function as both a snapshot of current conditions and as a monitor of longer term changes.

The procedure consists of placing a series of line transects perpendicular to the canyon bottom, and recording data in such a way that the

proportion of the vegetation attributable to different classes (ecological groupings or species) can be determined. This process is repeated numerous times in the canyon bottom containing the road or trail and in the canyon bottom lacking the trail or road. We would recommend running 50 lines in each treatment. Each line should go across the canyon, or in very wide places be the average canyon width wide. The lines should be equally spaced over the treatment, and marked by driving rebar poles into the ground on each end so that they can be relocated in the future for remeasurement of the line. Each line should be measurable in 30 to 60 minutes, when two people are working.

Once a line is located in space, a fiberglass measuring tape (graduated in centimeters) should be stretched between the two ends. Care should be made that the line is straight and does not contain major bends around trees or other structures as this could introduce bias into the results. One individual records data, the other calls it out. The following data is recorded onto a data sheet as the caller walks along the line: length of bare ground, length of bare ground including both true bare ground = no plants - and bare ground overtopped by trees (this counts as vegetated ground when looking at total plant coverage, but is probably considered bare ground by rodents), coverage by each plant class (= ecological plant group, or species if you want that detail), width of disturbed stream channel (disturbance caused by water flow), width of trails or roads, and width of total transect. Remember to measure all plants even when one species overtops another. Record one data sheet for each transect, with subject class (e.g., grasses, or bare ground) listed across the top of the page. Sum the numbers in each column to get totals for each category for each line

transect. Divide the total for a category (for example grass coverage) by total transect width to get the proportion of the transect that is covered by grass coverage. Transform the data with an arc sign transformation to facilitate parametric statistical analysis. The procedure is described in statistical books (Zar 1974, has a table, and most statistical programs will do the transformation). Combine data from the different transects to get 100 estimates of each plant parameter (e.g., total grass coverage), 50 in the canyon bottom with the road or trial and 50 in the canyon bottom lacking the road or trail. Counts per 50 m of transect can be used in lieu of density figures, to give an estimate of frequency of occurrence across treatments. Use chi-square tests for these analyses. For comparison of proportions of transects occupied, use t tests, or 2 way analysis of variance tests for making comparisons both across treatments and across years. This sort of analysis will give you a good feel for how much of the canyon bottom is being taken up by the trail or road, and whether this value changes over years. Interpret the changes in your studies in future years in light of the results that we have presented in this report. Once every 5 to 10 years you might want to measure plant coverages in belt transects located along your line transects. We would measure coverage in at least 250 m sq in each treatment. This is time consuming, but gives you higher caliber data and some sorts of data, like true densities, that you cannot get from transect data.

For small mammal sampling we would recommend live trapping grids, similar to those we have used. We would use daily counts as the estimates of population size, and trap at least four 70-trap grids in the trailed and nontrailed areas (8 grids total). This is a lot of work, and could be done every 3 to 5 years. See the Canyonlands results for recommended analyses.

The aquatic organisms are best sampled with visual surveys, because of the complex nature of the substrate which prevents accurate sampling with nets. Again the Canyonlands results provide a good guide for protocol and analysis.

ABSTRACT FOR NATURAL BRIDGES NATIONAL MONUMENT

Several plant species or ecological plant groupings differed in plant coverage or in frequency of occurrence across the canyon bottom containing the trail, the canyon bottom lacking the trail, or the trail right of way per se. Mormon tea, and dropseed were more frequently encountered, and had greater coverages, in the canyon bottom lacking the trail, while rabbit brush, mountain mahogany, and Lepidium were more frequently encounter or had greater coverages in the canyon bottom containing the trail. Grasses were more frequent in the canyon bottom lacking the trail relative to the canyon bottom containing the trail. The greatest plant differences occurred between the canyon bottom containing the trail and trail right of way per se. Oaks, Morman tea, and Lepidium all had lower coverages in the trail relative to the surrounding canyon bottom. Herbs, shrubs and all plants combined had lower coverages in the trail relative to the adjoining canyon bottom. Many of these differences in coverages were on the order of 200 percent reductions. There were more grass species encountered per m sq in the canyon bottom lacking the trail relative to the canyon bottom containing the trail. More herb, shrub, and total plant species were observed per m sq in canyon bottom containing the trail relative to the trail right of way.

Pinon mice were more common in the canyon bottom containing the trail relative to the canyon bottom lacking the trail. Trap success in the trail was higher than that in the surrounding canyon bottom. The most salient characteristic of the trapping results was the low and highly variable number of mice caught per trap grid. The low numbers were most likely due to the near constant rains. The cause of the spatial heterogeneity in numbers is

unknown. Bird numbers were too low to allow us to draw any meaningful conclusions.

Aquatic invertebrates exhibited strong differences between the canyon bottom containing or lacking the trail. In both years the pools in the canyon bottom lacking the trail contained more individuals per species relative to pools in the canyon bottom containing the trail. In 1991, the pools in the canyon bottom lacking the trail contained more species than pools in the canyon bottom containing the trail. The pools in the area containing the trail were sandy bottomed, while those in the canyon bottom lacking the trail tended to be rocky. The species missing from the area containing the trail were species that are typically associated with rocks. Trail usage may be increasing sand infiltration into the stream, and burying rocky substrate, effectively removing this habitat from this area.

INTRODUCTION

At this site we examined plant and animal distributions with respect to three treatments: Trt 1, area above Sipapu Bridge (an area lacking a heavily used hiking trail), Trt 2, area between Sipapu and Kachina Bridges (area containing a heavily used hiking trail), and Trt 3, in the trail right of way. We have examined the distributions or abundances of numerous species. Many of these, especially plants and insects do not have common names. We have used common names where ever possible. All species that we encountered during regular surveys are listed in Appendix 3. There we comment on names and on our degree of confidence in our identifications.

STUDY AREA

The study area at Natural Bridges consisted of all canyon bottom between Sipapu Bridge and Kachina Bridge, and the canyon bottom for 4 km upstream of Sipapu Bridge. Pools were sampled throughout these areas. Small mammal grids were located for the first 3 km up and downstream of Sipapu Bridge. Plant quadrats were located for 2.5 km up and downstream of the bridge.

METHODS

Sampling Approach

From 1990 to 1992 we looked at birds, small mammals, aquatic organisms, and terrestrial plants. For all four taxa we made comparisons between a

downstream area (Sipapu Bridge to Kachina Bridge) that contained a heavily used hiking trail, and the canyon bottom immediately upstream of Sipapu Bridge which lacks a regularly used trail. We compared species presence or absence patterns, or the number of individuals per species. Birds, aquatic animals, and plants were studied in 1990. Aquatic animals were studied in 1991. In 1992, we examined both plants and small mammals.

Plant Sampling

The vegetation in White Canyon is quite heterogenous and varies a great deal over short distances. A lot of this variation appears to be due to the fact that the canyon has sheer walls and shifts directions over short distances. This creates a mosaic of shady and sunny areas on the canyon bottom. In 1990 we attempted to deal with this variation by sampling two plant grids above and two below Sipapu Bridge. In each area either above or below the bridge, one grid was located in an area that received much sun each day, the other in an area that received much less sun. Each grid consisted of 50 1 m sq quadrats arranged in 10 rows of 5 grids each. Each grid was similar to those described above for Canyonlands plant grids except that rows were only 5 m apart. The area with the trail received 50 quadrats per grid plus 10 quadrats (in the trail per se, which represents treatment 3).

In late May and early June 1992, we examined plant coverage on four plant grids above Sipapu Bridge and four plant grids between Sipapu and Kachina Bridge. These grids were similar to those described for the Canyonlands grids, except that there were only 40 quadrats (8 rows of 5 quadrats) in each plot in treatments 1 and 2, and 20 quadrats in treatment 3.

This breakdown of quadrats per grid gives us more power to detect differences between treatments 2 and 3. Rows were 50 m apart, and treatment 3 quadrats were placed in the trail 25 m apart. In both 1990 and 1992 the upstream grid started approximately 1 km upstream of Sipapu Bridge. In 1990 the first downstream grid was about 1 km downstream of the Sipapu Bridge while in 1992 the first grid started 50 m below this bridge.

In each quadrat we recorded the total coverage for each species present, and counted the number of individuals present per species. We subdivided the plants into four ecological plant groupings (herbs, grasses, shrubs, and trees) and computed total coverage for each of these ecological groupings and for a total coverage for all plant species. We used nonparametric analyses to compare coverage by species, coverage by ecological plant type, or percentage of 1 m sq quadrats occupied per species or plant group, across the three treatments. Following the overall comparison we compared these variables between treatments 1 and 2, and treatments 2 and 3. Species comparisons were made only for those species that were abundant enough to occur in more than 10 percent of at least one of the treatments. Sixteen plant species met this criteria in 1990, and 14 species in 1992.

Small Mammal Sampling

Small mammals were trapped in late May 1992 on four 70-trap grids upstream (= Trt 1 or area lacking the trail), and four grids downstream (= Trt 2 or area containing the trail) of Sipapu Bridge. Each grid consisted of 5 rows of 14 live traps each. Intertrap spacing was approximately 8 m between rows and 10 m between each trap within a row. Each grid was trapped

for four successive nights, except where heavy rainfall prevented this. Heavy and almost continuous rain occurred during the last two weeks of May 1992. We had 36 traps washed downstream during one flash flood event. Small mammals were identified to species, sexed, marked with a numbered ear tag and released. The total number of mice caught per species/grid, or the total number of mice of all species combined were compared across treatments with Mann-Whitney U tests or t tests. Finally, we compared the trap success of traps located in the trail to the trap success of traps not located in the trail with a chi-square test.

Bird Sampling

Birds were counted along four 600-m long transects, which were walked on two successive days in 1990. The vegetation was thick and the birds appeared to move around a great deal. These factors led to wide variation in the number of birds seen on each transect. Our original plan was to compute densities following the approach of Emlen (1976). Given the data in hand we feel that this is not worth pursuing (the confidence intervals will be so wide that they will mean nothing). We have compared the raw data (number of individuals per species, number of species, number of individuals) across treatments with t tests. No bird transects were examined after 1990.

Aquatic Animal Sampling

IN 1990 we examined 79 pools at Natural Bridges. We walked around the pools making visual counts of number of individuals per species. After this

we made dip net sweeps through each pool and recorded number of individuals per sweep. Around a dozen species were present in pools, however, only about half this many were present in greater than 10 percent of the samples. We analyzed these more abundant species for differences between treatments. We compared the number of species, number of individuals, or number of individuals per species present in each pool between treatments with a t test. We compared the frequency of occurrence of individual species in pools across treatments with chi square tests.

We compared the number of individuals per species sampled per dip net sweep across treatments with a t test. We compared the frequency of occurrence of species in sweeps across treatments with chi square tests. We also tested for regressions between environmental parameters and estimates of number of species or number of individuals per species. We tested for relationships between pool surface area, or depth and the number of species observed in visual surveys, and the number caught in the dip net surveys. Finally, we pooled the data from sweep and visual surveys to yield our best estimate of the number of species present per pool, and performed a regression between this variable and pool depth or pool surface area. We also tested for a relationship between pool surface area and the number of individuals per species for the surface-living invertebrates (whirligigs, notonectids, and water striders).

In 1991, we made one trip to Natural Bridges to sample aquatic organisms. Our main purpose in this trip was to try to relate the distribution and abundance patterns of aquatic animals to the physical characteristics of the pools. We measured 26 pools in the area lacking the trail (Trt 1), and 32 pools in the area containing the trail (Trt 2). We

walked around each pool and counted the number of individuals of each species. In each pool we measured the surface area and estimated average depth, we also assigned the pool to one of three bottom-composition classes: class 1 = > 90 % sand bottomed, class 2 = > 90% rock bottomed, and class 3 = <90% rock bottomed and < 90% sand bottomed. We used a Mann-Whitney test to compare the bottom-composition scores across the two treatments. We used Mann-Whitney U tests or t tests to compare physical attributes of the pools, number of species, or number of individuals per species across the two treatments.

In 1992, we planned on collecting samples of aquatic animals, but the presence of heavy rain lead to high stream flows which precluded sampling.

RESULTS

Plant Sampling

Plant distributions and abundances were examined on 4 plant grids at Natural Bridges National Monument in 1990. Many plants germinated or sprouted from roots early in the spring, but many either quit growing or dried up during the summer. Very few reached reproductive maturity (most never got past basal rosettes), and thus many species at this site were not identified to species. Twenty-seven to 30 species were observed per grid. Only 16 species were observed in > 10 percent of the quadrats and pursued further. We chose sampling sites at Natural Bridges so that there was one shaded site up and down stream and one open sunny site up and down stream. We analyzed these data as a one way analysis of variance with presence or

absence of the trail being the treatment.

Comparisons across treatments revealed that total herb coverage differed among all three treatments (Table 24). None of the ecological plant groupings differed between treatments 1 and 2. Total herb coverage did differ between trts 2 and 3 with lower coverages occurring in the trail per se (Table 24).

Twelve of the fifteen individual species examined had different coverages between the three treatments (at the $p = 0.05$ level, Table 25, Fig. 13), implying effects of the treatments on species coverages. Four species met the more restrictive requirements of the Bonferroni procedure (Table 25, Fig. 13). Eight of 15 species differed in coverage between treatments 1 and 2 ($p = 0.05$ level), and four differed following the Bonferroni procedure (Table 25, Fig. 13). Dropseed and Morman tea had greater coverages in the area lacking the trail, whereas rubber rabbitbush and mountain mahogany had greater coverages in the downstream area containing the trail. Three of 15 species exhibited differences in coverage between treatments 2 and 3 (at $p = 0.05$ level), only Gambel's oak exhibited a difference in coverage between the area containing the trail and the trail surface area per se following the Bonferroni procedure. Inspection of the magnitudes of the values suggests that the existence of only 1 species difference between treatments 2 and 3 is probably a function of the small sample size (20 quadrats) for treatment 3.

Three of five comparisons of presence or absence of ecological plant groups across the three treatments exhibited statistical significance (at the $p = 0.05$ level); grasses, herbs, and shrubs also met the Bonferroni criteria for significance (Table 26). Shrubs were more commonly encountered in the canyon bottom containing the trail relative to the canyon bottom lacking the

trail following either procedure for testing significance (Table 26). Two of three possible comparisons across treatments 2 and 3 were statistically significant (at p = 0.05). Only herbs differed in frequency of occurrence (being more common in treatment 2 relative to treatment 3) following the Bonferroni procedures.

Examination of species presence or absences in quadrats revealed that 12 of 16 species had distributions skewed enough to be regarded as statistically different across the three treatments (p = 0.05 level, Table 27, Fig. 14). This large number of differences suggests that the treatments are influencing species distributions, as we would expect to see only one difference by chance alone. Morman tea, Cercocarpus lepidium, rabbit brush, primrose, and dropseed all differed in frequency of occurrence across the three treatments (following the Bonferroni procedure). Seven of 16 possible comparisons across treatments 1 and 2 were significantly different, with two species being more commonly encountered in the area lacking the trail, and five species more commonly encountered in the area containing the trail (p = 0.05 level, Table 27, Fig. 14). Dropseed and morman tea were more commonly located in the canyon bottom lacking the trail, whereas Cercocarpus lepidium and rabbit brush were more commonly located in the canyon bottom containing the trail (following the Bonferroni procedure). Sample size was too small to allow statistical testing for 13 of 16 comparisons between treatments 2 and 3. In one of the three possible comparisons (Gambel's oak) a species was more often encountered in the canyon bottom surrounding the trail relative to the trail right of way per se (following either process for testing significance).

In 1992, the weather was more conducive to plant growth and most plants

matured and were easy to identify. Fourteen species were observed in at least 10 percent of quadrats for at least one treatment and were subjected to statistical analysis. Seven of 14 species had different coverages across the three treatments (Table 28,), again implying effects of the treatments on species coverages. Four of these seven species (Lepidium, Gambel's Oak, Morman tea and Western Virgin's Bower) also met the requirements of the Bonferroni procedure. Two species had higher coverages in the area lacking the trail, while two had higher coverages in the area containing the trail (p = 0.05 level. Only Lepidium, with greater coverage in the canyon bottom containing the trail met the more restrictive requirements of the Bonferroni procedure. Seven of 14 species had reduced coverages in the trail right of way relative to the adjacent canyon bottom (p = 0.05 level, Table 28). Of these, only Gambel's oak, Morman tea, and Senecio, could met the requirements of the Bonferroni procedure. Cottonwood had greater coverage in the trail right of way relative to the adjoining canyon bottom, but only at the p = 0.05 level (Table 28).

Four of five of the plant groupings (herbs, shrubs, grasses, and all plants) had different coverages following either the regular procedures or the more stringent Bonferroni procedure (Table 29, Fig. 15). Total grass coverage was greater in the area lacking the trail relative to the canyon bottom containing the trail following either procedure (Table 29, 15). None of the groups had greater coverage in the canyon bottom containing the trail relative to the canyon bottom lacking the trail. Total shrub and total plant coverage were reduced in the trail right of way relative to the adjoining canyon bottom (following either procedure Table 29, Fig. 15).

Eighteen species were encountered commonly enough to merit examination

of frequency of distribution across treatments. Seven of 18 species differed in frequency of occurrence across the three treatments (Table 30, Fig. 16), suggesting that plant distributions were influenced by trail location. Lepidium and Morman tea differed across the three treatments following the Bonferroni procedure. One of 18 species were more commonly found in quadrats in treatment 1 relative to quadrats in treatment 2 (with p = 0.05 procedure, Table 30, Fig. 16). Three of 18 species were more commonly found in the canyon bottom containing the trail relative to the canyon bottom lacking the trail (Table 30, Fig. 16). Of these three, only Lepidium also met the requirements for the Bonferroni procedure. Six of 18 species were more commonly encountered in the canyon bottom containing the trail relative to the trail right of way per se (Table 30, Fig. 16). Of these six, Gambel's oak, Morman tea, and Senecio also met the Bonferroni rules. Cottonwood was more often encountered in the trail right of way per se relative to the surrounding canyon bottom (following the regular rules but not the Bonferroni rules Table 30). Three of the five ecological plant groupings (grasses, shrubs, and all plants) differed if frequency of occurrence across the three treatments (following either the regular rules or the Bonferroni rules Table 31, Fig. 17). Grasses were more frequently encountered in the canyon bottom lacking the trail relative to the canyon bottom containing the trail (following either procedure for testing significance Table 31, Fig. 17). No species were more commonly encountered in the canyon bottom containing the trail relative to the canyon bottom lacking the trail. Shrubs were less commonly encountered in the trail right of way relative to the adjoining canyon bottom (following either statistical procedure Table 31, Fig. 17).

Comparisons of number of species present per quadrat in 1992 revealed

differences across the three treatments for 4 of 5 ecological plant groupings ($p = 0.05$ level, Table 32). Different numbers of herbs, grasses, shrubs, or all plant species combined were found in the three treatments (following the Bonferroni procedure). Number of grass species was greater in the canyon bottom lacking the trail relative to the canyon bottom containing the trail (following either test procedure). Herbs, shrubs, and all plants combined each contained more species in the canyon bottom surrounding the trail relative to the trail right of way (following either procedure).

Small Mammal Sampling

Eight species were caught in the grids located in the canyon bottom containing the trail, and eight species were caught in the canyon bottom lacking the trail. It rained almost every night we trapped. Number of mice caught was not very high, and varied a great deal between grids within a treatment (Table 33). Never-the-less comparisons across treatments 1 and 2 did reveal some differences. There were more Pinon mice per grid in the canyon containing the trail (2.75, 1.3; mean, s.d.) relative to the number per grid in the canyon bottom lacking the trail (0.5, 0.6, $t = 3.25$, 6 d.f., $p = 0.017$). There was no difference in the number of white-throated woodrats per grid (6.5, 6.9 area with no trail; 1.8, 1.7, area with trail, $t = 1.34$, 6 d.f., $p = 0.227$). The lack of difference here appears to be largely a consequence of the small sample size. There also was no difference in total number of mice caught per grid (13.0, 5.6 for the area lacking the trail; 10.8, 6.6 for the area containing the trail, $t = 0.52$, 6 d.f., $p = 0.62$). Twenty four mice were caught in the 208 trap nights in the trail (12 %) while

57 were caught in the 912 trap nights out of the trail (6 %) establishing that trap success was higher in the trail (chi square = 7.1, 1 d.f., $p < 0.01$).

Bird Sampling

Four bird transects were examined in White Canyon at Natural Bridges National Monument (Table 34) - two below Sipapu Bridge (area with a trail) and two above Sipapu Bridge (area lacking a heavily used trail). Ten species were observed in the area lacking the trail, while 7 were observed in the area containing the trail. Each species was rarely encountered along each transect (average for area with trail = 0.98 individuals/species, average for area lacking trail = 0.90 individuals/species). These numbers are far too low to merit analysis.

Aquatic Animal Sampling

1990

Sixteen animal species were observed in the pools during sampling in 1990 (Appendix 3). Three of these were amphibians and the rest were invertebrates, mainly insects. In addition to these species we also saw one tiger salamander adult and several Great Basin spadefoot toad tadpoles in the pools at times when we were not quantitatively sampling. Aquatic organisms were sampled by making a visual survey of each pool, and by making quantitative dip net samples. The results will be presented separately for

these two sampling methods.

Visual surveys - Of the 16 species present 9 were observed in greater than 10 percent of the pools and subjected to statistical analysis. Of these 9 species, two differed in abundance between pools in the canyon bottom lacking the trail (trt 1) and pools in the canyon bottom areas containing the trail (trt 2, Table 35). Both caddisfly larvae and water strider adults were approximately three times as abundant in pools in the area lacking a well used hiking trail relative to pools in an area with a trail. Number of species seen per pool did not differ between treatment 1 (3.7 + 0.2, X + s.e.) and treatment 2 (3.2 + 0.2, t = 1.5, 38,39 d.f., p = 0.14). Number of individuals per pool also did not differ between treatment 1 (127.1 + 56.7) and treatment 2 (98 + 28.3, t = 0.4, 38, 39 d.f., p = 0.66). Both pool surface area (F = 6.63, 1, 77 d.f., p = 0.012, R2 = 0.067) and pool depth (F = 6.47, 1, 77 d.f., p = 0.013, R2 = 0.066) exhibited significant positive regressions with number of species observed per pool. Neither variable (depth trt 1 2.3 + 0.1, trt 2 2.5 + 0.2, t = 1.0, 38, 39 d.f., p = 0.30; surface area trt 1 22.4 + 5.1 m2, trt 2 15.4 + 3.0, t = 1.2, 38, 39 d.f., p = 0.24) differed between the two treatments. Finally, five species were abundant enough to examine their frequency of pool usage between the two treatments. Chironomids (chi square = 2.07, 1 d.f., p > 0.10), whirligigs (chi square = 2.37, 1 d.f., p > 0.10) and water striders (chi square = 0.002, 1 d.f., p > 90) did not differ in frequency of pool usage between treatments. Horsehair worms showed a tendency towards significance (chi square = 3.53, 1 d.f., p = 0.064), as did caddisfly larvae (chi square = 5.75, 1 d.f., p <0.025; Bonferroni p value = 0.01).

Sweep Samples - Five species occurred in greater than 10 percent of the sweeps made. We analyzed these species for frequency of occurrence across treatments with chi square tests. Given five tests an appropriate alpha value would be 0.05/5 = 0.01. Only the comparison for a amphipod meets this criterion, although all four other species have probability values relatively close to significance (Table 36).

Four taxa were abundant enough to merit analyses of number of individuals per taxa per sweep. Notonectids (U = 43542, p = 0.055) and water striders (U = 43854, p = 0.024, Bonferroni p = 0.05/4 = 0.0125) did not differ between pools in an area lacking a trail and an area containing a trail. Amphipods (U = 45674, p < 0.0001, 0.16 + 0.09, X + S.E., near trail, 0.55 + 0.1 in area away from the trail) and chironomids (U = 43590, p < 0.011, 0.16 + 0.04 in area lacking trail, 0.08 + 0.04 in area with trail) did differ among treatments.

Pool depth appears to influence the number of species observed in a sweep (F = 29.4, 1, 77 d.f., p < 0.0001, R2 = 0.267). Similarly, pool surface area is also positively related to number of species per sweep (F = 45.2, 1, 77 d.f., p < 0.0001, R2 = 0.361). The number of species seen in pools during visual surveys and the number captured in pools by making sweeps was positively related (F = 39.4, 1, 77 d.f., p < 0.0001, R2 = 0.33). The number of species seen or dip netted per pool was related to both pool depth (F = 16.2, 1, 77 d.f., p < 0.0001) and pool surface area (F = 23.6, 1, 77 d.f., p < 0.0001). The number of species dip netted per pool did not differ between treatments (trt 1 4.2 + 0.3, trt 2 3.5 + 0.2, MWU = 954, 1 d.f., p = 0.084). Number of individuals of surface living species was strongly

positively related to pool surface area (notonectids, $r = 0.351$, 77 d.f., $p < 0.002$; whirligigs $r = 0.226$, 77 d.f., $p < 0.05$; water striders, $r = 0.632$, 77 d.f., $p < 0.001$).

1991

Analyses revealed that there were approximately twice as many species per pool in the area lacking the trail as the canyon bottom containing the trail (Table 37). Water striders, caddisflies, and mayflies were more abundant in the area lacking the trail (Table 37). Similarly, these three species occupied a higher proportion of pools in the area lacking the trail relative to area containing the trail (Table 38). Pools in the area containing the trail were primarily sand bottomed whereas those in the area lacking the trail were primarily rock bottomed (Figure 1, Mann-Whitney U test = 179, $p = 0.01$).

DISCUSSION

Plant sampling

Patterns for the ecological plant groups varied across years probably reflecting a combination of different sampling techniques and different precipitation regimes. There were few differences in coverage or frequency of occurrence between the canyon bottom containing or the canyon bottom lacking the trail. Grasses were encountered less often in the canyon bottom containing the trail. Herbs, shrubs, and all plants combined had lower coverages or were less often encountered in the quadrats in the trail right

of way per se relative to the canyon bottom containing the trail. This is strong evidence that the trail was influencing these groups.

In 1990, Morman tea and dropseed were more commonly found in the canyon bottom lacking the trail, whereas rabbit brush and mountain mahogany were more commonly found in the canyon bottom containing the trail. In 1992, Lepidium had greater coverage in the canyon bottom with the trail relative to the canyon bottom lacking the trail. Oaks, morman tea, and Senecio had greater coverages in the canyon bottom with the trail relative to the trail per se. Lepidium was more frequently encountered in the canyon bottom containing the trail relative to the trail right of way per se.

Number of species also differed across treatments with more grasses present in the canyon bottom lacking the trail, relative to the canyon bottom containing the trail. Again the main plant difference appeared to be between the canyon bottom containing the trail and the trail right of way. There were more herb, shrub, and all plant species combined in the canyon bottom containing the trail relative to the trail right of way. Plants tended to be largely absent from the trail right of way, with surrounding canyon bottom typically containing twice the coverage of trail per se. Shrubs were particularly under represented in the trail right of way.

Small mammal sampling

Pinon mice were more common in the canyon bottom containing the trial relative to the canyon bottom lacking the trail. Trap success in the trail was higher than that in the surrounding canyon bottom. This is unusual and opposite what one usually sees. The most salient characteristic of the

trapping results was the low and highly variable number of mice caught per grid. The low numbers were most likely due to almost daily rain showers. The cause of the high grid to grid variation in number of mice caught is unknown. A house mouse was caught in the canyon bottom lacking the trail in the general vicinity of some indian ruins. A microtine rodent was caught in the canyon bottom containing the trail. These rodents are usually associated with mesic habitats.

Bird sampling

Bird numbers were too low to allow us to make any meaningful comparisons. Rufus-sided-towhees were the most common species encountered in the canyon bottom.

Aquatic animals

In both years examined the area lacking the trail tended to have more species and more individuals per species relative to the pools in the area containing the trail. A large part of this difference appears to be due to the fact that many of the species that were less abundant downstream were species that are typically associated with rocky substrates. The area containing the trail tended to have pools that were 90 to 100 percent sand bottomed. Isolated rocks poked through the sand in many places downstream, and digging invariably revealed an underlying rocky substrate. It appears that the trail reduces plant coverage and increases erosion into the stream channel with cascading effects onto the stream living species. These

indirect effects (Morin 1987) appear to play major roles in many systems including in other aquatic systems (Woodward and Mitchell 1991). Increased erosion into the stream may be one of the more important consequences for heavy trail usage in this narrow canyon.

MANAGEMENT IMPLICATIONS

The canyon bottom in White Canyon at Natural Bridges National Monument is quite narrow, in some places only 25 m wide. This means that the trails, which are largely devoid of vegetation, are removing a sizeable portion of the vegetation in the canyon bottom. How this potential reduction in stream nutrient input is affecting the stream is unclear. In stream systems this input can be crucial (Moss 1980).

Comparisons of stream substrate in the area containing or lacking the trail reveals a large shift from primarily rocky bottoms in the area lacking the trail to predominantly sandy bottoms in the area containing the trail. The proximity of the trail to the stream, the lack of vegetation in the trail, and the difference in the nature of the pool substrates, suggest that the trail through removal of the vegetation is leading to major habitat changes in the stream. Correcting this problem will be difficult. Restricting travel to the stream channel, would likely solve the problem, however, enforcement of this option is not very workable.

The amount of hiking traffic between Sipapu and Kachina bridges appears to be more than the local vegetation can bear, as reflected in the many differences between the canyon bottom containing or lacking the trail, or the

trail per se and the surrounding canyon bottom. We can imagine three options to deal with this problem. The most effective, yet most extreme, is to close the trail, only allowing hiking down to the area around the two bridges. The second option would be to pave the trail to prevent further erosion. This would stop the problem at its current state. The negative consequences of this option are its aesthetic and financial costs. The third option, would be to relocate the trail away from the stream bank as much as is possible. This would reduce the erosion problem and shift the human impact away from the more mesic area and into the drier habitats more common in the monument. We would suggest this third option.

Several techniques could be used to direct human traffic patterns in the canyon bottom. Informational signs discussing the negative consequences of the trails for the stream invertebrates and riparian vegetation could be put up under both bridges. The signs would end by saying follow the arrows to stay on the trail. Where the preferred trail crosses another one that goes closer to the stream, downed branches, or rocks can be moved into place to show which way to go. Arrows can be added at these places if the public does not take the more subtle suggestion. An excellent way to keep people on a trail is to give them a positive reason to do so. For a small amount of money the Park Service could use its staff in Moab to prepare an interesting interpretive hike along the canyon bottom. Put 50 numbered posts in along the trail numerically keyed to a 4 or 5 page brochure. Tell the names of plants, or rock strata, explain erosion patterns, name birds nests, or pack rat middens, tell how that plant was used by prior inhabitants of the canyon, or by other animals, give ages of trees, etc.. You might discuss all these things once, then repeat them again later in the canyon as a self test for

the hikers. Each post could also bear an arrow pointing not only where the next post can be found, but also the direction you want the hiker to take to reduce trail effect in the canyon. This latter approach is desirable because you may ameliorate the erosion problem at the same time as you make a valuable addition to the hike itself.

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Table 1. Comparisons of the frequency of occurence of various plant species in the meter square plant quadrats at Canyonlands in 1990. There were 150 quadrats in the area lacking the road (trt 1), 150 in the area with the road (trt 2), and 50 additional in the road per se (trt 3). Data analyses were performed on the actual counts not the frequency. No test means that N was too small to meet the assumptions of the test. * = statistically significant following Bonferroni procedure.

	proportion of quadrats occupied (no.)			statistics (X2, d.f., p)		
Species	trt 1	trt 2	trt 3	overall	trt 1 vs trt 2	trt 2 vs trt 3
Opuntia	0.4 (6)	0.19 (29)	0.0 (0)	22.6, 2, < 0.001*	17.1, 1, < 0.001*	6.9, 1, < 0.01*
Lepidium	0.15 (22)	0.12 (18)	0.02 (1)	3.0, 2, 0.088	0.2, 1, > 0.50	3.0, 1, 0.10
Sphaeralcea	0.03 (4)	0.25 (37)	0.0 (0)	38.1, 2, < 0.001*	30.6, 1, < 0.001*	9.4, 1, < 0.005*
Eriogeron	0.15 (22)	0.10 (15)	0.02 (1)	3.8 2, 0.05*	1.5, 1, > 0.30	no test
Sporobolus	0.19 (29)	0.43 (65)	0.08 (4)	24.8, 2, < 0.001*	20.1, 1, < 0.001*	9.5, 1, < 0.01*
Stipa	0.09 (14)	0.15 (23)	0.0 (0)	6.9, 2, < 0.01*	3.8, 1, 0.05 *	5.2, 1, < 0.025*
Chrysothamnus	0.21 (32)	0.17 (26)	0.02 (1)	5.6, 2, < 0.025*	0.8, 1, > 0.30	3.8, 1, < 0.05*
Artemisia tri-	0.28 (42)	0.28 (42)	0.0 (0)	11.2, 2, < 0.005*	0.0, 1, 0.99	11.0, 1, < 0.001*
Atriplex	0.11 (16)	0.21 (32)	0.0 (0)	12.5, 2, < 0.005*	6.4, 1, < 0.02*	7.7, 1, < 0.01*
Populus	0.35 (53)	0.03 (5)	0.04 (2)	56.2, 2, < 0.001*	50.6, 1, < 0.001*	no test
Tamarix	0.19 (29)	0.07 (11)	0.0 (0)	15.8, 2, < 0.001*	10.2, 1, < 0.005*	no test

Table 2. Comparisons of number of species or of proportion of the volume occupied (scaled where 1 = < 25 %, 2 = 25 - 50 %, 3 50 - 75 %, and 4 = > 75 %) in 1990 by plants in the hypothetical cubes located over the plant quadrats at Canyonlands. Comparisons were made between quadrats located in Salt Creek Canyon in an area lacking a road (trt 1), in an area with the road (trt 2), and in the road right of way per se (trt 3). The test parameters were highly nonnormal and were analyzed with nonparametric statistics (Kruskal Wallis tests = KW, or Mann Whitney U tests = MW). Each cube was 1 m x 1 m in basal area. * = statistically significant following Bonferroni procedure.

No. species in cube (X + S.D.)

Variable	Trt 1	Trt 2	Trt 3	Statistics
Cube 0 - 0.5 m high	2.5 + 1.3	3.1 + 1.3	0.9 + 1.1	KW = 55.98, 2, d.f., p < 0.0001*
	2.5 + 1.3	3.1 + 1.3		MW = 8567, 1, d.f., p < 0.0001*
		3.1 + 1.3	0.9 + 1.1	MW = 4011, 1 d.f., p < 0.0001*
Cube 0.5 - 1.0 m high	1.2 + 1.0	0.9 + 1.1	0.0 + 0.0	KW = 51.92, 2 d.f., p < 0.0001*
	1.2 + 1.0	0.9 + 1.1		MW = 13470, 1 d.f., p < 0.0001*
		0.9 + 1.1	0.0 + 0.0	MW = 3585, 1 d.f., p < 0.0001*
Cube 1.0 - 3.0 m high	0.6 + 0.7	0.3 + 0.5	0.0 + 0.2	KW = 33.6, 2 d.f., p < 0.0001*
	0.6 + 0.7	0.3 + 0.5		MW = 14032, 1 d.f., p < 0.0001*
		0.3 + 0.5	0.0 + 0.2	MW = 2747, 1 d.f., p = 0.008*
Cube > 3m high	0.3 + 0.5	0.1 + 0.3	0.1 + 0.3	KW = 35.9, 2 d.f., p < 0.0001*
	0.3 + 0.5	0.1 + 0.3		MW = 14175, 1 d.f., p < 0.0001*
		0.1 + 0.3	0.1 + 0.3	MW = 2280, 1 d.f., p = 0.804
Total number of species	3.1 + 1.2	3.2 + 1.3	1.0 + 1.2	KW = 52.98, 2 d.f., p < 0.0001*
	3.1 + 1.2	3.2 + 1.3		MW = 10536, 1 d.f., p = 0.325
		3.2 + 1.3	1.0 + 1.2	MW = 4019, 1 d.f., p < 0.001*

Percentage of cube occuppied (scaled 1 - 4)

Variable	Trt 1	Trt 2	Trt 3	Statistics
Cube 0 - 0.5 m high	1.2 + 0.6	1.4 + 0.8	0.5 + 0.5	KW = 54.04, 2 d.f., p < 0.0001*
	1.2 + 0.6	1.4 + 0.8		MW = 9378, 1 d.f., p = 0.002*
		1.4 + 0.8	0.5 + 0.5	MW = 3720, 1 d.f., p < 0.0001*
Cube 0.5 - 1.0 m high	1.1 + 1.1	0.9 + 1.1	0.0 + 0.0	KW = 51.08, 2 d.f., p < 0.0001*
	1.1 + 1.1	0.9 + 1.1		MW = 13053, 1 d.f., p = 0.009*
		0.9 + 1.1	0.0 + 0.0	MW = 3585, 1 d.f., p < 0.0001*
Cube 1.0 - 3.0 m high	0.6 + 0.8	0.3 + 0.7	0.0 + 0.1	KW = 32.9, 2 d.f., p < 0.0001*
	0.6 + 0.8	0.3 + 0.7		MW = 13981, 1 d.f., p < 0.0001*
		0.3 + 0.7	0.0 + 0.1	MW = 2748, 1 d.f., p = 0.008*
Cube > 3 m high	0.3 + 0.5	0.1 + 0.3	0.1 + 0.3	KW = 35.49, 2 d.f., p < 0.0001*
	0.3 + 0.5	0.1 + 0.3		MW = 14175, 1 d.f., p < 0.0001*
		0.1 + 0.3	0.1 + 0.3	MW = 2280, 1 d.f., p = 0.804

Table 3. Analyses of plant coverage data (cm squared) for the more abundant species in Salt Creek Canyon at Canyonlands in 1990. The data were bimodial and analyzed with nonparametric statistics. We compared all three treatments or treatments 1 and 2, and 2 and 3. * = statistically significant following the Bonferroni procedures.

	X, S.E.							
Species	no road	road present	in road	Kruskal Wallis	d.f.	p value
Populus	2530, 328.8	220.7, 110.8	666.7, 463.2	55.14	2	< 0.0001*
Tamarix	1001, 217.6	424.9, 148.8	0.0, 0.0	15.24	2	< 0.0001*
Atriplex	224.3, 71.2	309.4, 78.8	0.0, 0.0	11.72	2	0.003*
Artemisia tri-	596.3, 117.6	755.9, 169.2	0.0, 0.0	11.1	2	0.004*
Sarcobatus	199.3, 105.5	124.5, 51.5	0.0, 0.0	3.35	2	0.187
Chrysothamnus	569.2, 146.1	384.1, 123.3	4.0, 4.0	6.44	2	0.04
Salix exigua	212.9, 72.6	139.1, 64.3	17.0, 12.2	5.21	2	0.74
Erigeron	205.4, 53.3	72.6, 24.6	10.0, 10.0	4.27	2	0.118
Opuntia	10.7, 5.9	156.8, 45.4	0.0, 0.0	22.9	2	< 0.0001*
Lepidium	117.1, 36.8	55.5, 19.5	3.5, 3.5	3.58	2	0.167
Sporobolus	140.6, 37.9	508.8, 80.2	178.3, 127.0	26.3	2	< 0.0001*
Stipa hymen-	46.0, 14.5	99.6, 23.8	0.0, 0.0	7.73	2	0.021
Distichlis	23.7, 13.1	208.2, 84.2	426.0, 236.5	9.82	2	0.007
Muhlenbergia	208.2, 71.4	137.8, 59.2	76.7, 55.8	1.41	2	0.494

Table 3. continued.

Comparison across trts 1 and 2

X, S.E.

Species	no road	road present	Mann Whitney U test	d.f.	p value
Populus	2530, 328.8	220.7, 110.8	14938	1	< 0.0001*
Tamarix	1001, 217.6	424.9, 148.8	12649	1	0.002*
Atriplex	224.3, 71.2	309.4, 78.8	10112	1	0.018
Artemisia tri-	596.3, 117.6	753.9, 169.2	11313	1	0.917
Sarcobatus	199.3, 105.5	124.5, 51.5	10889	1	0.203
Chrysothamnus	569.2, 146.1	384.1, 123.3	11827	1	0.269
Salix exigua	212.9, 72.6	139.1, 64.3	12135	1	0.024
Erigeron	205.4, 53.3	72.6, 24.6	11844	1	0.166
Opuntia	10.7, 5.9	156.8, 45.4	9496	1	< 0.0001*
Lepidium	117.1, 36.8	55.5, 19.5	11647	1	0.377
Sporobolus	140.6, 37.9	508.8, 80.2	8356	1	< 0.0001*
Stipa hymen-	46.0, 14.5	99.6, 23.8	10472	1	0.073
Distichlis	23.7, 13.1	208.2, 84.2	10112	1	0.003*
Muhlenbergia	209.2, 71.4	137.8, 59.2	11696	1	0.335

Table 3. continued.

Comparison across trts 2 and 3

Species	X, S.E. in road	X, S.E. road present	Mann Whitney U test	d.f.	p value
Populus	666.7, 463.2	220.7, 110.8	2172	1	< 0.371
Tamarix	0.0, 0.0	424.9, 148.8	2415	1	0.127
Atriplex	0.0, 0.0	309.4, 78.8	2730	1	0.006
Artemisia tri-	0.0, 0.0	753.9, 169.2	2880	1	0.001*
Sarcobatus	0.0, 0.0	124.5, 51.5	2400	1	0.147
Chrysothamnus	4.0, 4.0	384.1, 123.3	2576	1	0.044
Salix exigua	17.0, 12.2	139.1, 64.3	2173	1	0.491
Erigeron	10.0, 10.0	72.6, 24.6	2402	1	0.239
Opuntia	0.0, 0.0	156.8, 45.4	2685	1	0.009
Lepidium	3.5, 3.5	55.5, 19.5	2453	1	0.144
Sporobolus	178.3, 127.0	508.8, 80.2	2930	1	0.003*
Stipa hymen-	0.0, 0.0	99.6, 23.8	2610	1	0.019
Distichlis	426.0, 238.5	208.2, 84.2	2193	1	0.722
Muhlenbergia	76.7, 55.8	137.8, 59.2	2310	1	0.688

Table 4. Comparisons of plant coverages for total coverage and coverage for broad ecological plant groupings at Canyonlands in 1990. Comparisons were made between an area of Salt Creek Canyon that lacked a road (trt 1), an area immediately downstream that contained a road (trt 2), and the road right of way per se (trt 3). Statistical comparisons were made with ANOVAs between all three treatments, then contrast analyses were used to compare trt 1 to trt 2 and trt 2 to trt 3. * = statistically significant following Bonferroni procedure.

	X + S.D. in cm sq			
Plant Grouping	Trt 1	Trt 2	Trt 3	Statistics
Total grass	450 + 105	1050 + 1490	740 + 1440	F = 7.4, 2, 327 d.f., p < 0.0001*
	450 + 105	1050 + 1490		F = 14.7, 1, 327 d.f., p < 0.0001*
		1050 + 1490	740 + 1440	F = 1.4, 1, 327 d.f., p = 0.237
Total herbs	660 + 1090	790 + 1000	90 + 200	F = 6.1, 2, 327 d.f., p = 0.003*
	660 + 1090	790 + 1000		F = 1.3, 1, 327 d.f., p = 0.258
		790 + 1000	90 + 200	F = 12.1, 1, 327 d.f., p = 0.001*
Total shrubs	1680 + 2530	1640 + 2550	20 + 70	F = 6.3, 2, 327 d.f., p = 0.003*
	1680 + 2530	1640 + 2550		F = 0.0, 1, 327 d.f., p = 0.903
		1640 + 2550	20 + 70	F = 11.2, 1, 327 d.f., p = 0.001*
Total trees	3530 + 4590	710 + 2360	670 + 1530	F = 25.8, 2, 327 d.f., p < 0.0001*
	3530 + 4590	710 + 2360		F = 47.0, 1, 327 d.f., p < 0.0001*
		710 + 2360	670 + 1530	F = 0.0, 1, 327 d.f., p = 0.955
Total coverage	6560 + 4580	4490 + 3750	1530 + 3320	F = 22.4, 2, 327 d.f., p < 0.0001*
	6560 + 4580	4490 + 3750		F = 19.0, 1, 327 d.f., p < 0.0001*
		4490 + 3750	1530 + 3320	F = 12.9, 1, 327 d.f., p < 0.0001*

Table 5. Comparisons of the frequency of various plant species in the meter square plant quadrats in 1991. There were 200 quadrats in the area lacking a road (trt 1), 200 in the area containing the road (trt 2), and an additional 40 in the road per se (trt 3). Data analyses were performed on the actual counts not the frequency. No test means that N was too small to meet the assumptions of the test. * = statistically significant following Bonferroni procedure.

Species	proportion of quadrats occupied (No.) trt 1	trt 2	trt 3	statistics (chi square, p) overall (2 d.f.)	trt 1 vs trt 2 (1 d.f.)	trt 2 vs trt 3 (1 d.f.)
Populus	0.25 (49)	0.04 (8)	0.03 (1)	40.9, < 0.001*	78.4, < 0.001*	0.06, > 0.90
Tamarix	0.03 (5)	0.19 (38)	0.00 (0)	44.9, < 0.001*	190.1, < 0.001*	9.00, < 0.005
A. tridentata	0.20 (39)	0.16 (32)	0.05 (2)	5.9, 0.05	0.7, > 0.50	3.38, > 0.05
A. campestris	0.16 (31)	0.06 (11)	0.00 (0)	16.2, < 0.001*	10.8, < 0.001*	no test
S. exigua	0.32 (64)	0.09 (18)	0.03 (1)	42.3, < 0.001*	32.4, < 0.001*	2.63, > 0.05
A. canescens	0.13 (26)	0.09 (17)	0.03 (1)	5.2, 0.07	2.4, > 0.05	1.72, > 0.05
Chrysothammus	0.18 (35)	0.17 (33)	0.05 (2)	3.7, > 0.10	0.1, > 0.90	3.50, 0.065
Castilleja	0.28 (55)	0.15 (30)	0.00 (0)	18.8, < 0.001*	9.4, < 0.005	6.80, < 0.01
O. pallida	0.07 (13)	0.19 (38)	0.00 (0)	20.9, < 0.001*	14.0, < 0.0018	9.00, < 0.005
Machaeranthera	0.10 (19)	0.23 (45)	0.20 (8)	12.9, < 0.005	12.6, < 0.001*	0.10, > 0.90
Clematis	0.11 (22)	0.01 (2)	0.00 (0)	22.0, < 0.001*	17.6, < 0.0018	no test
M. alba	0.22 (44)	0.09 (18)	0.03 (1)	18.8, < 0.001*	13.0, < 0.001*	1.90, > 0.10
Heterotheca	0.15 (29)	0.14 (28)	0.08 (3)	1.5, > 0.50	0.2, > 0.50	1.43, > 0.25
Hymenopappus	0.05 (9)	0.12 (23)	0.05 (2)	7.1, < 0.05	6.6, 0.01	1.52, > 0.10
Opuntia	0.03 (5)	0.09 (18)	0.00 (0)	10.9, < 0.005	7.8, < 0.005	3.85, 0.05
Sphaeralcea	0.03 (6)	0.16 (32)	0.05 (2)	21.9, < 0.001*	19.6, < 0.001*	3.38, 0.06
Thelypodium	0.08 (15)	0.01 (1)	0.00 (0)	15.5, < 0.001*	12.8, < 0.001*	no test
Stipa	0.00 (0)	0.07 (13)	0.00 (0)	17.0, < 0.001*	13.4, < 0.001*	2.73, 0.25
Muhlenbergia	0.13 (26)	0.21 (42)	0.05 (2)	8.8, < 0.025	4.6, < 0.05	5.70, < 0.025
Sporobolus	0.22 (43)	0.35 (70)	0.15 (6)	12.3, < 0.005	9.0, < 0.005	6.10, < 0.025
Distichlis	0.13 (26)	0.31 (62)	0.33 (13)	20.6, < 0.001*	19.0, < 0.001*	0.04, > 0.90
Muhl and Dis	0.26 (52)	0.52 (104)	0.38 (15)	28.9, < 0.001*	28.4, < 0.001*	2.70, > 0.10
Agrosis alba	0.22 (44)	0.07 (14)	0.00 (0)	26.1, < 0.001*	18.2, < 0.001*	2.97, 0.08
Stipa hymen-	0.06 (12)	0.32 (64)	0.08 (3)	49.2, < 0.001*	44.0, < 0.001*	10.00, < 0.005
Juncus	0.19 (37)	0.08 (15)	0.03 (1)	15.1, < 0.001*	10.8, < 0.005	1.52, > 0.05

Table 6. 1991 comparisons of proportion of the volume occupied by plants in the hypothetical cubes located over the plant quadrats at Canyonlands. Comparisons were made between quadrats located in Salt Creek Canyon in an area lacking a road (trt 1), in an area with the road (trt 2), and in the road right of way (trt 3). The test parameters were highly nonnormal and were analyzed with nonparametric statistics (Kruskal-Wallis tests = KW, or Mann-Whitney U tests = MW). Each cube was 1 m x 1 m in basal area. The test statistic for "volume occupied" is the proportion of the volume occupied, which was scored as: 1 = 0 - 25 %, 2 = 26 - 50 %, 3 = 51 - 75 %, and 4 = 76 - 100 %. * = statistically significant following Bonferroni procedure.

Volume occupied

mean + S.E.

Variable	trt 1	trt 2	trt 3	Statistics
Cube 0 - 0.5 m high	1.4 + 0.05	1.1 + 0.03	0.6 + 0.08	KW = 55.4, p < 0.0001*
	1.4 + 0.05	1.1 + 0.03		MW = 22568, p 0.002*
		1.1 + 0.03	0.6 + 0.08	MW = 5753, p < 0.0001*
Cube 0.5 - 1.0 m high	1.2 + 0.06	0.9 + 0.04	0.0 + 0.03	KW = 98.8, p < 0.0001*
	1.2 + 0.06	0.9 + 0.04		MW = 24440, p < 0.0001*
		0.9 + 0.04	0.0 + 0.03	MW = 6889, p < 0.0001*
Cube 1.0 - 3.0 m high	0.8 + 0.05	0.3 + 0.04	0.1 + 0.08	KW = 87.8, p < 0.0001*
	0.8 + 0.05	0.3 + 0.04		MW = 27885, p < 0.0001*
		0.3 + 0.04	0.1 + 0.08	MW = 5071, p < 0.0001*
Cube > 3.0 m high	0.3 + 0.03	0.0 + 0.01	0.1 + 0.04	KW = 44.8, p < 0.0001*
	0.3 + 0.03	0.0 + 0.01		MW = 24400, p < 0.0001*
		0.0 + 0.01	0.1 + 0.04	MW = 3920, p = 0.52

Table 7. Analyses of plant coverage data (cm squared) for the more abundant species in Salt Creek Canyon at Canyonlands in 1991. The data were bimodal and analyzed with nonparametric statistics. We compared all three treatments, or the canyon bottom lacking the road to the canyon bottom containing the road, or the canyon bottom containing the road to the road surface per se. Statistics were the Kruskal-Wallis nonparametric analysis of variance for comparing all three treatments, or the Mann-Whitney U test for comparing any two treatments. * = statistically significant following the Bonferroni procedure.

	X + S.E.			Statistics		
	trt 1	trt 2	trt 3	all three	trt 1 vs 2	trt 2 vs 3
Species	no road	road present	in road			
Populus	1367 + 223	167 + 87	250 + 250	42.5, < 0.0001*	24238, < 0.0001*	4058, 0.66
Tamarix	457 + 118	467 + 113	0 + 0	9.9, 0.007	20680, 0.39	4680, < 0.005
A. tridentata	401 + 87	254 + 70	3 + 3	6.2, 0.045	20889, 0.25	4466, 0.055
A. campestris	68 + 19	18 + 8	0 + 0	17.7, < 0.0001*	22117, 0.001*	4200, 0.150
S. exigua	1157 + 180	88 + 30	4 + 4	46.2, < 0.0001*	24902, < 0.0001*	4266, 0.156
S. lutea	179 + 71	21 + 21	0 + 0	15.5, < 0.0001*	21396, < 0.0001*	4020, 0.655
A. canescens	337 + 80	120 + 53	3 + 3	5.1, 0.078	20919, 0.135	4245, 0.182
Chrysothamnus	245 + 64	270 + 67	25 + 12	4.6, 0.101	20169, 0.826	4506, 0.042
Castilleja	210 + 43	76 + 25	0 + 0	22.6, < 0.0001*	22801, 0.0018	4600, 0.009
O. pallida	5 + 2	39 + 9	0 + 0	22.0, < 0.0001*	17398, < 0.0001*	4760, 0.003
Machaeranthera	13 + 4	36 + 7	39 + 15	13.9, 0.001 *	17246, < 0.0001*	4079, 0.787
Clematis	176 + 59	4 + 3	0 + 0	19.7, < 0.0001*	21919, < 0.0001*	4060, 0.437
M. alba	343 + 77	115 + 43	6 + 6	19.1, < 0.0001*	22643, < 0.0001*	4262, 0.163
Heterotheca	109 + 31	78 + 18	17 + 11	1.6, 0.454	20171, 0.807	4261, 0.258
Hymenopappus	7 + 3	46 + 13	3 + 2	7.7, 0.021	18568, 0.008	4278, 0.192
Sphaeralcea	6 + 4	54 + 13	2 + 1	20.7, < 0.0001*	17470, < 0.0001*	4442, 0.066
Elymus spp	11 + 4	24 + 14	0 + 0	3.9, 0.144	19518, 0.338	4320, 0.065
E. candensis	15 + 4	11 + 4	2 + 2	2.7, 0.260	20526, 0.341	4182, 0.279
Muhlenbergia	154 + 48	164 + 51	14 + 12	8.2, 0.016	18502, 0.045	4651, 0.016
Distichlis	117 + 47	199 + 43	170 + 102	19.4, 0.0001*	16443, 0.0001*	3986, 0.966
M and D	271 + 66	362 + 64	183 + 102	20.2, < 0.0001*	15593, 0.0001*	4555, 0.131
Sporobolus	67 + 13	131 + 22	18 + 10	13.0, 0.002*	17341, 0.004	4899, 0.007
Agrostis alba	353 + 79	98 + 40	0 + 0	38.4, < 0.0001*	24010, < 0.0001*	4280, 0.085
Orzopsis	37 + 17	224 + 43	21 + 13	47.1, < 0.0001*	14856, < 0.0001*	4987, 0.002*

Table 8. 1991 analysis of plant coverages (in cm squared) in four ecological plant groupings, across three treatments. The three treatments were: trt 1 = area lacking road, trt 2 = area containing the road, and trt 3 = area in the road right of way. Statistics were either Kruskal-Wallis nonparametric analysis of variance tests (= KW), or Mann-Whitney U tests (= MW). * = statistically significant following Boneronni procedure.

	coverage in cm squared (X + S.E.)			
Ecological grouping	trt 1	trt 2	trt 3	Statistics
Total tree	1832 + 244	653 + 141	250 + 250	KW = 35.0, p < 0.0001*
	1832 + 244	653 + 141		MW = 24291, p < 0.0001*
		653 + 141	250 + 250	MW = 4761, p = 0.005*
Total herb	1156 + 116	620 + 61	152 + 43	KW = 27.4, p < 0.001*
	1156 + 116	620 + 61		MW = 22117, p = 0.066
		620 + 61	152 + 43	MW = 5881, p < 0.0001*
Total grass	753 + 100	979 + 97	224 + 103	KW = 35.3, p < 0.0001*
	753 + 100	979 + 97		MW = 15578, p < 0.0001*
		979 + 97	224 + 103	MW = 6180, p < 0.0001*
Total shrub	2499 + 210	859 + 131	25 + 12	KW = 95.9, p < 0.0001*
	2499 + 210	859 + 131		MW = 28458, p < 0.0001*
		859 + 131	25 + 12	MW = 5737, p < 0.0001*
Total coverage	6660 + 311	3558 + 372	621 + 273	KW = 139.8, p < 0.0001*
	6660 + 311	3558 + 372		MW = 29551, p < 0.0001*
		3558 + 372	621 + 273	MW = 7272, p < 0.0001*

Table 9. Total number of individuals of each species caught on each grid over four nights of trappings in 1990. Each individual was counted only once, even if they were recaptured. # = statistically significant following Bonferroni procedures.

	Number of individuals													
	area with road Grid no.						area lacking a road Grid no.						Statistics	
Species	1	2	3	4	X	S.E.	2	3	4	5	X	S.E.	t or U*	p
Peromyscus boylii	7	9	7	7	7.5	0.5	14	16	4	13	11.8	2.7	12*	0.24
P. truei	1	10	1	2	3.5	2.2	0	0	0	0	0.0	0.0	0*	0.013
P. maniculatus	9	10	1	11	7.8	2.3	3	8	1	10	5.5	2.1	0.7	0.50
P. difficilus	1	0	1	1	0.8	---	0	0	1	0	0.3	---	---	---
Reithrodontomys megalotis	1	0	0	2	0.3	0.3	2	2	4	2	2.5	0.5	4.0	0.007#
Neotoma albigula	6	8	1	0	3.8	1.9	5	0	1	4	2.5	1.2	0.5	0.60
N. mexicana	1	2	0	0	0.8	0.5	7	8	9	10	8.5	0.6	9.6	0.0001#
Dipodomys ordii	0	3	2	0	1.3	0.8	0	0	0	0	0.0	0.0	4*	0.131
No. of species	7	6	6	5	6.0	0.4	5	5	6	5	5.3	0.3	1.6	0.17
No. of individuals	26	42	14	21	25.8	5.9	31	34	20	39	31.0	4.0	0.7	0.49

Table 10. Total number of small mammals caught per species , total number of species, and total number of small mammals caught per grid in 1991 at Canyonlands. Statistical comparisons were made between four grids located in a canyon bottom containing a road and four grids located upstream in an area lacking the road. # = statistically significant following the Bonferroni procedure.

Species	area lacking road mean, s.e.	area containing road mean, s.e.	statistics t or MWU (=*), p
Reithrodontomys megalotis	4.5, 2.2	1.8, 0.9	1.16, 0.29
Peromyscus boylii	3.3, 1.4	0.8, 0.8	1.54, 0.17
P. crinitus	6.8, 1.1	1.8, 0.5	4.14, 0.006#
P. truei	0.3, 0.3	2.5, 0.6	3.25, 0.017
P. maniculatus	16.5, 2.1	5.5, 1.6	4.21, 0.006#
Pcrin and Pboy	10.0, 2.3	2.5, 1.0	2.96, 0.025#
All Peromyscus	26.9, 4.2	10.5, 1.3	3.71, 0.01#
Neotoma mexicana	4.0, 0.8	1.3, 0.5	2.91, 0.027
N. cinerea	3.3, 1.7	0.0, 0.0	14*, 0.047
N. albigula	1.5, 1.0	1.3, 0.3	0.25, 0.81
All Neotoma	8.8, 2.6	2.5, 0.6	16*, 0.029
Dipodomys ordii	1.3, 0.9	1.5, 1.0	0.19, 0.86
Total mice	42.8, 6.0	16.3, 2.2	4.14, 0.006#
Total no. species	6.5, 0.3	6.3, 0.5	0.45, 0.67

Table 11. Comparisons of pool characteristics or number of individuals or species present in June 1990 in 13 pools in an area lacking a road (trt 1) and in 20 pools in an area containing a road (trt 2) in Salt Creek Canyon. * = statistically significant following the Bonferroni procedures.

Comparison	Location (X, S.E.) trt 1	trt 2	(t or MWU*, p)
Notonectids	21.6, 7.5	20.8, 7.5	0.073, 0.94
Damselflies	12.2, 3.0	43.3, 13.2	73*, 0.035
Bufo tadpoles	66.1, 41.8	93.1, 51.1	0.38, 0.71
Whirligigs	39.2, 9.9	34.6, 17.3	174*, 0.092
Water striders	29.8, 7.8	29.0, 11.4	161*, 0.253
Horse hair wms	1.9, 1.0	0.8, 0.3	141*, 0.638
Coleoptera	8.0, 5.7	22.1, 13.0	115*, 0.526
Pool area (m sq)	8.0, 2.7	9.9, 4.0	108*, 0.550
No. species	5.4, 0.6	5.4, 0.4	0.05, 0.963
No. individ.	186.0, 55.0	317.1, 92.5	130*, 0.985

Table 12. Comparisons of pool characteristics or number of species or number of individuals between 13 pools in an area lacking a road (trt 1) and in 20 pools containing a road (trt 2) in Salt Creek Canyon in Canyonlands. The sample was collected in late July 1990. ♯ = statitically significant following the Bonferroni procedure.

Comparison	Location (X, S.E.) trt 1	trt 2	Statistics (t or MWU*, p)
Notonectids	10.0, 2.8	4.4, 1.6	1.84, 0.078
Damselflies	30.7, 7.3	20.9, 4.0	1.28, 0.213
Bufo tadpoles	3.2, 1.8	25.9, 11.3	60*, 0.453
Whirligigs	24.3, 7.1	19.7, 6.4	0.46, 0.65
Water striders	27.3, 8.5	17.6, 3.0	78*, 0.734
Horse hair worms	1.4, 0.4	0.0, 0.0	128*, 0.0001♯
Coleoptera	4.6, 2.3	3.2, 2.3	0.39, 0.703
Snails	11.9, 4.4	119.6, 38.7	38*, 0.052
Pool depth (m)	0.25, 0.04	0.25, 0.04	0.04, 0.966
Pool area (sq. m)	8.1, 3.05	13.1, 2.48	1.30, 0.220
No. species	6.6, 0.44	4.7, 0.36	3.18, 0.004♯
No. individuals	114.1, 24.53	212.3, 39.76	45*, 0.126

Table 13. Comparisons of number of individuals per species per dip net sweep between pools in an area containing a road (trt 2) and pools from an area lacking the road (trt 1). Sweeps were made in late July 1990 in Salt Creek canyon in Canyonlands. # = statistically significant following the Bonferroni procedure.

Species	Location (X, S.E.) trt 1	trt 2	Statistics (MWU, p)
Notonectids	0.62, 0.19	0.33, 0.09	3353, 0.092
Damselfys	0.64, 0.26	0.19, 0.11	3406, 0.005#
Bufo tadpoles	0.02, 0.02	0.41, 0.12	2717, 0.027
Whirlygigs	1.13, 0.37	0.48, 0.13	3170, 0.474
Water striders	0.98, 0.33	0.37, 0.07	3262, 0.306
Coleoptera	0.11, 0.08	0.04, 0.04	3107, 0.221

Table 14. Comparisons of number of aquatic organisms observed in 1991 in pools in an area containing a road (trt 2), or in an area lacking a road (trt 1) in Salt Creek Canyon in Canyonlands. Pool characteristics and number of species and number of individuals observed per pool are also compared. # = statistically significant following the Bonferroni procedure = 0.05/5 = 0.01 for species comparisons.

	number seen per pool		t test * or	
Taxa	trt 1	trt 2	Mann-Whitney U	p
Notonectids	8.3 + 1.9	16.9 + 4.2	84	0.277
Damselflys	36.6 + 6.4	66.0 + 17.3	92	0.395
Waterstriders	40.3 + 8.7	50.3 + 16.0	122	0.693
Snails	217.8 + 101.8	385.4 + 264.3	114	0.950
Bufo tadpoles	29.9 + 15.5	70.9 + 66.4	130	0.438
Total species per pool	6.3 + 0.5	6.5 + 0.3	0.46*	0.645
Total individuals per pool	310.3 + 88.6	659.2 + 273.0	83	0.221
Pool surface area (m sq)	14.8 + 3.7	17.2 + 5.2	0.37*	0.712
Pool depth (cm)	29.7 + 4.5	24.1 + 4.6	0.88*	0.386

Table 15. Results of 1991 chi square analyses exaiming the distribution of aquatic organisms across pools in two treatments. The two treatments were an area containing a road and an area lacking a road in Salt Creek Canyon at Canyonlands. The test examines presence or absence in pools as a result of the visual survey. All comparisons have 1 degree of freedom. * = statistically significant following Bonferroni procedure.

Taxa	area lacking road	area with road	chi square	p
Hydrophilid larvae	6/15	12/15	5.0	< 0.05
Dragonfly	5/15	5/15	0.0	> 0.99
Bufo tadpoles	8/15	7/15	0.1	> 0.50

Table 16. Results of chi square analyses examining the distribution of seven taxa in sweeps across pools along a four wheel drive road in Salt Creek Canyon, or from an area that lacks the road in 1991. All comparisons have 1 degree of freedom. Samples were the results of dip net sweeps. * = statistically significant following the Bonferroni procedure = 0.05/7 = 0.007.

	Number of times present in a sweep			
Taxa	area lacking road	area with road	chi square	p
Notonectids	70/159	43/140	5.6	< 0.02
Brn damselfly	76/159	44/140	8.3	< 0.01*
Whirlygigs	60/159	52/140	0.0	> 0.50
Water striders	67/159	68/140	1.0	> 0.50
Hydrophilids	4/159	9/140	2.7	0.10
Grn damselfly	13/159	15/140	0.6	> 0.50
Snails	38/159	13/140	11.3	< 0.01*

Table 17. Results of 1991 experiment at Canyonlands in which wire mesh baskets were placed into Salt Creek at three locations: immediately below road crossings (= trt 1), immediately above road crossings (= trt 2), and upstream of the end of the road (= trt 3). Each basket was filled with small stones. In one half of the baskets at each location sand was added to fill the interstices between the stones. We collected the baskets at the end of the experiment and measured sand volume and made counts of numbers of individuals of the various species that had occuppied the baskets. * = statistically significant following the Bonferroni procedure.

(X + S.E./per cage)

Variable	Location			statistics	p
	trt 1	trt 2	trt3		
Sand volume (ml)	371 + 66	223 + 34	217 + 36	F = 4.29	0.018*
No. tadpoles	0.38 + 0.25	0.04 + 0.04	1.21 + 0.45	KW = 9.32	0.009 *
	0.38 + 0.25	0.04 + 0.04		MW = 325	0.155
No. damselflies	0.00 + 0.00	0.29 + 0.14	0.21 + 0.13	KW = 5.21	0.074
	0.00 + 0.00	0.29 + 0.14		MW = 228	0.020*
Total indiv.	0.71 + 0.29	0.67 + 0.25	2.08 + 0.54	KW = 5.26,	0.72
	0.71 + 0.29	0.67 + 0.25		MW = 288,	1.00
Total species	0.46 + 0.15	0.54 + 0.18	1.08 + 0.24	KW = 4.49,	0.106
	0.46 + 0.15	0.54 + 0.18		MW = 283,	0.892

Table 18. Coverages (mean, s.e.) in percentage of ground covered, for individual plant species in 1 m square plots at Arches National Park. The data were collected in 1992 in the area lacking a trail above the bridge crossing Courthouse Wash near "The Wall" (Trt 1), the area below this bridge that contains a heavily used hiking trail (Trt 2), and in the trail right of way per-se (Trt 3). * indicates that the observed difference is statistically significant following the Bonferonni procedure = 0.05/9 = 0.006.

				Statistics		
Species	Trt 1	Trt 2	Trt3	H or MWU#	d.f.	p
Juncus	8.32, 2.39	16.13, 3.05	12.25, 3.19	5.91	2	0.052
	8.32, 2.39	16.13, 3.05		4501#	1	0.095
		16.13, 3.05	12.25, 3.19	2359#	1	0.490
Muhlenbergia	3.93, 1.66	9.25, 2.36	2.83, 1.09	2.54#	2	0.280
	3.93, 1.66	9.25, 2.36		4533#	1	0.121
		9.25, 2.36	2.83, 1.09	2586#	1	0.660
Melolotus	6.85, 1.33	7.19, 1.62	2.47, 1.13	9.31	2	0.010
	6.85, 1.33	7.19, 1.62		5475#	1	0.209
		7.19, 1.62	2.47, 1.13	2931#	1	0.048
Populus	5.80, 1.87	7.26, 2.41	1.79, 1.60	3.53	2	0.171
	5.80, 1.87	7.26, 2.41		5189#	1	0.512
		7.26, 2.41	1.79, 1.60	2710#	1	0.182
Salix	9.00, 1.93	5.80, 1.54	0.21, 0.10	15.70	2	0.0001*
	9.00, 1.93	5.80, 1.54		5511#	1	0.153
		5.80, 1.54	0.21, 0.10	3084#	1	0.003*
Equisetum	0.00, 0.00	0.40, 0.16	0.14, 0.07	10.58	2	0.005*
	0.00, 0.00	0.40, 0.16		4500#	1	0.001*
		0.40, 0.16	0.14, 0.07	2508#	1	0.952
Tamarix	18.86, 3.44	7.42, 2.19	1.76, 1.24	24.51	2	0.0001*
	18.86, 3.44	7.42, 2.19		6006#	1	0.003*
		7.42, 2.19	1.76, 1.24	2916#	1	0.008
Chrysothamnus	1.78, 0.95	6.23, 1.82	0.06, 0.03	8.58	2	0.014
	1.78, 0.95	6.23, 1.82		4390#	1	0.016
		6.23, 1.82	0.06, 0.03	3862#	1	0.026
Ambrosia	0.08, 0.04	0.31, 0.13	0.12, 0.05	1.96	2	0.375
	0.08, 0.04	0.31, 0.13		4708#	1	0.171
		0.31, 0.13	0.12, 0.05	2524#	1	0.871

Table 19. Comparisons of the proportion of one meter square plots that were occupied by common plants across three locations in 1992 in Courthouse Wash at Arches National Park. The three treatments were: Trt 1, area above the bridge over Courthouse Wash which lacks a hiking trail, Trt 2 area below this bridge which has a heavily used hiking trail, and Trt 3, within the trail right of way. There were 100 plots each in treatments 1 and 2 and 50 in treatment 3. The data were analyzed with chi square tests. * = statistically significant following the Bonferonni procedure = 0.05/9 = 0.006.

	Proportion (number)						Statistics		
Plant Species	Trt 1		Trt 2		Trt 3		overall	Trt 1 vs Trt 2	Trt 2 vs Trt 3
Juncus	0.19	(19)	0.27	(27)	0.34	(17)	4.27, >0.05	1.82, >0.05	0.76, >0.05
M. alba	0.54	(54)	0.40	(40)	0.28	(14)	14.20, <0.001*	3.92, <0.05	2.08, >0.05
Muhlenbergia	0.19	(19)	0.27	(27)	0.26	(13)	1.98, >0.05	1.82, >0.05	0.12, >0.05
Populus	0.22	(22)	0.18	(18)	0.10	(5)	3.26, >0.05	0.50, >0.05	1.69, >0.05
Salix exigua	0.42	(42)	0.35	(35)	0.12	(6)	13.77, <0.001*	1.04, >0.05	8.95, <0.01
Tamarix	0.40	(40)	0.21	(21)	0.04	(4)	23.85, <0.001*	8.52, <0.01	7.49, <0.01
Equisetum	0.00	(0)	0.11	(11)	0.10	(5)	11.46, <0.01	11.64, <0.001*	0.03, >0.05
Chrysothamnus	0.11	(11)	0.22	(22)	0.04	(2)	10.20, <0.01	4.38, <0.05	8.04, <0.02
Ambrosia	0.07	(7)	0.12	(12)	0.08	(8)	1.51, >0.05	1.46, >0.05	0.54, >0.05

Table 20. Plant coverages (mean, s.e.) in percentage of the ground covered, for ecological plant groupings at Arches National Park in 1992. Data were collected from three sites: Trt 1, canyon above bridge across Horseshoe canyon near "The Wall" (= area lacking heavy usage of a hiking trail), Trt 2, canyon below this same bridge (= area receiving heavy hiking trail use), and Trt 3, in the trail right of way per se. * = statistically significant difference following the Bonferonni procedure = 0.05/5 = 0.01.

	% of ground covered					
Ecological Plant grouping	Trt 1	Trt 2	Trt 3	Statistics H or MWU#	d.f.	p
Herb	11.08, 1.84	9.94, 1.85	3.25, 1.29	20.25	2	0.0001*
	11.08, 1.84	9.94, 1.85		5698#	1	0.084
		9.94, 1.85	3.25, 1.29	3205#	1	0.003*
Grass	5.13, 1.89	9.38, 2.36	2.90, 1.09	0.22	2	0.898
	5.13, 1.89	9.38, 2.36		4859#	1	0.666
		9.38, 2.36	2.90, 1.09	2561#	1	0.764
Shrub	29.76, 3.74	21.19, 3.31	2.03, 1.25	44.28	2	0.0001*
	29.76, 3.74	21.19, 3.31		5823#	1	0.041
		21.19, 3.31	2.03, 1.25	3734#	1	0.0001*
Tree	6.02, 1.88	7.35, 2.41	1.79, 1.60	4.04	2	0.133
	6.02, 1.88	7.35, 2.41		5192#	1	0.510
		7.35, 2.41	1.79, 1.60	2737#	1	0.140
Total Plant Coverage	59.32, 4.69	64.33, 5.43	20.53, 3.89	36.18	2	0.0001*
	59.32, 4.69	64.33, 5.43		4896#	1	0.799
		64.33, 5.43	20.53, 3.89	3851#	1	0.0001

Table 21. Number of plant species/1 m sq quadrat (mean, s.e.) for ecological plant groupings at Arches National Park in 1992. Data were collected from three sites: Trt 1, canyon above the bridge crossing in Courthouse Wash near "The Wall" (= area lacking a heavily used hiking trail), Trt 2, canyon below this bridge (= area containing a well used hiking trail), and Trt 3, in the trail right of way per se. * = statistically significant difference following the Bonferonni procedure = 0.05/5 = 0.01.

	No. species/ 1 m sq plot					
Ecological				Statistics		
Plant grouping	Trt 1	Trt 2	Trt 3	F or MWU#	d.f.	p
Herb	1.0, 0.1	0.8, 0.1	0.5, 0.1	17.87	2	0.0001*
	1.0, 0.1	0.8, 0.1		5789#	1	0.036
		0.8, 0.1	0.5, 0.1	3068#	1	0.014
Grass	0.3, 0.1	0.3, 0.1	0.3, 0.1	0.04	2	0.981
	0.3, 0.1	0.3, 0.1		4971#	1	0.928
		0.3, 0.1	0.3, 0.1	2476#	1	0.904
Shrub	0.9, 0.1	0.8, 0.1	0.3, 0.1	32.92	2	0.0001*
	0.9, 0.1	0.8, 0.1		5443#	1	0.235
		0.8, 0.1	0.3, 0.1	3552#	1	0.0001*
Tree	0.2, 0.0	0.2, 0.1	0.1, 0.0	3.68	2	0.159
	0.2, 0.0	0.2, 0.1		5000#	1	0.489
		0.2, 0.1	0.1, 0.0	2725#	1	0.158
All Plants	2.7, 0.1	2.5, 0.1	1.7, 0.2	21.08	2	0.0001*
	2.7, 0.1	2.5, 0.1		5242#	1	0.541
		2.5, 0.1	1.7, 0.2	3458#	1	0.0001*

Table 22. Comparisons of the proportion of one meter square plots that were occupied by plants of four ecological plant groupings across three locations in 1992 in Courthouse Wash at Arches National Park. The three treatments were: Trt 1, area above the bridge over Courthouse Wash which lacks a hiking trail, Trt 2 area below this bridge which has a heavily used hiking trail, and Trt 3, within the trail right of way. There were 100 plots each in treatments 1 and 2 and 50 in treatment 3. The data were analyzed with chi square tests. * = statistically significant following the Bonferonni procedure = 0.05/5 = 0.01.

	Proportion (number)			Statistics		
Ecological grouping	Trt 1	Trt 2	Trt 3	overall	Trt 1 vs Trt 2	Trt 2 vs Trt 3
Total Herb	0.78 (78)	0.62 (62)	0.42 (21)	19.27, <0.001*	6.08, <0.02	5.44, <0.02
Total Grass	0.27 (27)	0.29 (29)	0.30 (15)	0.19, >0.05	0.10, >0.05	0.01, >0.05
Total Shrub	0.73 (73)	0.74 (74)	0.22 (11)	45.64, <0.001*	0.02, >0.05	36.59, <0.001*
Total Tree	0.23 (23)	0.20 (20)	0.10 (5)	3.69, >0.05	0.30, >0.05	2.34, > 0.05
Total plant	0.99 (99)	0.96 (96)	0.74 (37)	33.72, <0.001*	no test	15.87, < 0.001*

Table 23. Total number of small mammals caught, and a Petersen estimate of number of small mammals present on two small mammal trap grids in Courthouse Wash at Arches National Park. Each grid contained 100 live traps in a 5 x 20 array and covered approximately 0.75 Ha. One grid was located above the bridge near "The Wall" in an area that receives light hiking use; the other immediately downstream of the bridge, in an area that receives heavy usage.

	Area with trail		Area lacking trail	
	no. caught	Petersen estimator	no. caught	Petersen estimator
Species				
Peromyscus maniculatus (Deer mouse)	19	21.7	29	31.6
P. boylii (Brush mouse)	7	7.0	6	6.0
P. crinitus	1	no estimate	0	no estimate
Neotoma albigula (White-throated woodrat)	1	no estimate	0	--
N. cinerea (Bushy-tailed woodrat)	4	4.5	0	--
Reithrodontomys megalotis (Western Harvest mouse)	2	no estimate	2	no estimate
Onchymys leucogaster (Northern Grasshopper mouse)	0	--	1	no estimate
Dipodomys ordii (Ord's Kangaroo Rat)	2	2.0	7	9.0
Perognathus (Pocket mouse)	0	--	2	2.0
All mice	37	40.8	47	53.3
Mustela	1	no estimate	0	no estimate

Table 24. Results of comparisons of plant coverages for broad ecological plant groups across three treatments at Natural Bridges. The three treatments were: trt 1 area lacking a trail, trt 2 area containing a heavily used hiking trail, and trt 3 surface of the hiking trail. * = statistically significant following the Bonferonni procedure (=0.05/5 = 0.01). F = f test, K = Kruskal-Wallis nonparametric F test, U = Mann-Whitney U test.

Plant Grouping	% of ground covered Trt 1	Trt 2	Trt 3	Statistics
Total grass	6.7 + 1.2	4.4 + 1.0	0.0 + 0.0	K = 21.4, 2 d.f., p = 0.0001*
	6.7 + 1.2	4.4 + 1.0		U = 5414, 1 d.f.,p = 0.293
		4.4 + 1.0	0.0 + 0.0	U = 1570, 1 d.f., p = 0.0001*
Total herb	3.5 + 0.4	3.3 + 0.4	0.5 + 0.2	F = 4.5, 2, 217 d.f., p = 0.01*
	3.5 + 0.4	3.3 + 0.4		F = 0.15, 1, 217 d.f., p = 0.70
		3.3 + 0.4	0.5 + 0.2	F = 7.57, 1, 217 d.f., p = 0.006*
Total shrub	45.3 + 28.3	21.3 + 3.3	1.6 + 0.7	K = 12.7, 2 d.f., p = 0.002*
	45.3 + 28.3	21.3 + 3.3		U = 4113, 1 d.f., p = 0.027
		21.3 + 3.3	1.6 + 0.7	U = 1501, 1 d.f., p = 0.0001*
Total tree	25.8 + 4.2	44.3 + 6.1	10.8 + 6.9	K = 10.0, 2 d.f., p = 007*
	25.8 + 4.2	44.3 + 6.1		U = 4240, 1 d.f., p = 0.04
		44.3 + 6.1	10.8 + 6.9	U = 1354, 1 d.f., p = 0.006*
Total coverage	63.6 + 12.2	72.4 + 6.3	27.5 + 9.6	K = 21.3, 2 d.f., p = 0.0001*
	63.6 + 12.2	72.4 + 6.3		U = 4164, 1 d.f., p = 0.04
		72.4 + 6.3	27.5 + 9.6	U = 1616, 1 d.f., p = 0.0001*

Table 25. Plant coverage comparisons for 15 individual species at Natural Bridges in 1990. Comparisons are across three treatments: trt 1 where there was no trail, trt 2 where there was a heavily used hiking trail, and trt 3 which was the trail surface per se. * = statistically significant following the Bonferonni procedure, p = 0.05/15 = 0.003. K = Kruskal Wallis statistic, U = Mann-Whitney U statistic. The three treatment comparison has 2 d.f., the two treatment comparisons 1 d.f.

							Proportion of ground covered Mean, SEM		
	trt 1 vs trt2 vs trt3		trt 1 vs trt 2		trt 2 vs trt 3		trt 1	trt 2	trt3
Species	K	p	U	p	U	p			
Gambel's Oak	11.1	0.004	4487	0.132	1360	0.002*	19.4, 3.9	34.2, 5.5	0, 0
Morman Tea	21.4	0.0001*	6046	0.0001*	1050	0.309	8.3, 2.4	2.1, 1.2	0, 0
Rubber Rabbitbush	13.7	0.001*	3823	0.001*	1273	0.033	4.5, 1.5	7.1, 1.5	0.2, 0.09
Mountain Mahogany	13.0	0.002*	4342	0.001*	1160	0.057	0.2, 0.1	2.8, 1.0	0, 0
Indian Rice Grass	3.73	0.155	5158	0.528	1130	0.090	1.5, 0.6	0.9, 0.3	0, 0
Western Virgin's bower	5.92	0.052	4602	0.073	1150	0.066	0.2, 0.08	0.4 0.1	0, 0
Dropseed	20.18	0.0001*	6123	0.0001*	1140	0.077	4.3, 1.1	0.9, 0.5	0, 0
Grass sp4	9.01	0.011	4503	0.010	1130	0.090	0.2, 0.1	0.6, 0.2	0, 0
plantain	3.93	0.140	5195	0.437	1130	0.090	0.2, 0.09	0.07,0.02	0, 0
Spreading daisy	7.92	0.019	4180	0.014	1233	0.056	1.0, 0.3	1.9, 0.4	0.3, 0.2
Artemisia dracunculus	7.58	0.023	5490	0.034	1070	0.255	0.6, 0.2	0.3, 0.1	0, 0
Primrose	5.85	0.054	5390	0.068	1060	0.263	0.2, 0.06	0.06,0.03	0, 0
Cymopterus	10.78	0.005	4402	0.005	1160	0.057	0.04,0.02	0.2, 0.06	0, 0
Tall peppergrass	1.14	0.566	4852	0.495	1072	0.347	0.08,0.04	0.1, 0.04	0.01,0.01
Grass sp5	7.01	0.030	4535	0.056	1180	0.041	0.4, 0.2	1.7, 0.8	0, 0
								Number	
Total number of species	25.06	0.0001*	3989	0.011	1630	0.001*	3.2, 0.1	3.7, 0.1	1.7, 0.4

Table 26. Comparisons of the proportion of one meter square plots that were occupied by plants of four ecological plant groupings across three locations in 1990 in White Canyon at Natural Bridges National Monument. The three treatments were: Trt 1, area above Sipapu Bridge which lacks a hiking trail, Trt 2 area between Sipapu and Kachina Bridges which has a heavily used hiking trail, and Trt 3, within the trail right of way. There were 160 plots each in treatments 1 and 2 and 80 in treatment 3. The data were analyzed with chi square tests. * = statistically significant following the Bonferonni procedure = p = 0.01.

	Proportion (number)			Statistics		
Ecological grouping	Trt 1	Trt 2	Trt 3	overall	Trt 1 vs Trt 2	Trt 2 vs Trt 3
Total Herb	0.80 (80)	0.81 (81)	0.35 (7)	14.7, <0.001*	0.1, >0.05	18.2, <0.001*
Total Grass	0.64 (64)	0.59 (59)	0.05 (1)	24.2, <0.001 *	0.6, >0.05	no test
Total Shrub	0.58 (58)	0.78 (78)	0.65 (13)	9.2, <0.01*	9.2, <0.01*	2.6, >0.05
Total Tree	0.40 (40)	0.50 (50)	0.25 (5)	4.9, >0.05	2.2, >0.05	4.2, <0.05
Total plant	1.00 (100)	1.00 (100)	0.80 (16)	no test	no test	no test

Table 27. Frequency of occurrence of various plants in 1 m square plant quadrats in Natural Bridges near Sipapu Bridge in 1990. * = statistically significant following the Bonferonni procedure = 0.05/16 = 0.003. No test means that sample sizes were too small to meet the assumptions of the test.

Species	Proportion of plant quadrats occupied per grid			statistics
	trt 1	trt 2	trt 3	X2, d.f, p
Quercus gambelii	.29	.36	.00	10.6, 2, 0.005
	.29	.36		1.1, 1, > 0.30
		.36	.00	10.3, 1, 0.001*
Ephedra viridis	.26	.07	.00	18.0, 2, < 0.0001*
	.26	.07		13.1, 1, < 0.001*
		.07	.00	no test
Cercocarpus lepidium	.03	.16	.00	15.5, 2, < 0.001*
	.03	.16		9.7, 1, 0.002*
		.16	.00	no test
Chrysothamnus naseousus	.21	.45	.30	13.2, 2, 0.002*
	.21	.45		13.0, 1, < 0.0001*
		.45	.30	1.5, 1, > 0.25
Oenothera sp	.14	.06	.00	14.6, 2, < 0.0001*
	.14	.06		3.6, 1, 0.06
		.06	.00	no test
Plantain	.16	.13	.00	3.7, 2, > 0.10
	.16	.13		0.4, 1, > 0.50
		.13	.00	no test
Erigeron divergens	.23	.39	.20	7.7, 2, 0.025
	.23	.39		6.0, 1, 0.020
		.39	.20	2.7, 1, > 0.100
Cymopterus	.04	.16	.00	10.9, 2, 0.005
	.04	.16		8.0, 1, 0.005
		.16	.00	no test
Lepdium montanum	.09	.11	.05	0.9, 2, > 0.900
	.09	.11		0.2, 1, > 0.900
		.11	.05	no test
Artemisia dracunculus	.17	.07	.00	7.9, 2, 0.025
	.17	.07		4.7, 1, < 0.050
		.07	.00	no test
Toothed leaf	.10	.12	.00	2.7, 2, > 0.250
	.10	.12		0.2, 1, > 0.900
		.12	.00	no test
Sporobolus spp	.35	.11	.00	23.3, 2, < 0.001*
	.35	.11		16.3, 1, < 0.001*
		.11	.00	no test
Stipa hymenoides	.16	.12	.00	3.9, 2, > 0.100
	.16	.12		0.7, 1, > 0.250
		.12	.00	no test
Grass sp4	.03	.13	.00	9.2, 2, 0.01
	.03	.13		6.8, 1, 0.01
		.13	.00	no test
Grass sp5	.09	.18	.00	6.9, 2, 0.03

	.09	.18		2.2, 1, 0.07
		.18	.00	no test
Clematis ligusticifolia	.07	.15	.00	6.0, 2, 0.05
	.07	.15		3.3, 1, 0.07
		.15	.00	no test

Table 28. Coverages (mean, s.e.) in percentage ground covered, for individual plant species at Natural Bridges National Monument. The data were collected in a series of 1 m sq plotsin 1992 in the area lacking a trail above Sipapu Bridge (Trt 1), the area containing a trail between Sipapu and Kachina Bridges (Trt 2), and in the road right of way per se (Trt 3). * indicates that the observed difference is statistically significant following the Bonferonni procedure = 0.05/14 = 0.0035.

				Statistics		
Species	Trt 1	Trt 2	Trt3	H or MWU#	d.f.	p
Populus	8.94, 2.17	5.53, 1.78	15.06, 3.96	5.34	2	0.069
	8.94, 2.17	5.53, 1.78		13353#	1	0.176
		5.53, 1.78	15.06, 3.96	5790#	1	0.021
Juniperus	4.69, 1.50	3.92, 1.34	2.95, 1.60	0.23	2	0.891
	4.69, 1.50	3.92, 1.34		12739#	1	0.881
		3.92, 1.34	2.95, 1.60	6520#	1	0.629
Quercus	13.89, 2.51	18.26, 2.81	3.57, 1.83	11.94	2	0.003*
	13.89, 2.51	18.26, 2.81		12117#	1	0.264
		18.26, 2.81	3.57, 1.83	7619#	1	0.001*
Chrysothamnus	4.99, 1.37	2.42, 0.66	0.95, 0.48	2.04	2	0.360
	4.99, 1.37	2.42, 0.66		13323#	1	0.382
		2.42, 0.66	0.95, 0.48	6632#	1	0.506
Ephedra	2.22, 0.81	2.98, 0.88	0.00, 0.00	17.70	2	0.0001*
	2.22, 0.81	2.98, 0.88		11727#	1	0.027
		2.98, 0.88	0.00, 0.00	7520#	1	0.0001*
Salix	2.73, 1.12	2.82, 1.01	0.30, 0.13	0.73	2	0.695
	2.73, 1.12	2.82, 1.01		12565#	1	0.508
		2.82, 1.01	0.30, 0.13	6354#	1	0.846
Symphoricarpus	0.65, 0.30	0.98, 0.39	0.00, 0.00	6.67	2	0.036
	0.65, 0.30	0.98, 0.39		12849#	1	0.899
		0.98, 0.39	0.00, 0.00	6880#	1	0.012
Heterotheca	3.79, 0.81	3.34, 0.58	2.85, 0.66	1.11	2	0.575
	3.79, 0.81	3.34, 0.58		12278#	1	0.458
		3.34, 0.58	2.85, 0.66	6233#	1	0.707
Plantain	1.80, 0.60	0.69, 0.30	0.02, 0.01	6.31	2	0.043
	1.80, 0.60	0.69, 0.30		13183#	1	0.420
		0.69, 0.30	0.02, 0.01	6906#	1	0.042
Opuntia	0.36, 0.18	0.55, 0.27	0.09, 0.05	4.37	2	0.112
	0.36, 0.18	0.55, 0.27		12099#	1	0.059
		0.55, 0.27	0.09, 0.05	6227#	1	0.178
Oenothera	0.23, 0.06	0.08, 0.04	0.16, 0.08	3.81	2	0.149
	0.23, 0.06	0.08, 0.04		13019#	1	0.050
		0.08, 0.04	0.16, 0.08	6163#	1	0.306
Lepidium	0.01, 0.01	0.10, 0.03	0.02, 0.02	15.87	2	0.0001*
	0.01, 0.01	0.10, 0.03		11590#	1	0.0001*
		0.10, 0.03	0.02, 0.02	6924#	1	0.027
Senecio	0.29, 0.08	0.35, 0.09	0.06, 0.03	10.96	2	0.004
	0.29, 0.08	0.35, 0.09		12074#	1	0.179
		0.35, 0.09	0.06, 0.03	7430#	1	0.001*
Clematis	2.44, 0.84	1.56, 0.66	0.03, 0.03	11.87	2	0.003*
	2.44, 0.84	1.56, 0.66		13353#	1	0.0269
		1.56, 0.66	0.03, 0.03	7087#	1	0.005

Table 29. Plant coverages (mean, s.e.) in percentage of ground covered, for ecological plant groupings at Natural Bridges National Monument in 1992. Data were collected from three sites: Trt 1, canyon above Sipapu Bridge (= area lacking a hiking trail), Trt 2, canyon between Sipapu and Kachina Bridges (= area containing a hiking trail), and Trt 3, in the trail right of way per se. * = statistically significant difference following the Bonferonni procedure = 0.05/5 = 0.01.

	% ground covered					
Ecological Plant grouping	Trt 1	Trt 2	Trt 3	Statistics H or MWU‡	d.f.	p
Herb	11.42, 1.22	7.83, 0.94	4.20, 0.75	13.64	2	0.001*
	11.42, 1.22	7.83, 0.94		14126‡	1	0.106
		7.83, 0.94	4.20, 0.75	7697‡	1	0.100
Grass	9.00, 1.35	4.51, 1.00	2.63, 0.96	32.18	2	0.0001*
	9.00, 1.35	4.51, 1.00		16121‡	1	0.0001*
		4.51, 1.00	2.63, 0.96	7454‡	1	0.028
Shrub	14.99, 2.18	13.58, 1.89	1.68, 0.78	21.36	2	0.0001*
	14.99, 2.18	13.58, 1.89		12883‡	1	0.915
		13.58, 1.89	1.68, 0.78	8313‡	1	0.0001*
Tree	30.35, 3.34	32.62, 3.52	22.83, 4.42	2.88	2	0.237
	30.35, 3.34	32.62, 3.52		12509‡	1	0.700
		32.62, 3.52	22.83, 4.42	7159‡	1	0.097
Total Plant Coverage	70.46, 3.90	60.56, 3.72	31.69, 4.66	44.70	2	0.0001*
	70.46, 3.90	60.56, 3.72		14160‡	1	0.100
		60.56, 3.72	31.69, 4.66	9152‡	1	0.0001*

Table 30. Comparisons of the proportion of one meter square plots that were occupied by common plants across three locations in 1992 in White Canyon at Natural Bridges National Monument. The three treatments were: Trt 1, area above the Sipapu Bridge, this area lacks a hiking trail, Trt 2 area below this bridge and above Kachina Bridge, which has a heavily used hiking trail, and Trt 3, within the trail right of way. There were 160 plots each in treatments 1 and 2 and 80 in treatment 3. The data were analyzed with chi square tests. * = statistically significant following the Bonferonni procedure = p = 0.0028.

	Proportion (number)			Statistics		
Plant Species	Trt 1	Trt 2	Trt 3	overall	Trt 1 vs Trt 2	Trt 2 vs Trt 3
Quercus	0.21 (33)	0.26 (41)	0.08 (6)	11.35, <0.01	1.12, >0.05	11.19, <0.001*
Chrysothamnus	0.24 (38)	0.20 (32)	0.23 (14)	1.42, >0.05	0.66, >0.05	0.17, >0.05
Ephedra	0.08 (13)	0.18 (28)	0.00 (0)	19.06, <0.001	6.28, <0.05	15.76, <0.001*
Salix exigua	0.06 (10)	0.08 (12)	0.09 (7)	0.53, >0.05	0.19, >0.05	0.13, >0.05
Symphoricarpus	0.08 (13)	0.08 (12)	0.00 (0)	6.72, <0.05	0.04, >0.05	6.32, <0.05
Calamogrostis	0.19 (31)	0.19 (30)	0.04 (3)	11.19, <0.01	0.02, >0.05	10.11, <0.01
Phragmites	0.09 (15)	0.03 (4)	0.03 (2)	9.12, <0.02	6.76, <0.01	no test
Sporobolis	0.16 (26)	0.11 (17)	0.13 (10)	2.26, >0.05	2.18, >0.05	1.68, >0.05
Stipa hymenoides	0.13 (21)	0.13 (21)	0.10 (8)	0.48, >0.05	0.00, >0.05	0.51, >0.05
Stipa comata	0.06 (10)	0.08 (13)	0.14 (11)	3.90, >0.05	0.44, >0.05	1.88, >0.05
Heterotheca	0.32 (51)	0.38 (60)	0.41 (33)	2.31, >0.05	1.10, >0.05	0.31, >0.05
Planaria	0.14 (22)	0.11 (17)	0.04 (3)	5.70, >0.05	0.74, >0.05	3.37, >0.05
O. pallida	0.13 (20)	0.06 (10)	0.08 (6)	4.09, >0.05	3.68, >0.05	0.16, >0.05
Lepidium	0.01 (2)	0.11 (17)	0.03 (2)	15.65, <0.001	12.58, <0.001	4.74, <0.05
Opuntia	0.04 (7)	0.10 (16)	0.05 (4)	4.51, >0.05	3.80, =0.05	1.80, >0.05
Senecio	0.14 (22)	0.20 (32)	0.04 (3)	11.58, <0.01	2.24, >0.05	11.40, <0.001*

Table 31. Comparisons of the proportion of one meter square plots that were occupied by plants of four ecological plant groupings across three locations in 1990 in White Canyon at Natural Bridges National Monument. The three treatments were: Trt 1, area above Sipapu Bridge which lacks a hiking trail, Trt 2 area between Sipapu and Kachina Bridges which has a heavily used hiking trail, and Trt 3, within the trail right of way. There were 160 plots each in treatments 1 and 2 and 80 in treatment 3. The data were analyzed with chi square tests. * = statistically significant following the Bonferonni procedure = 0.05/5 = 0.01.

	Proportion (number)				Statistics	
Ecological grouping	Trt 1	Trt 2	Trt 3	overall	Trt 1 vs Trt 2	Trt 2 vs Trt 3
Total Herb	0.75 (120)	0.75 (120)	0.66 (53)	2.51, >0.05	0.00, >0.05	2.05, >0.05
Total Grass	0.30 (48)	0.44 (71)	0.54 (43)	14.14, <0.001	7.08, <0.01	1.89, >0.05
Total Shrub	0.51 (82)	0.50 (80)	0.29 (23)	12.41, <0.01	0.04, >0.05	9.78, <0.01*
Total Tree	0.48 (76)	0.46 (74)	0.38 (30)	2.33, >0.05	0.04, >0.05	1.69, > 0.05
Total plant	0.99 (158)	0.98 (156)	0.86 (69)	26.88, <0.001	no test	0.20, > 0.05

Table 32. Number of plant species/1 m sq plot (mean, s.e.) for ecological plant groupings at Natural Bridges National Monument in 1992. Data were collected from three sites: Trt 1, canyon above Sipapu Bridge (= area lacking a hiking trail), Trt 2, canyon between Sipapu and Kachina Bridges (= area containing a hiking trail), and Trt 3, in the trail right of way per se. * = statistically significant difference following the Bonferonni procedure = 0.05/5 = 0.01.

Ecological Plant grouping	No. species/ 1 m sq plot			Statistics		
	Trt 1	Trt 2	Trt 3	H or MWU#	d.f.	p
Herb	1.5, 0.1	1.8, 0.1	1.2, 0.1	9.65	2	0.008*
	1.5, 0.1	1.8, 0.1		11612#	1	0.140
		1.8, 0.1	1.2, 0.1	7900#	1	0.002 *
Grass	0.9, 0.1	0.7, 0.1	0.6, 0.1	13.29	2	0.001*
	0.9, 0.1	0.7, 0.1		15069#	1	0.003 *
		0.7, 0.1	0.6, 0.1	6796#	1	0.390
Shrub	0.6, 0.1	0.7, 0.1	0.4, 0.1	12.42	2	0.002*
	0.6, 0.1	0.7, 0.1		12491#	1	0.682
		0.7, 0.1	0.4, 0.1	7874#	1	0.001 *
Tree	0.5, 0.0	0.6, 0.1	0.4, 0.1	3.55	2	0.170
	0.5, 0.0	0.6, 0.1		12285#	1	0.480
		0.6, 0.1	0.4, 0.1	7221#	1	0.064
All Plants	3.8, 0.1	3.9, 0.1	2.6, 0.2	28.57	2	0.0001*
	3.8, 0.1	3.9, 0.1		12401#	1	0.625
		3.9, 0.1	2.6, 0.2	8874#	1	0.0001*

Table 33. Total number of small mammals caught per species per grid in 1992 at Natural Bridges National Monument. Each grid contained 70 live traps in a 5 x 14 array and covered approximately 0.52 Ha. Four grids were located above Sipapu bridge, the other four downstream of Sipapu bridge, in an area that receives heavy trail usage. * = statistically significant following the Bonferroni procedure = 0.05/

	Area lacking trail					Area with trail				
	no. caught					no. caught				
Grid	1	2	3	4	total	1	2	3	4	total
Species										
Peromyscus maniculatus (Deer mouse)	3	2	2	0	7	1	3	0	1	5
P. boylii (Brush mouse)	4	4	3	1	12	5	6	0	4	15
P. crinitus	0	0	1	0	1	0	0	0	0	0
P. truei	1	1	0	0	2	3	4	1	3	11
Peromyscus	1	0	0	1	2	0	0	0	0	0
Neotoma albigula (White-throated woodrat)	2	9	0	15	26	1	4	0	2	7
N. lepida (Desert woodrat)	0	0	0	0	0	0	1	1	0	2
N. cinerea (Bushy-tailed woodrat)	0	0	0	0	0	0	1	0	0	1
Mus musculus (House mouse)	0	0	0	1	1	0	0	0	0	0
Microtus sp (Vole)	0	0	0	0	0	0	0	1	0	1
Perognathus parvus (Great Basin Pocket mouse)	0	1	0	0	1	0	0	0	1	1
All mice	11	17	6	18	52	10	19	3	11	43

Table 34. Number of birds observed per 600 m long transect in White Canyon at Natural Bridges National Monument. Each transect was walked on two successive days. Two transects were located above Sipapu Bridge in an area lacking a well used hiking trail (trt 1), and two transects were located below the bridge in an area containing a heavily used hiking trail (trt 2).

	Mean no./transect		No. of transects occupied	
Species	trt 1	trt 2	trt 1	trt2
Rufus-sided towhee	4.5	4.5	4	3
Kestrels	0.5	0.0	1	0
White-throated swifts	1.5	5.0	3	2
Violet-green swallows	1.0	0.0	1	0
Broad-tailed hummingbird	0.8	0.3	3	1
Rufus hummingbird	0.5	0.0	1	0
Hummingbird	0.0	0.8	0	2
Raven	0.5	0.3	2	1
Scrub jays	0.5	0.3	1	1
White-crowned sparrow	0.5	0.0	1	0
Black-capped chickadee	0.5	0.0	1	0
Common bushtits	0.0	0.5	0	1
Overall mean no. birds/ species	0.90	0.98		
Total no. of species	10.0	7.0		

Table 35. Comparisons via t tests or Mann Whitney U tests of number of individuals in various taxa observed per pool in two treatments at Natural Bridges. Treatment 1 is an area lacking a well used hiking trail, treatment 2 is an area containing a well used hiking trail. All comparisons involve 38 and 39 d.f.. Each taxon appears to be represented by only one species. # = statistically significant.

	X + S.E.			
	site			
Taxa	Trt 1	Trt 2	t or U*	p
Coleoptera	0.3 + 0.1	0.3 + 0.1	0.1	0.90
Notonectid	1.9 + 0.7	1.3 + 0.6	0.7	0.51
Chironomid	0.3 + 0.1	16.7 + 8.6	671*	0.076
Cadisfly	3.8 + 1.0	1.3 + 0.7	1049*	0.002#
Bufo tadpoles	87.6 + 55.1	45.3 + 26.1	799*	0.84
Crustacean	11.4 + 3.6	8.6 + 3.3	0.6	0.6
Mosquito	3.4 + 1.4	13.0 + 6.4	708*	0.35
Whirlygigs	2.3 + 1.1	0.6 + 0.3	1.5	0.14
Water striders	14.8 + 2.2	5.8 + 1.2	112	0.001#

Table 36. Results of chi square analyses examining the distribution of five taxa across pools along a hiking trail or from an area lacking a trail at Natural Bridges. All comparisons have 1 d.f.. Samples were the results of a sweep netting survey. * = statistically significant following the Bonferroni procedure = 0.05/5 = 0.01.

Taxa	Number of times present in a sweep area with trail	area lacking trail	X2	p
Notonectid	18/248	40/335	3.52	0.064
Chironomid	8/248	26/335	5.39	0.02
Amphipoda	8/248	44/335	17.18	0.001*
Water striders	16/248	40/335	4.92	0.03
Mosquitos	16/248	9/335	4.99	0.028

Table 37. Characteristics of pools and number of individuals observed per species per pool in pools at Natural Bridges National Monument in 1991. The data come from an area containing a trail or an area lacking a trail. Statistics = t or F tests or their nonparametric equivalents (indicated by *), p value. The values in the body of the table are means, standard errors, and sample sizes. # = statistically significant following the Bonferroni procedure = 0.005/6 = 0.008 for species comparisons; = 0.05/3 = 0.02 for physical comparisons.

Comparison	trail area	nontrail area	statistics	rocky bottom	sandy bottom	statistics
Pool surface area	41.5, 7.7, 32	47.8, 14.4, 25	397*, 0.955	17.0, 3.4, 20	55.9, 10.6, 19	296*, 0.003#
Pool depth	30.0, 4.1, 32	33.4, 5.1, 24	0.53, 0.599	28.5, 4.5, 19	31.8, 5.5, 19	193*, 0.724
Bottom type	1.6, 0.2, 26	2.1, 0.1, 23	179*, 0.01#	---	---	---
No. species	3.3, 0.4, 32	5.9, 0.5, 26	159*, 0.0001#	4.6, 0.5, 20	4.2, 0.5, 19	170*, 0.571
No. notonectids	1.3, 0.7, 32	1.4, 0.5, 26	347*, 0.176	0.2, 0.1, 20	2.0, 1.0, 19	247*, 0.045
No. water striders	1.9, 1.0, 32	4.2, 0.9, 26	201*, 0.0001#	2.2, 0.5, 20	3.3, 1.6, 19	159*, 0.360
No. caddisfly	0.3, 0.2, 32	4.7, 1.4, 26	176*, 0.0001#	1.4, 0.4, 20	1.2, 0.9, 19	143*, 0.115
No. sm water	16.1, 6.8, 32	9.7, 3.4, 26	360*, 0.372	6.6, 2.4, 20	11.3, 5.4, 19	212*, 0.542
No. bottom beetle	3.9, 1.1, 32	8.4, 2.4, 26	304*, 0.070	5.8, 1.4, 20	3.8, 1.4, 19	151*, 0.254
No. mayfly	2.1, 0.8, 31	37.5, 26.7, 26	140*, 0.0001#	8.2, 2.3, 19	5.3, 2.2, 19	137*, 0.187

Table 38. Results of chi square analyses examining the distribution of aquatic organisms across pools in an area lacking a trail (trt 1) and an area containing a trail (trt 2) in White Canyon at Natural Bridges National Monument. All comparisons have 1 degree of freedom. Statistically significant following the Bonferroni procedure = 0.05/6 = 0.01.

Taxa	Number of times observed in a pool trt 1	trt 2	chi square	p
Notonectid	10/26	7/32	1.93	> 0.10
Lg Water strider	20/26	10/32	12.16	< 0.001*
Trichoptera	17/26	3/32	19.70	< 0.001*
Sm water strider	21/26	23/32	0.65	> 0.70
Bottom beetle	19/26	16/32	3.17	0.079
Mayfly	19/26	12/32	7.36	< 0.01*

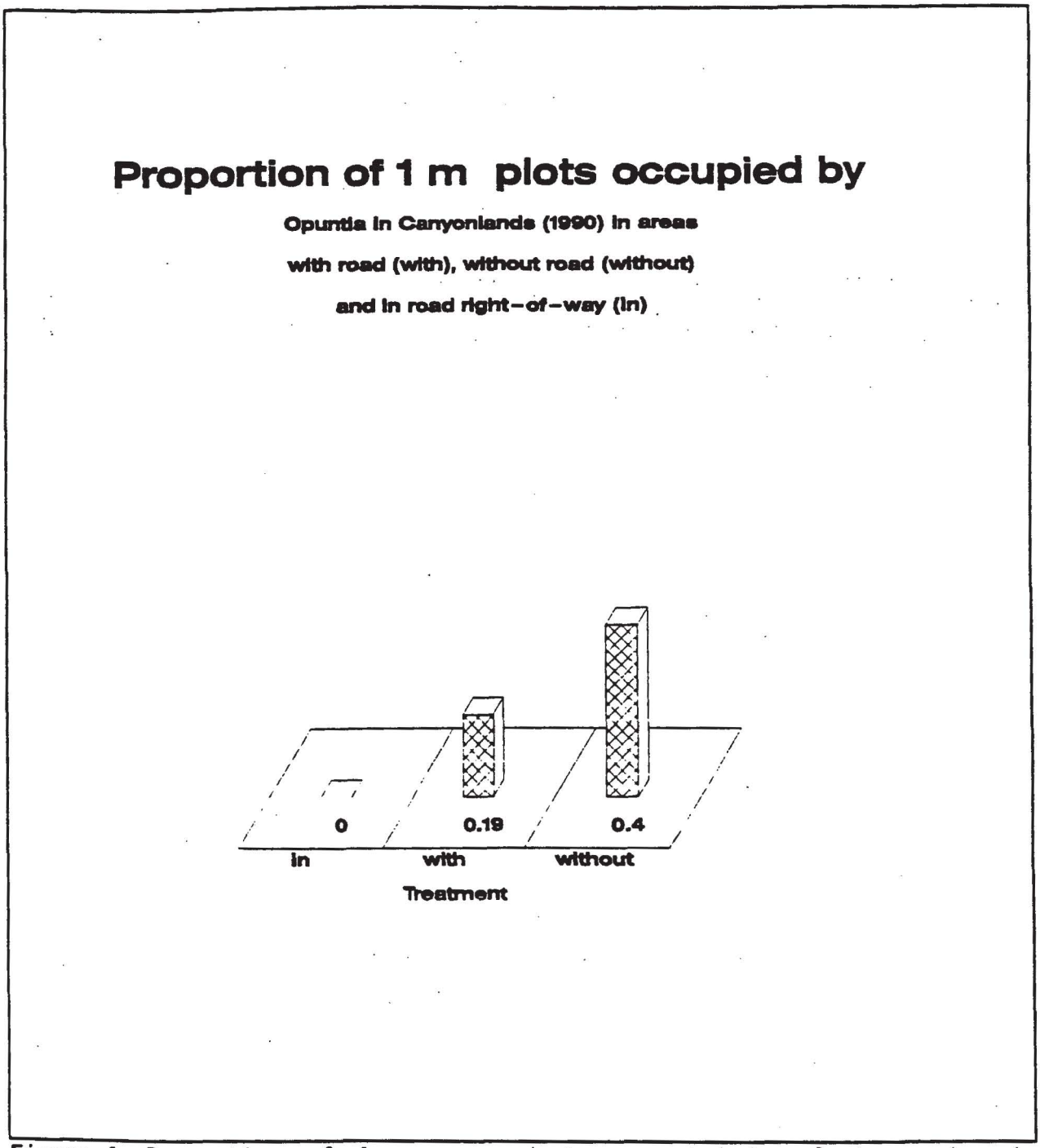
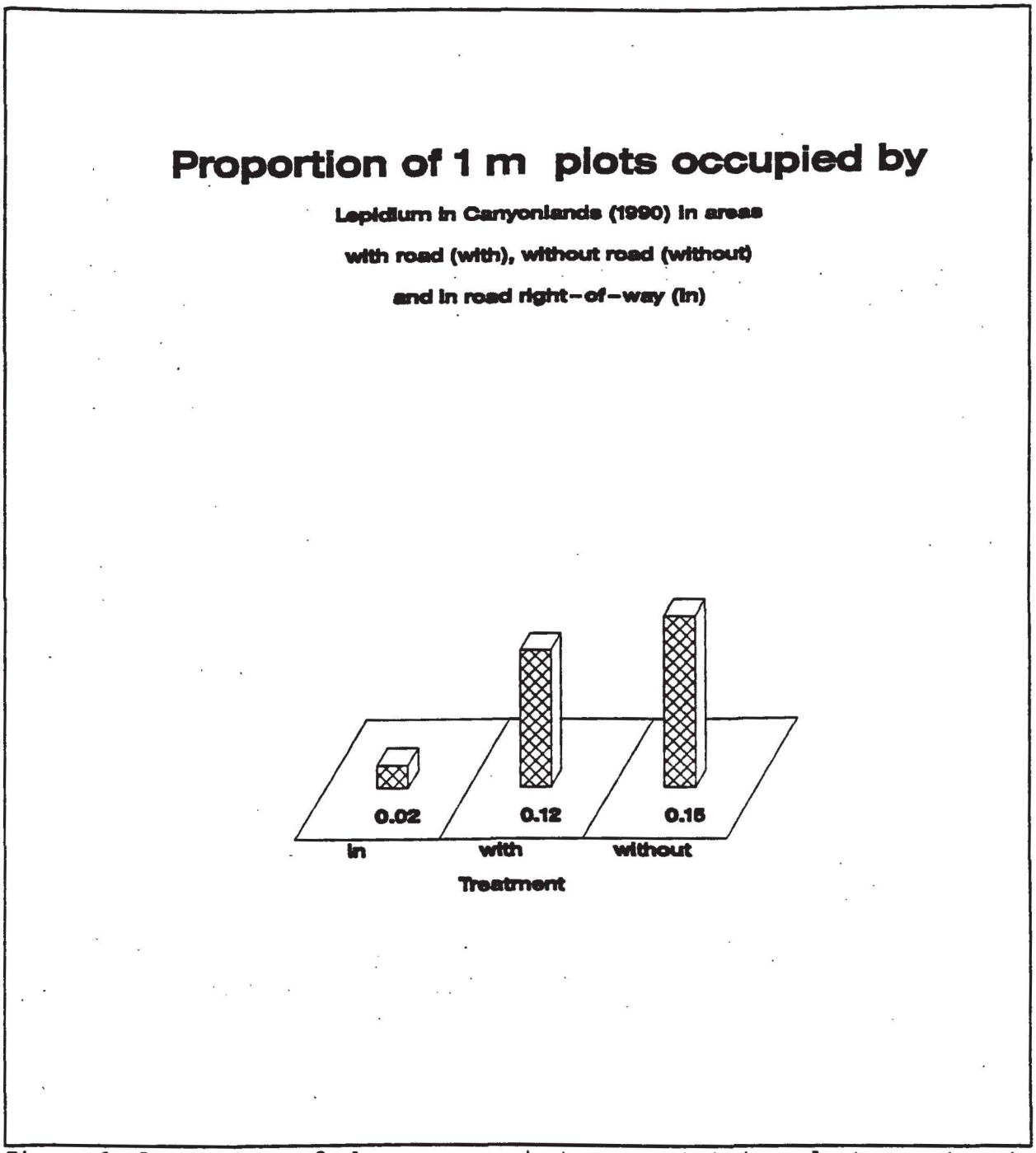


Figure 1 Proportion of 1 m sq quadrats occupied by plant species in Canyonlands in 1990.



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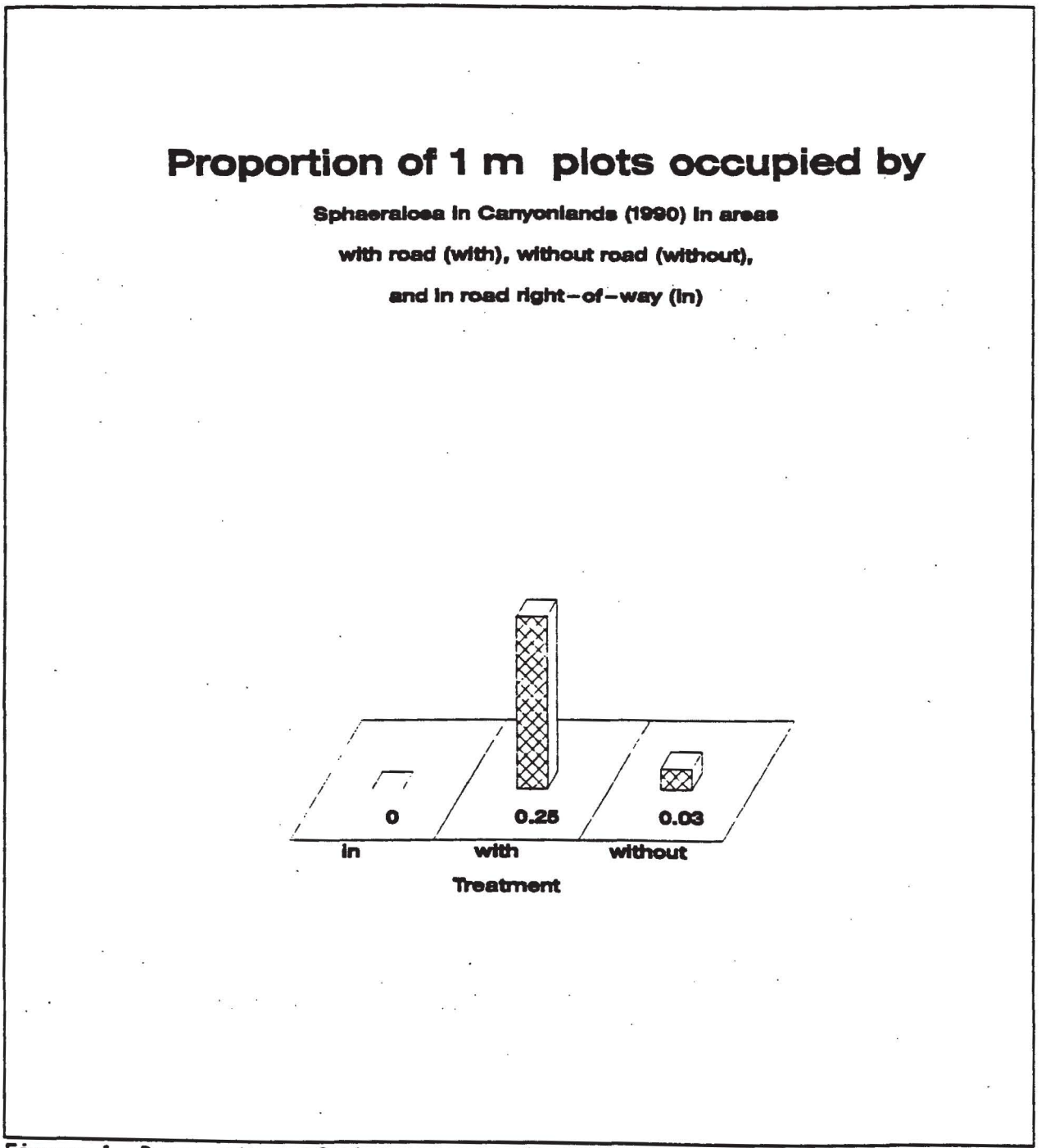

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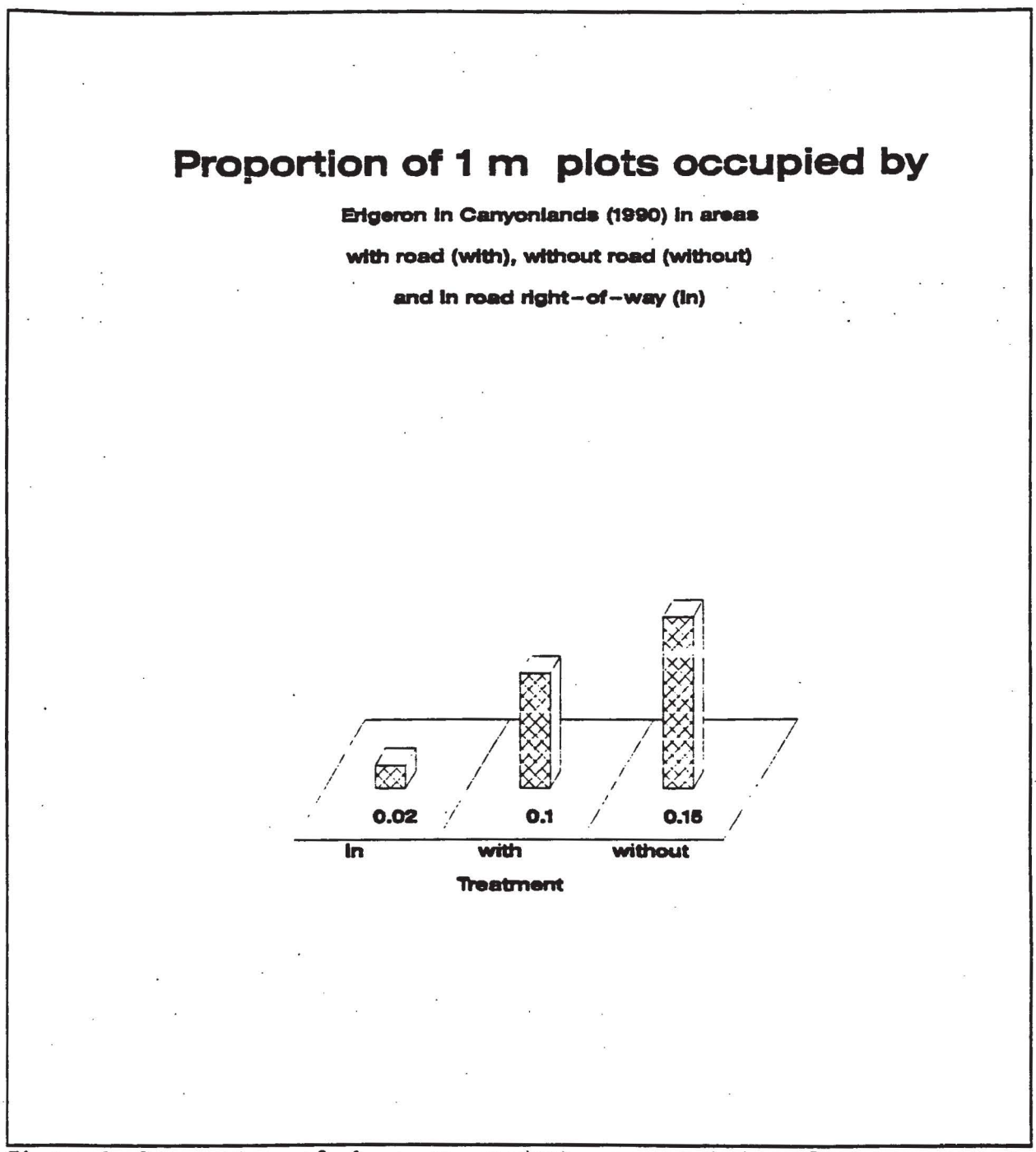

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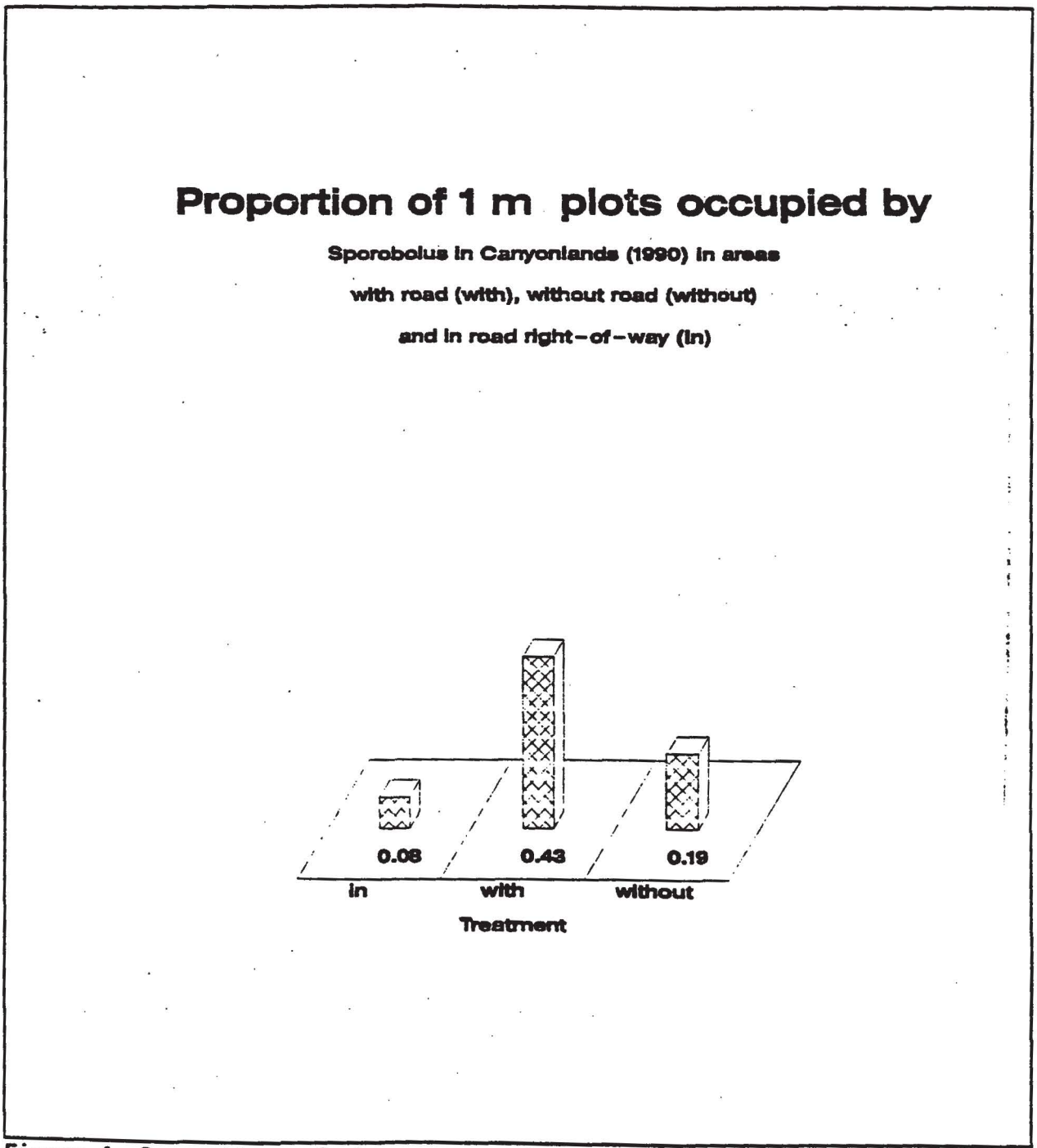

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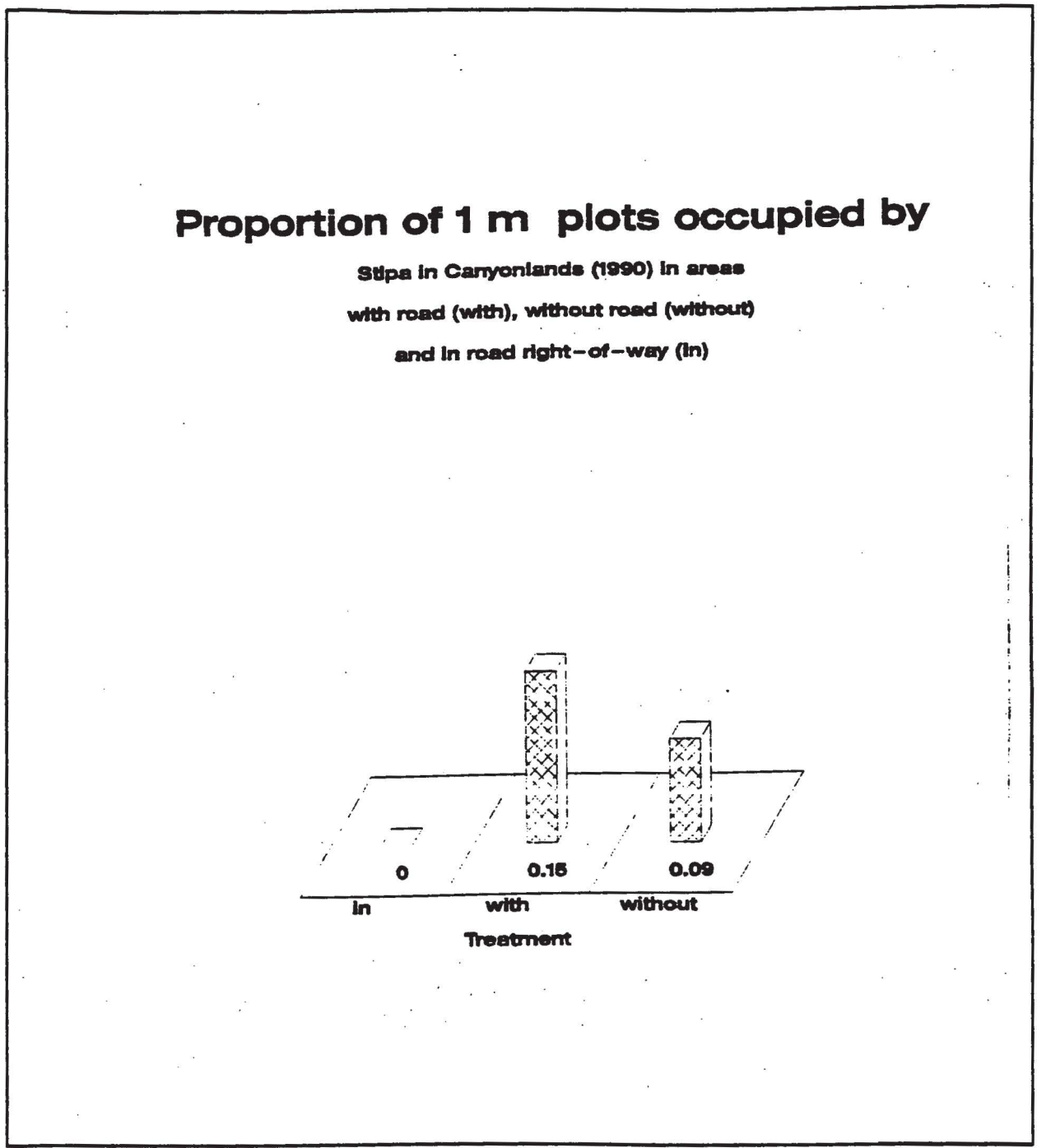

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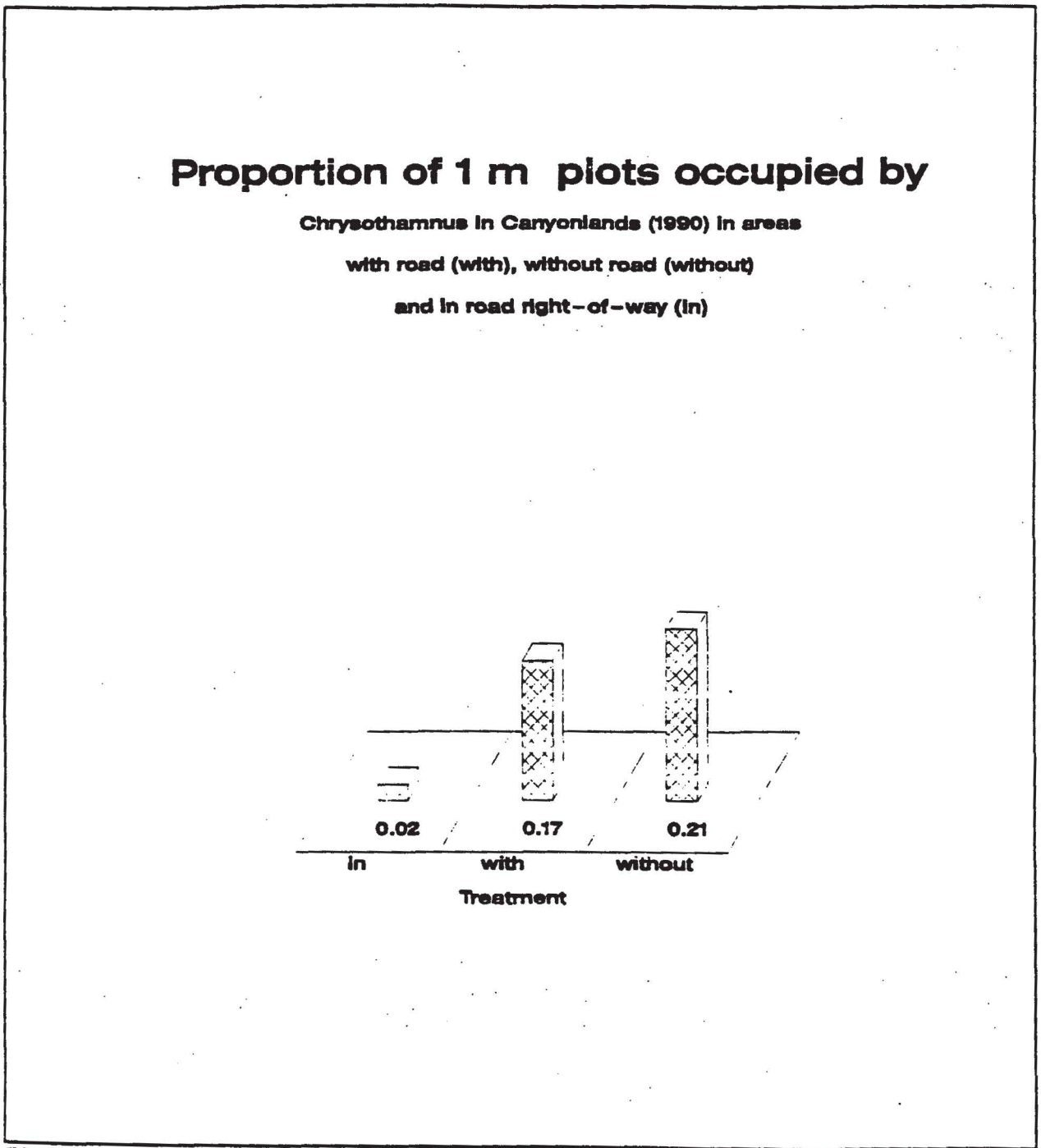

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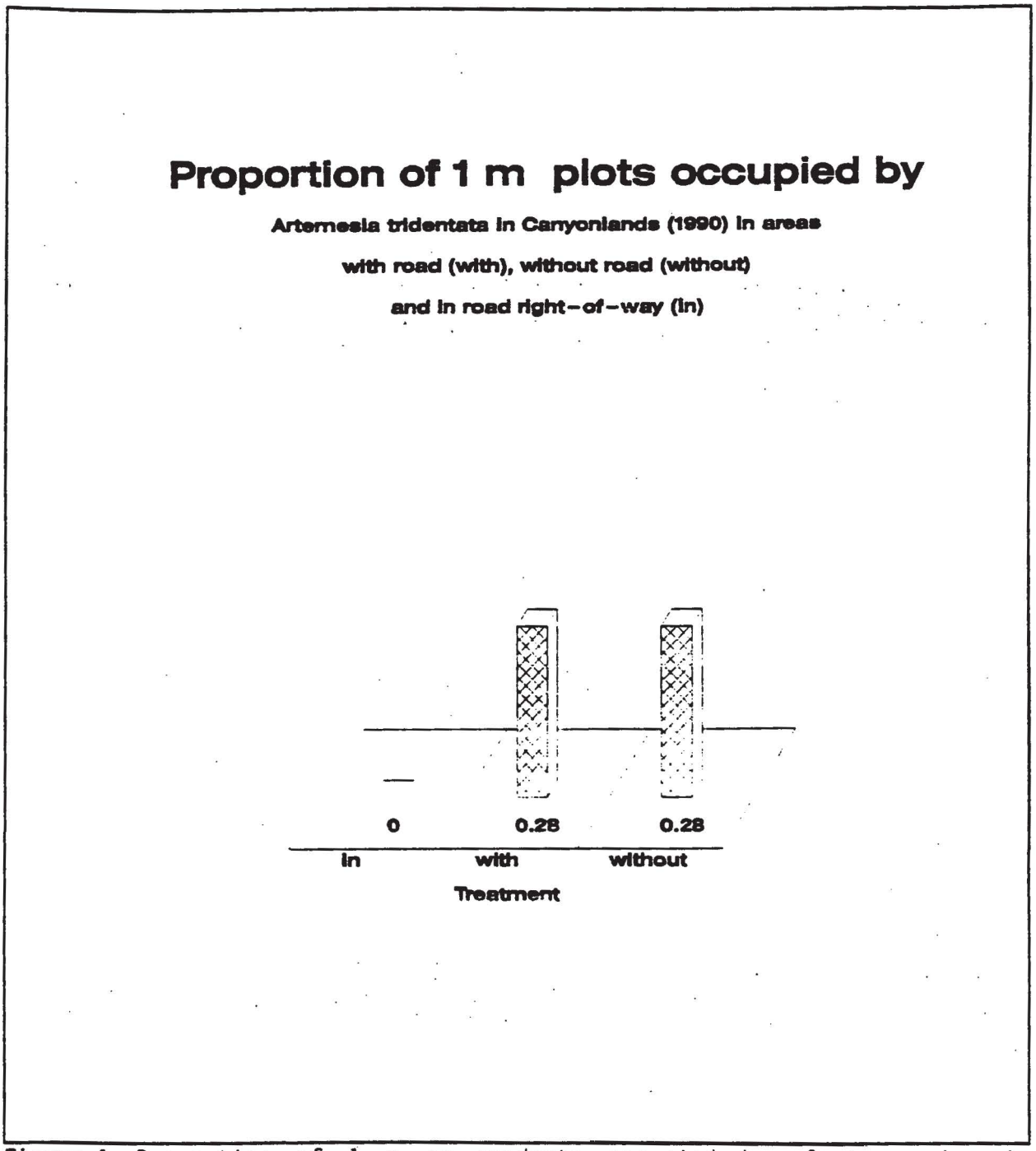

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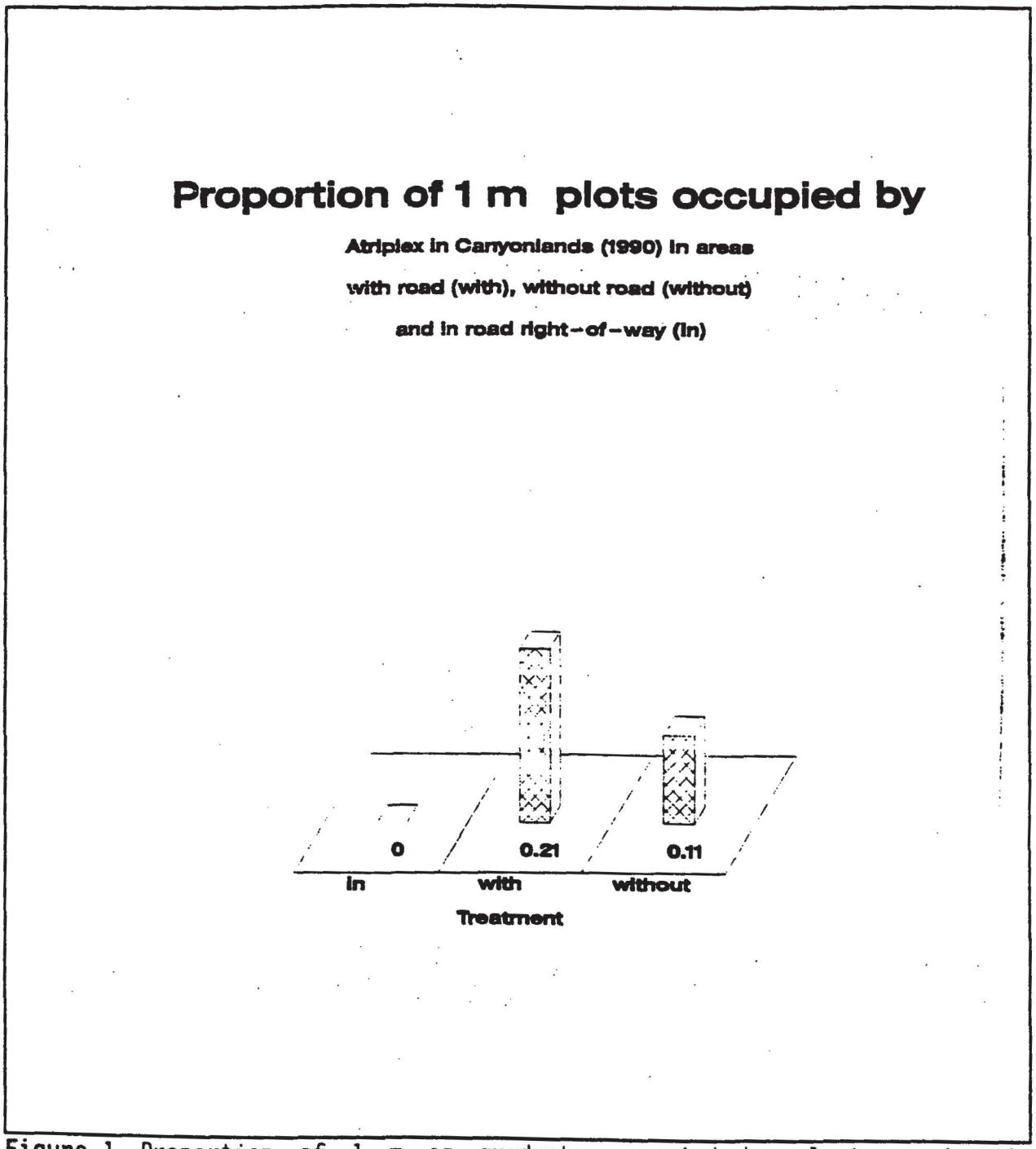

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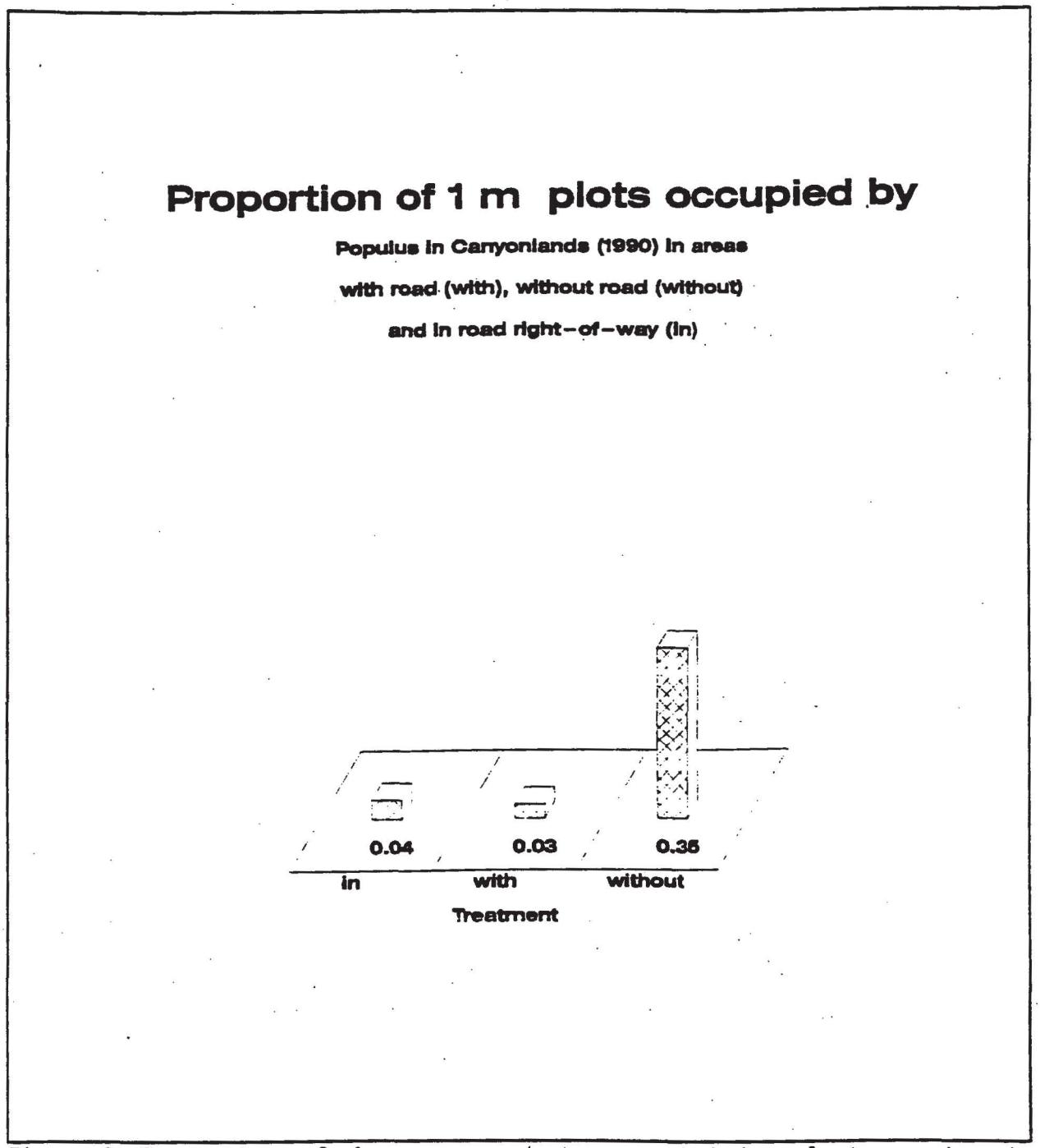

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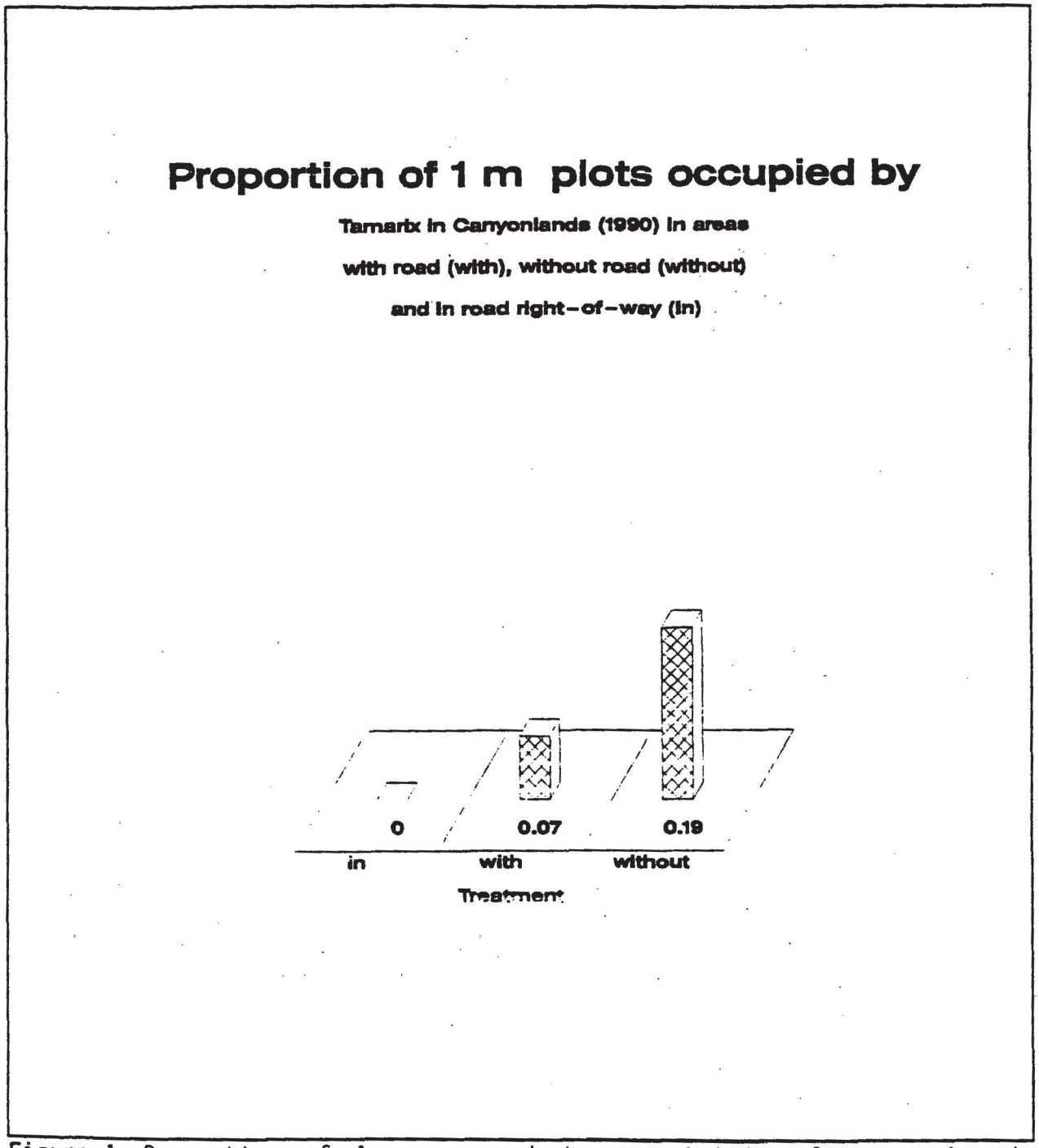

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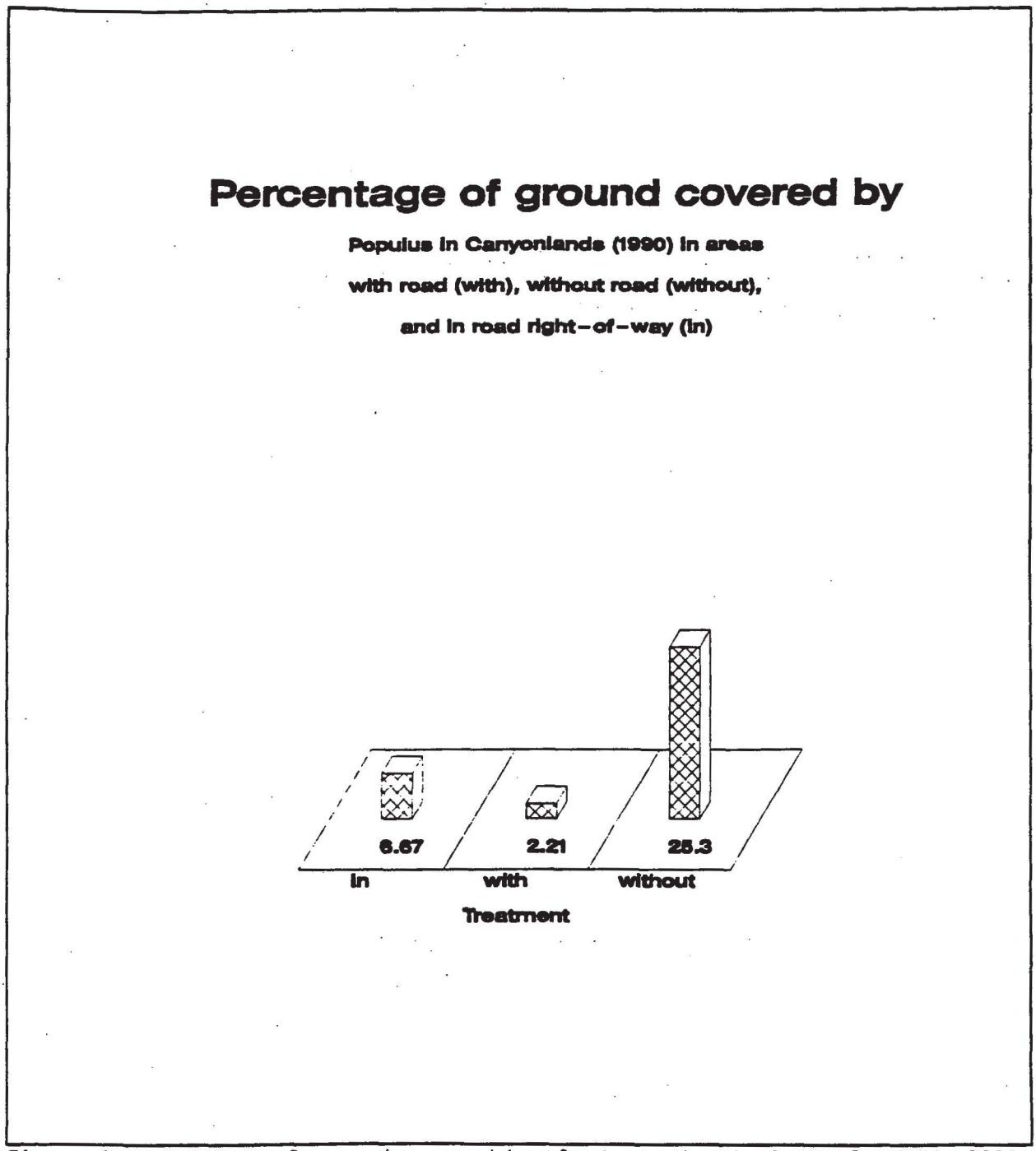
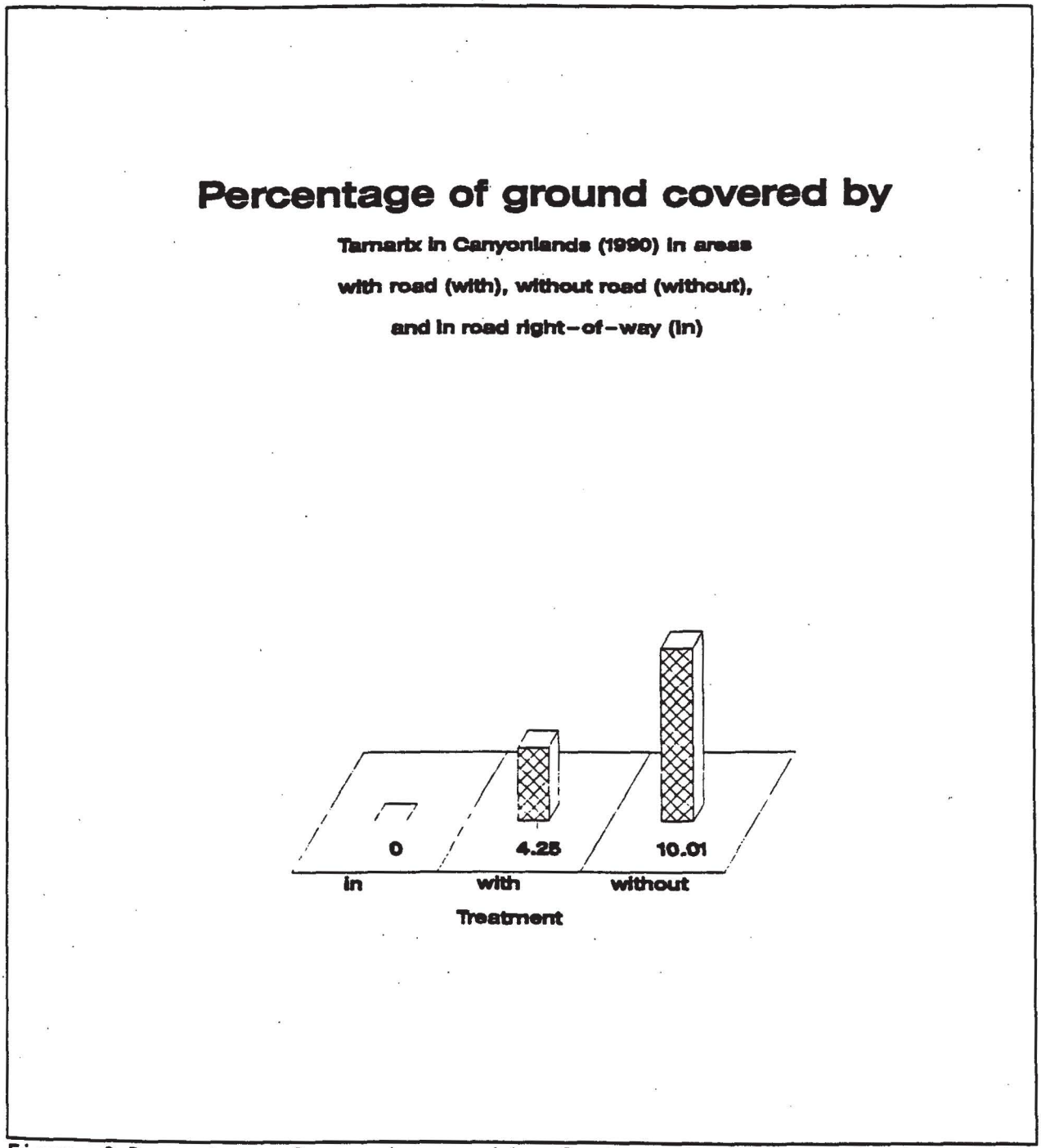


Figure 2 Percentage of ground covered by plant species in Canyonlands in 1990.



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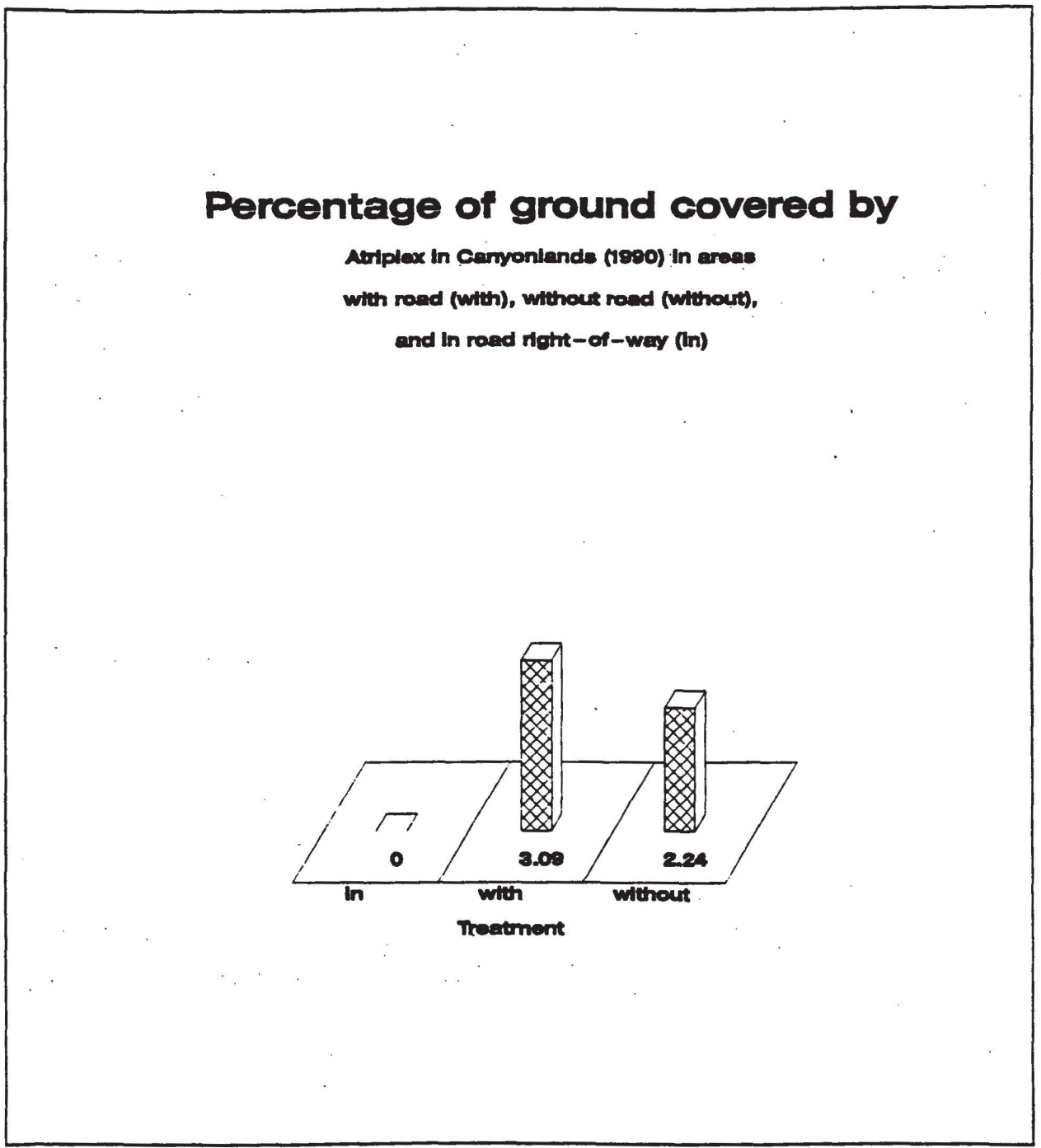

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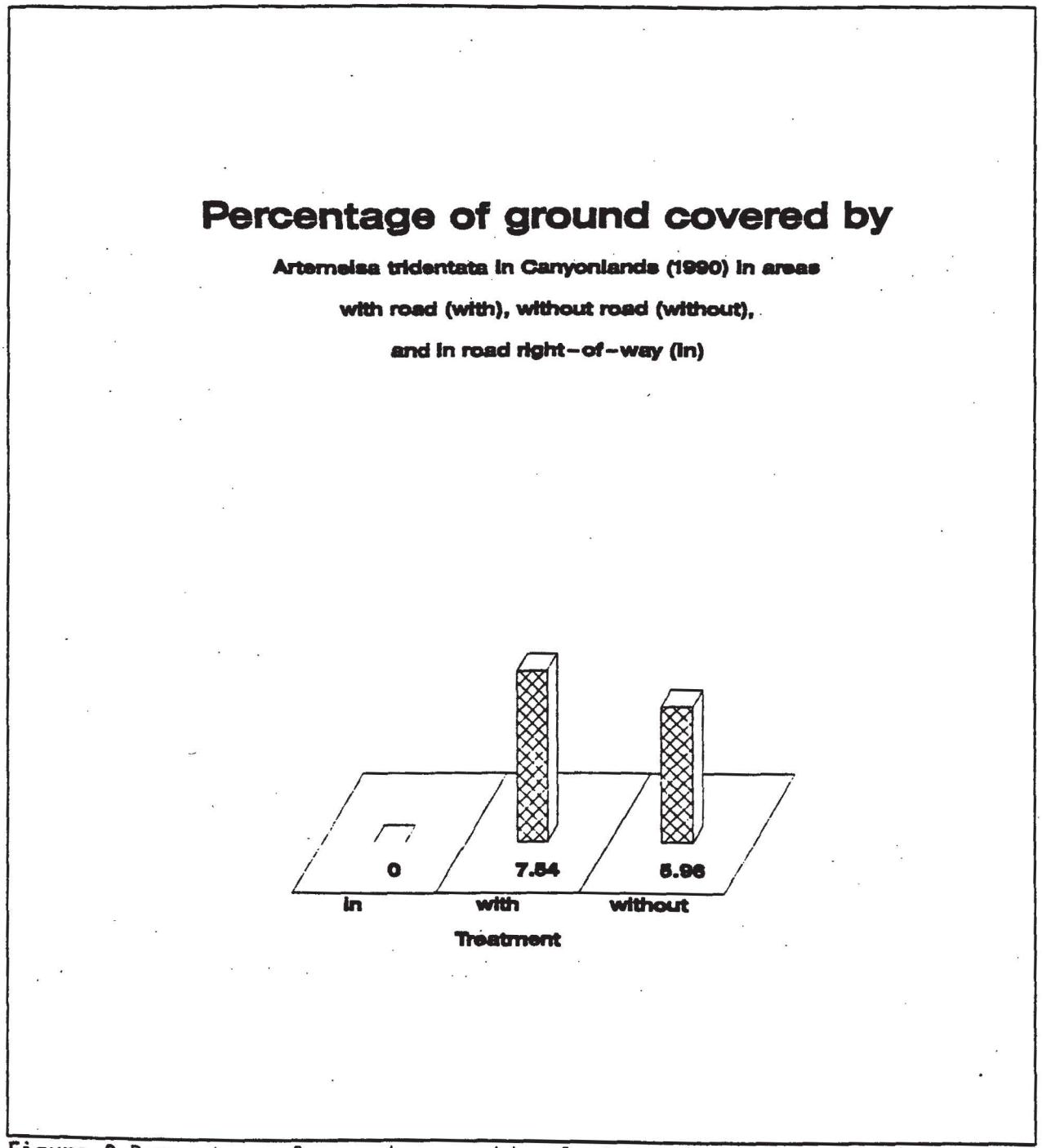

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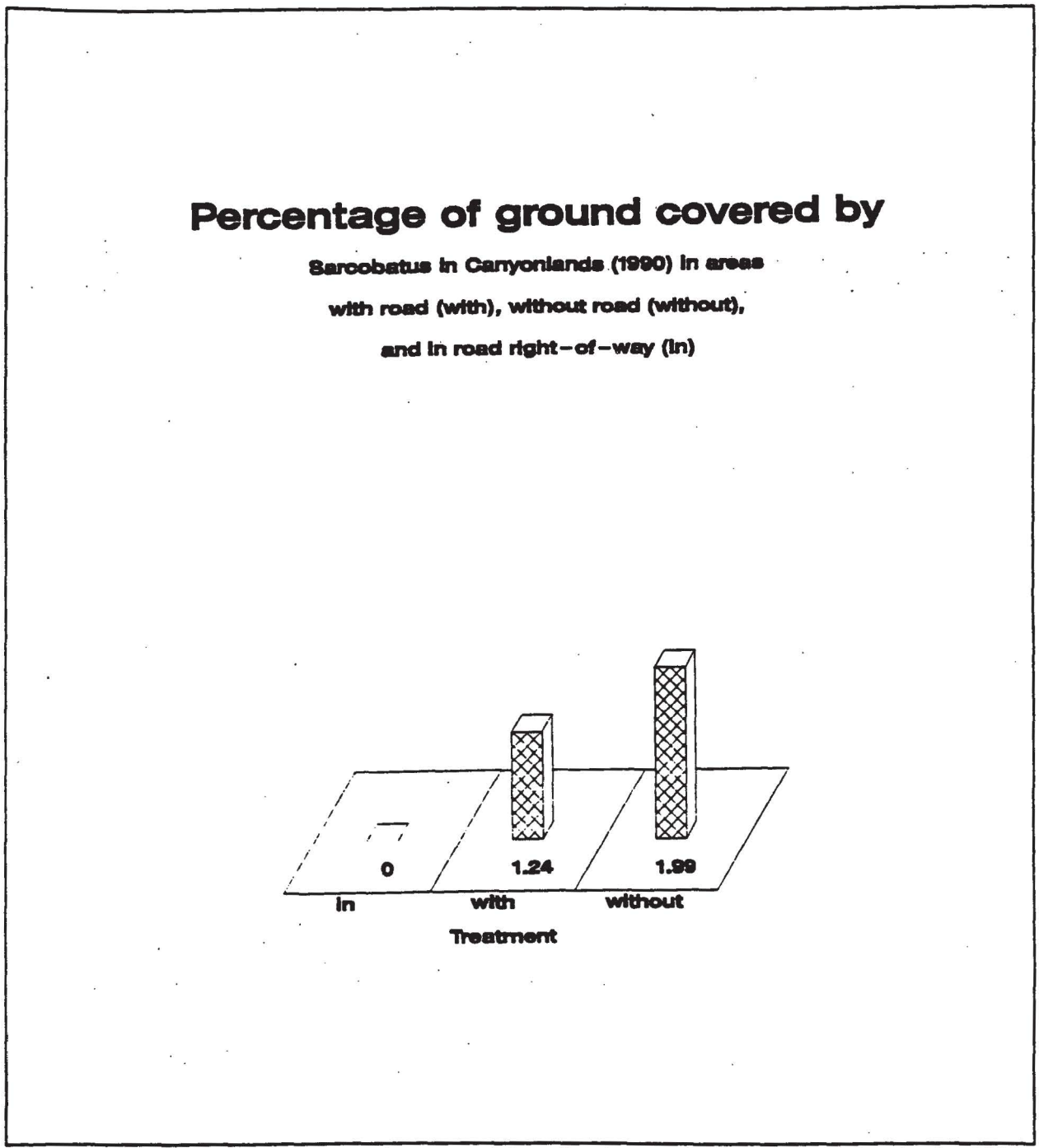

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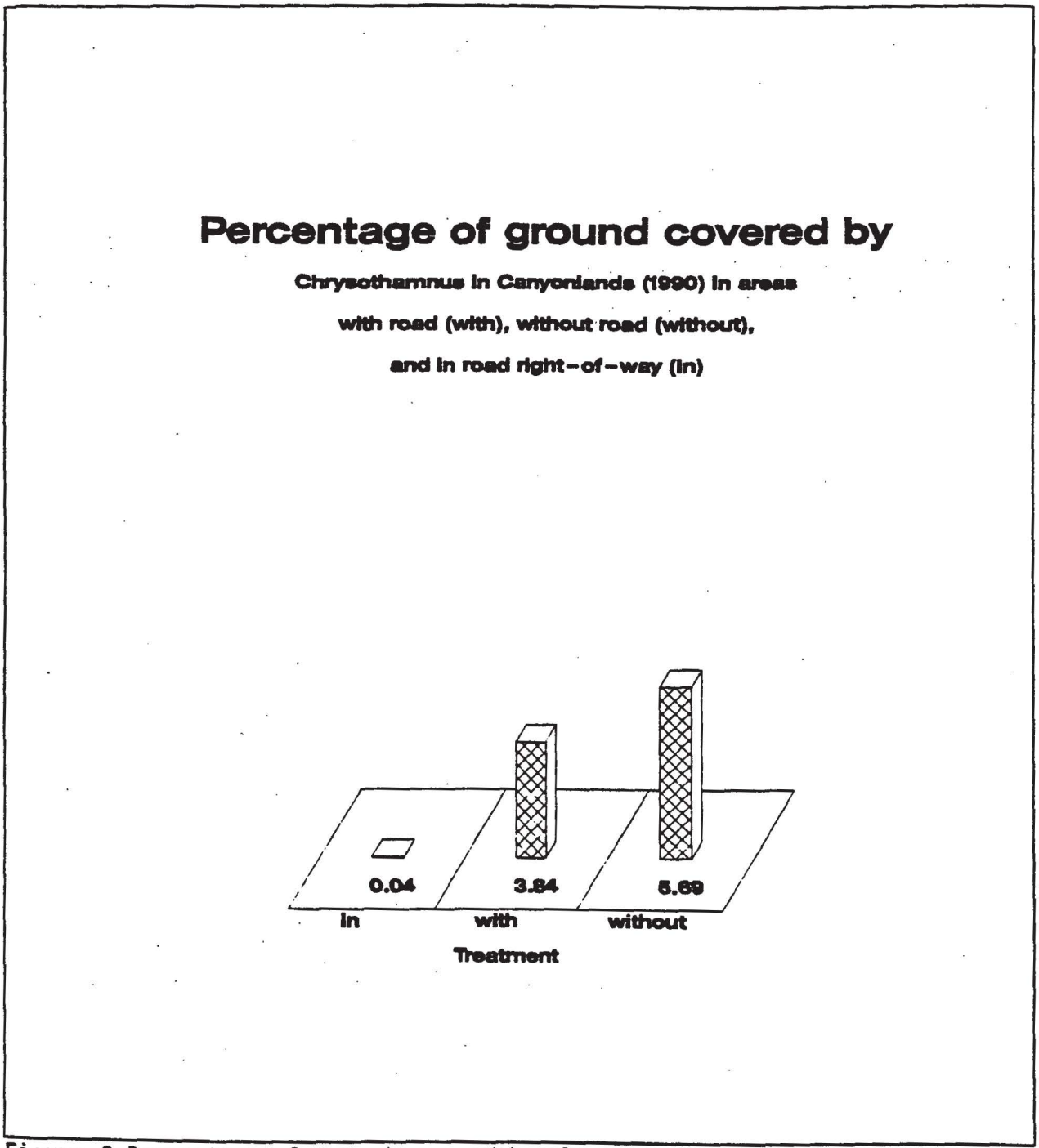

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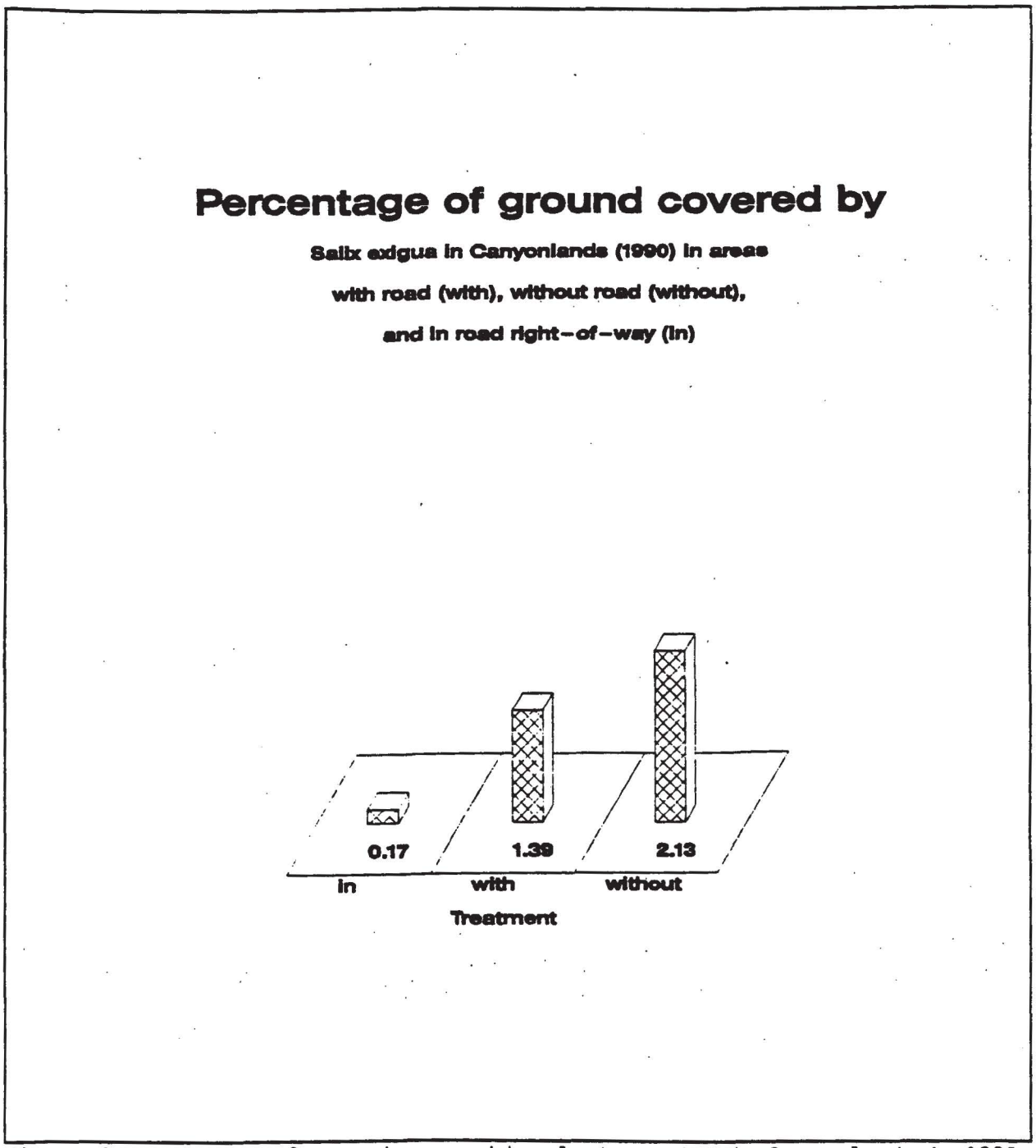

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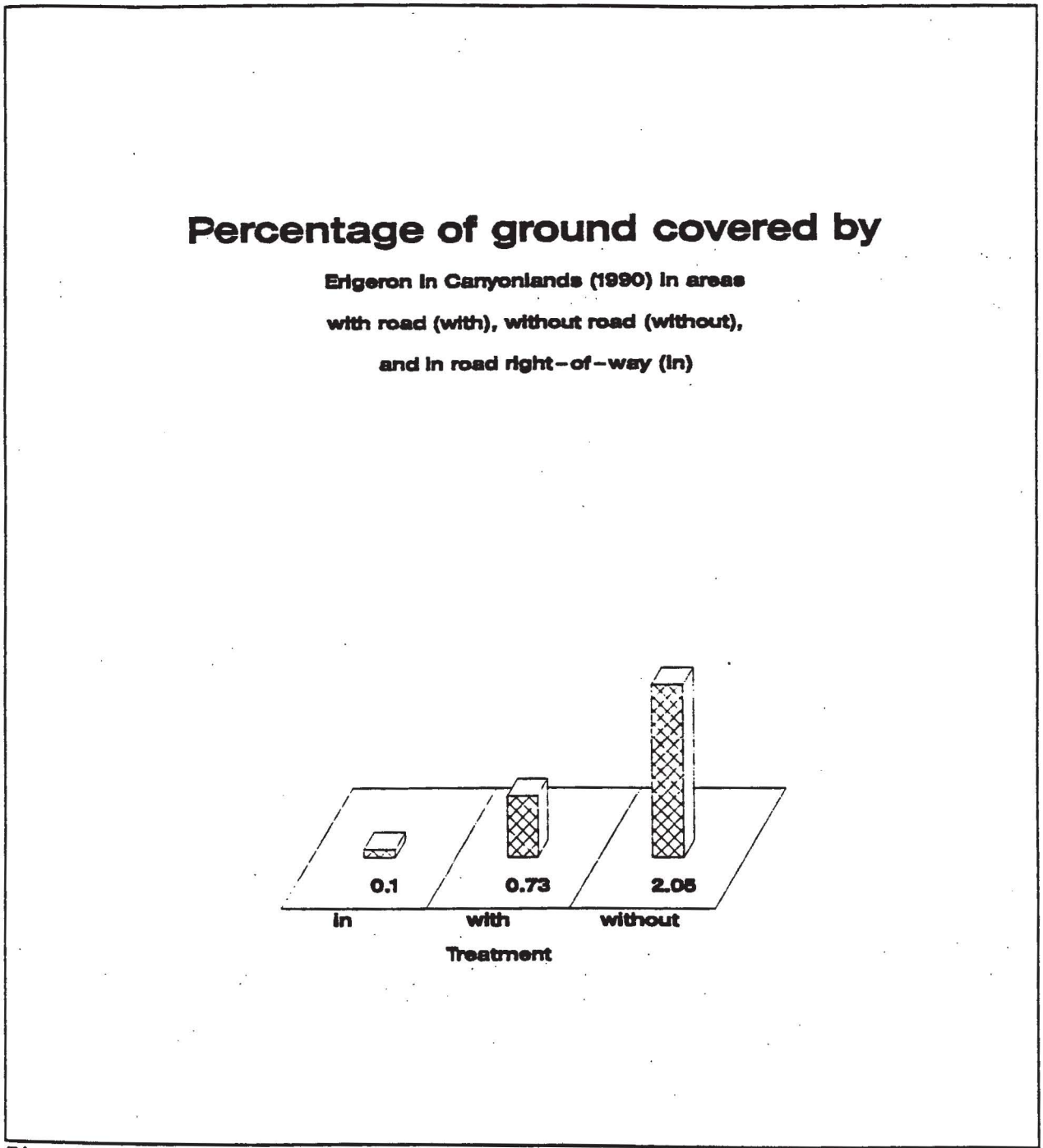

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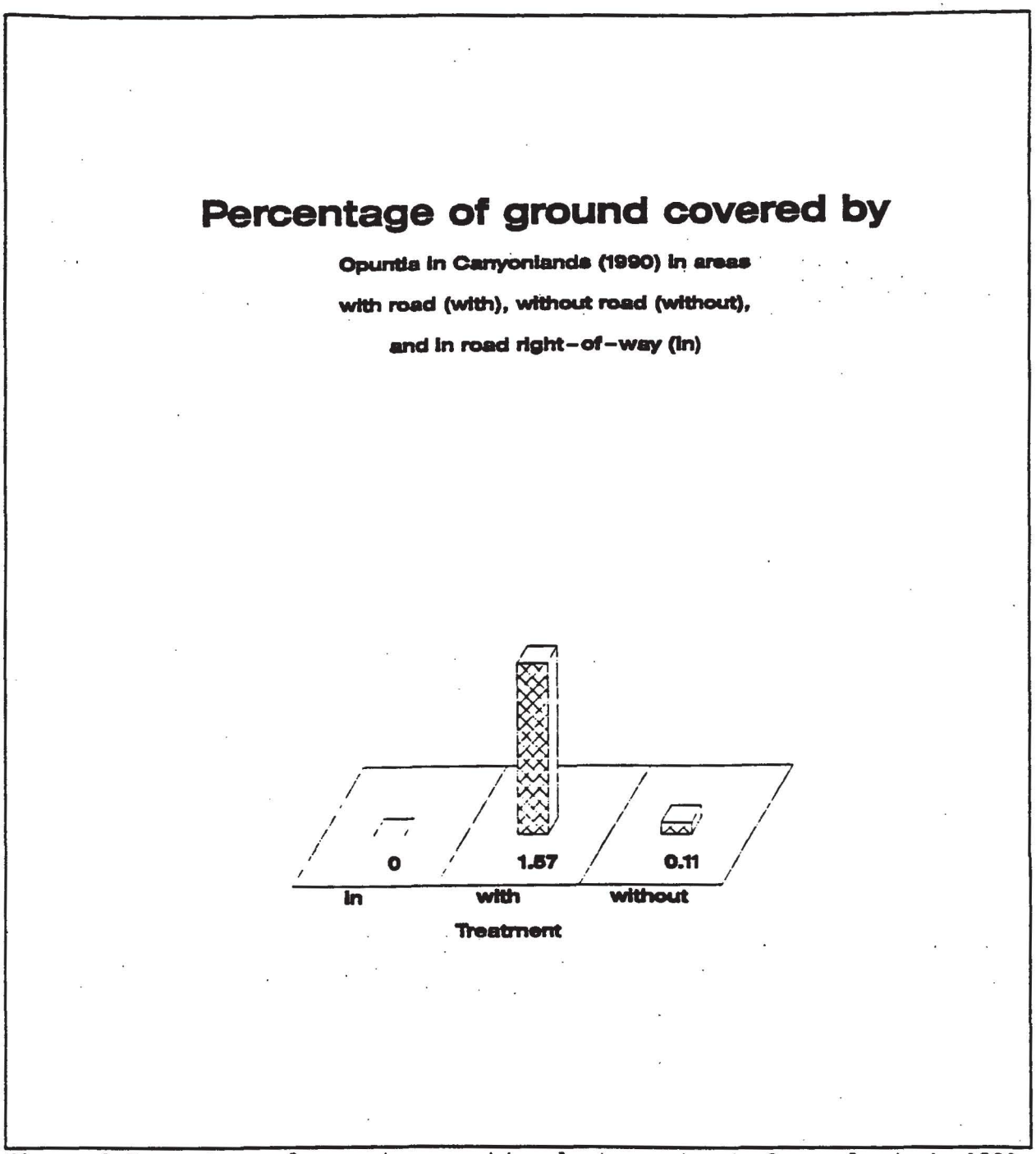

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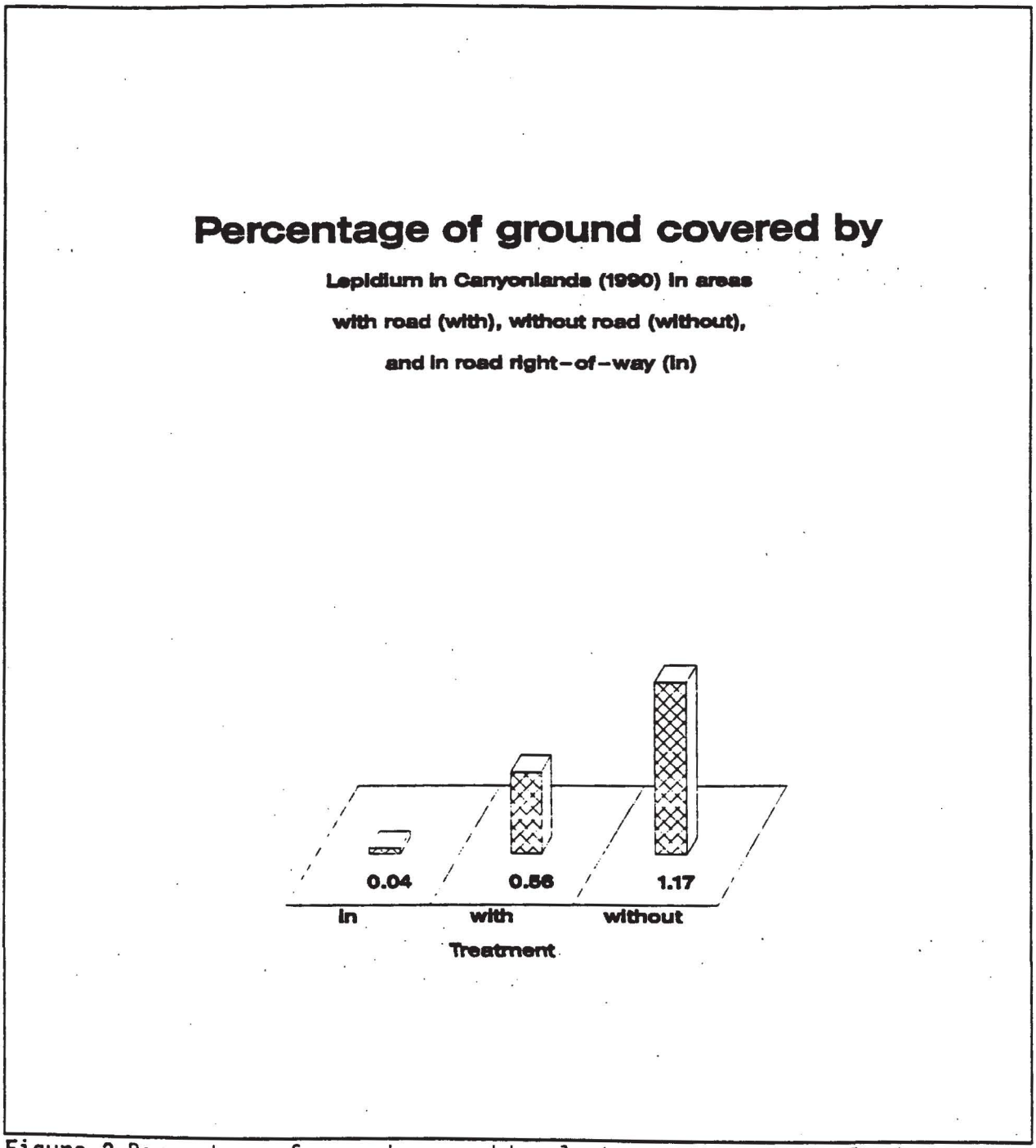

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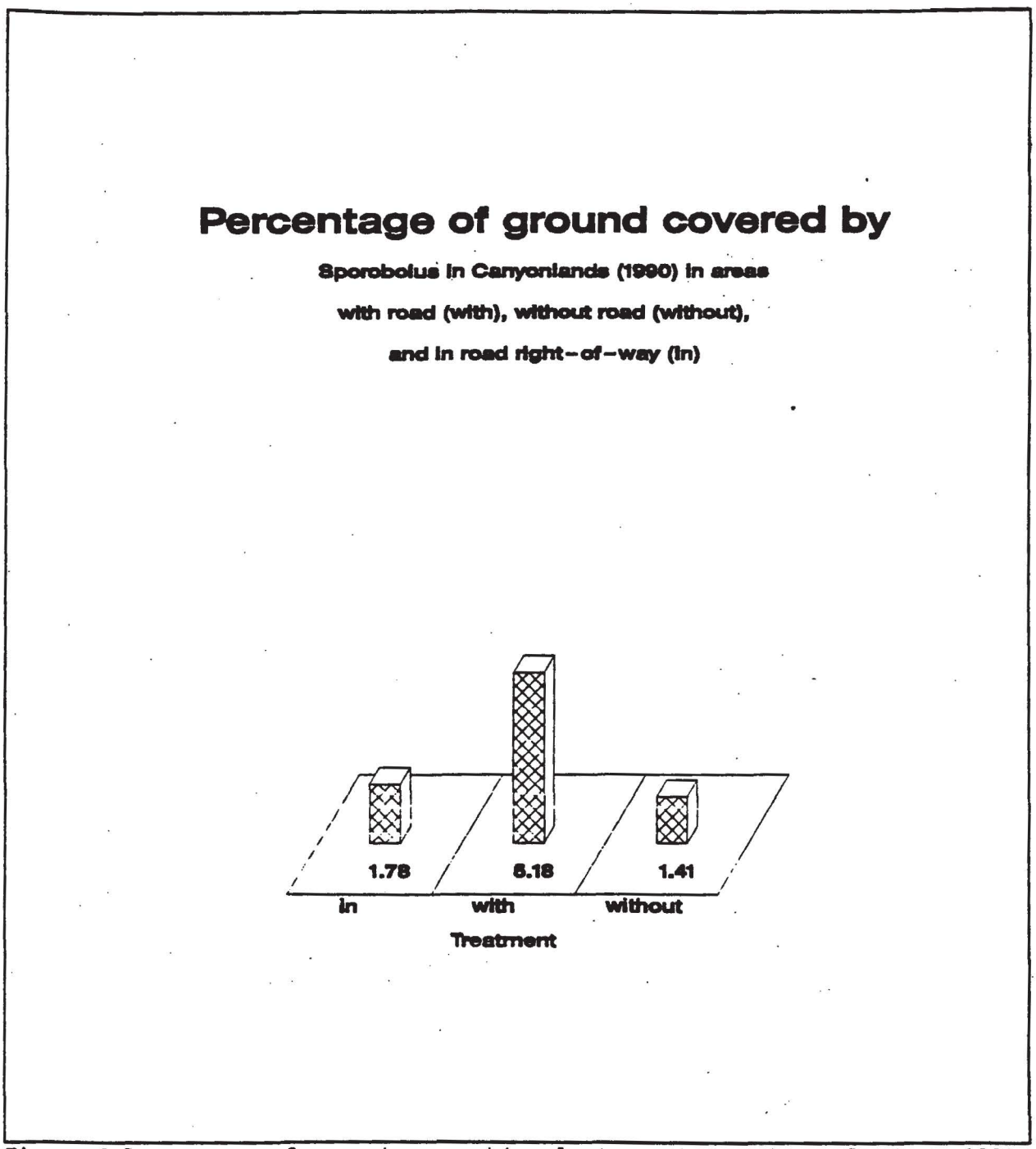

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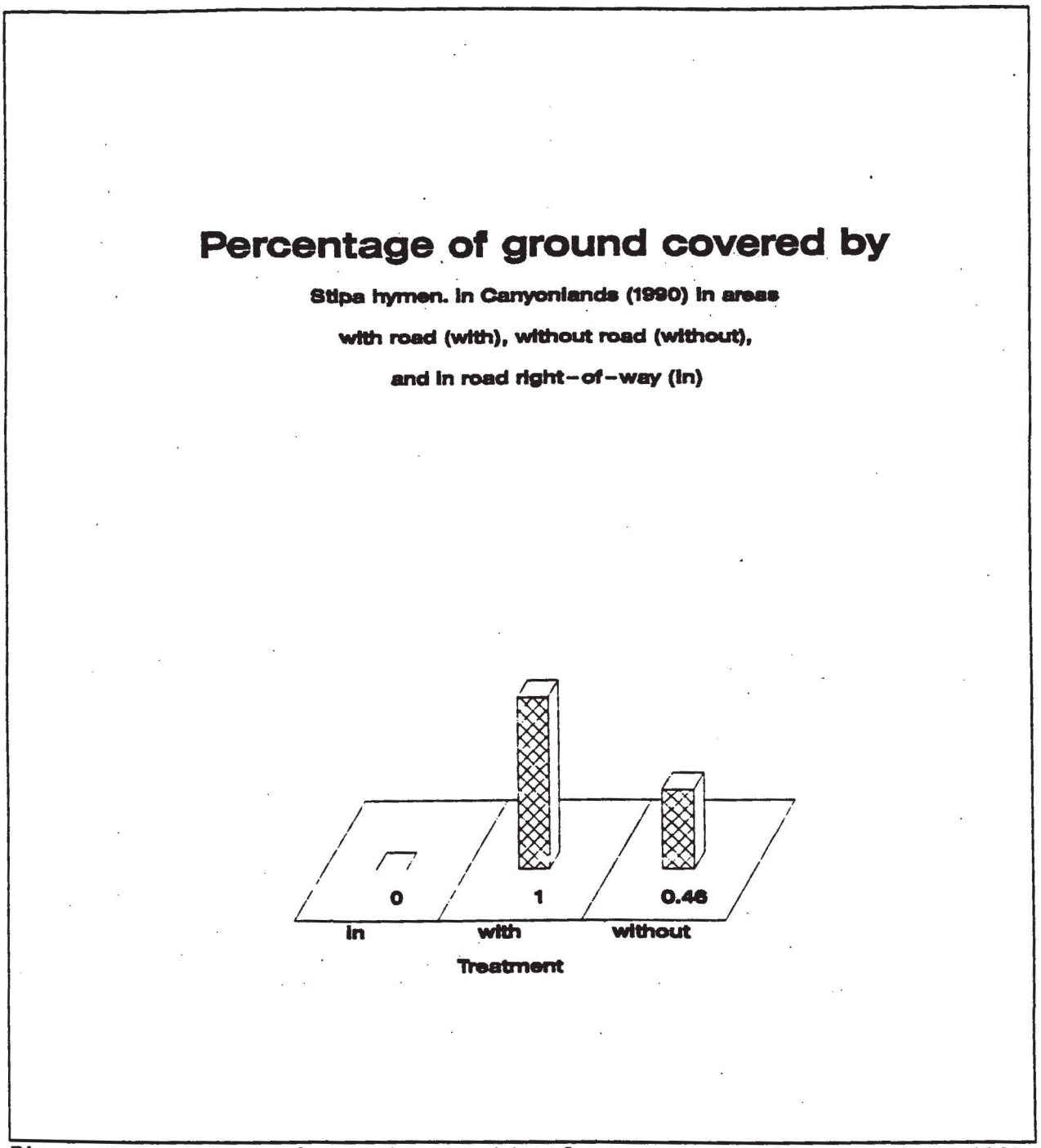

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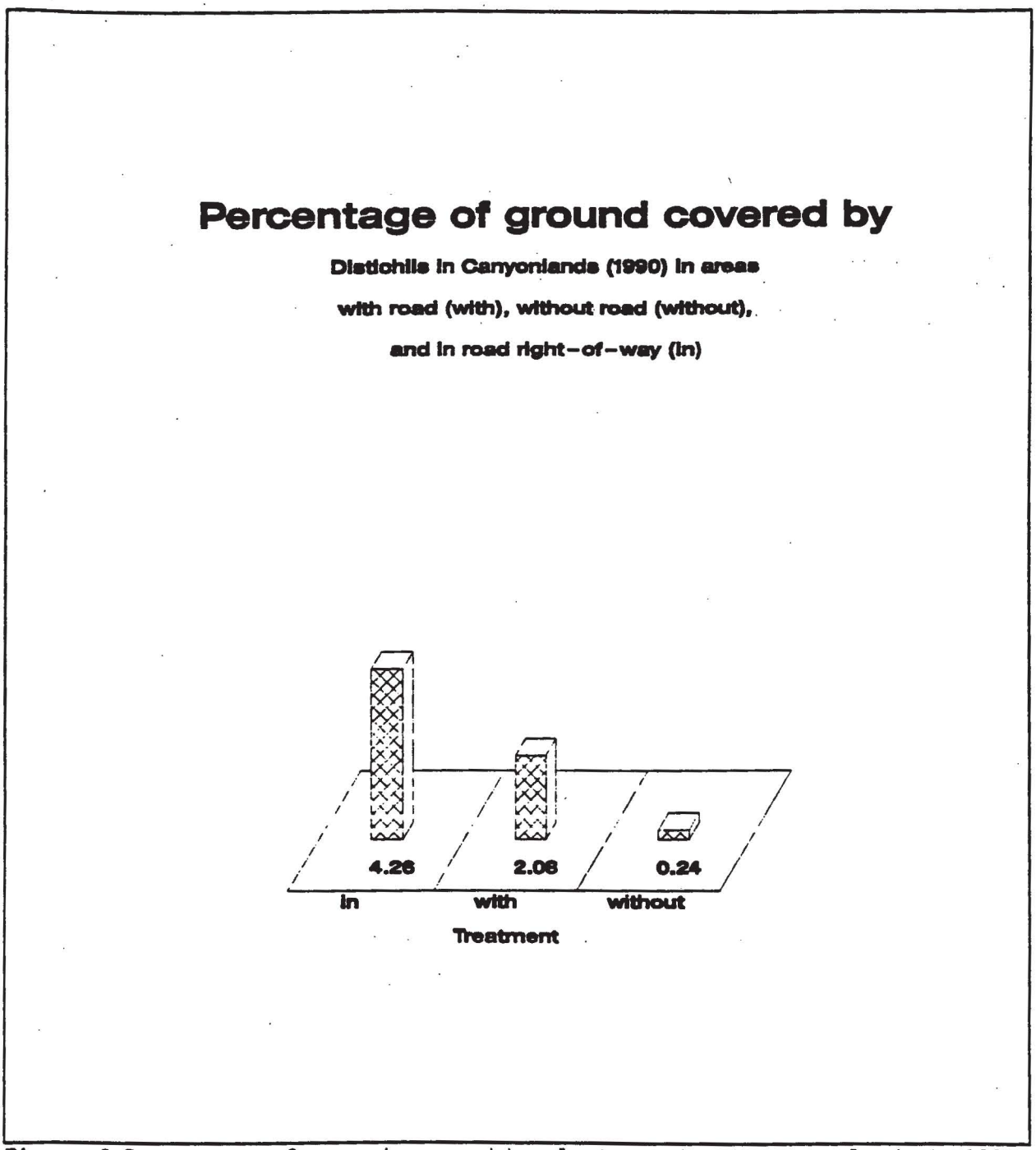

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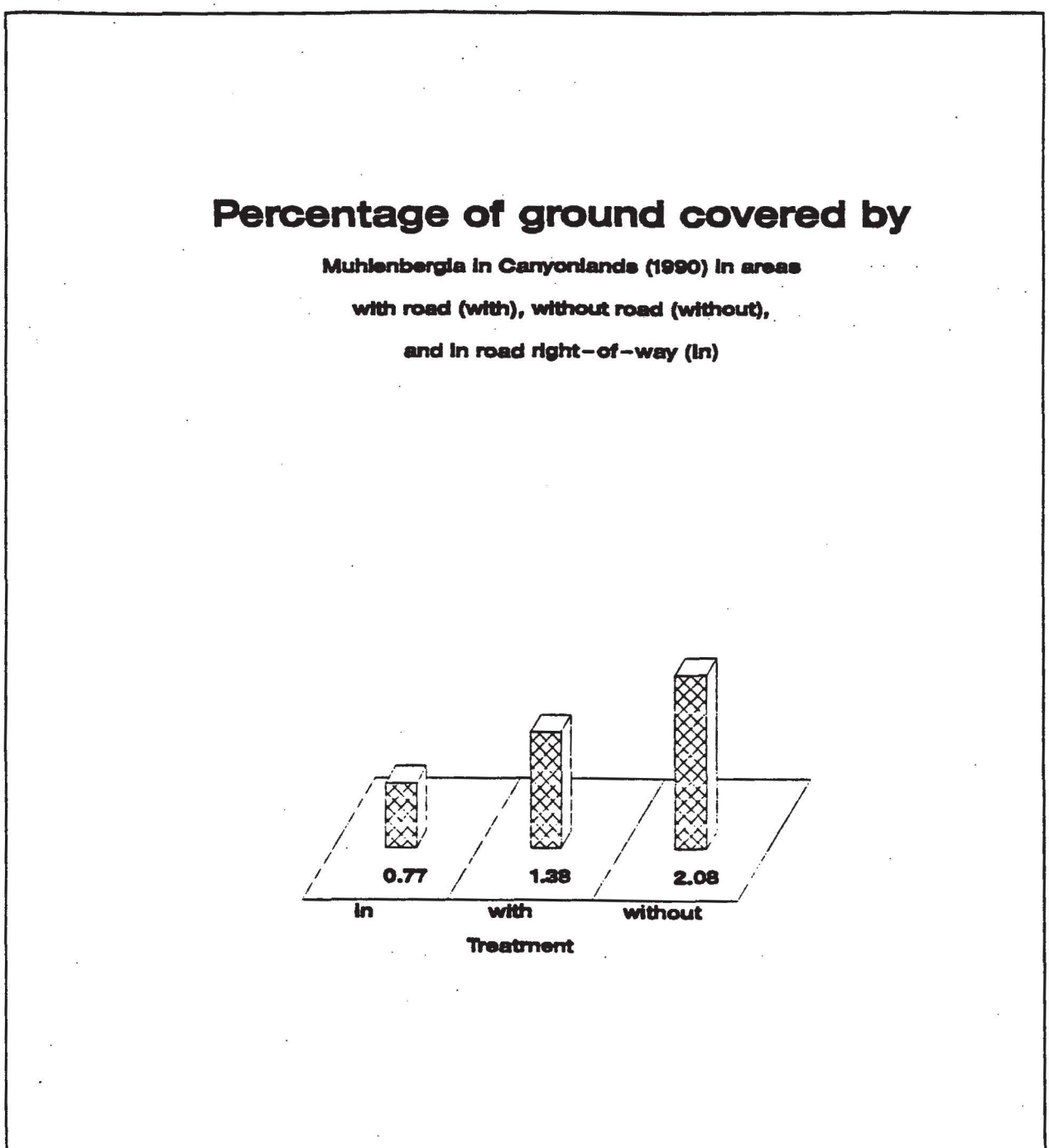

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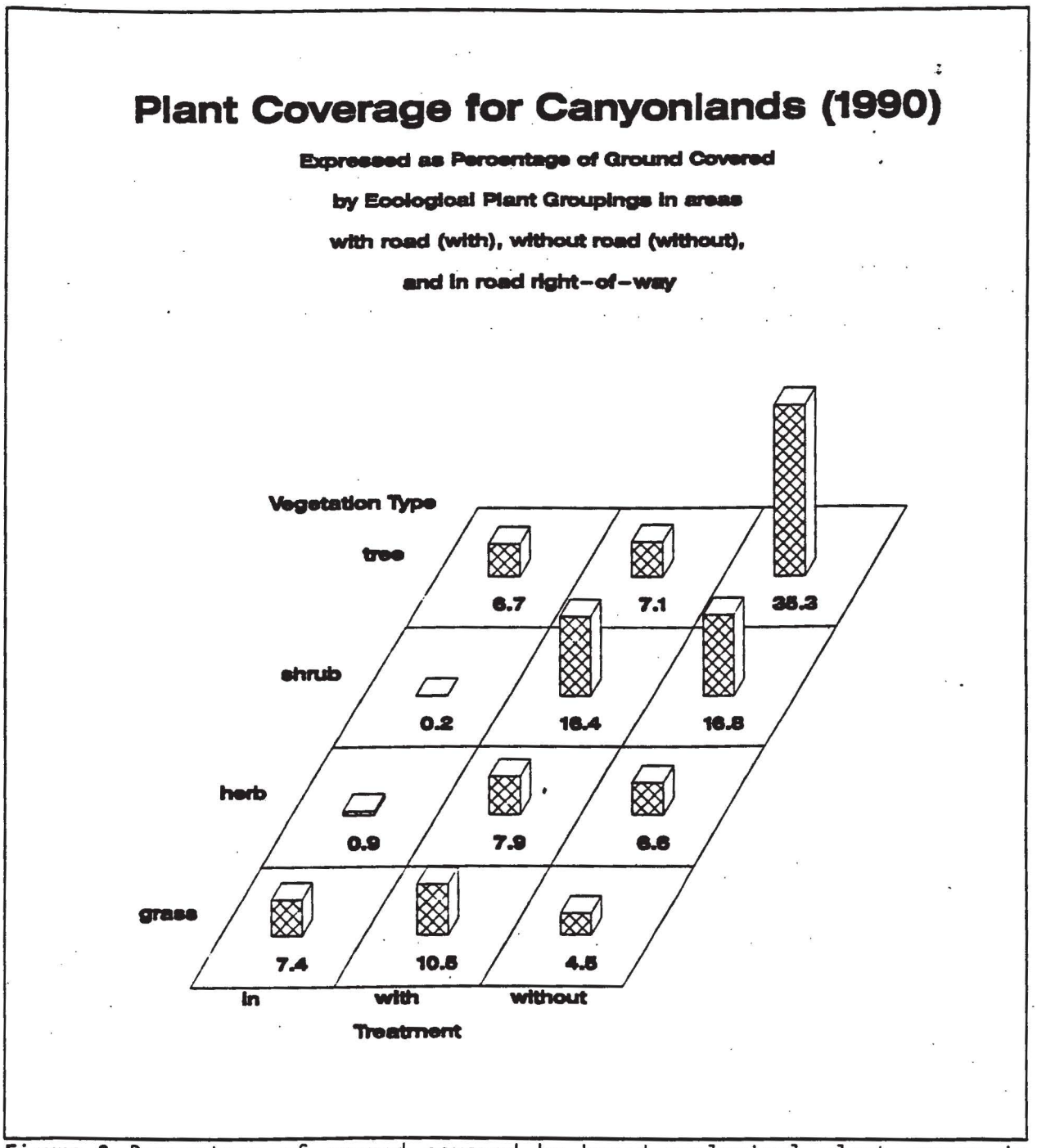
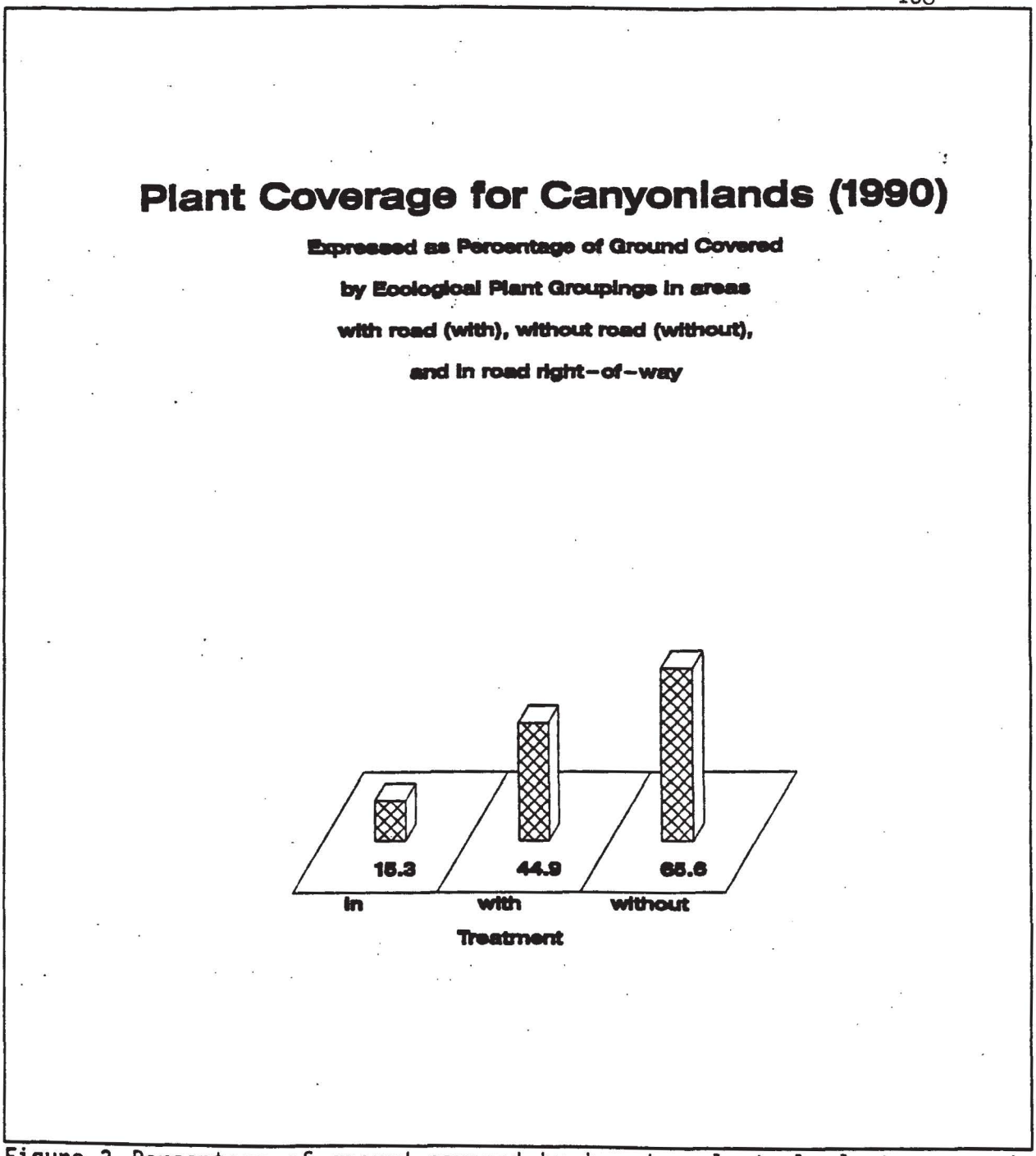


Figure 3 Percentage of ground covered by broad ecological plant groups in Canyonlands in 1990.



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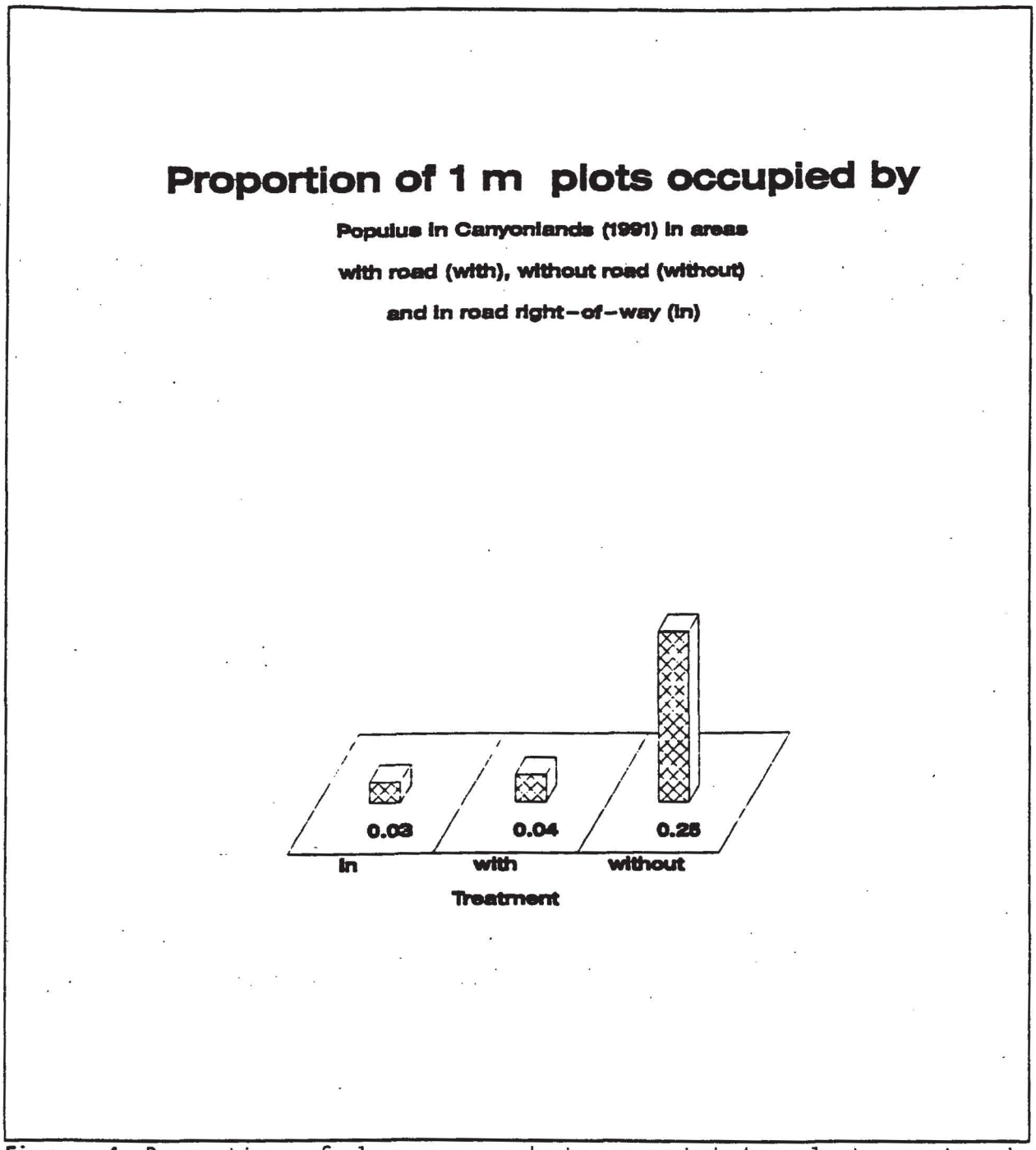
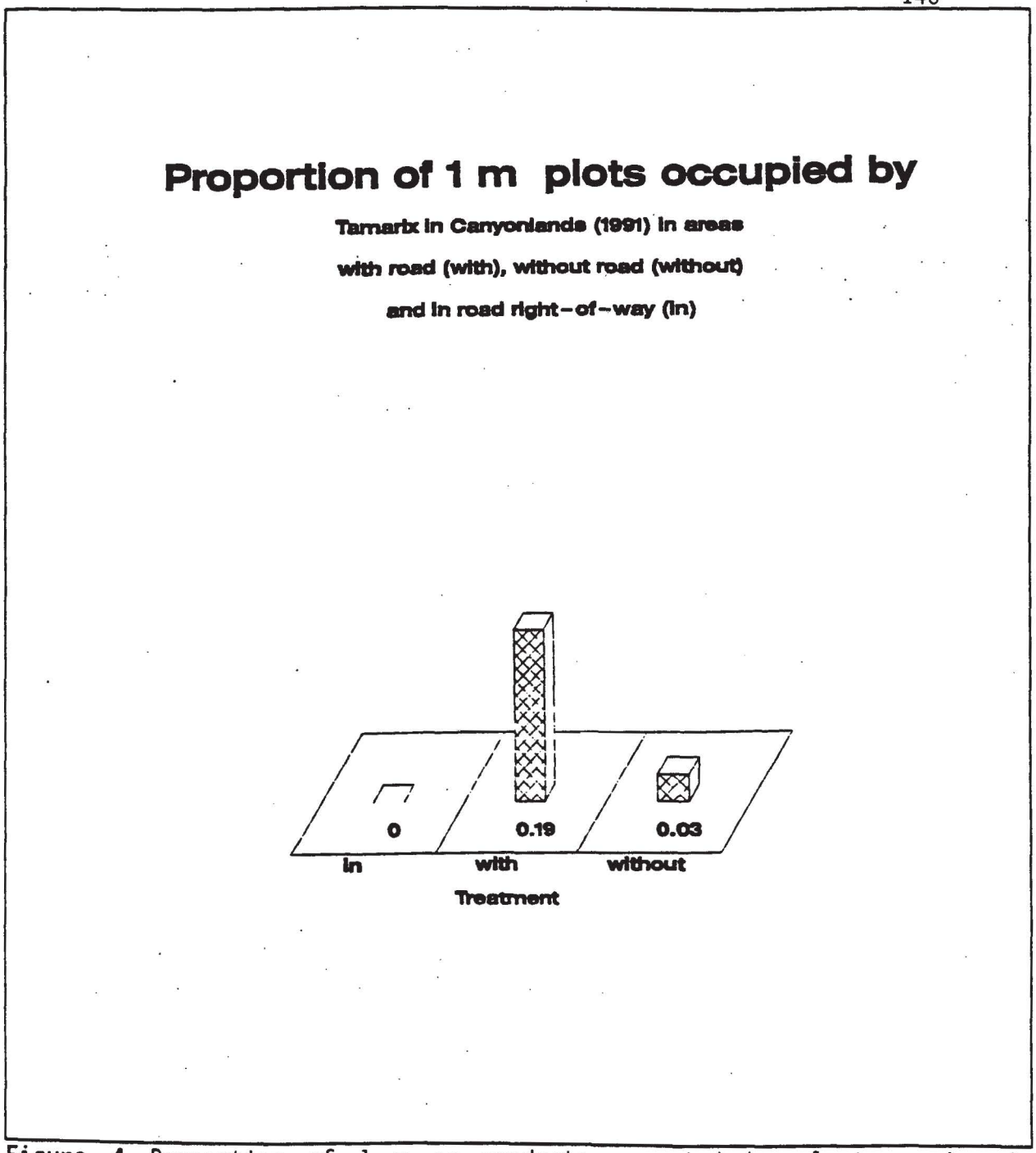


Figure 4 Proportion of 1 m sq quadrats occupied by plant species in Canyonlands in 1991.



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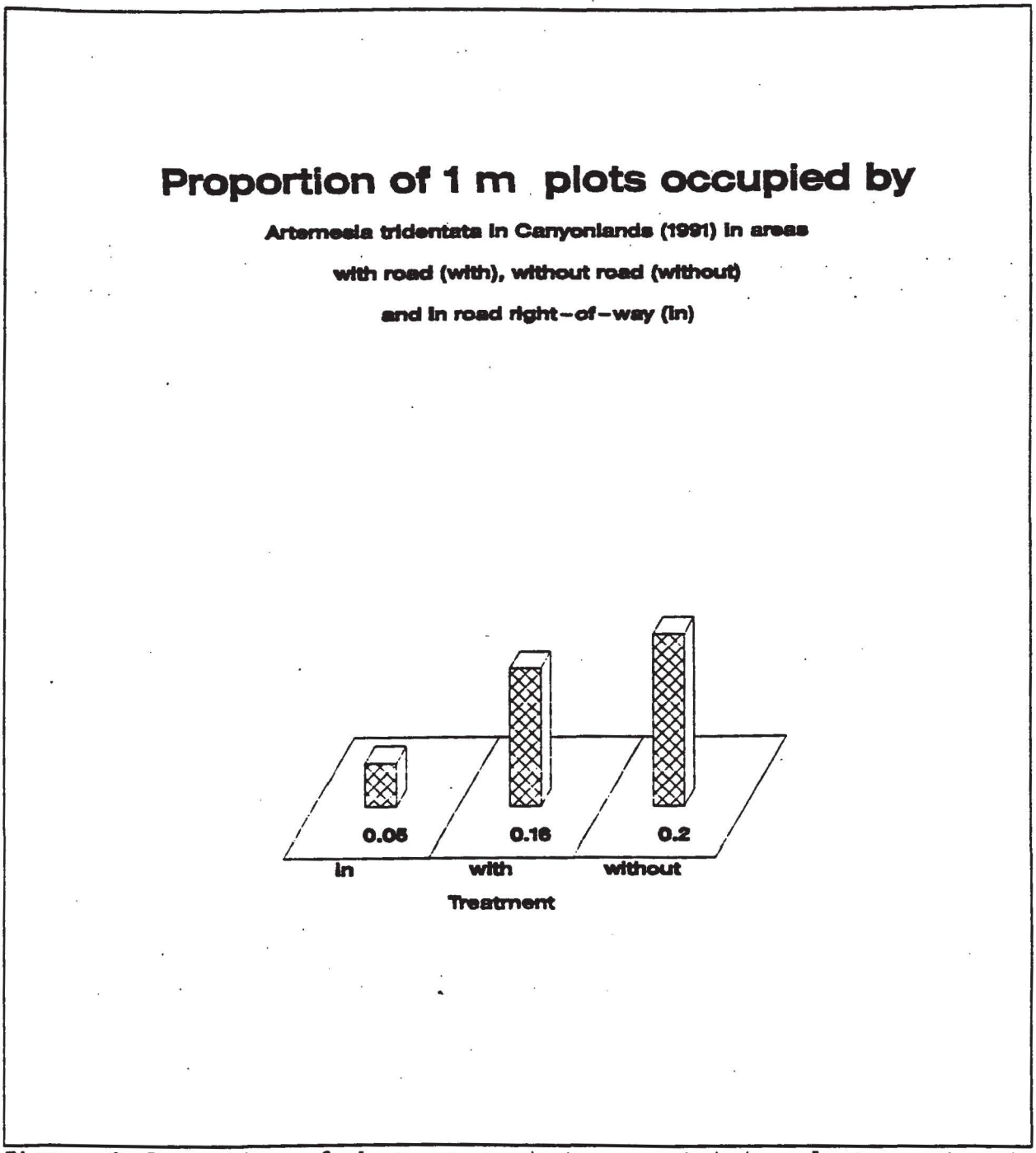

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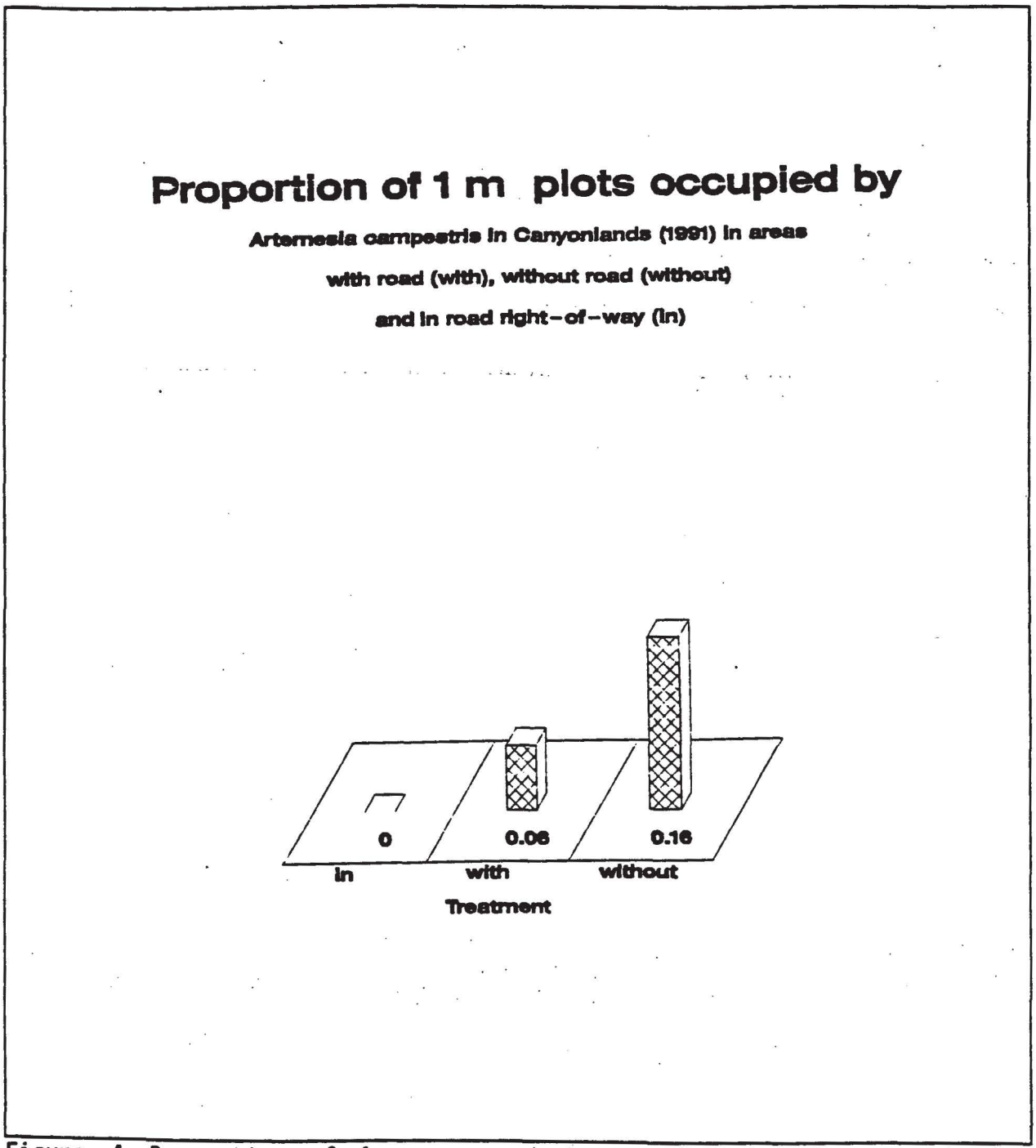

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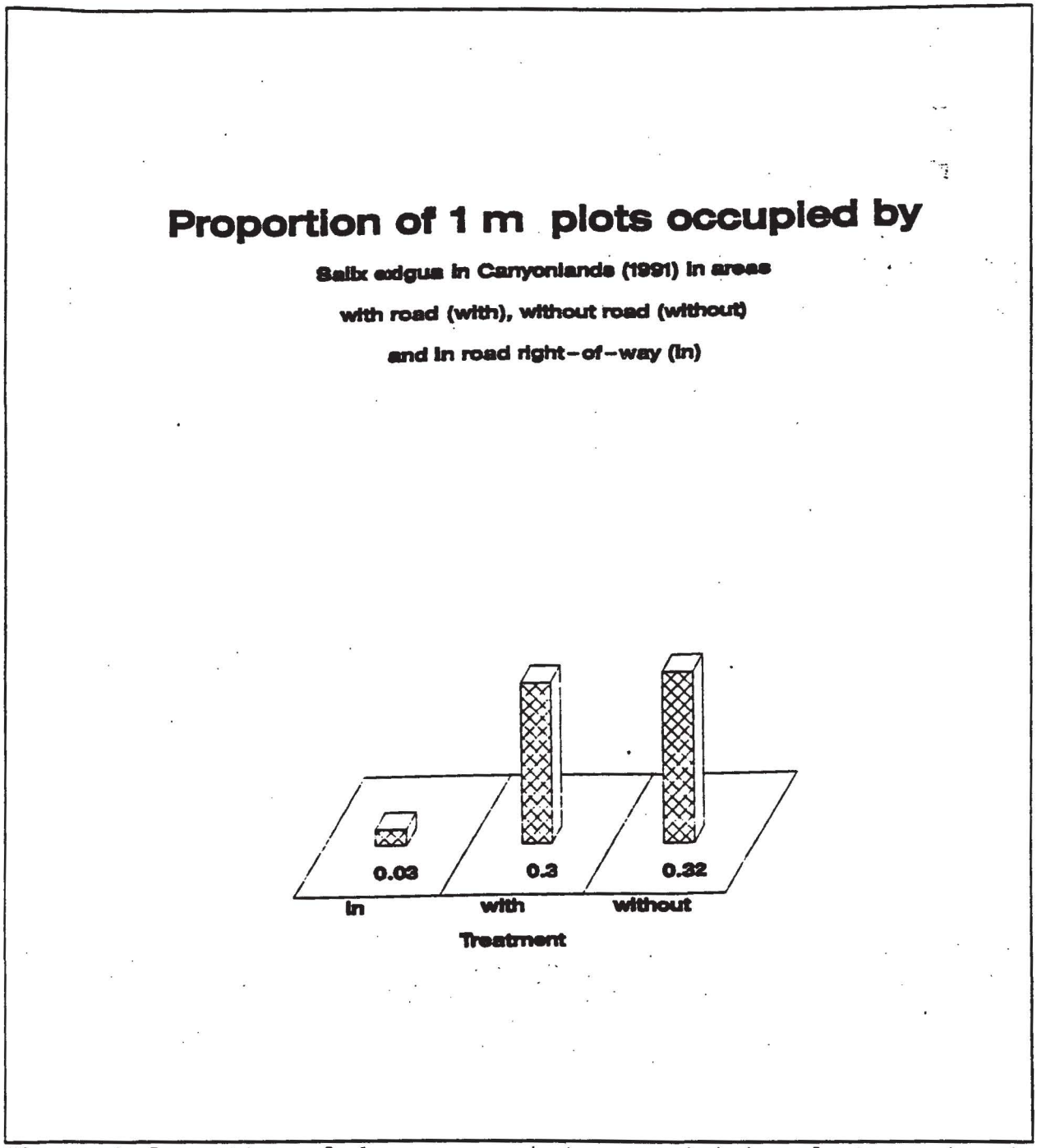

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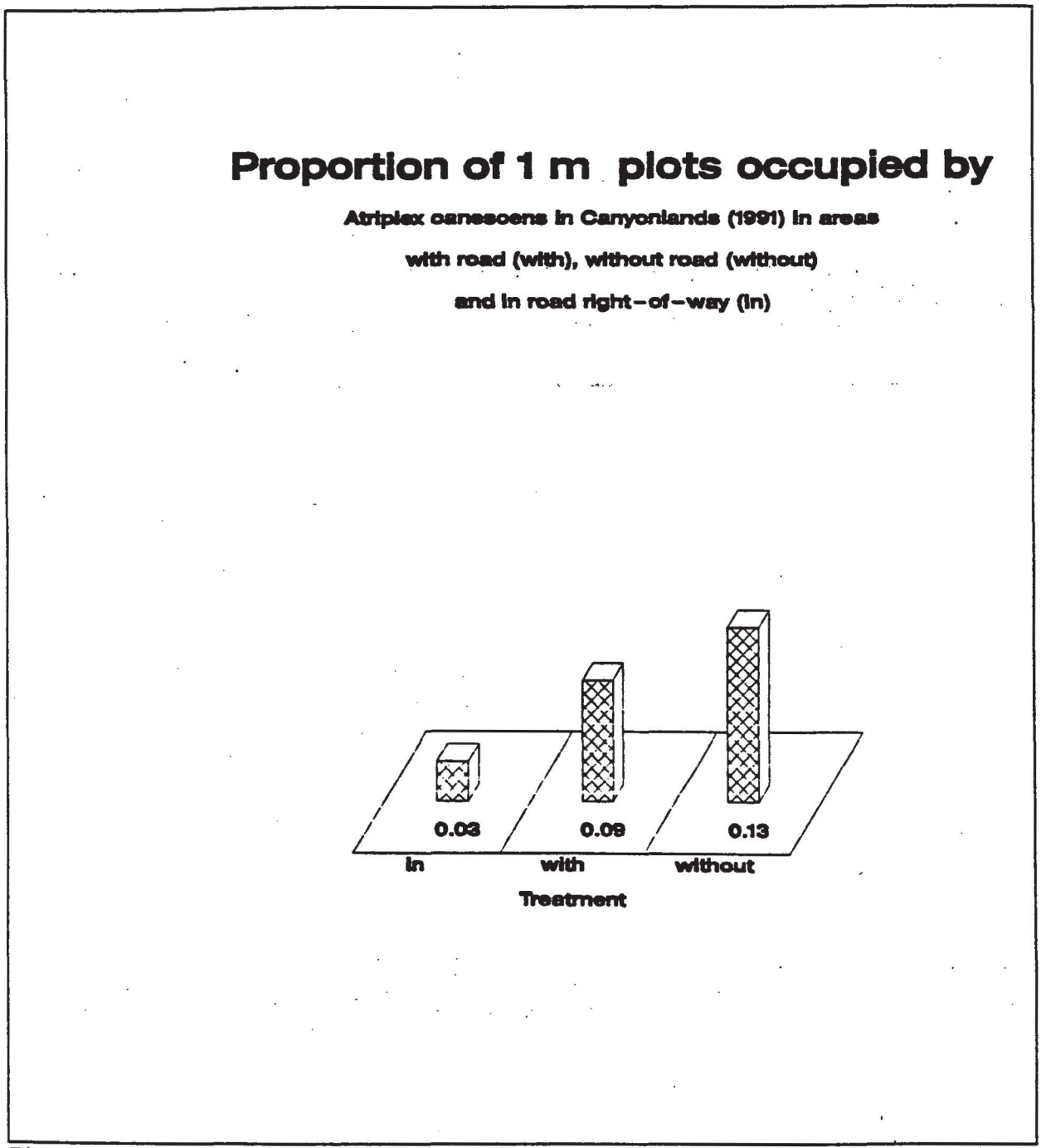
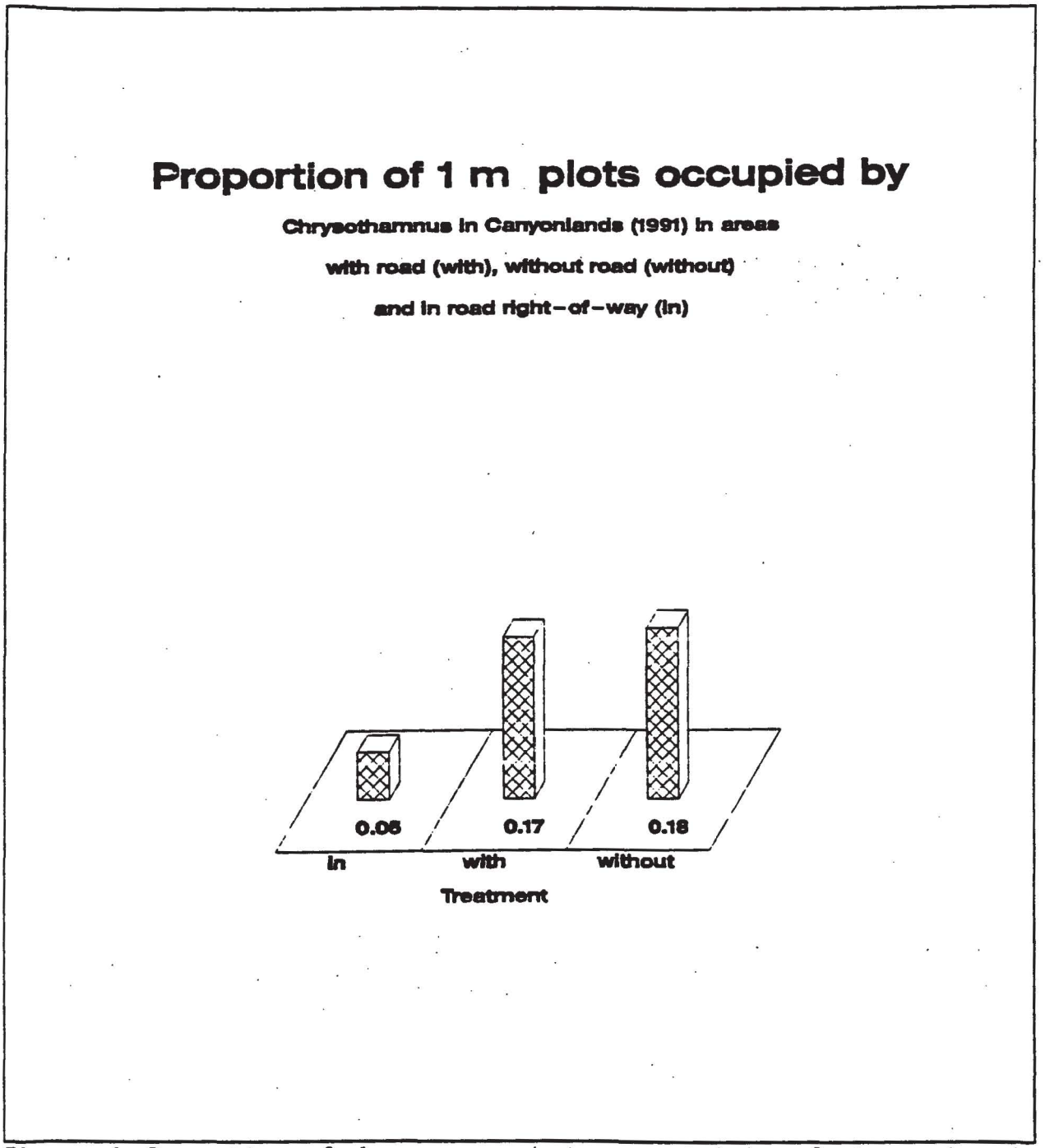


Figure 4 Percentage of ground covered by plant species in Canyonlands in 1991.



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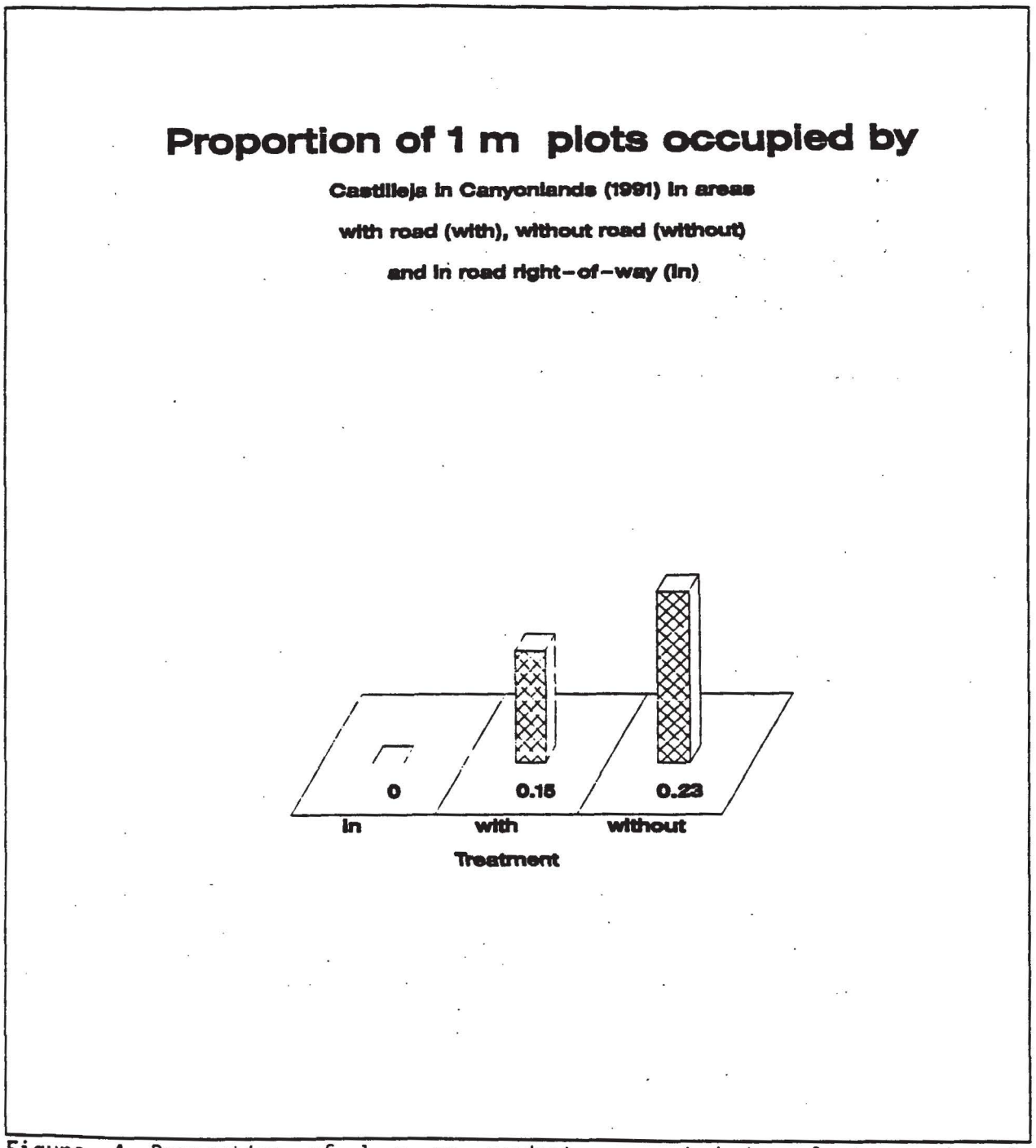

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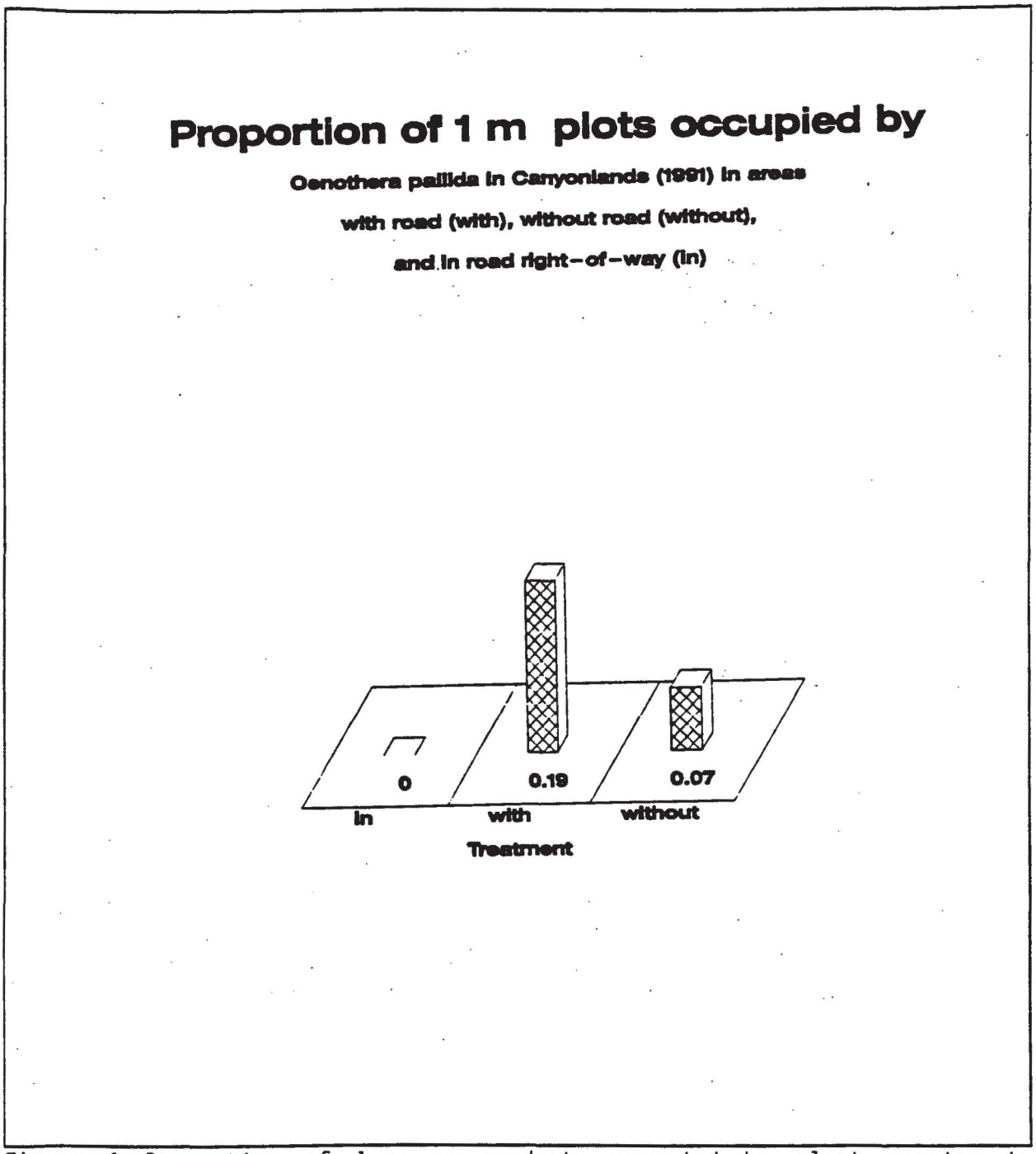

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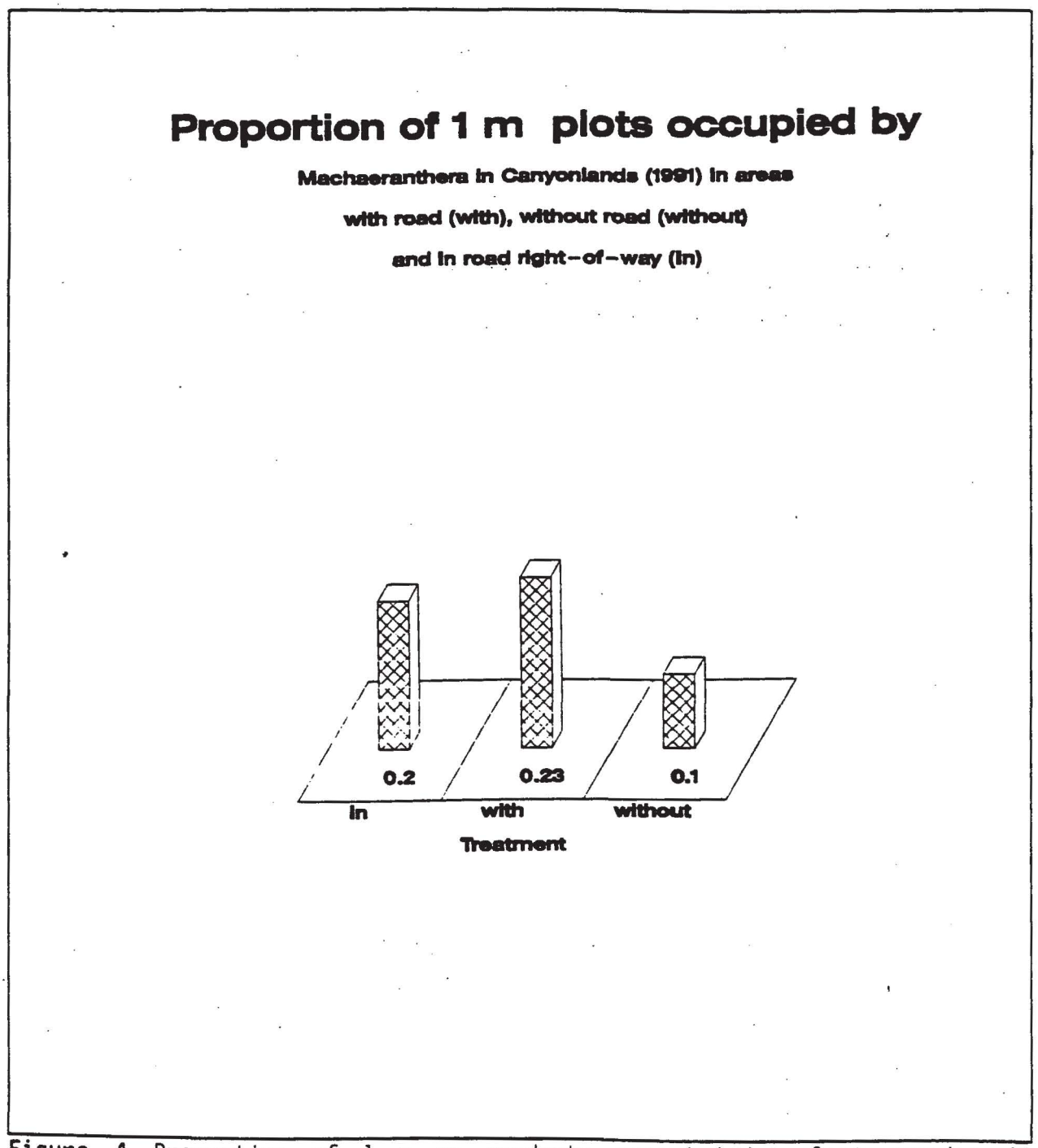

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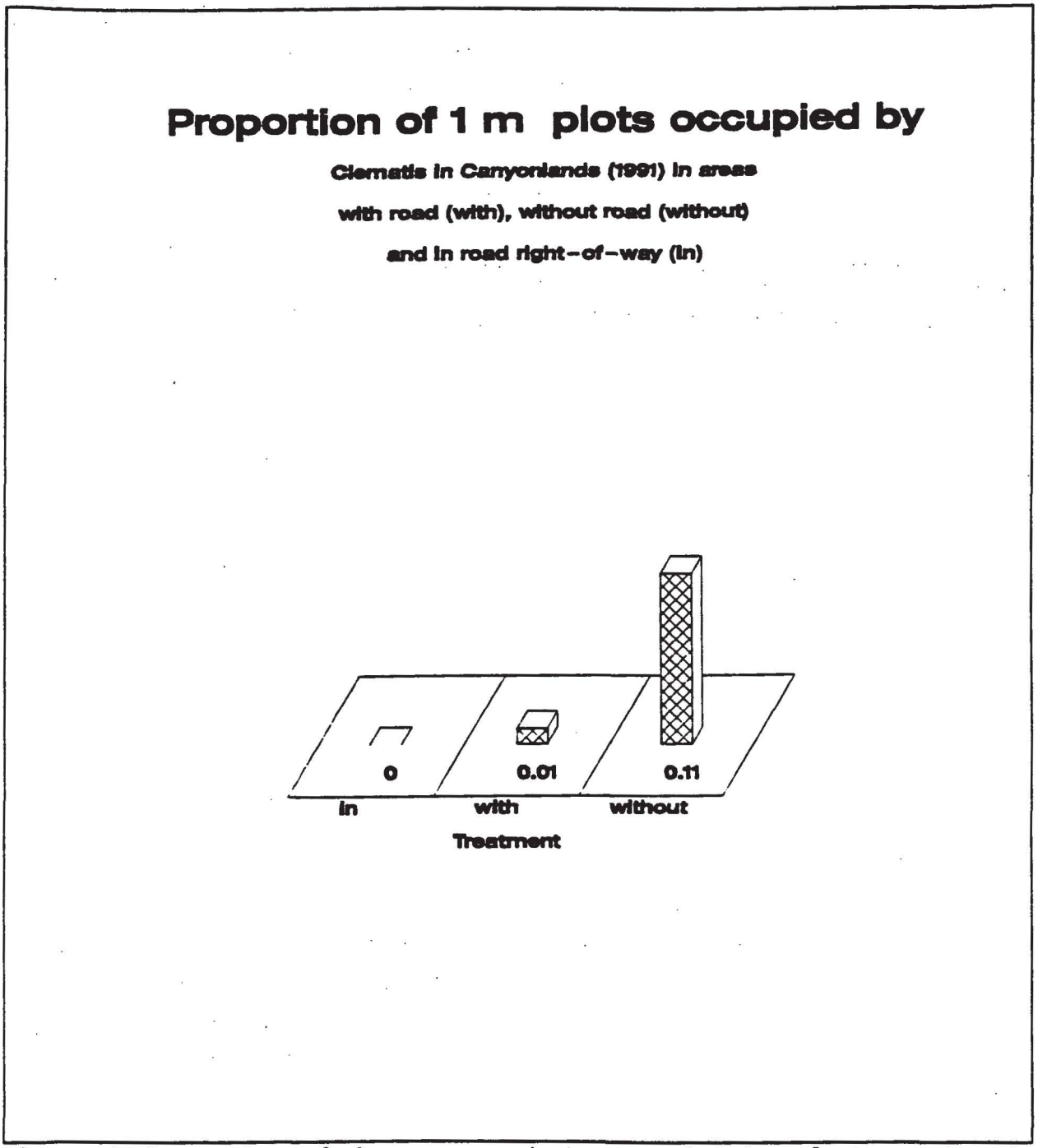

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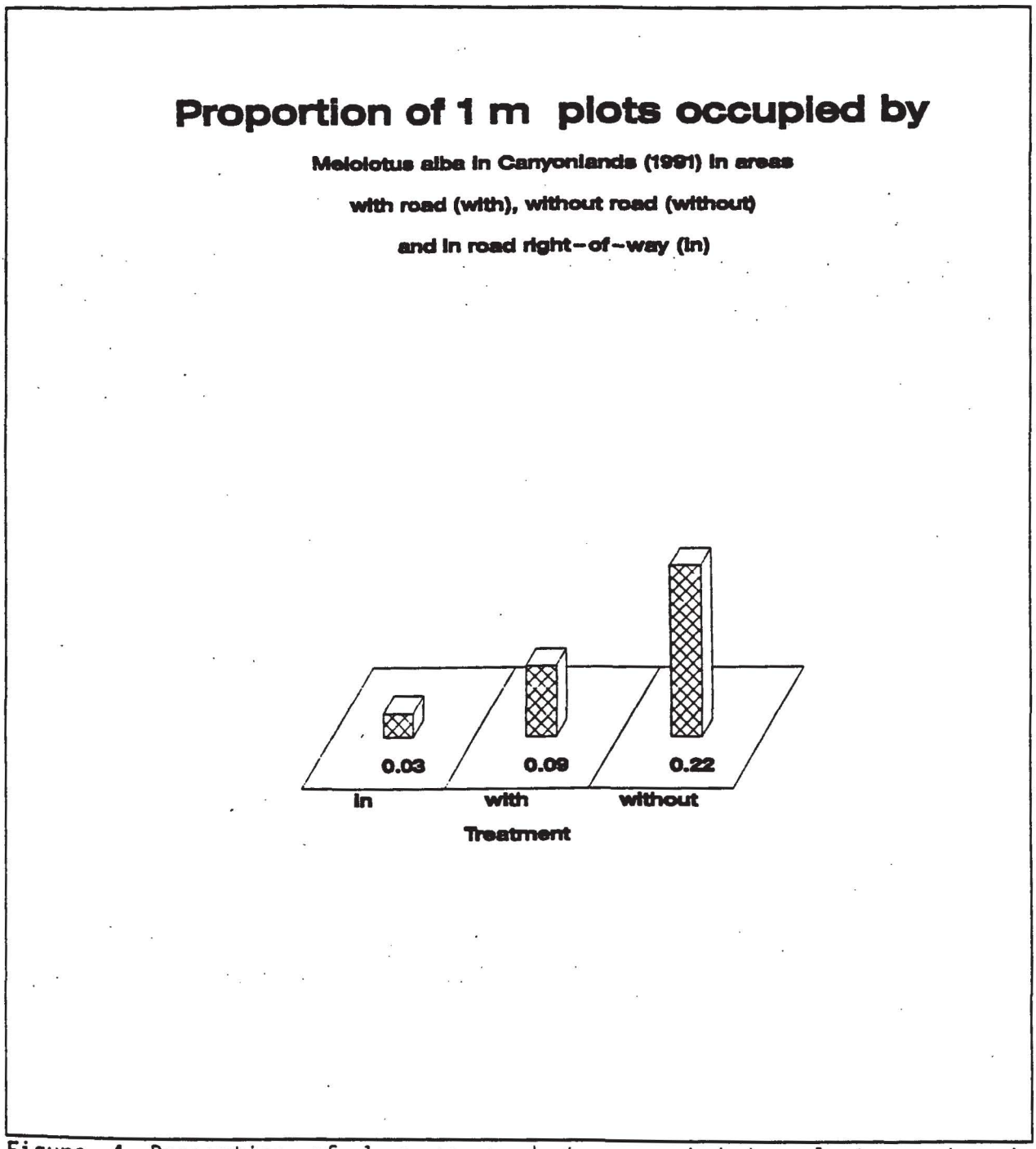

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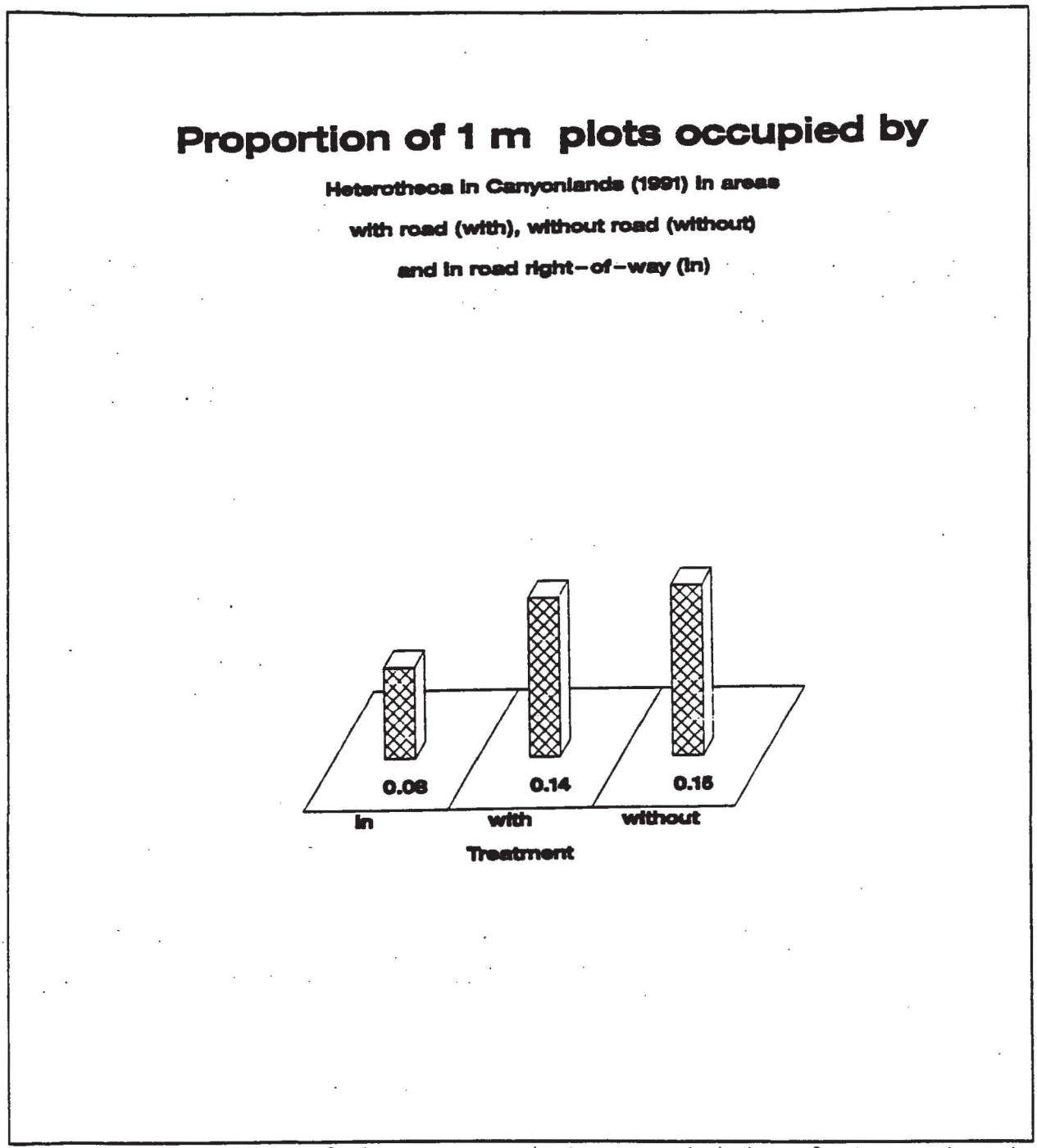

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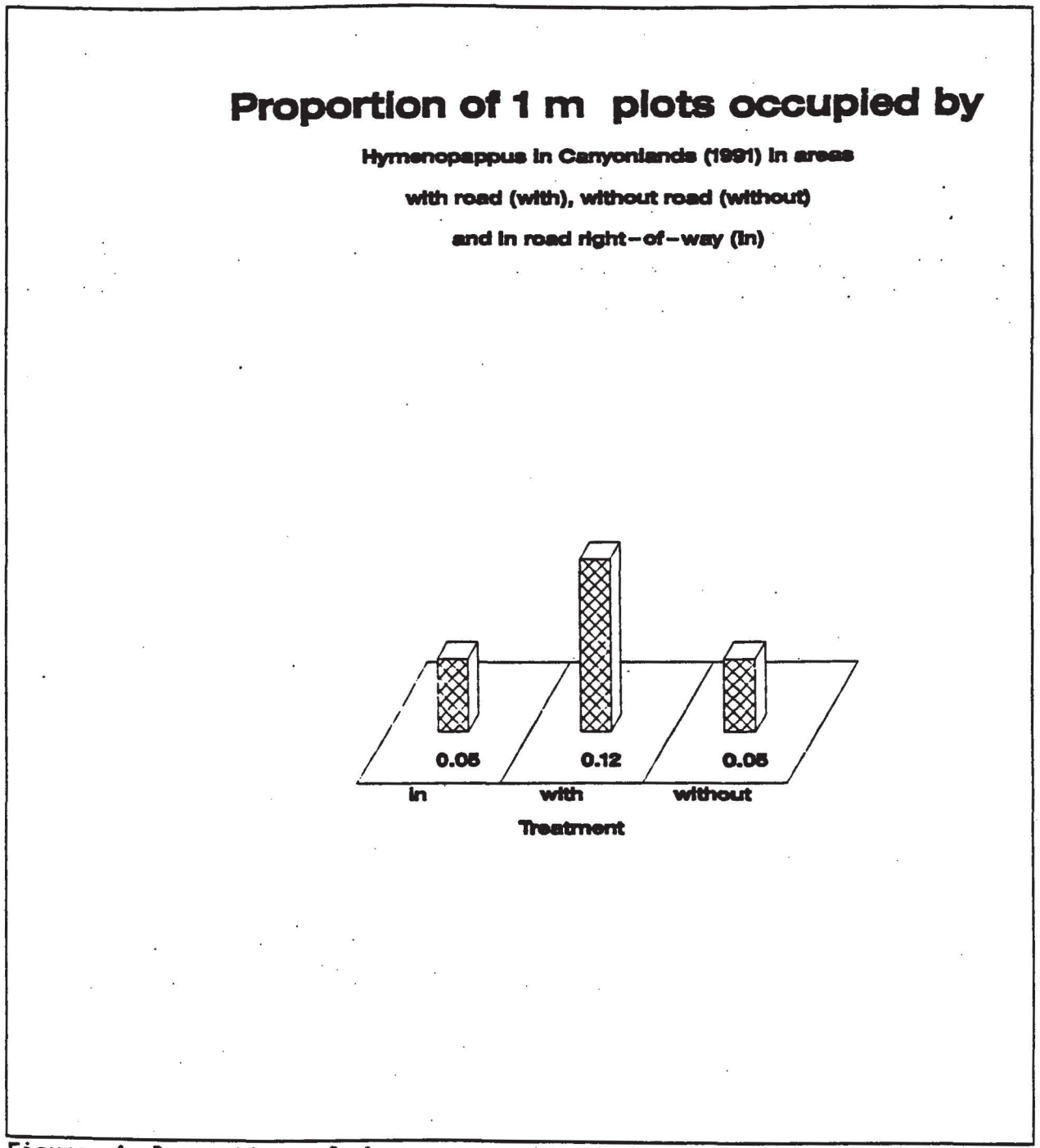

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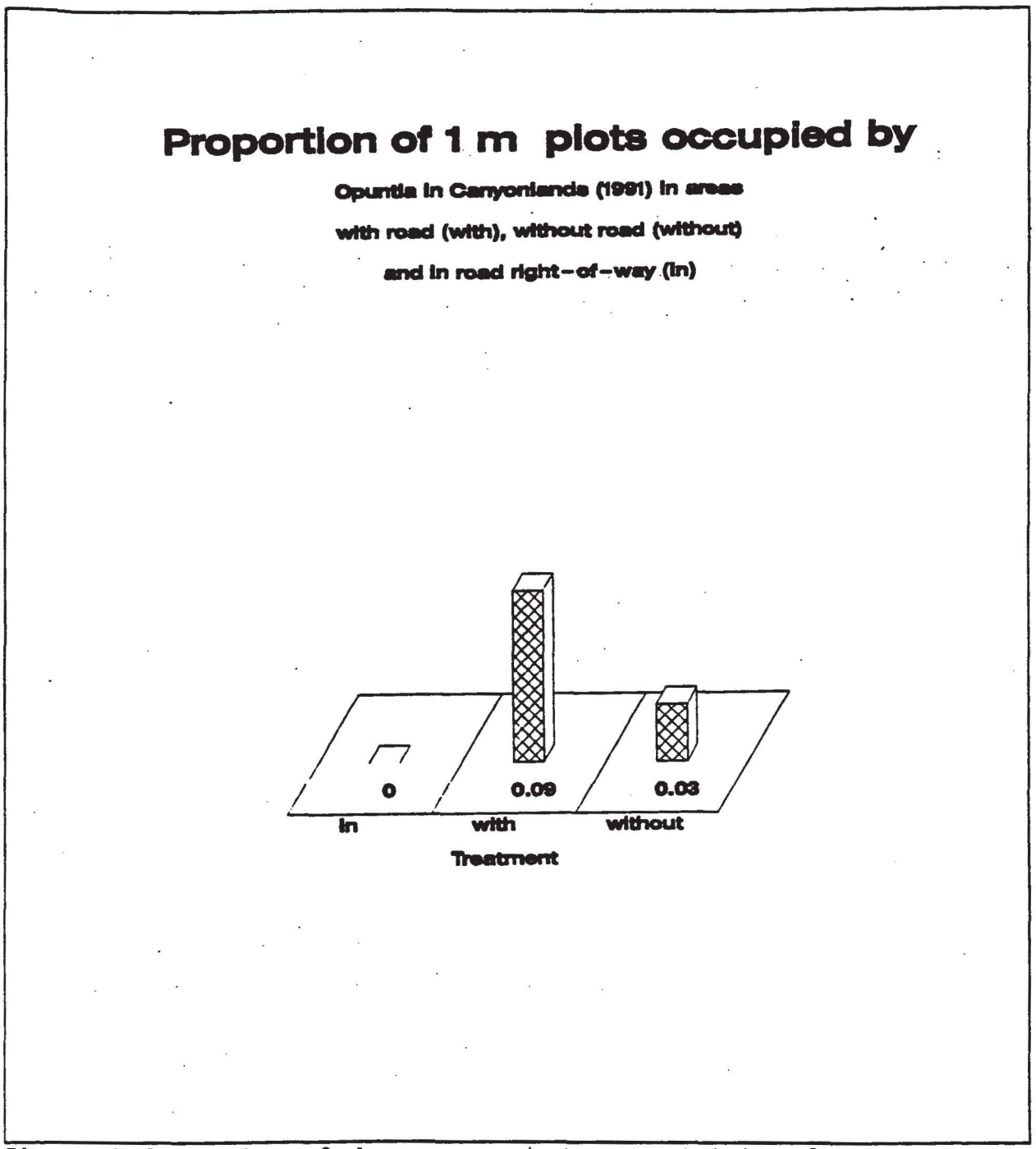

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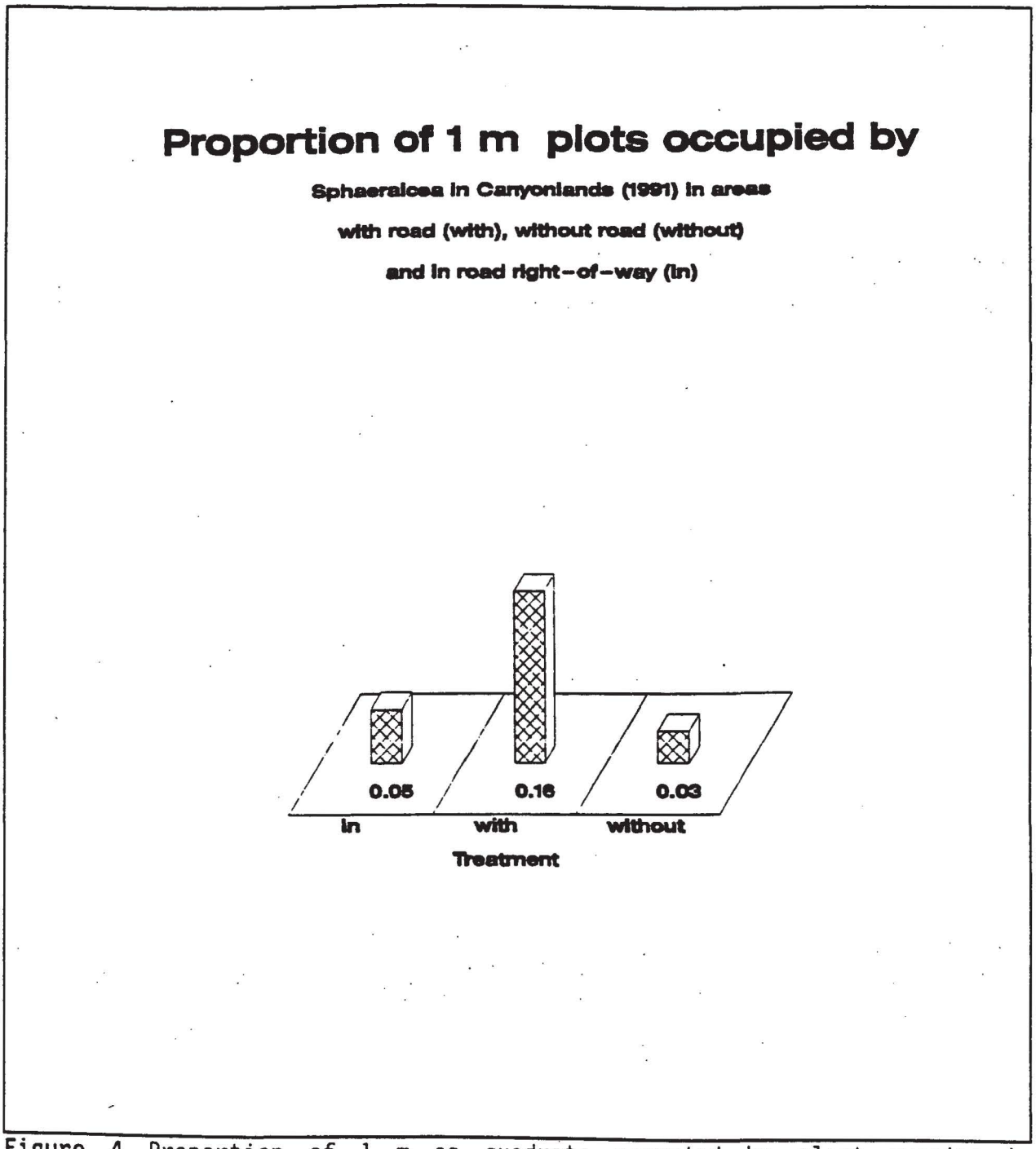

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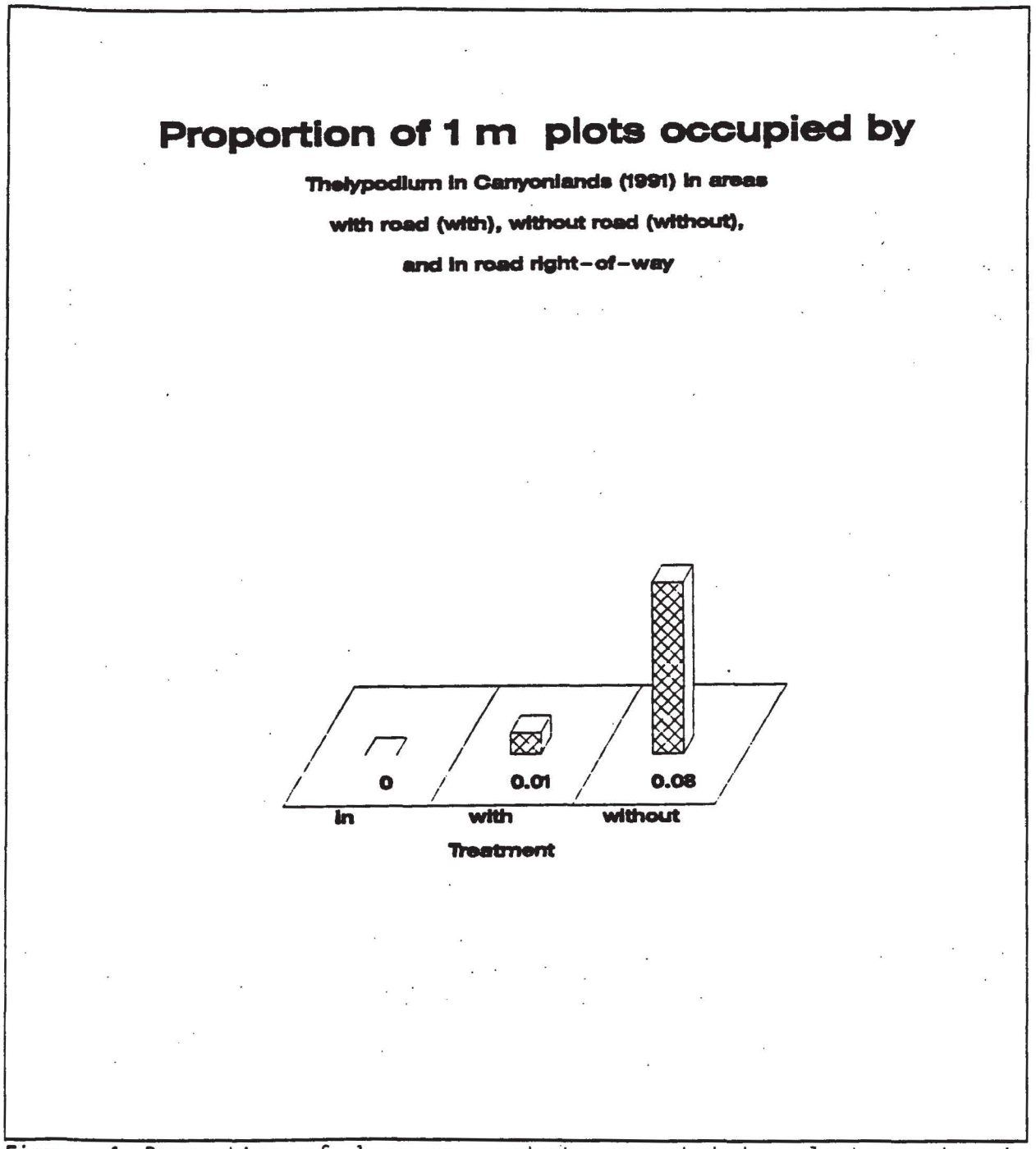

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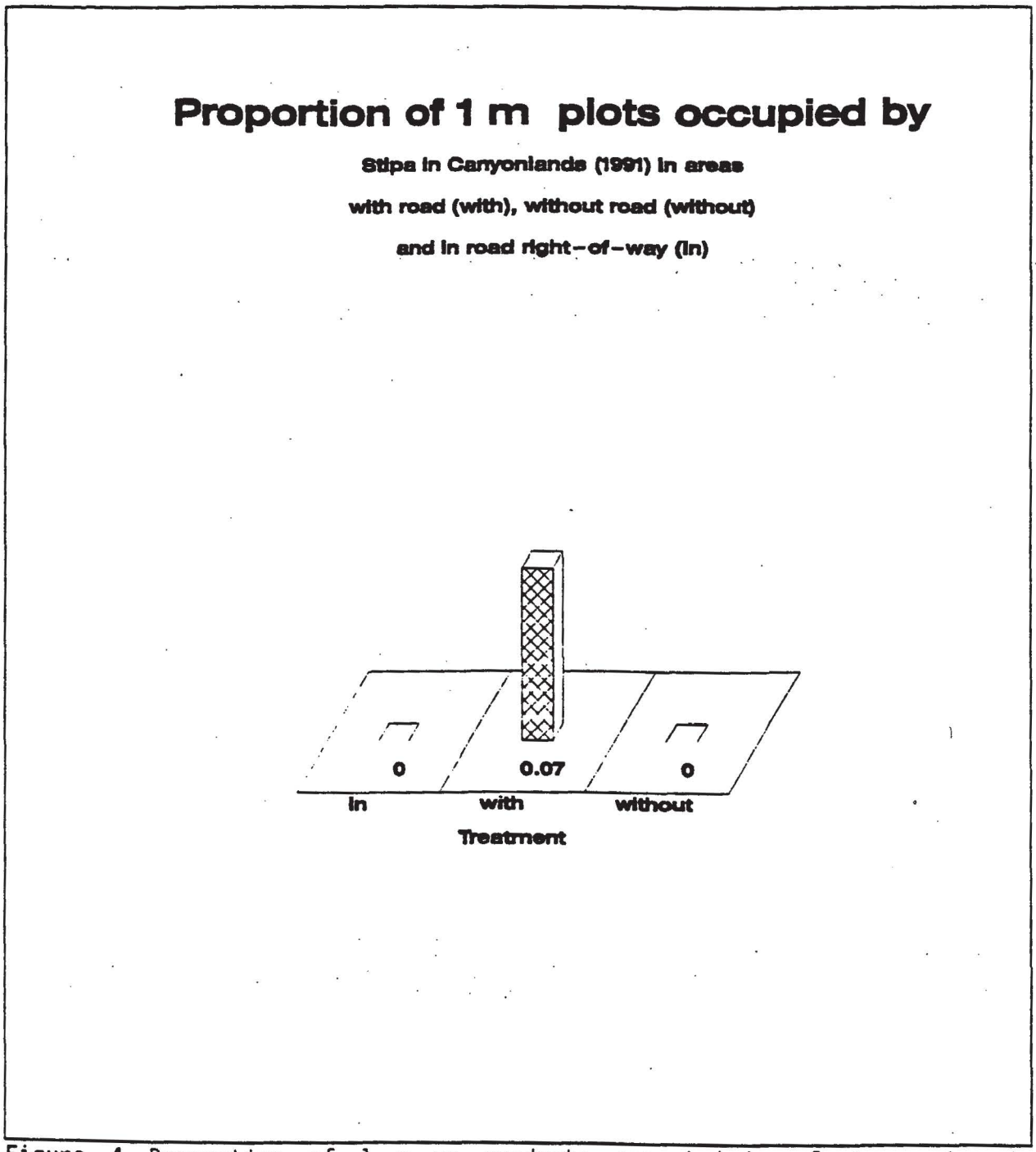

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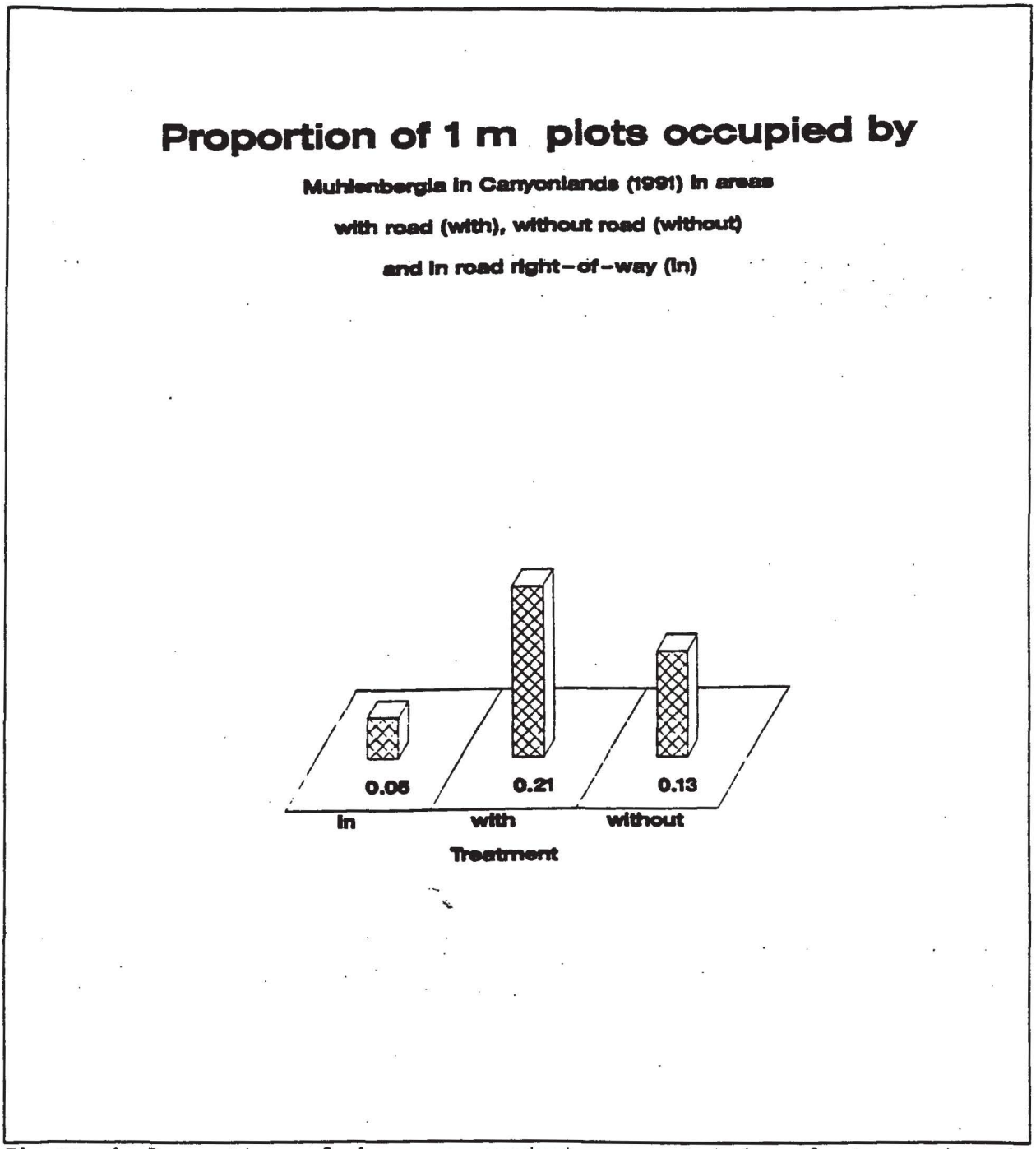

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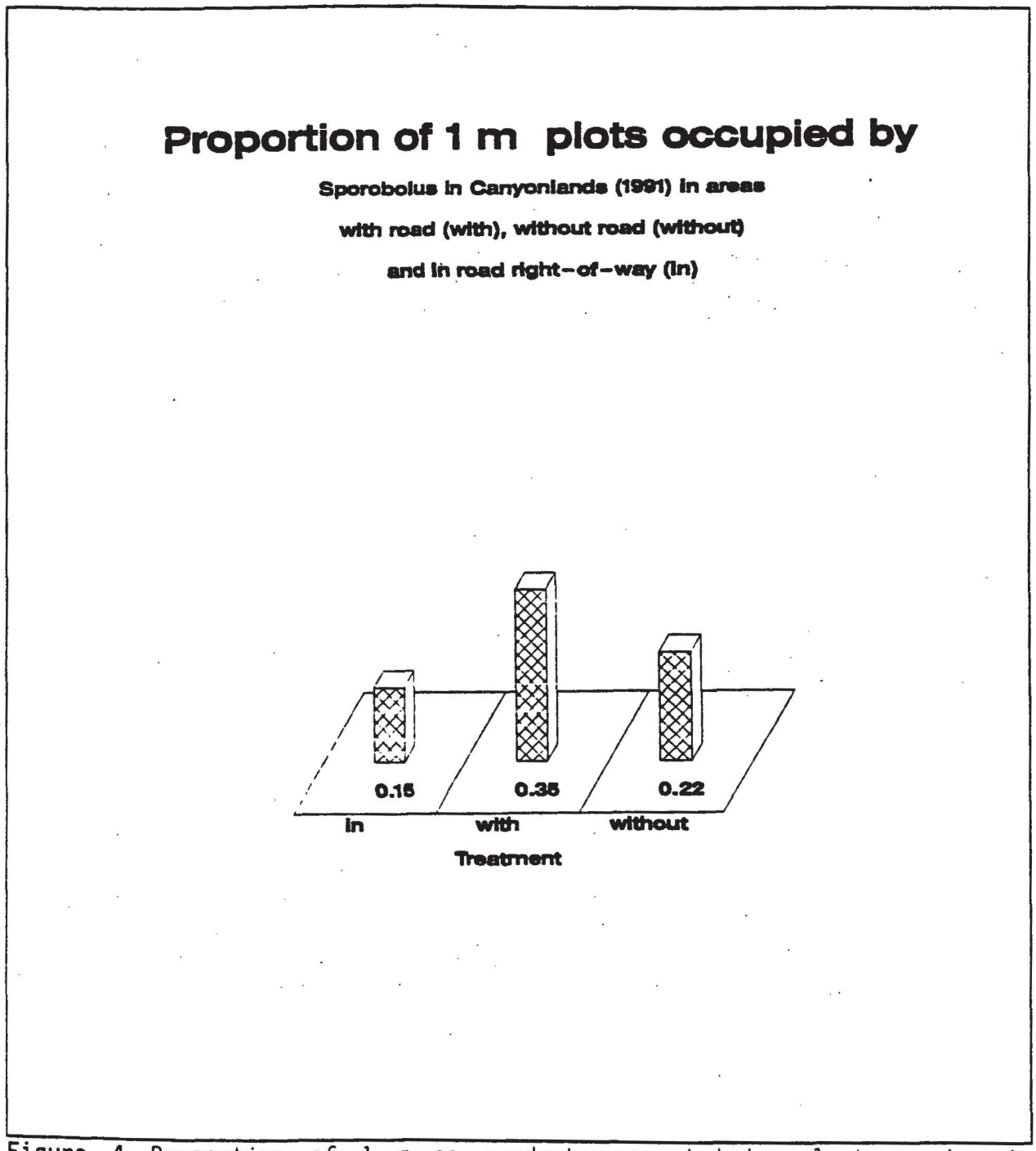

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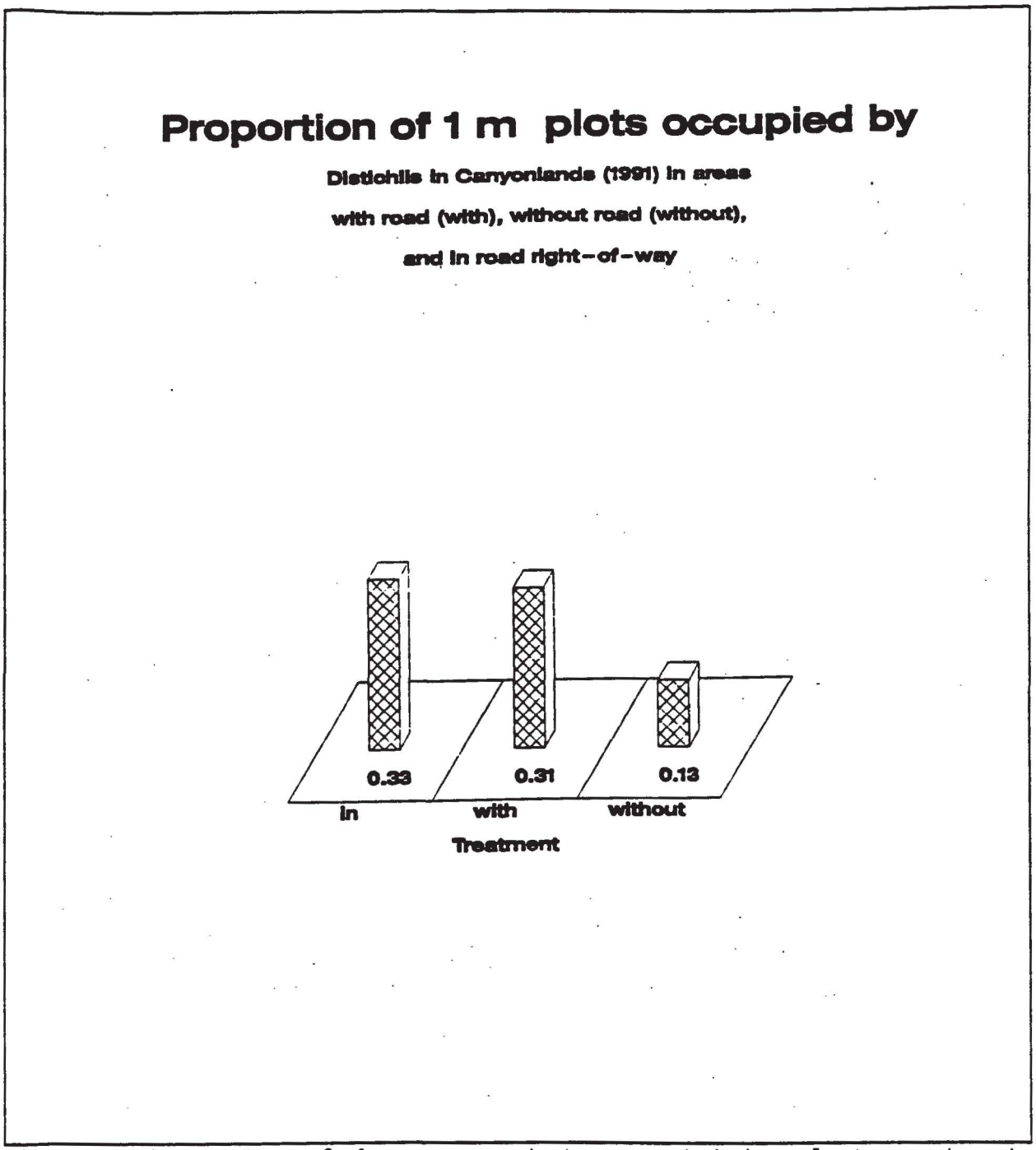

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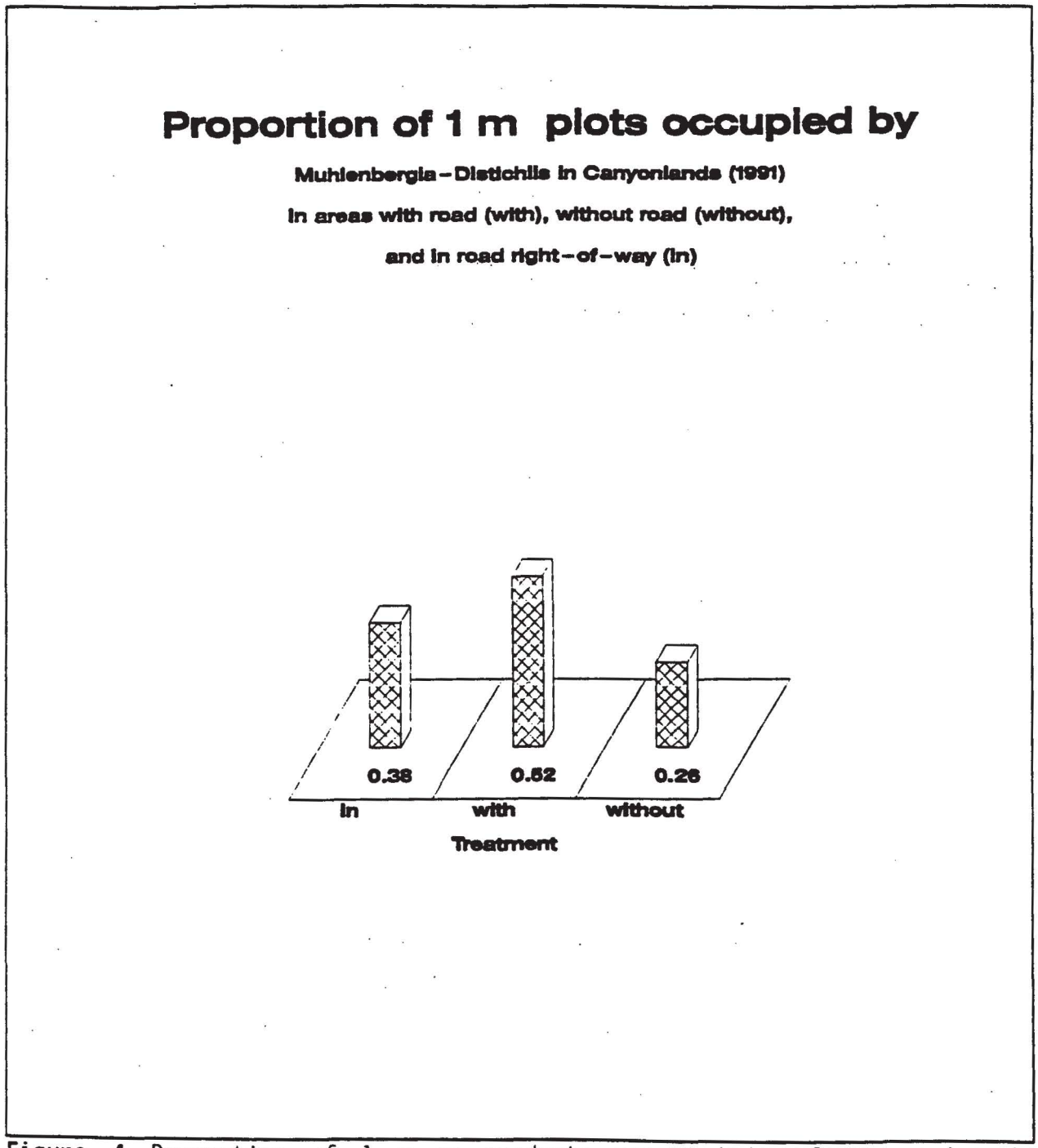

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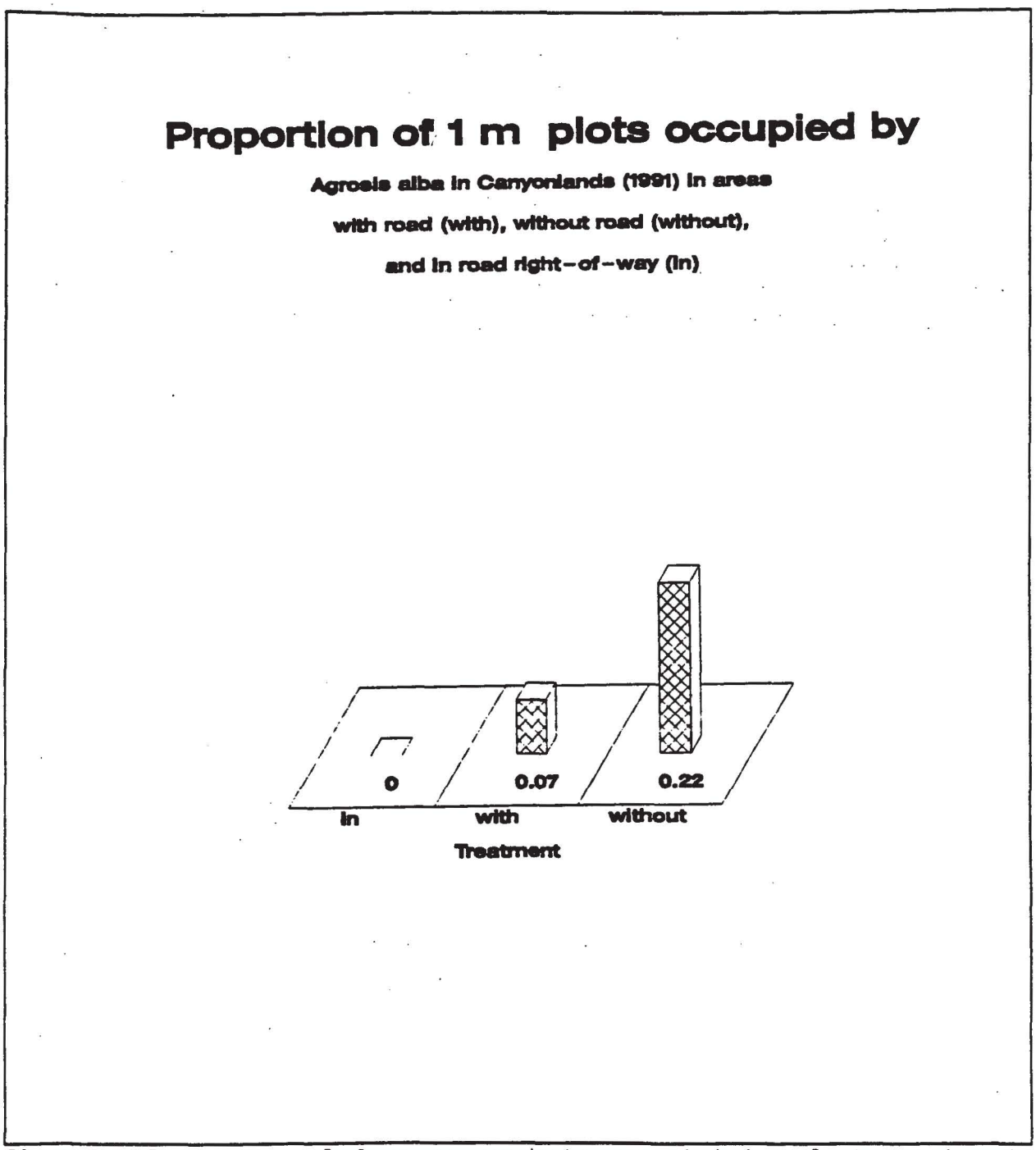

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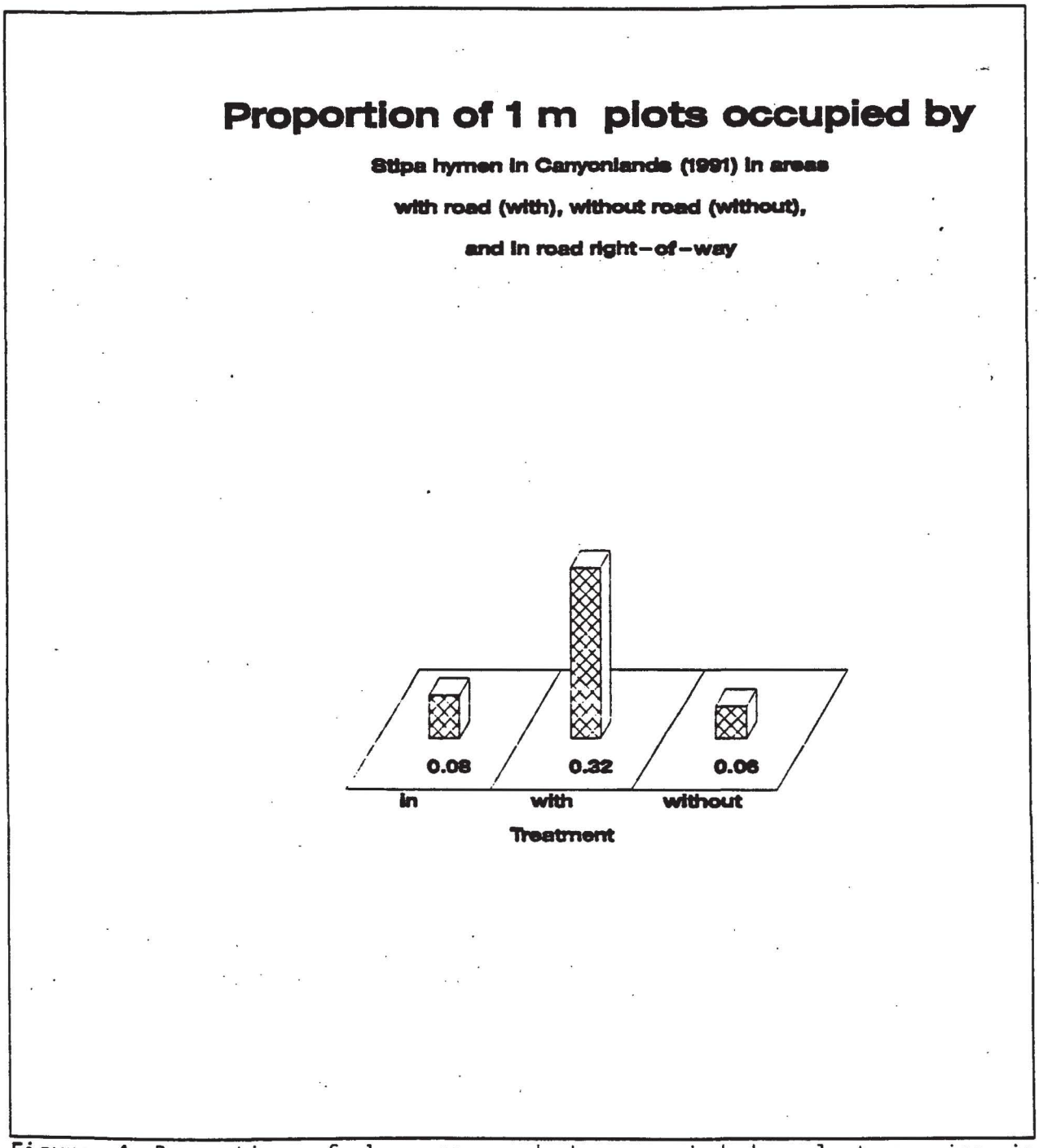

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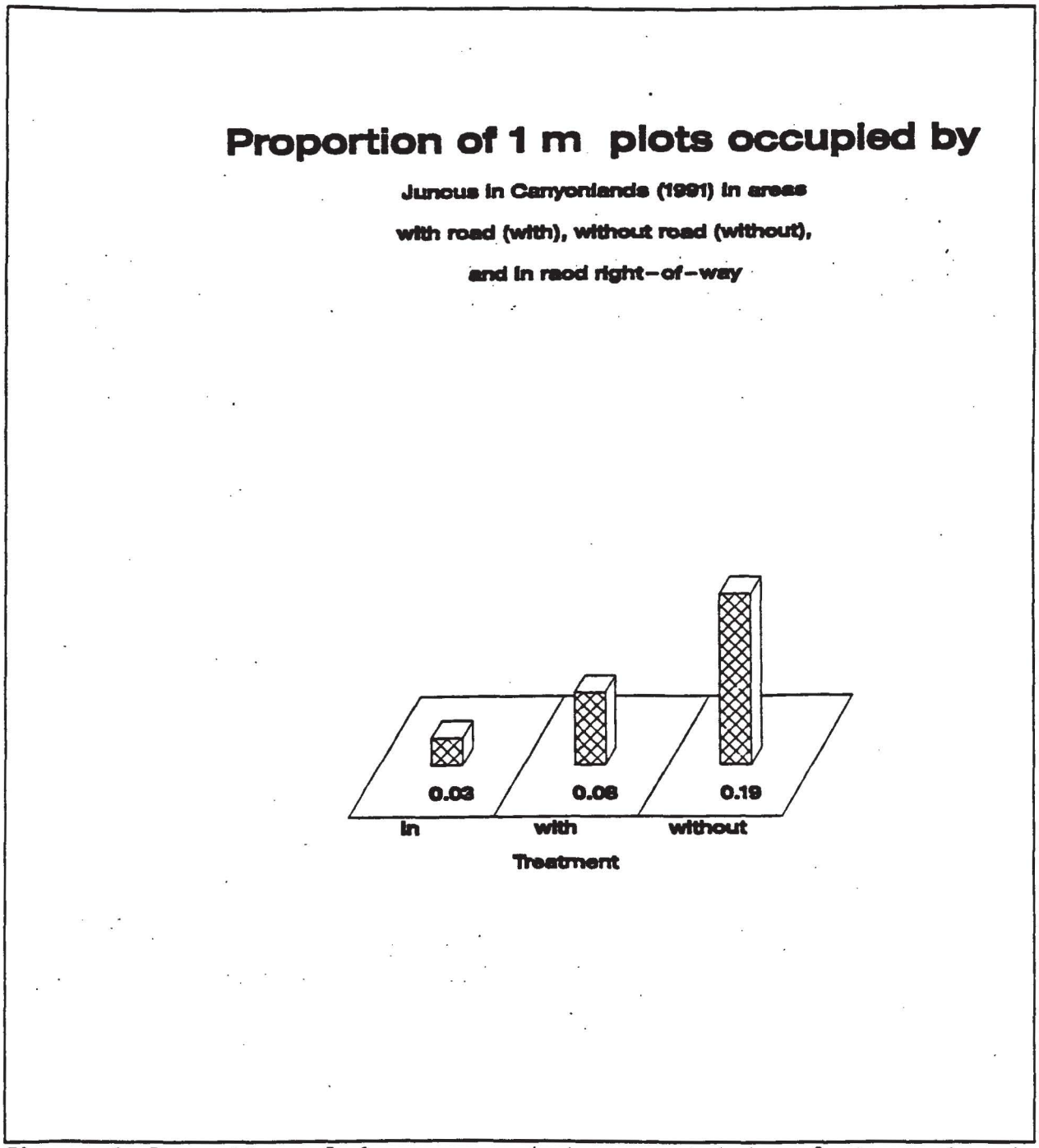

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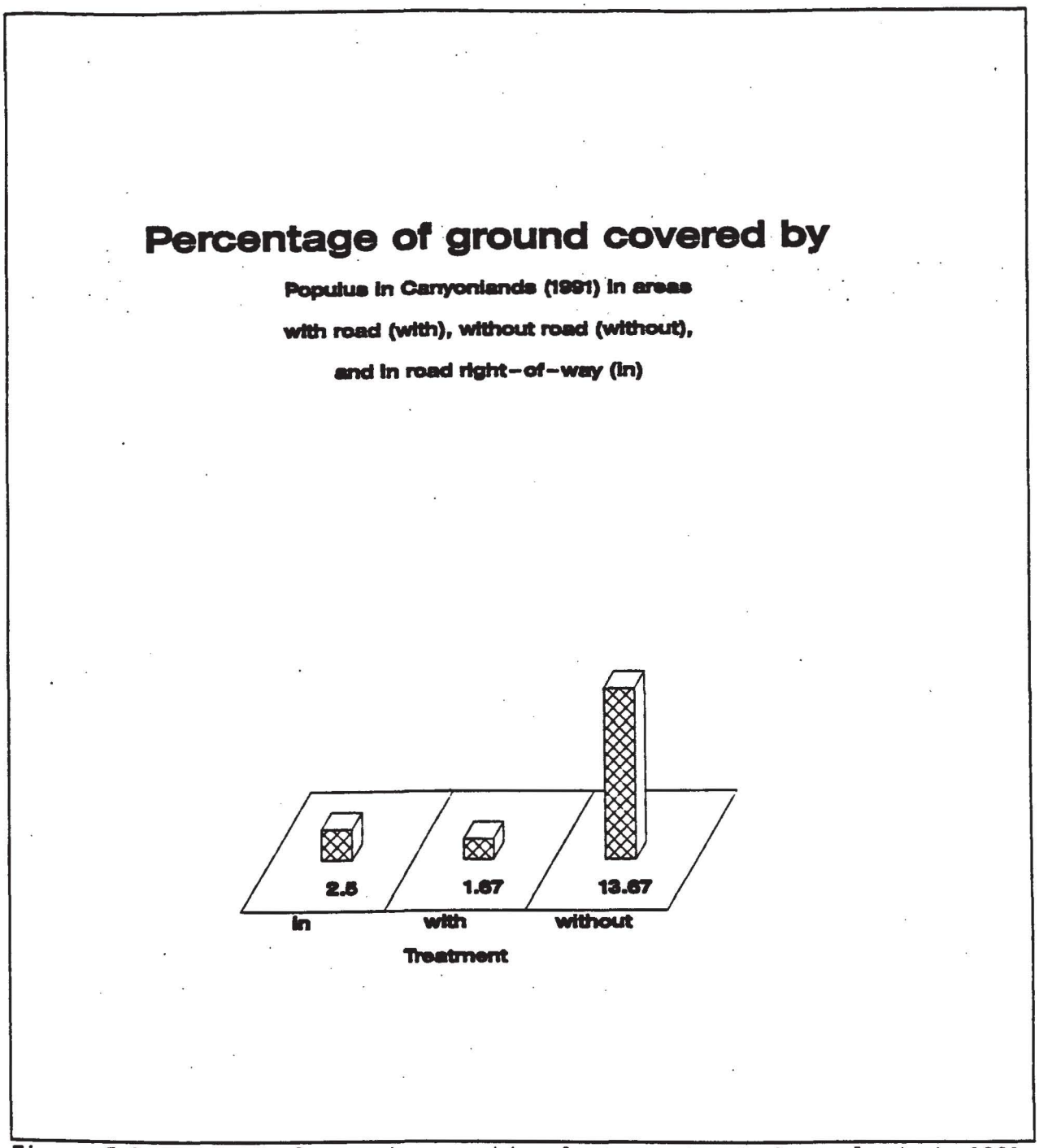
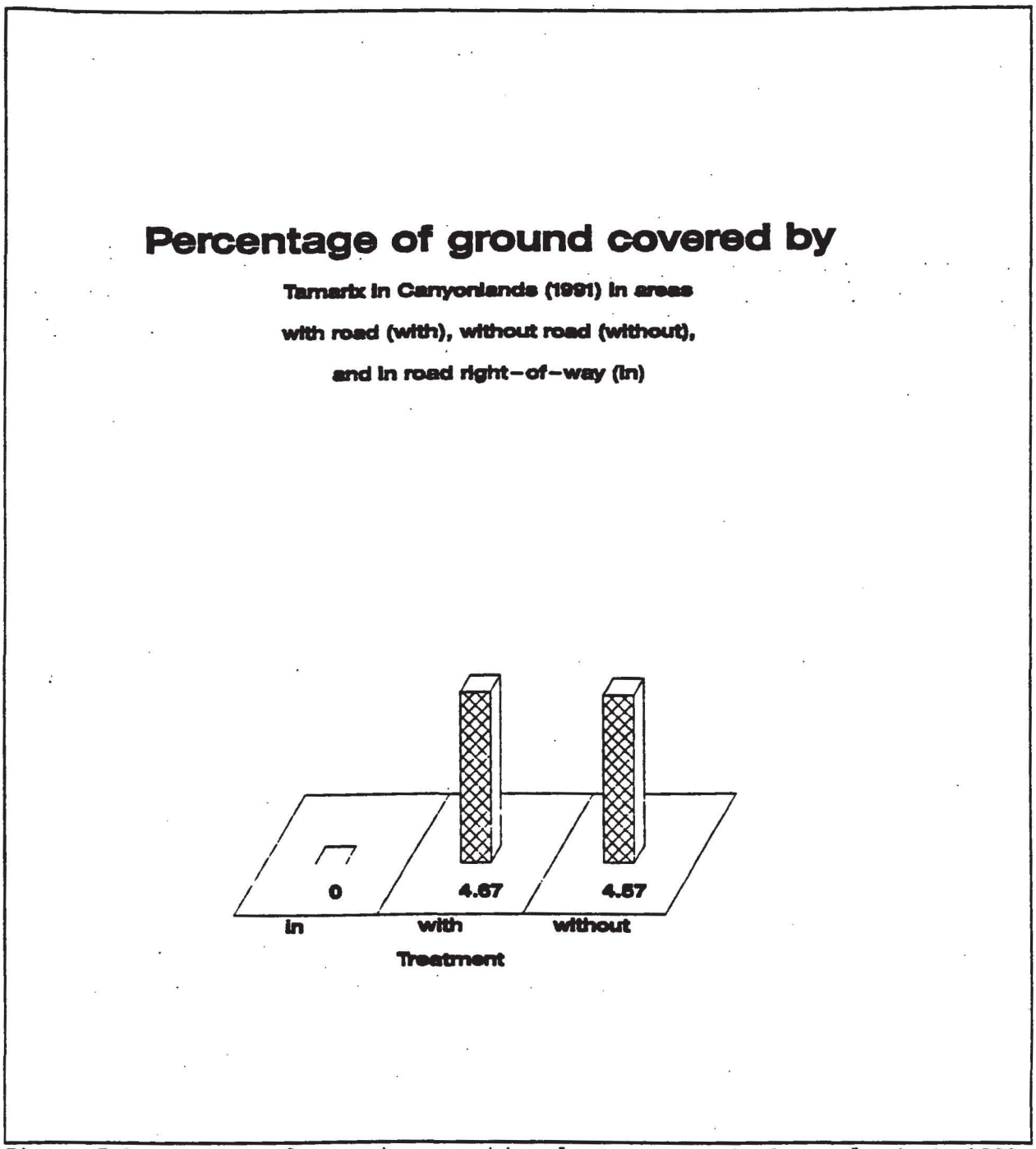


Figure 5 Percentage of ground covered by plant species in Canyonlands in 1991.



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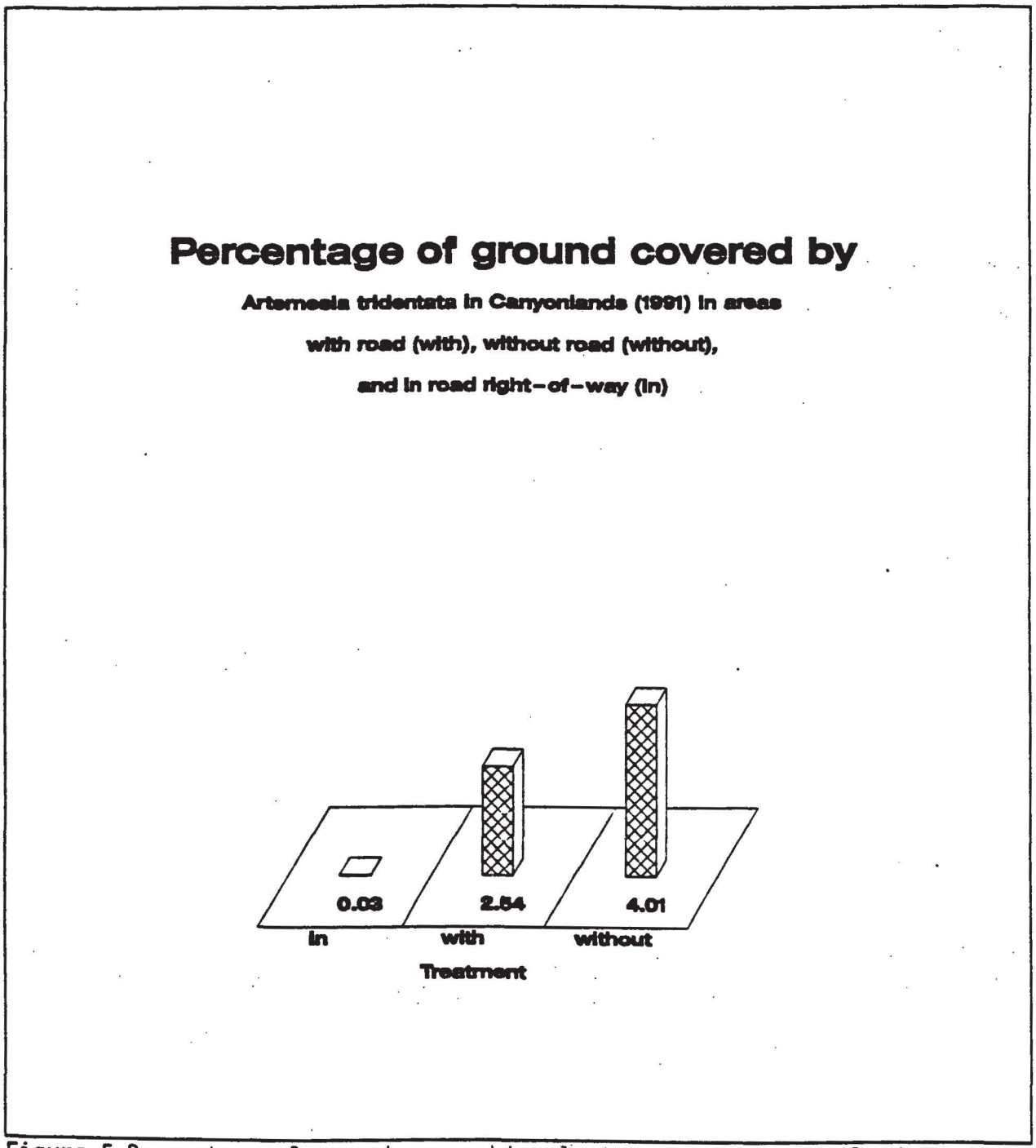

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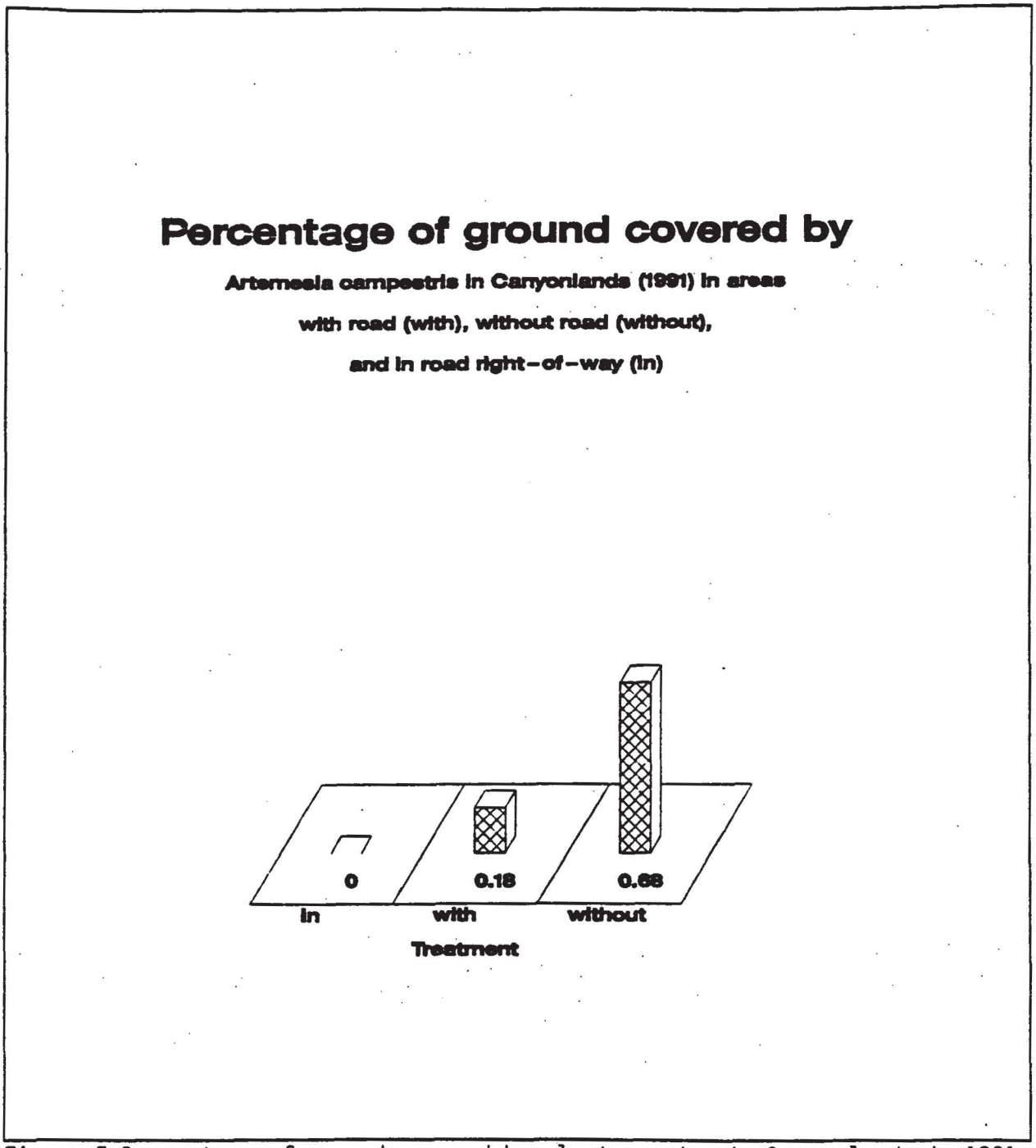

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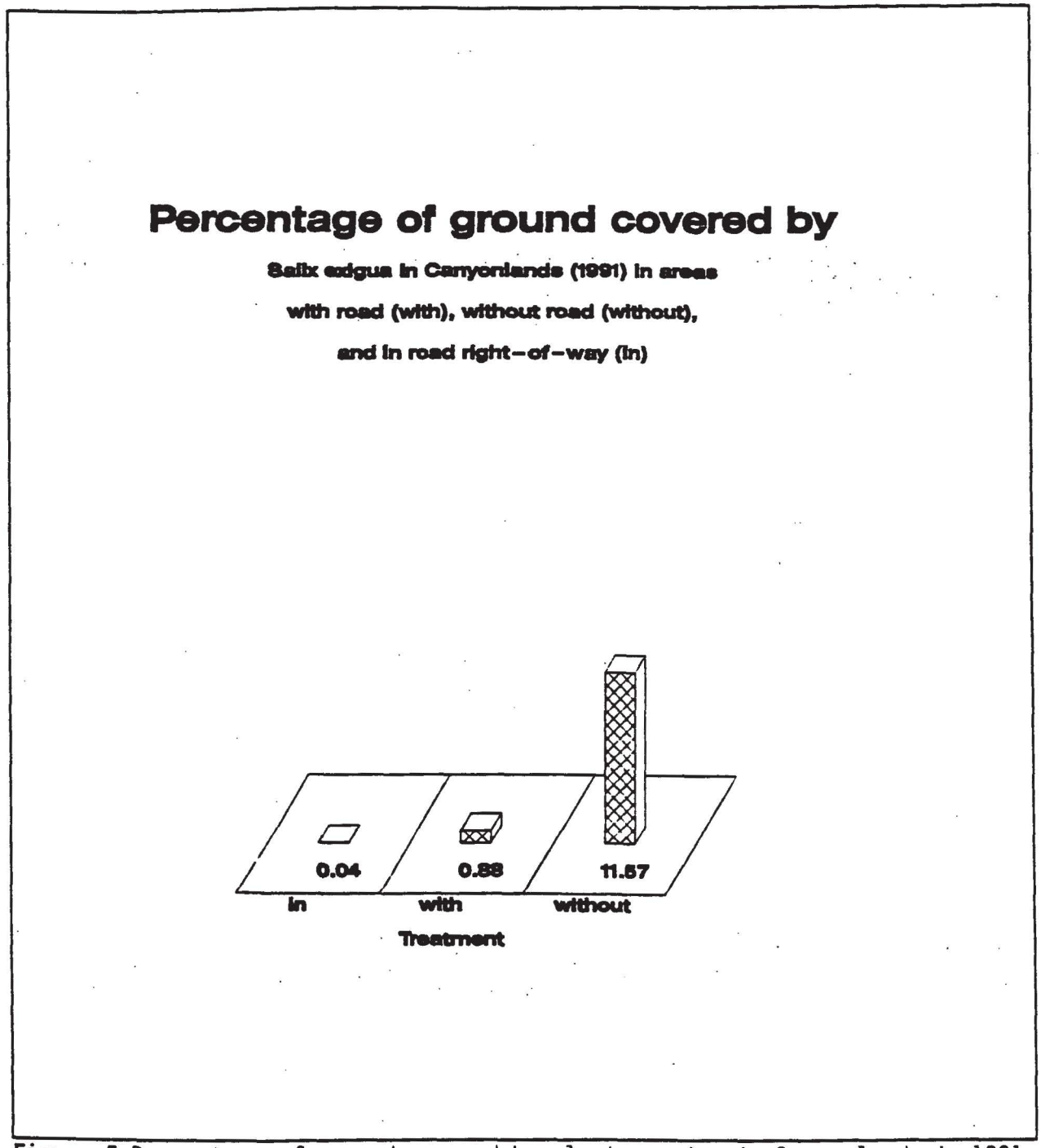

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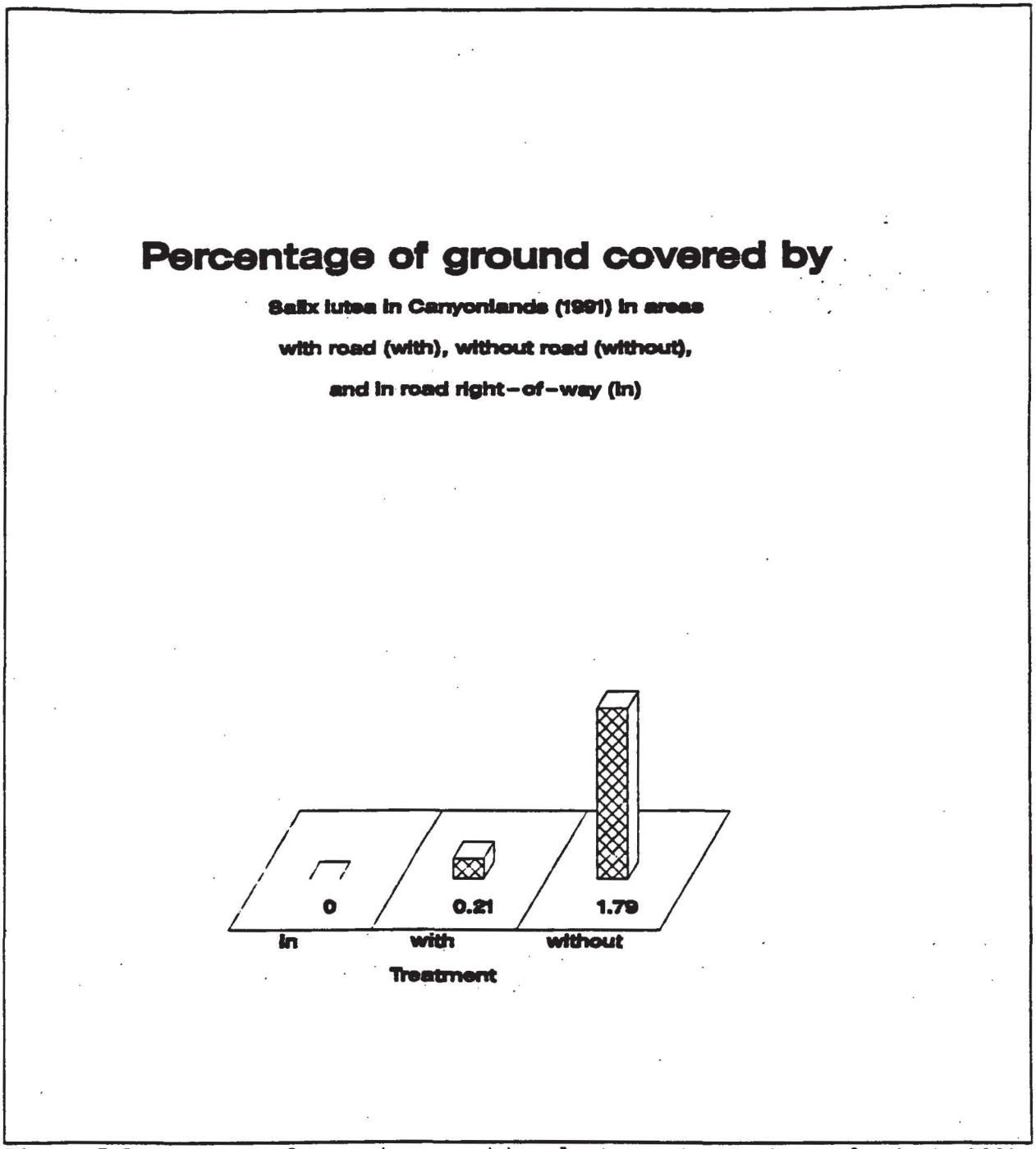

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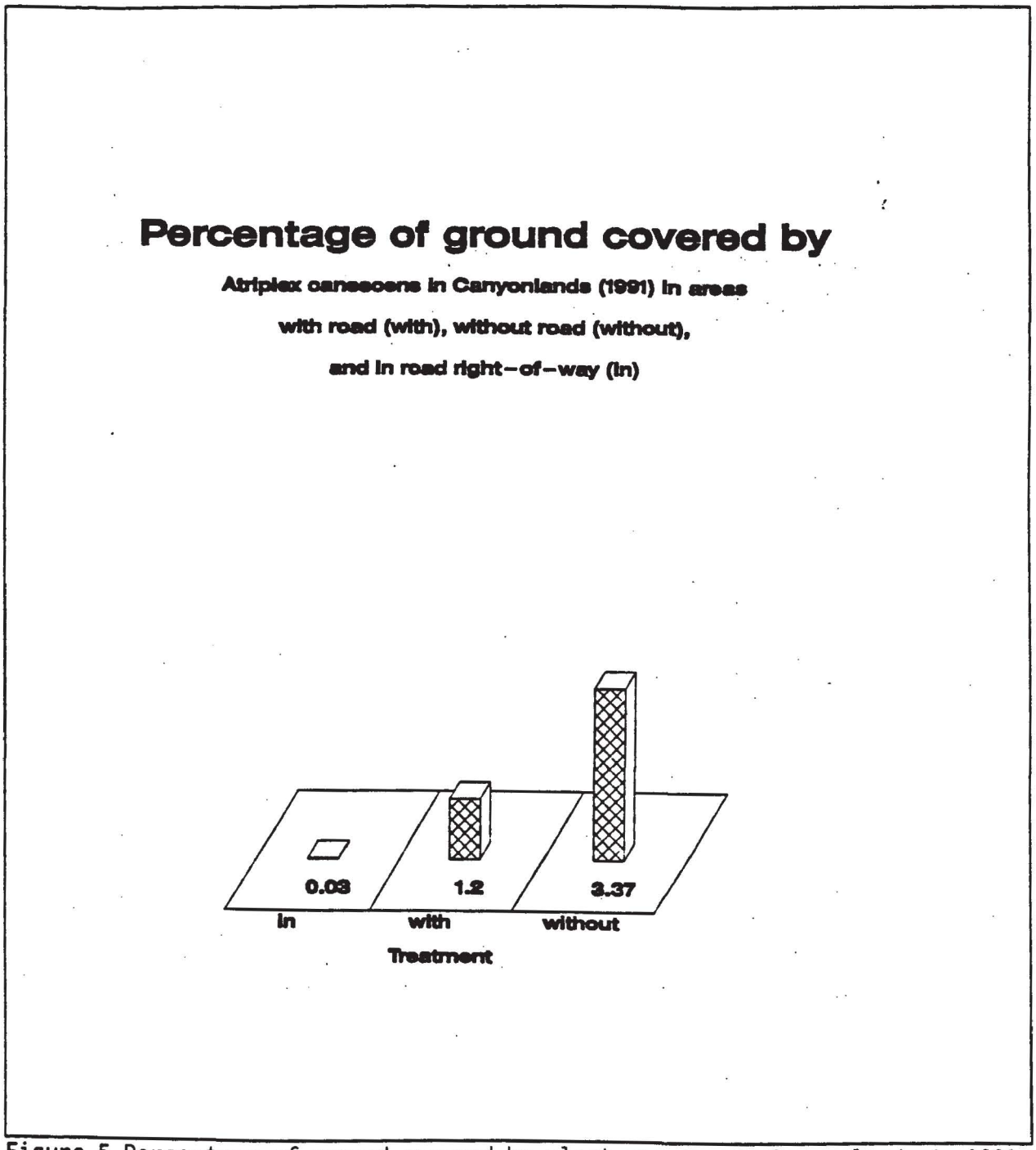

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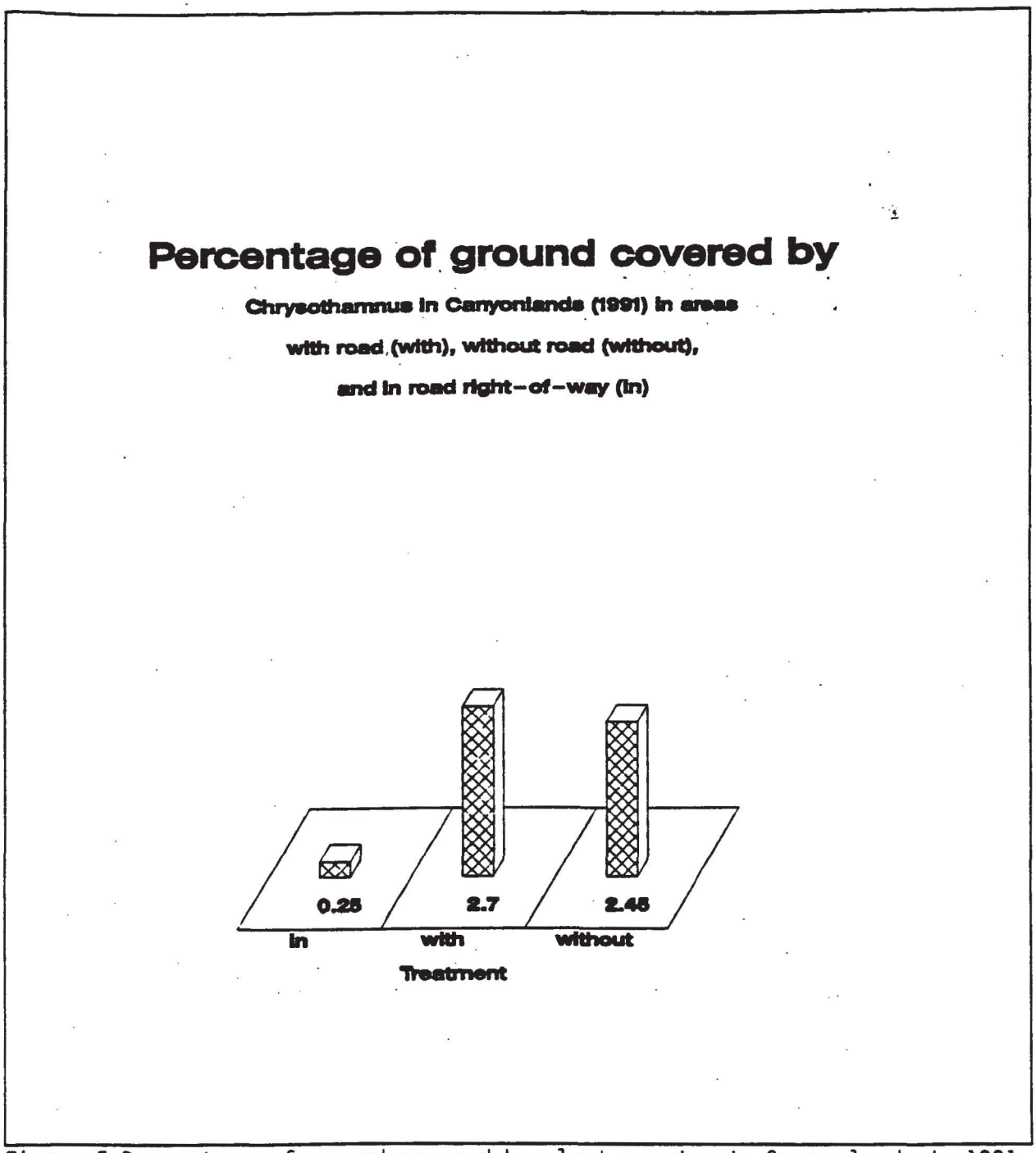

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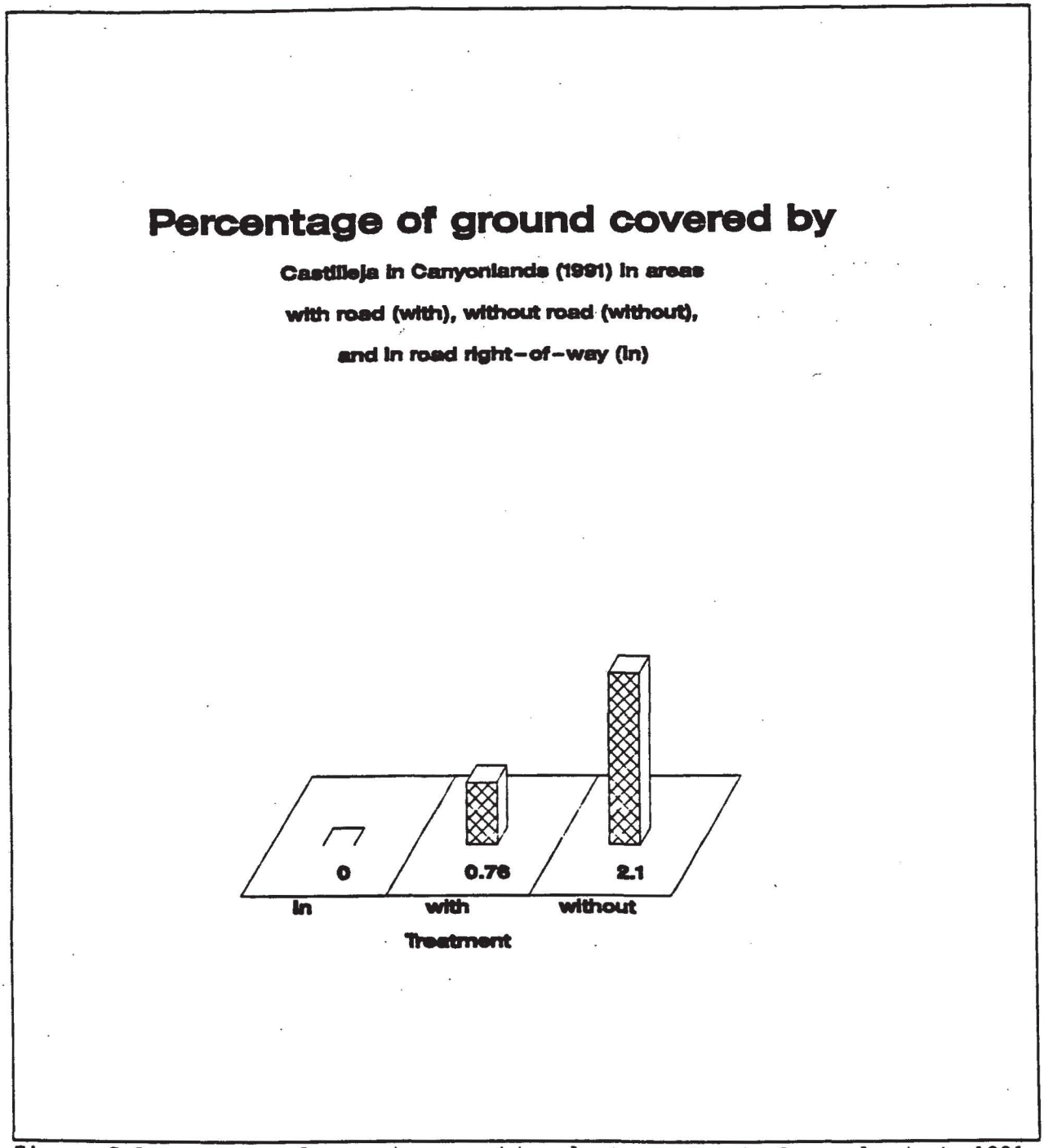

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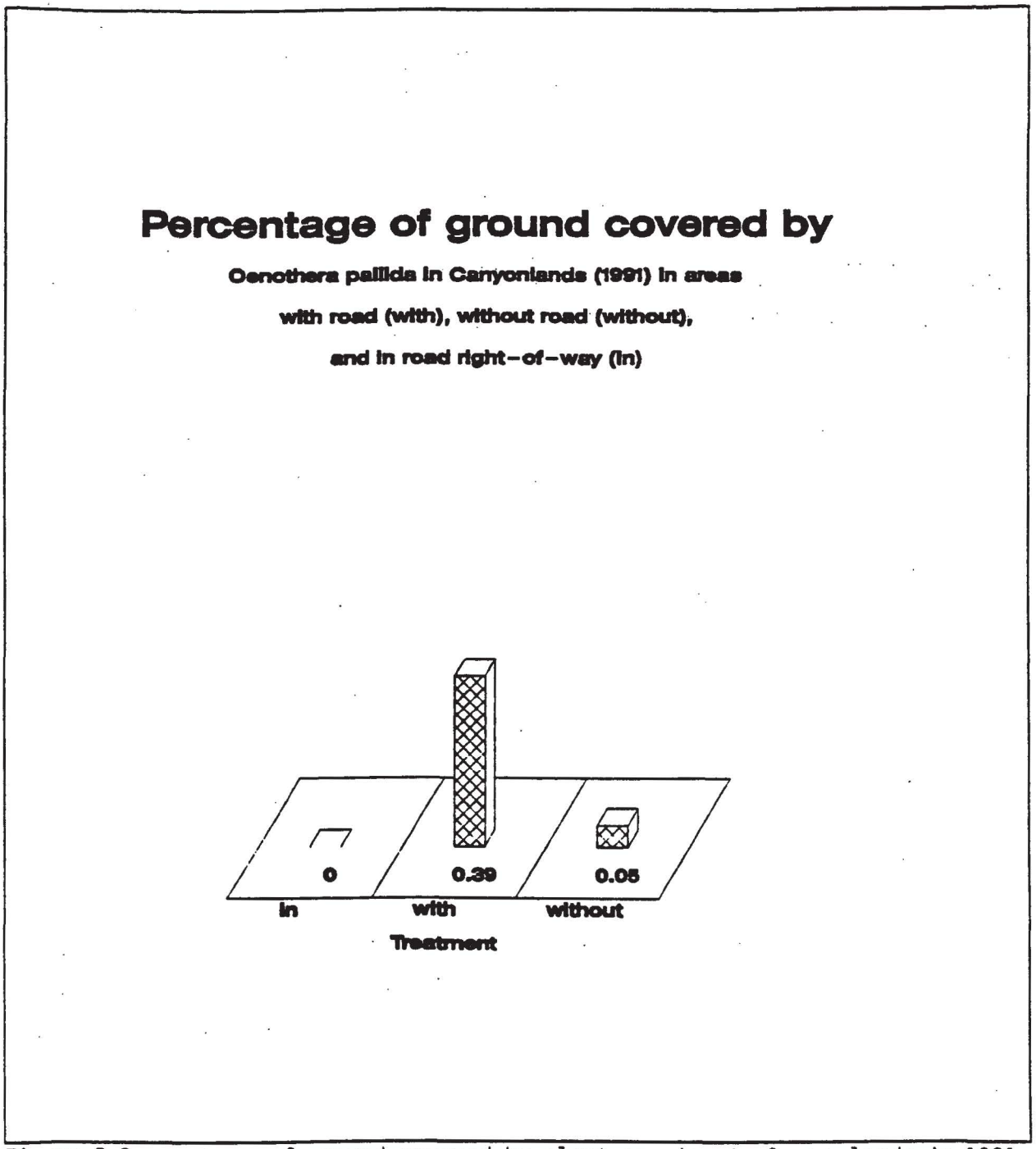

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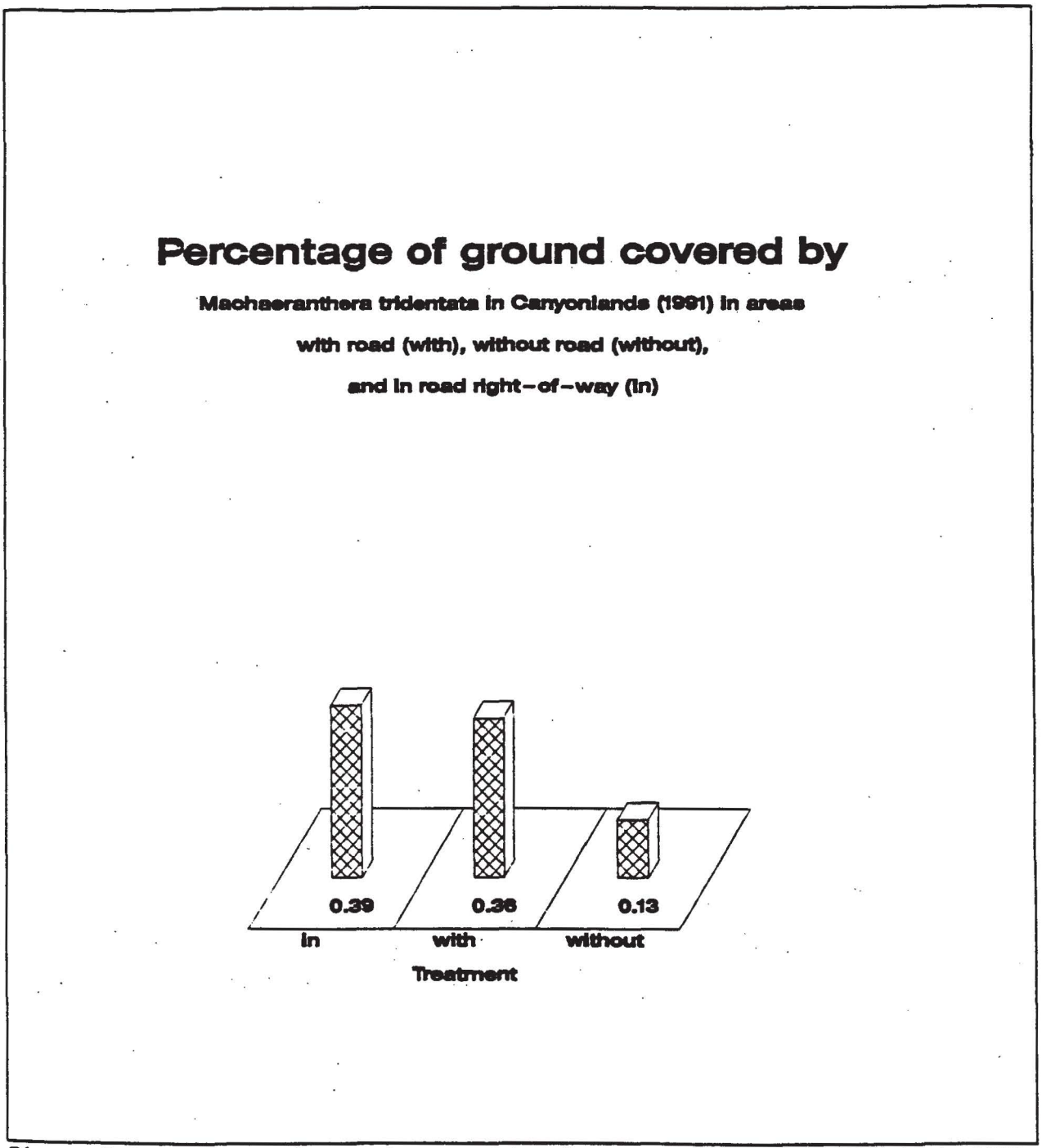

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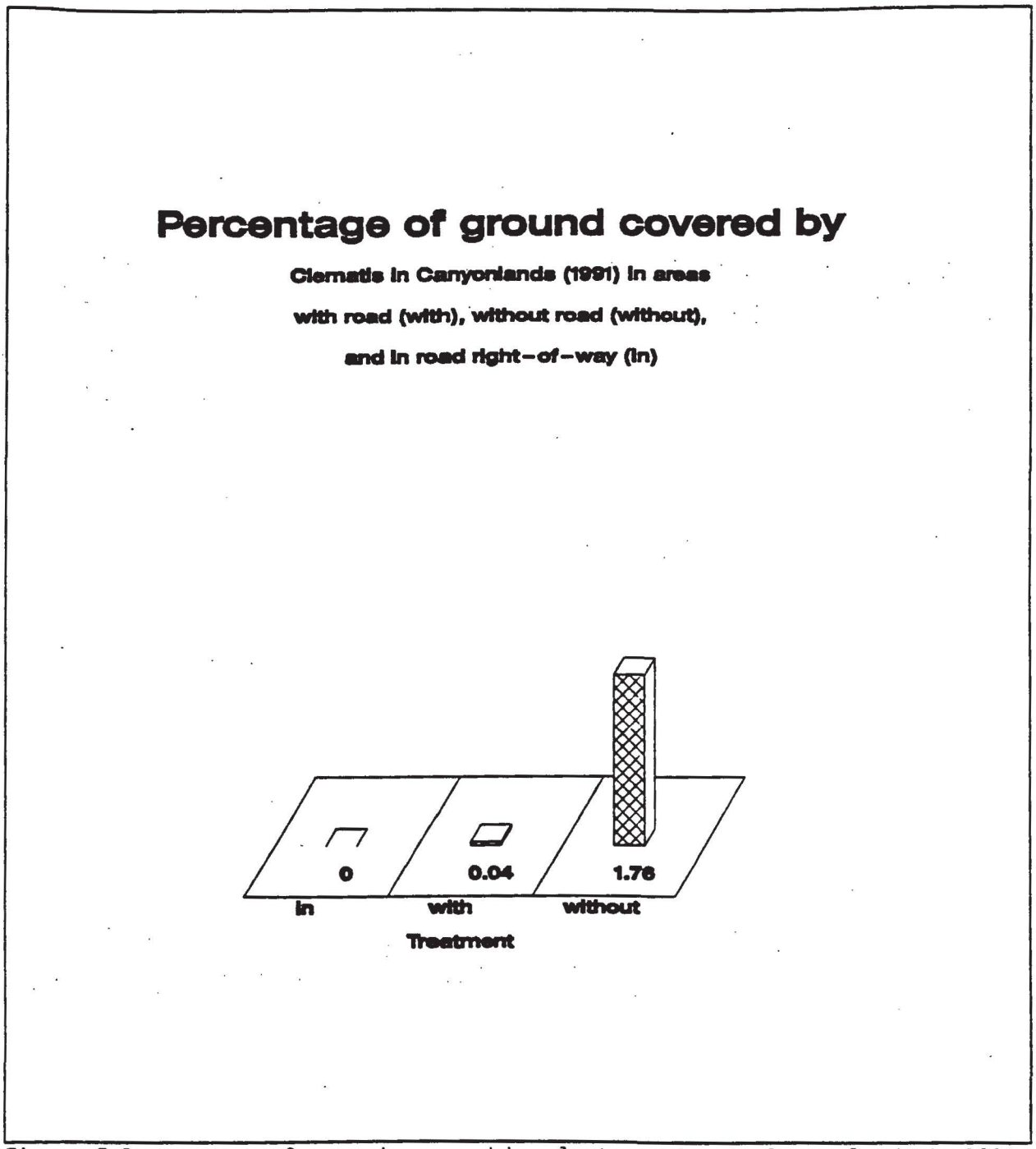

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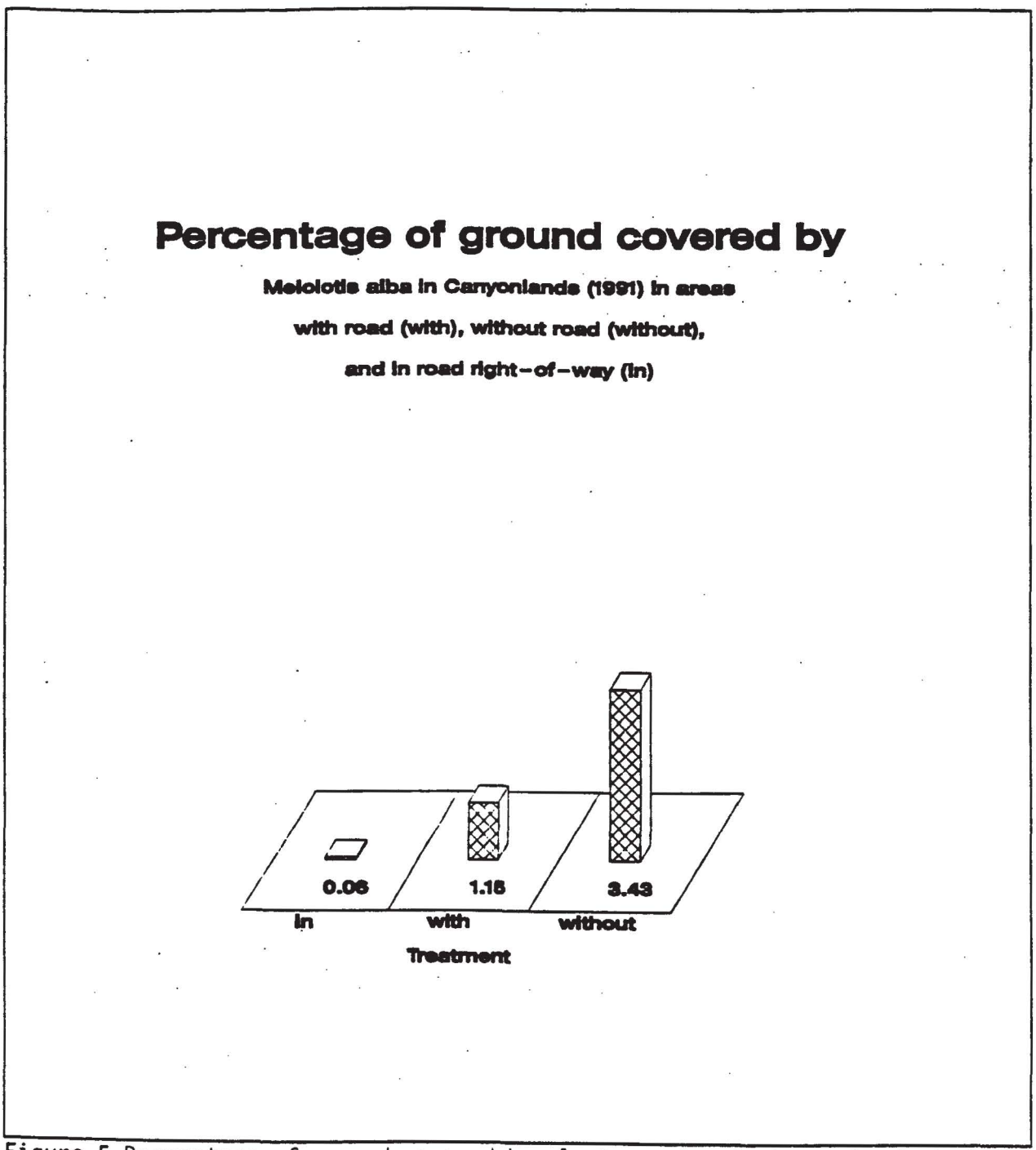

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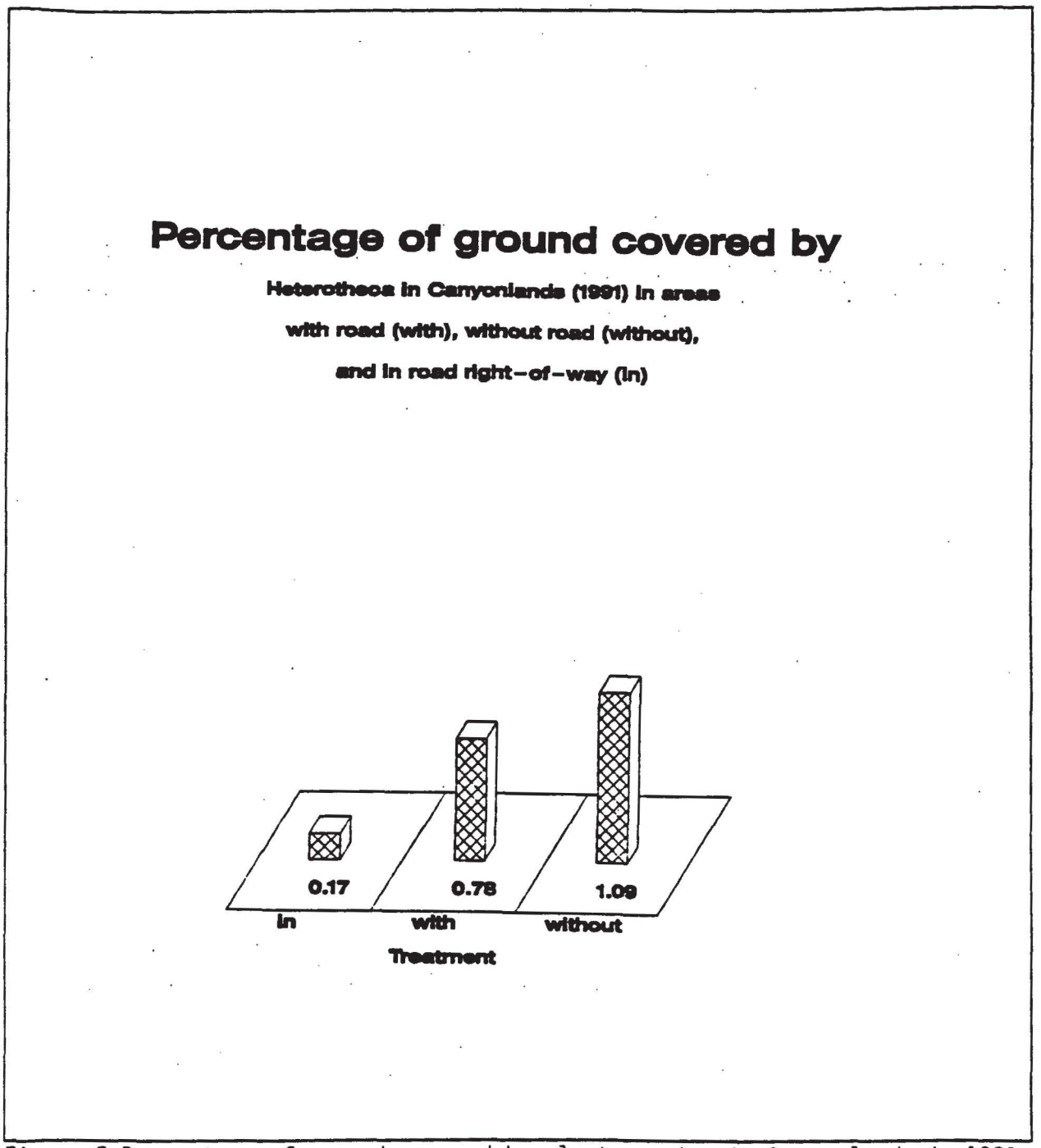

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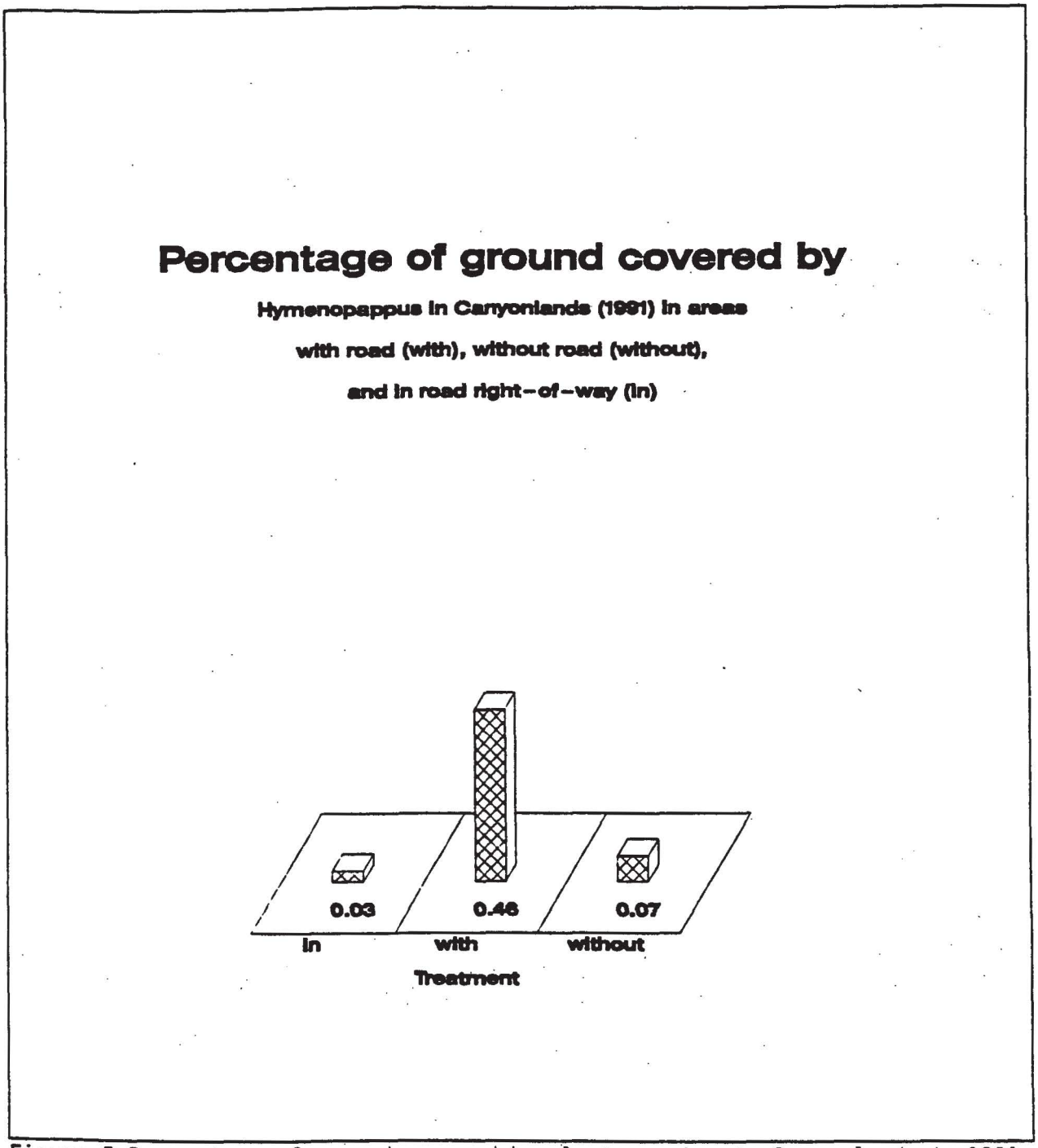

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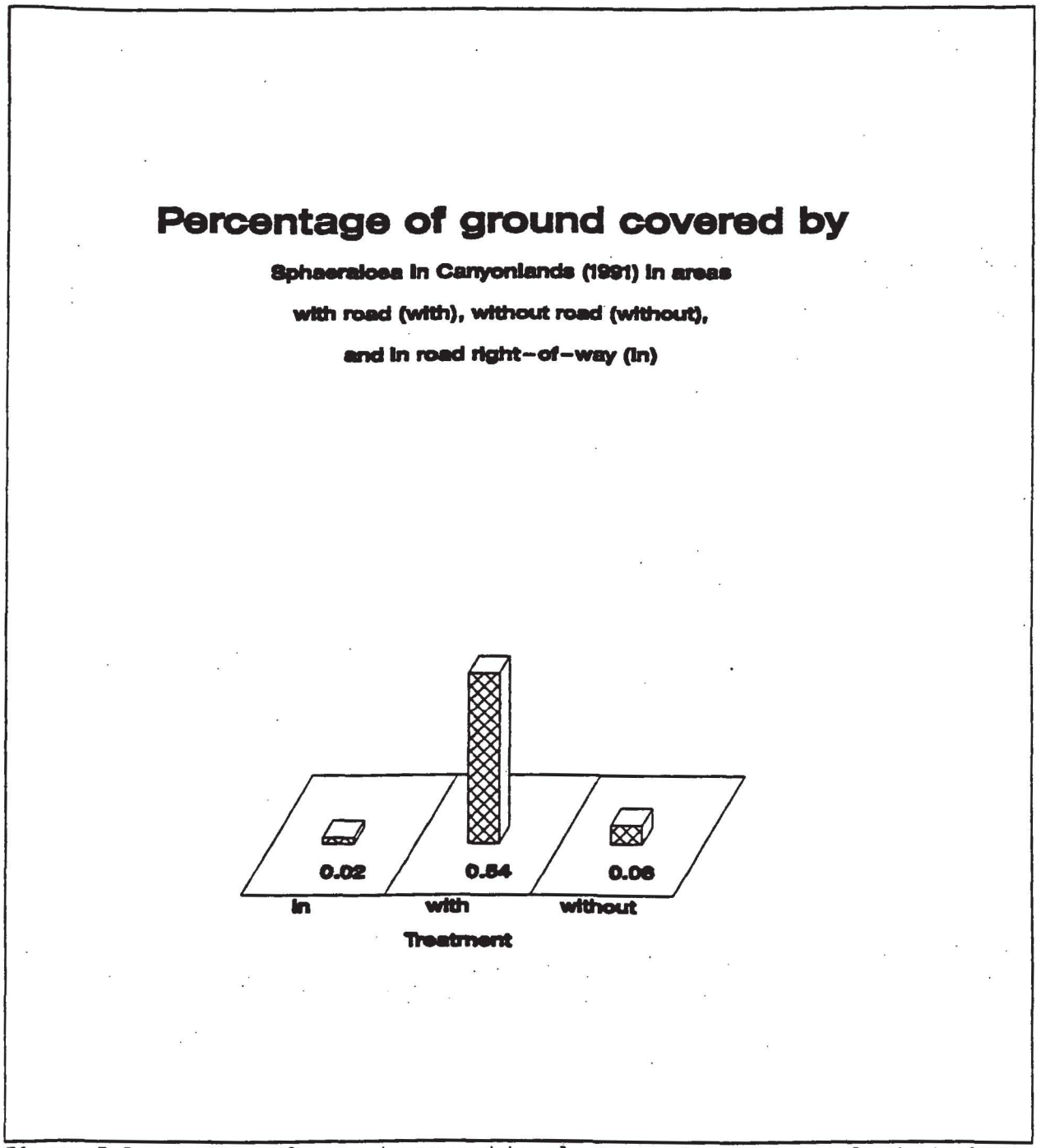

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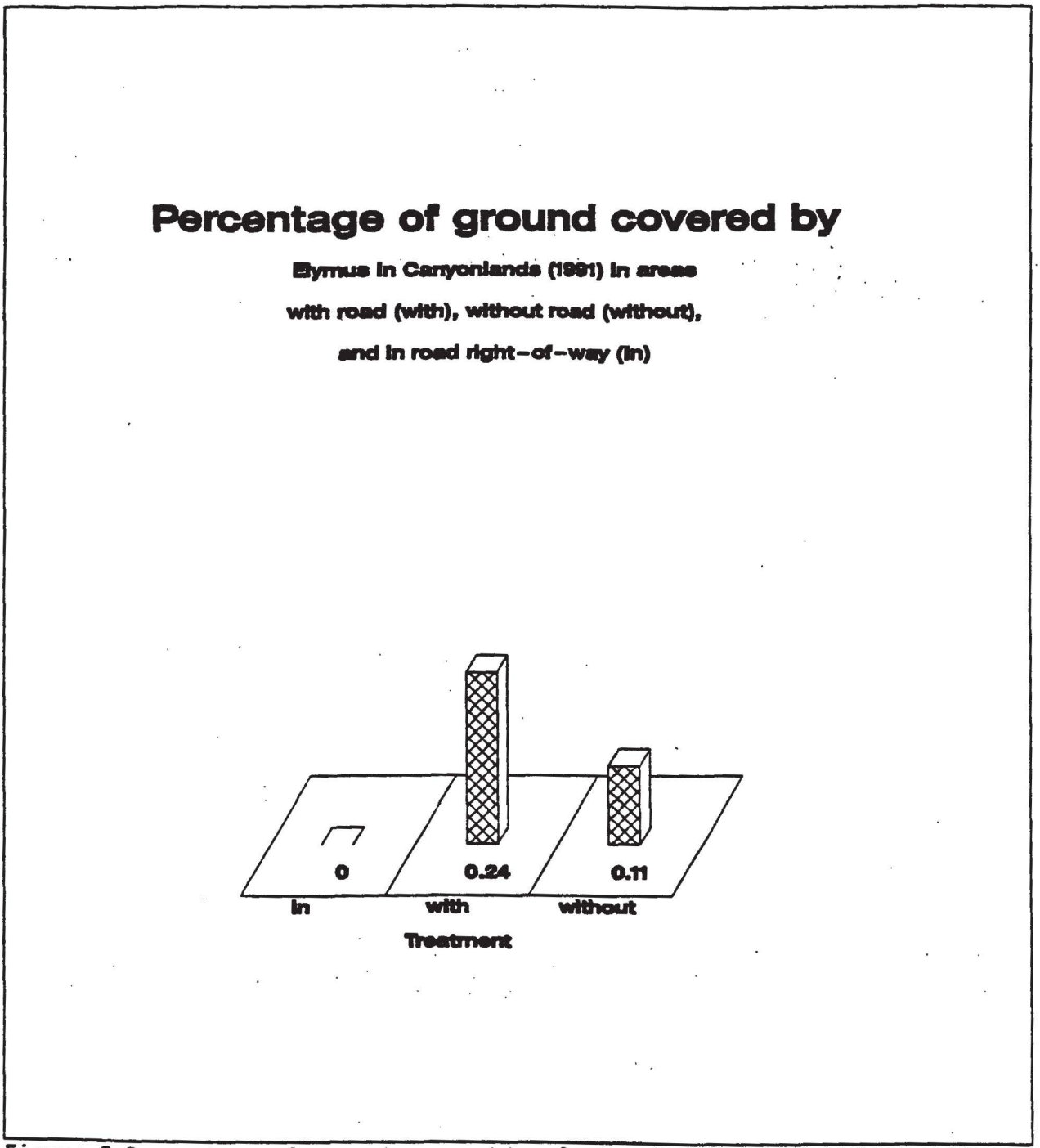

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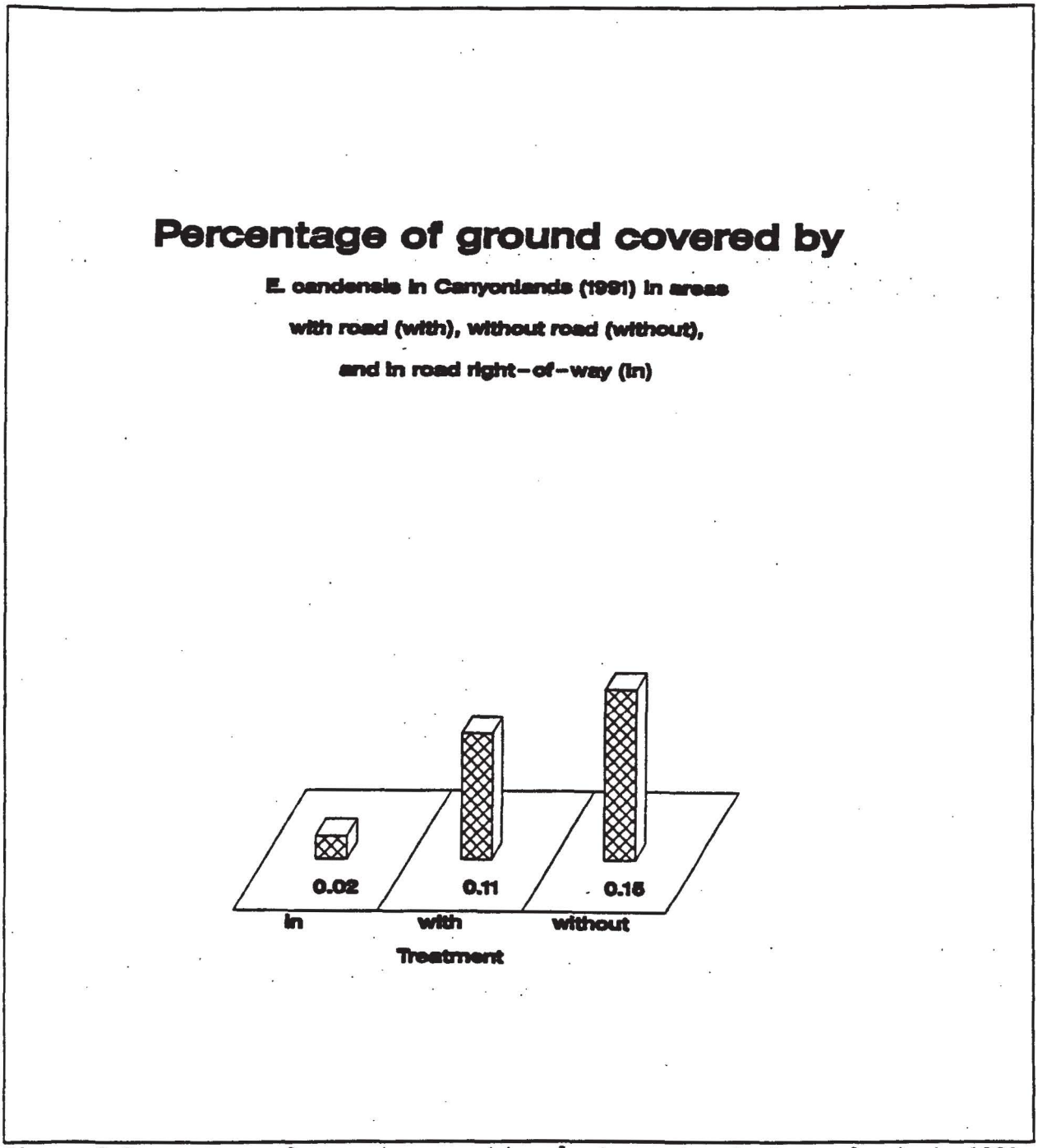

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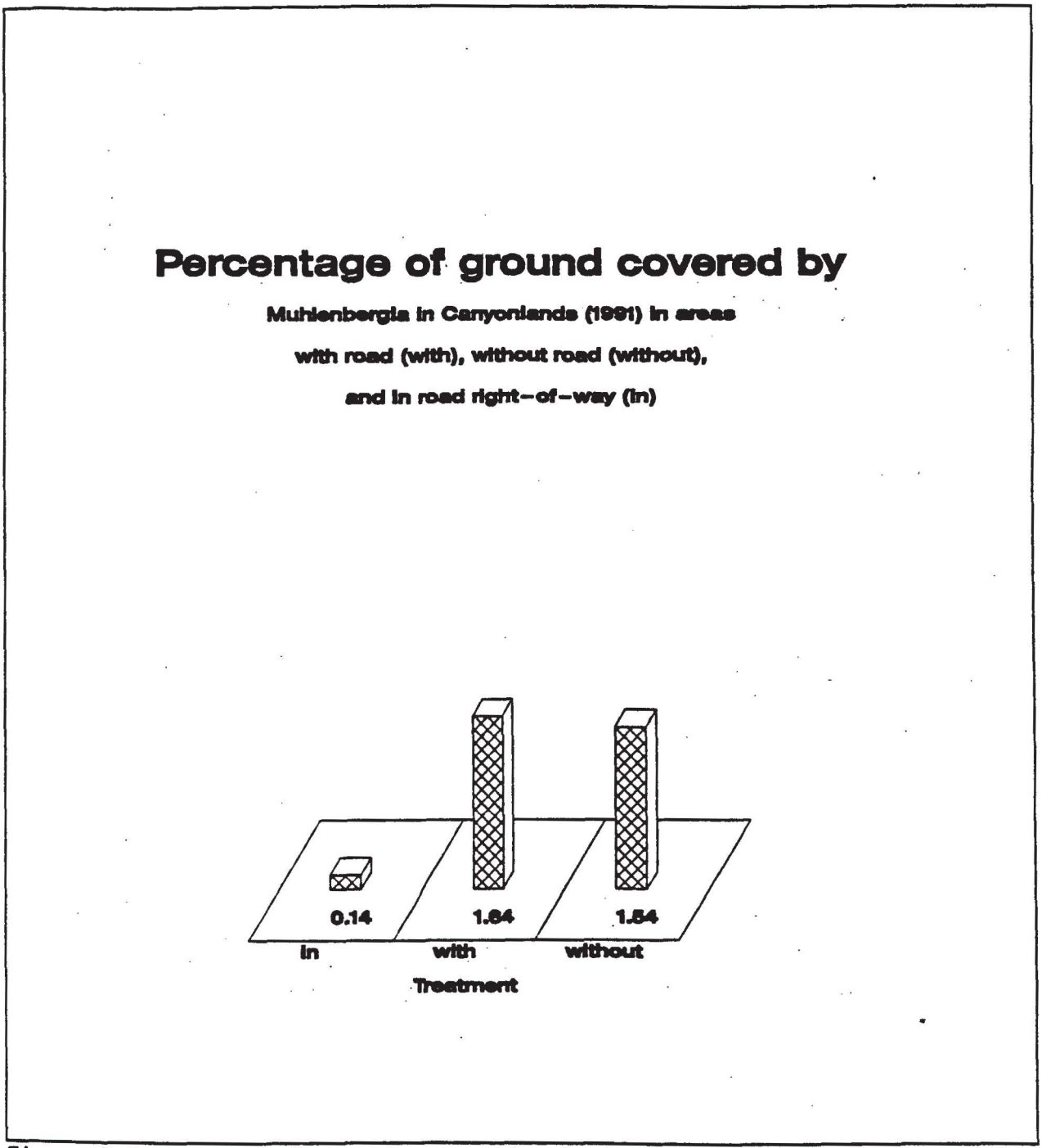

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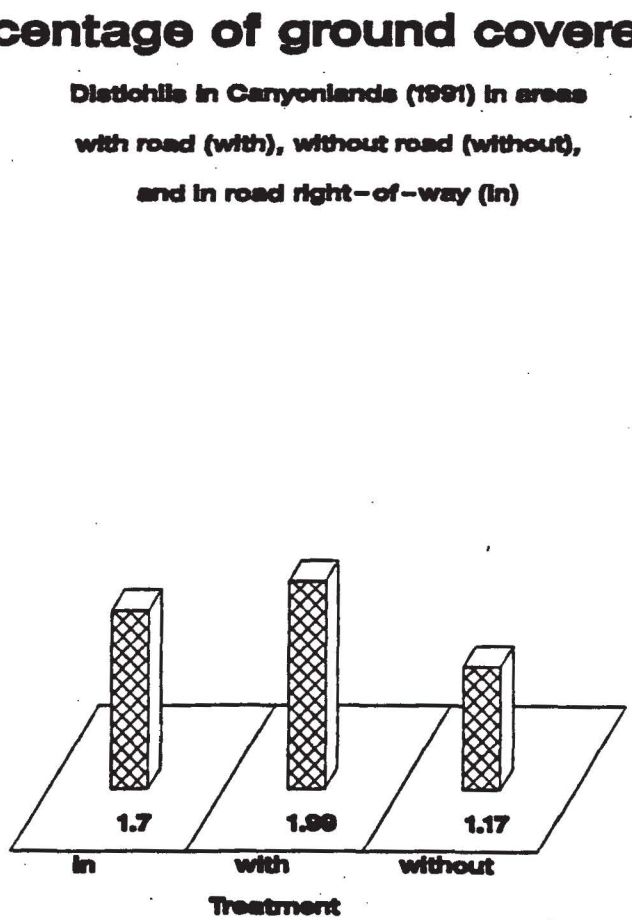

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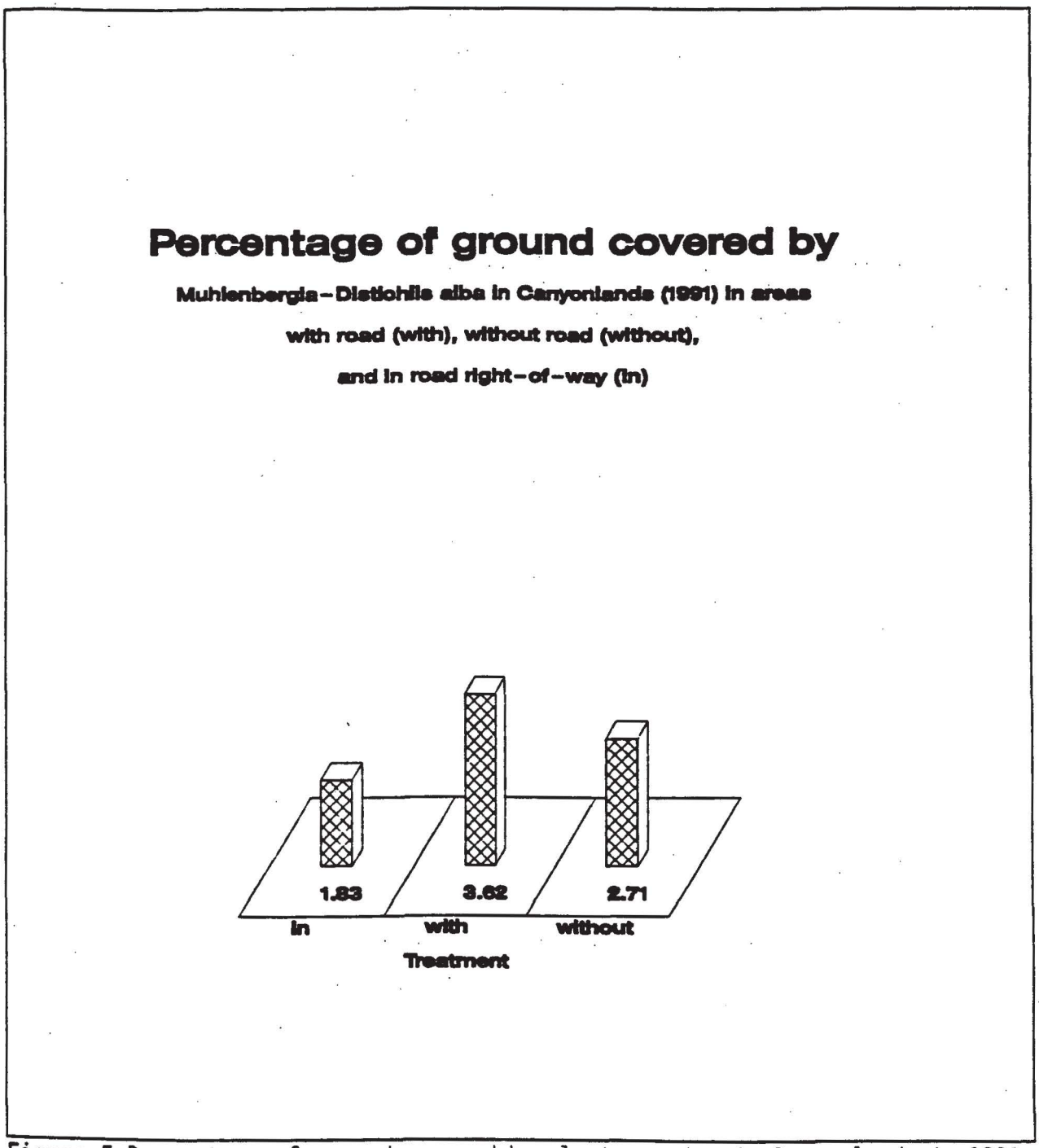

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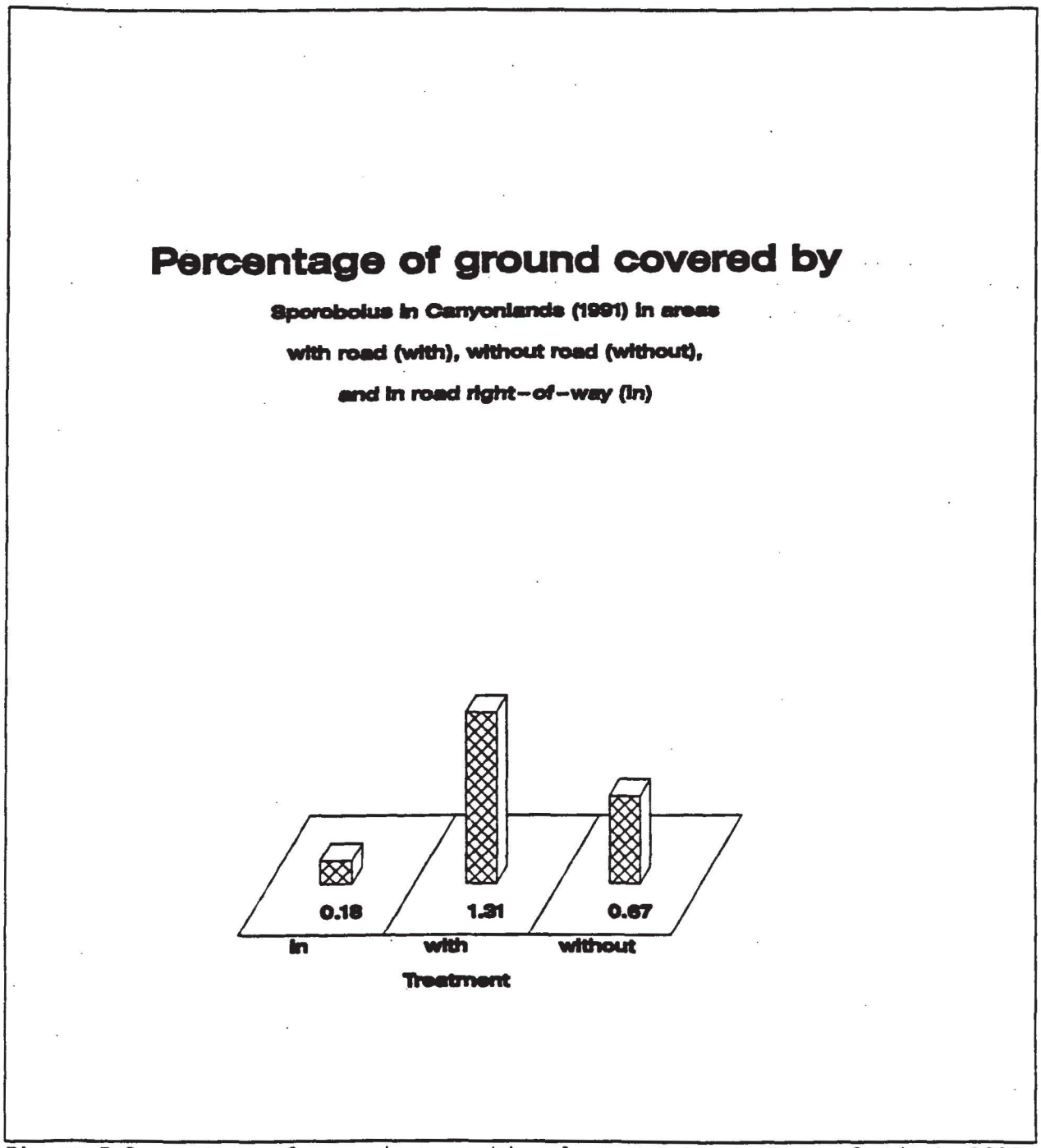

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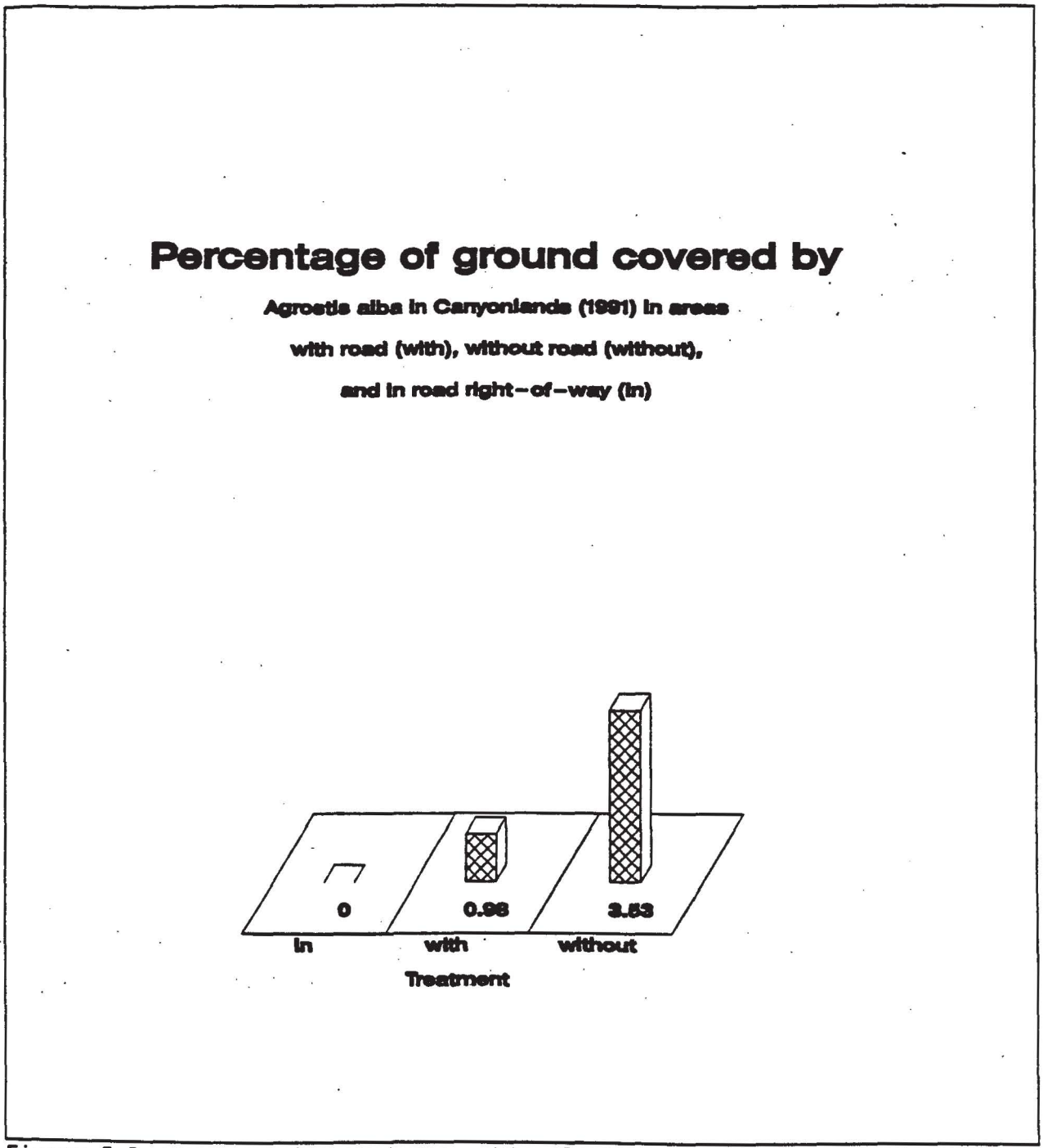

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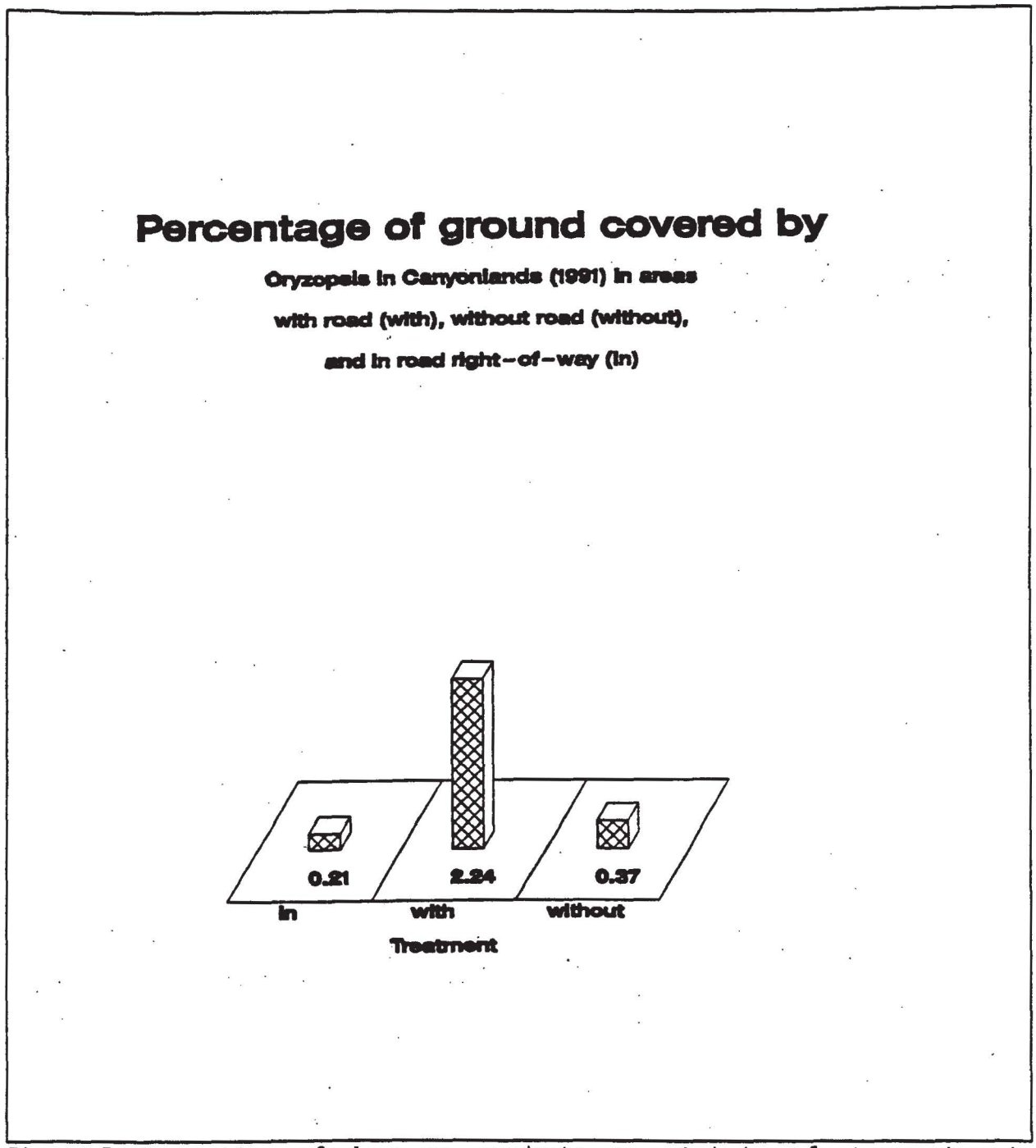


Figure 5 Proportion of 1 m sq quadrats occupied by plant species in Canyonlands in 1991.

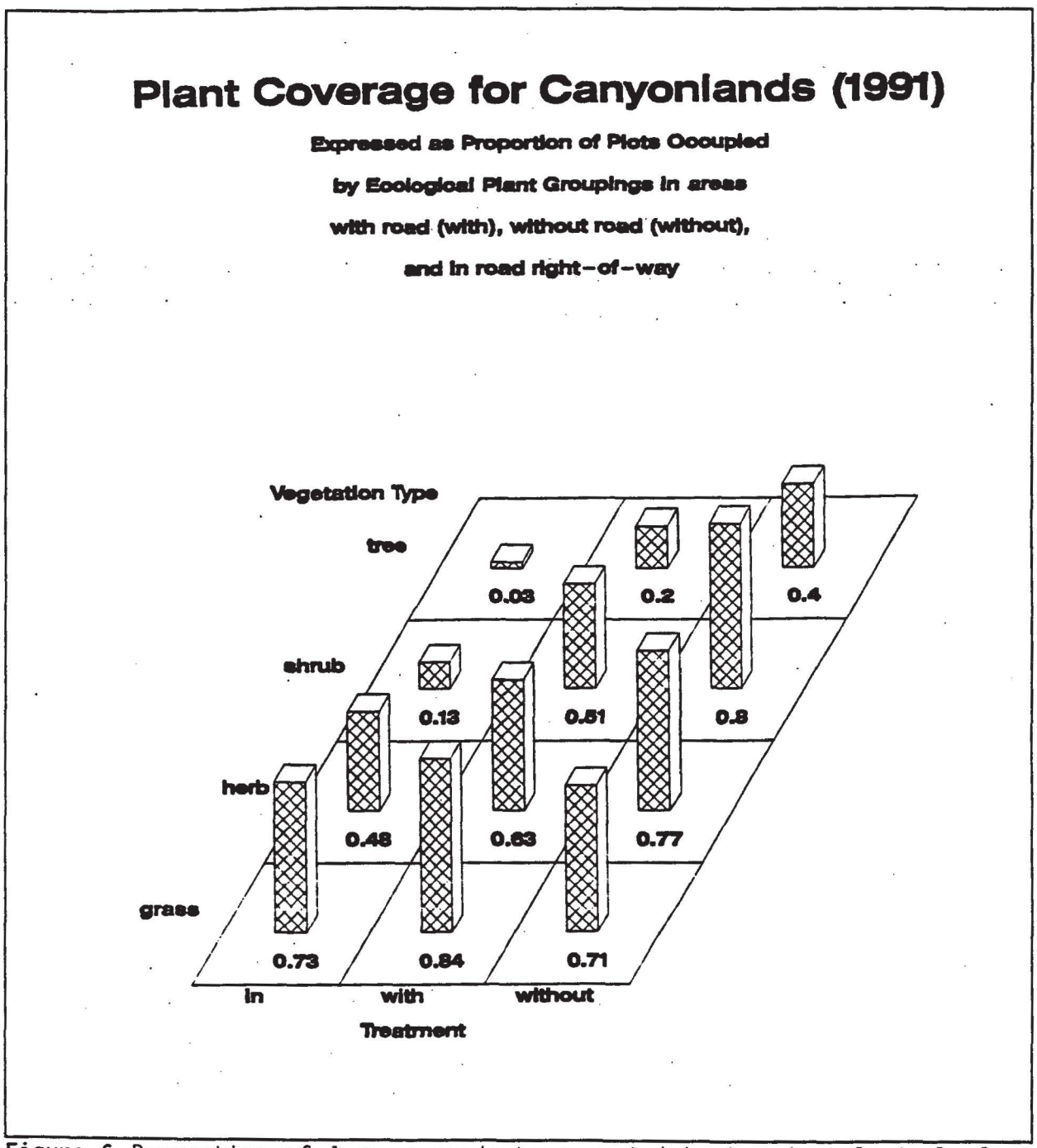
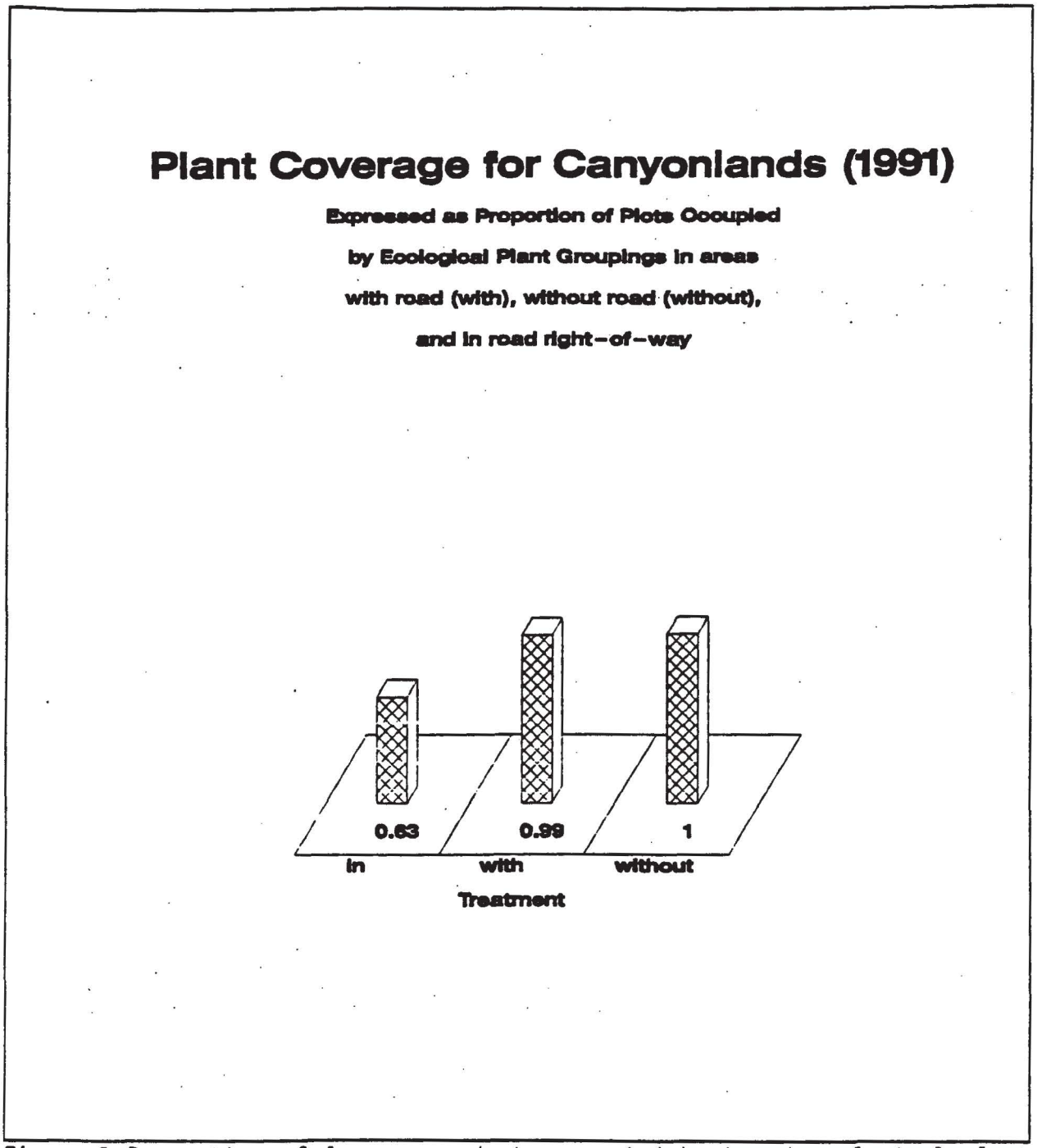


Figure 6 Proportion of 1 m sq quadrats occupied by broad ecological plant groups in Canyonlands in 1991.



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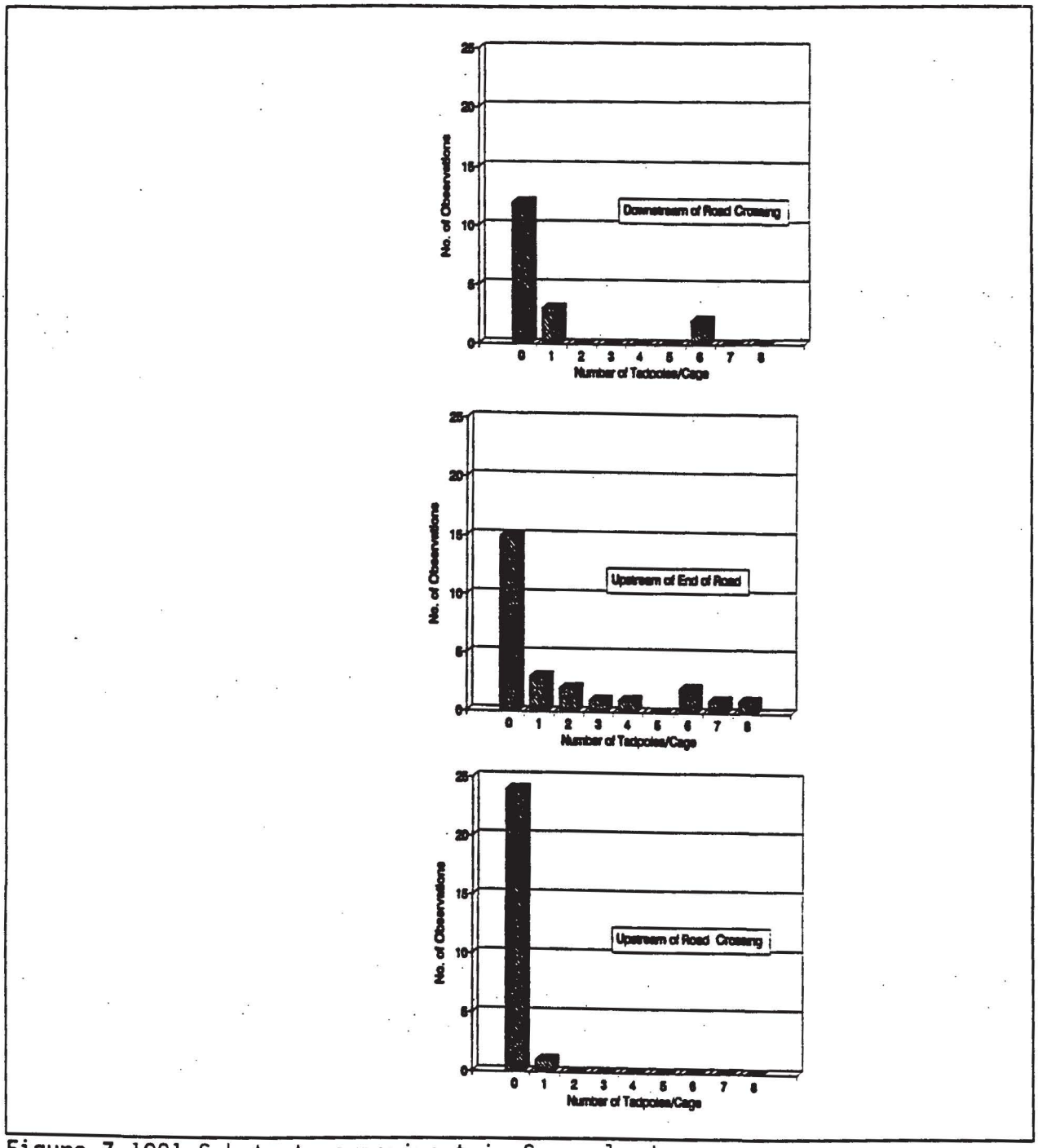
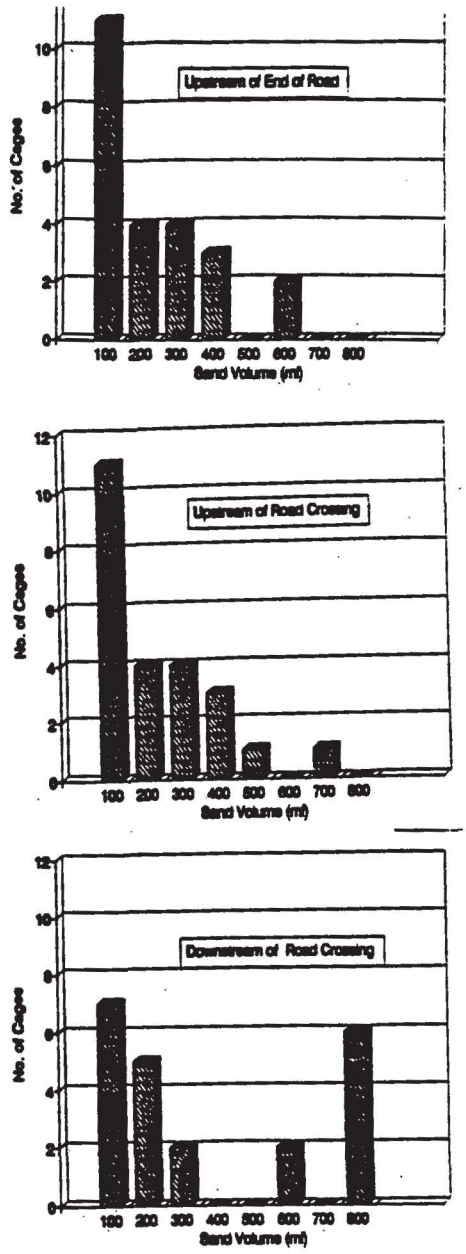


Figure 7 1991 Substrate experiment in Canyonlands.



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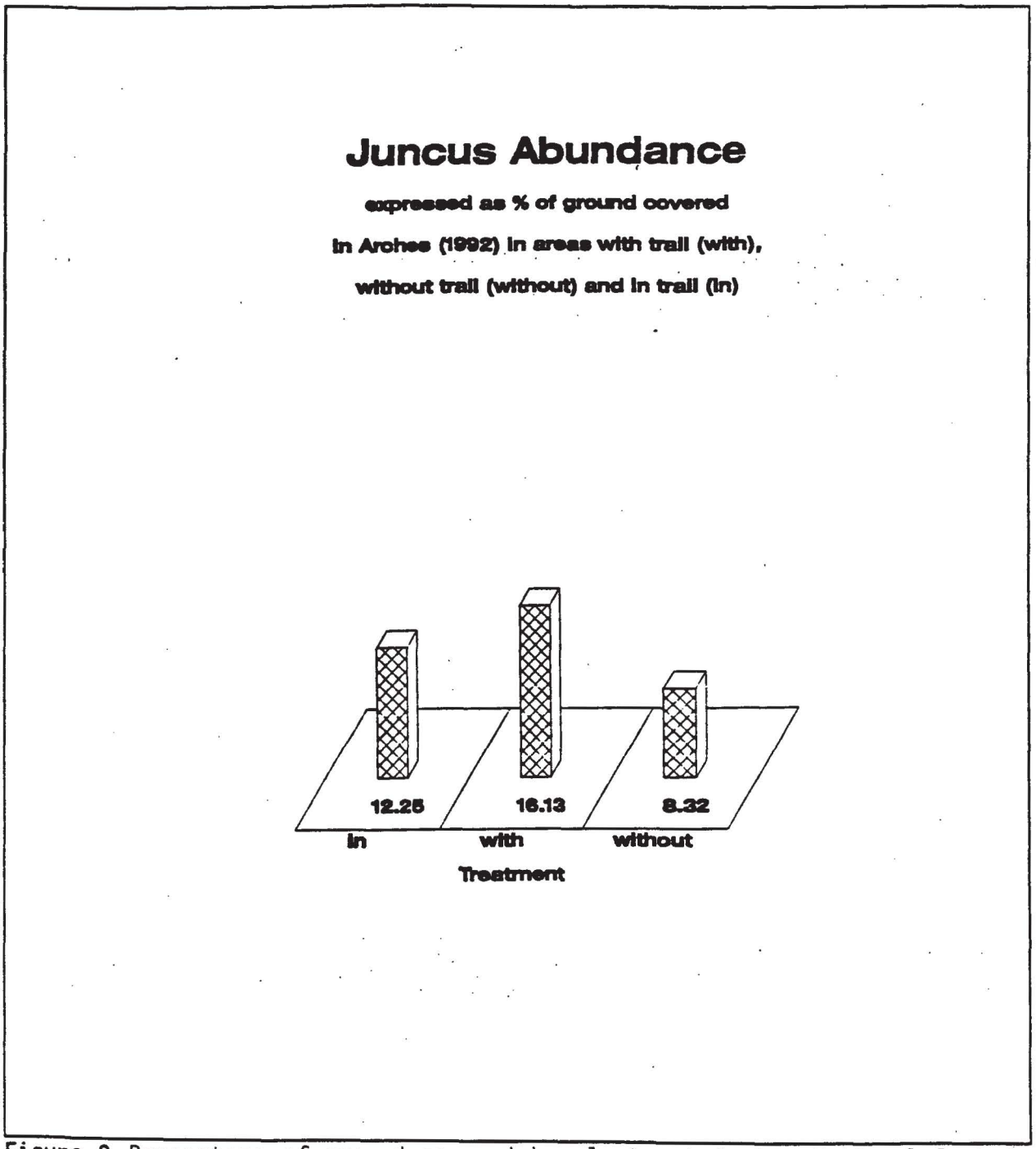
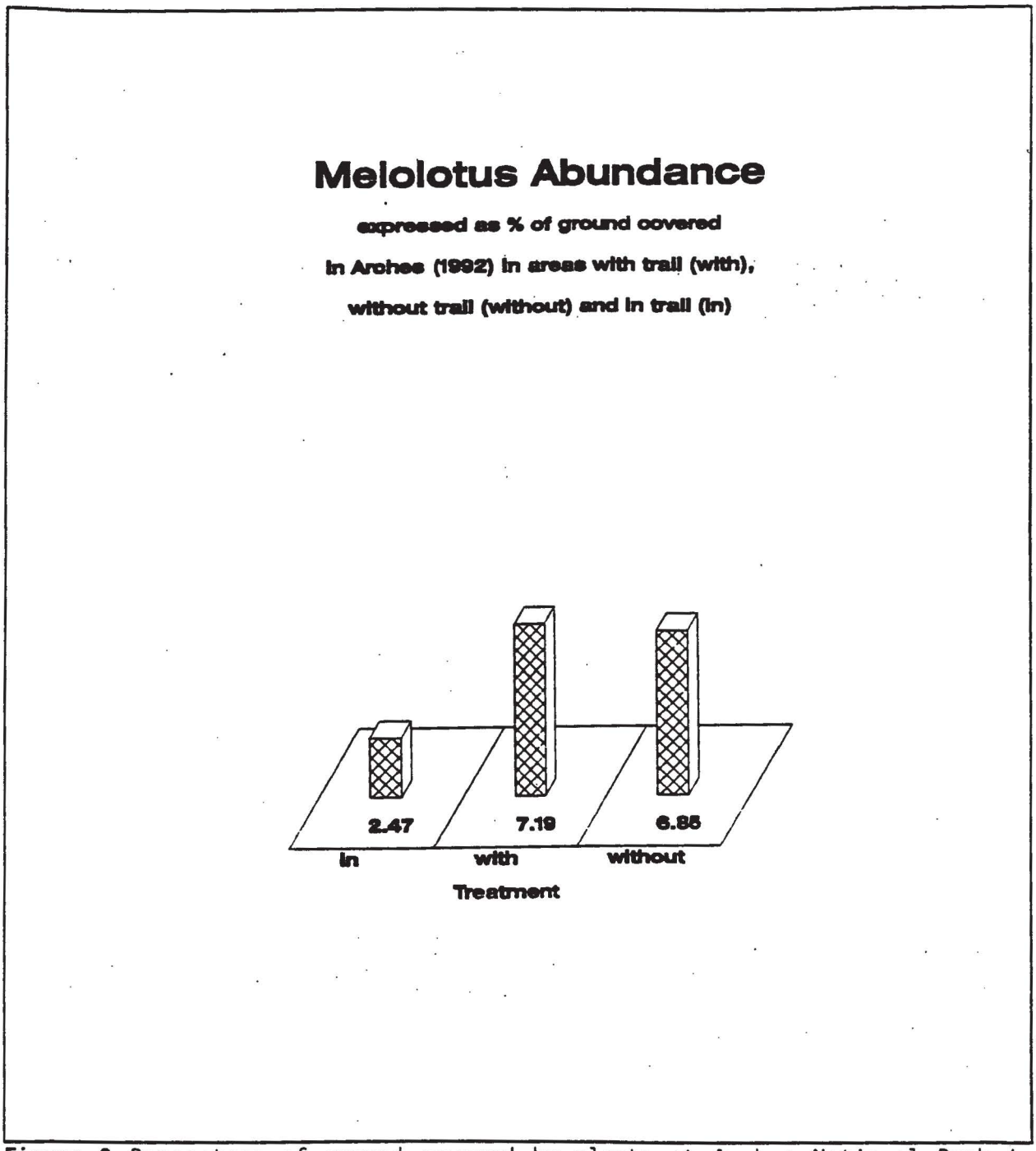


Figure 8 Percentage of ground covered by plants at Arches National Park in 1992.



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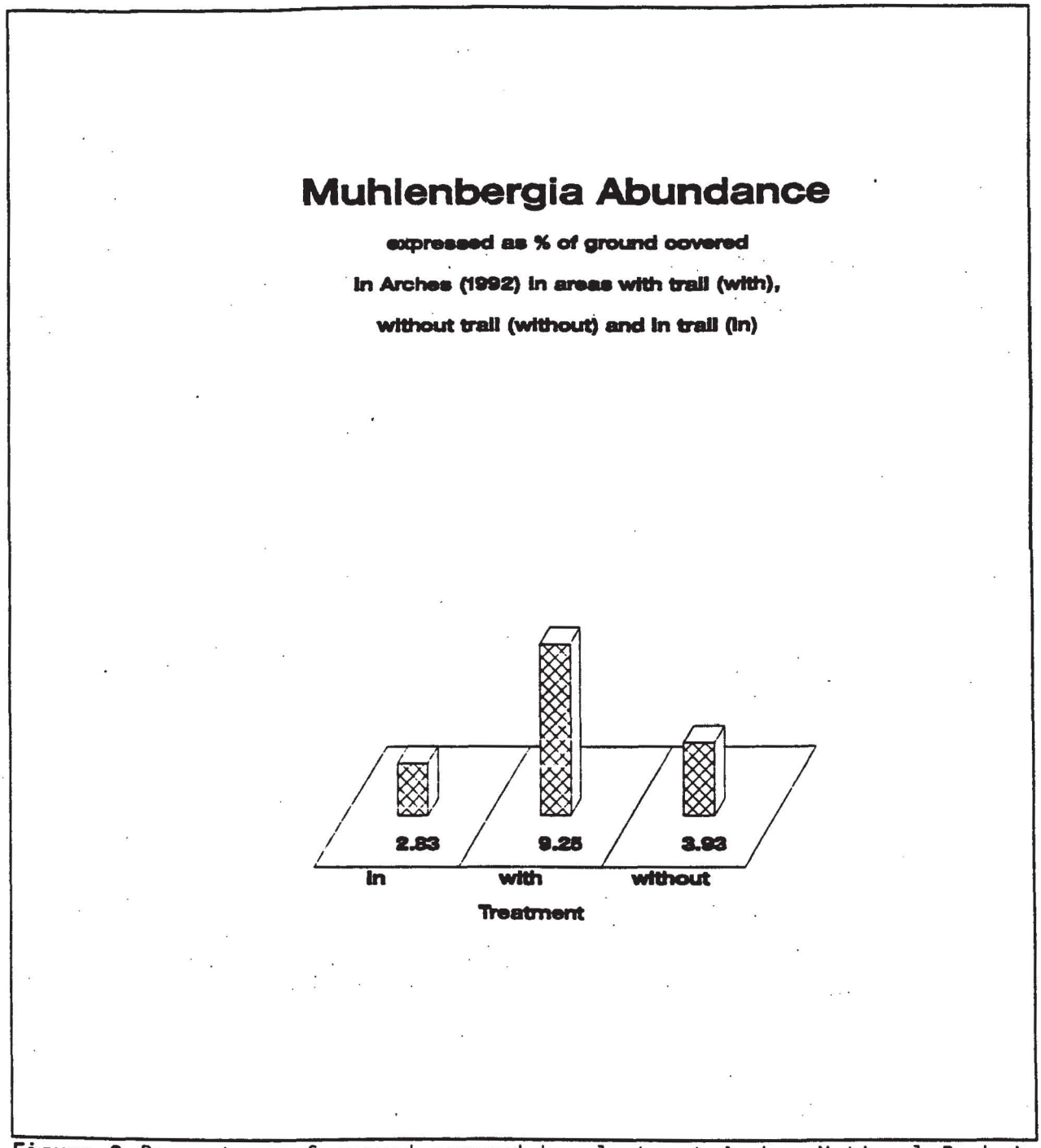

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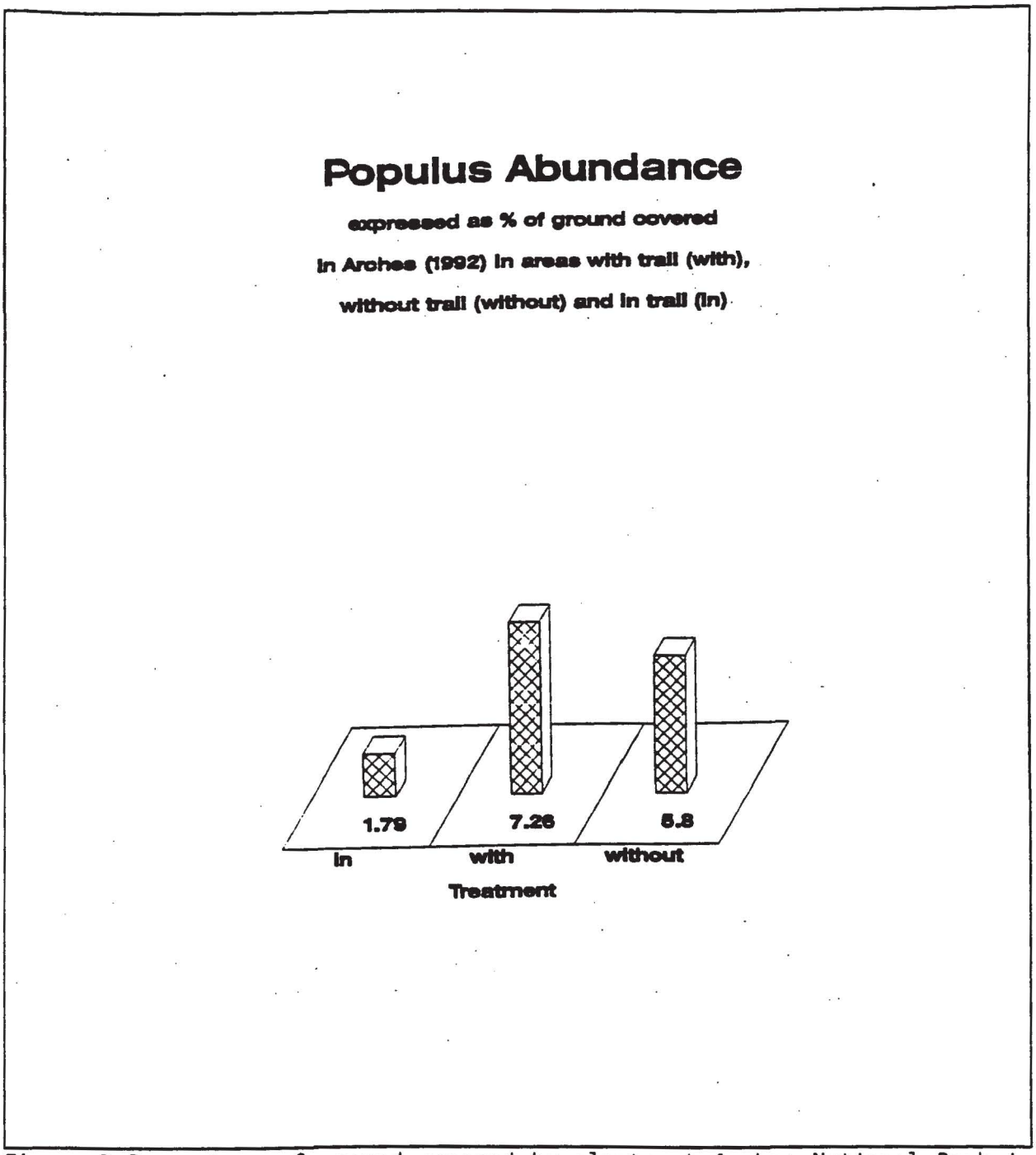

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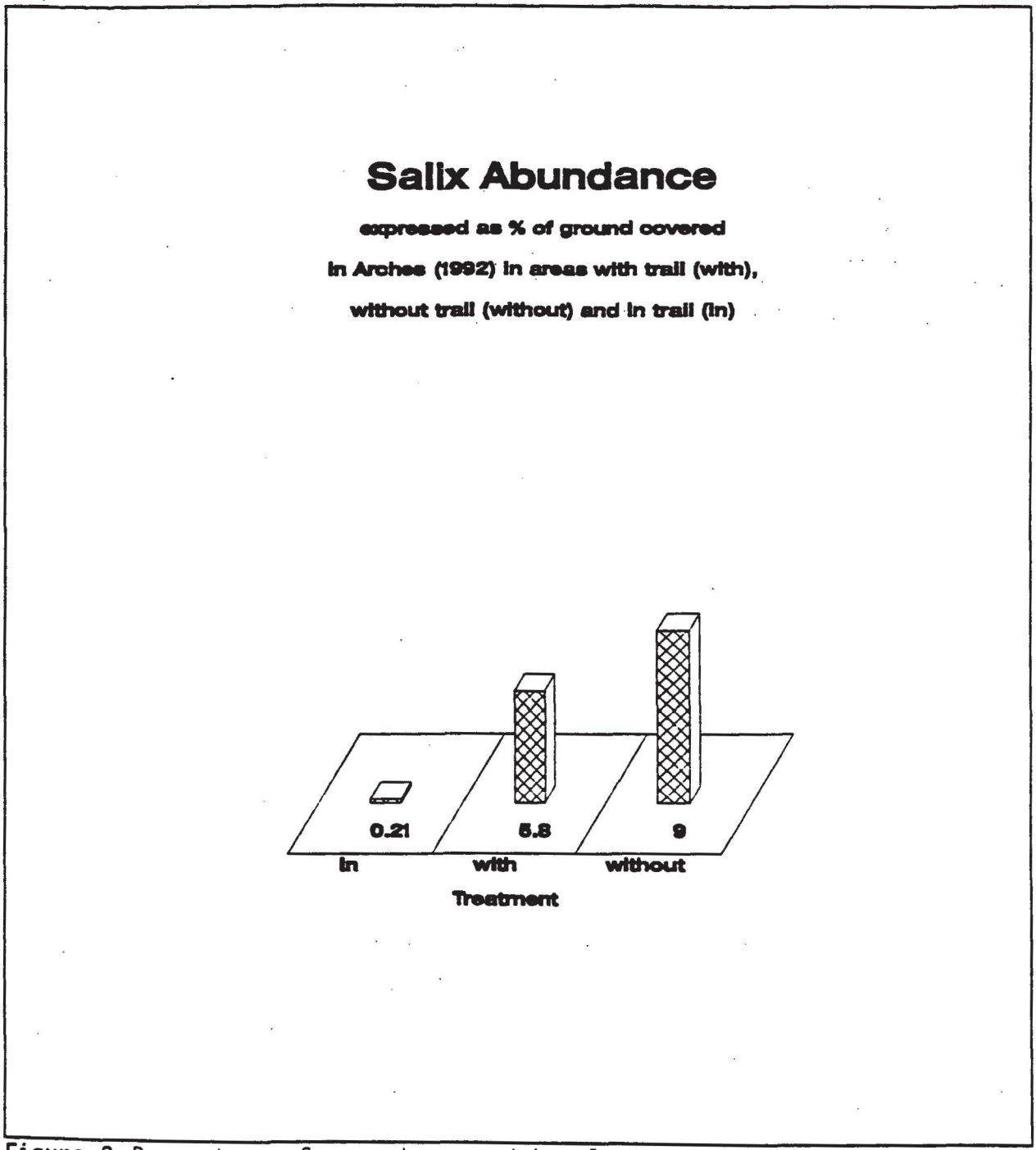

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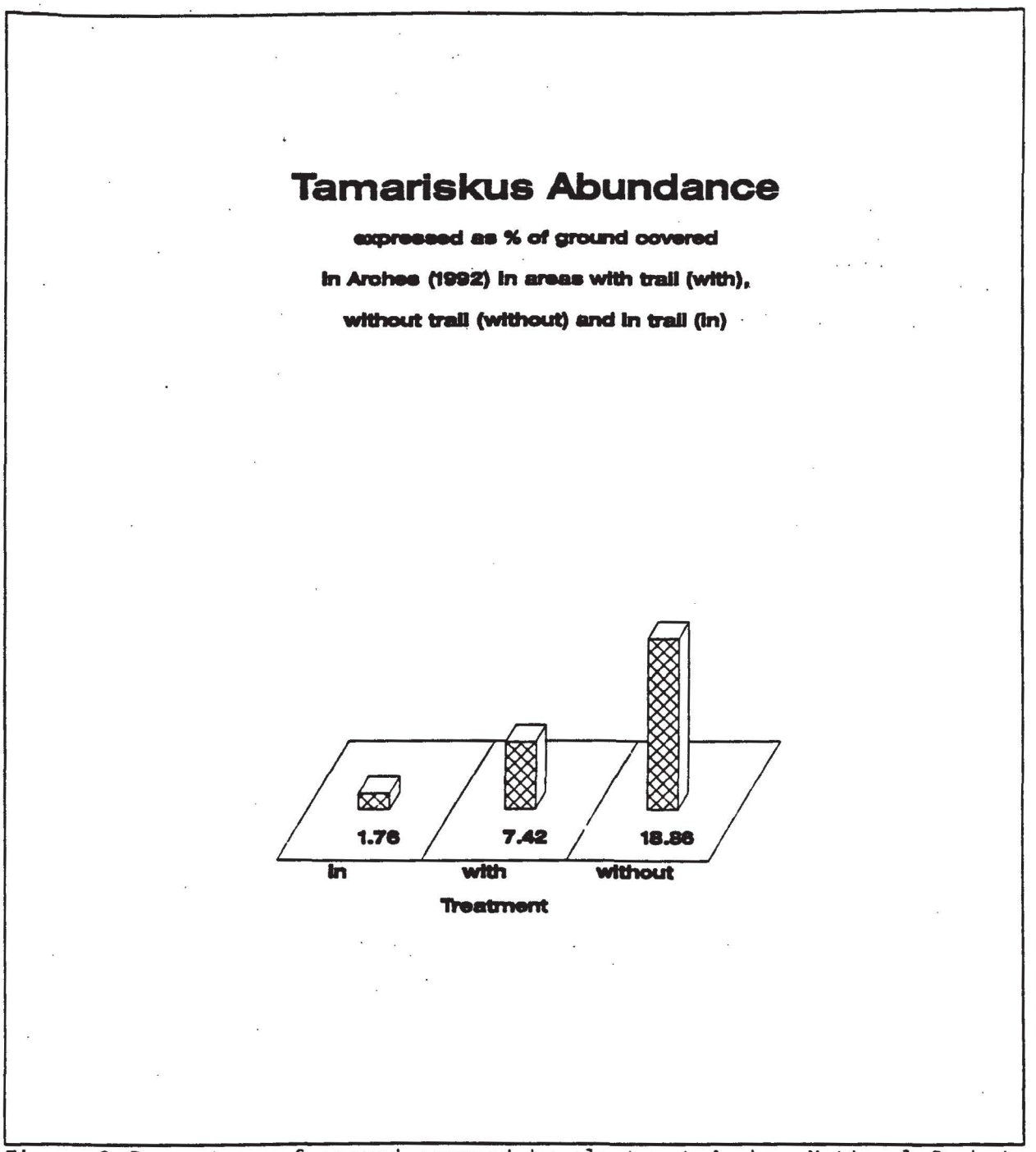

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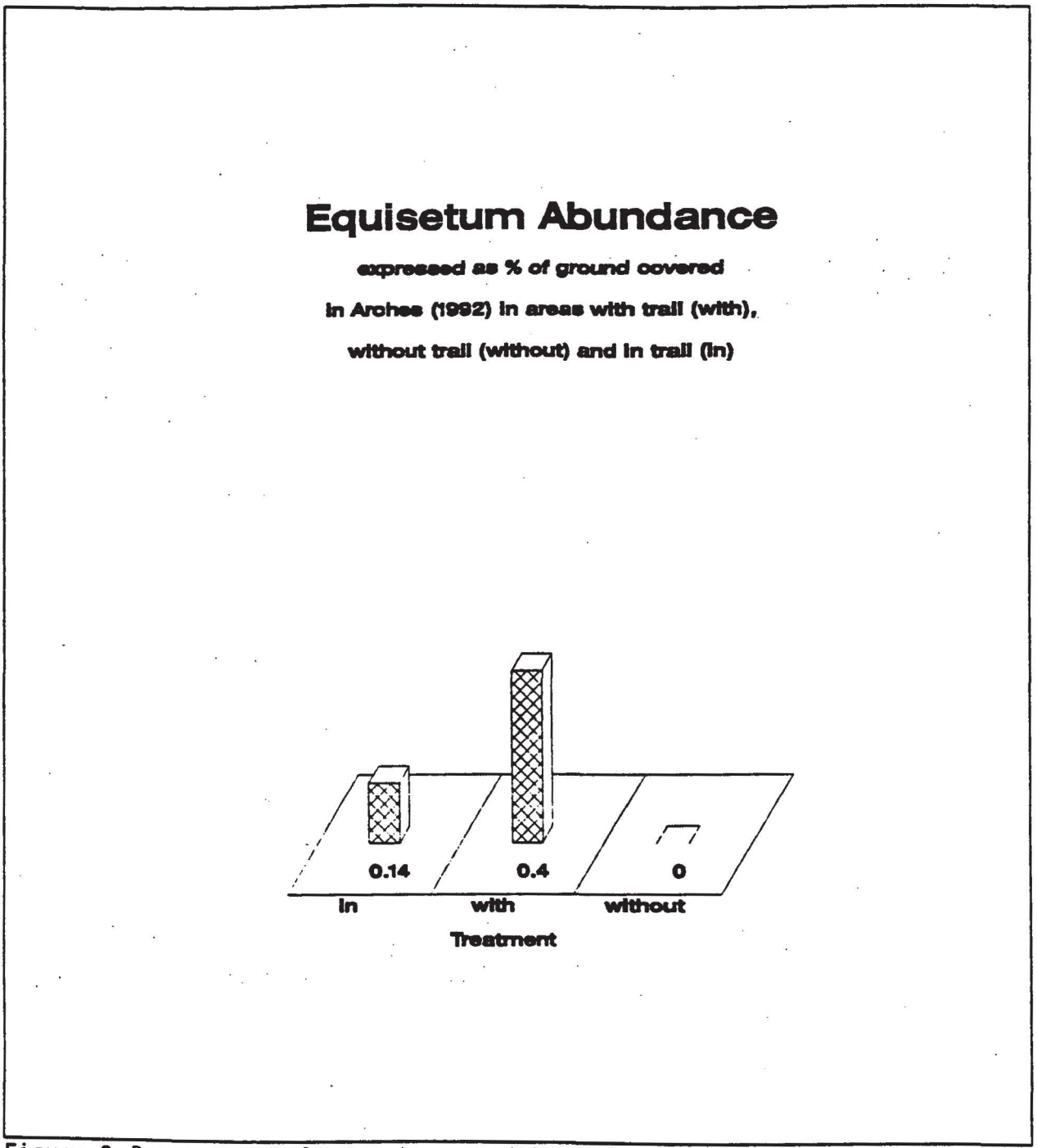

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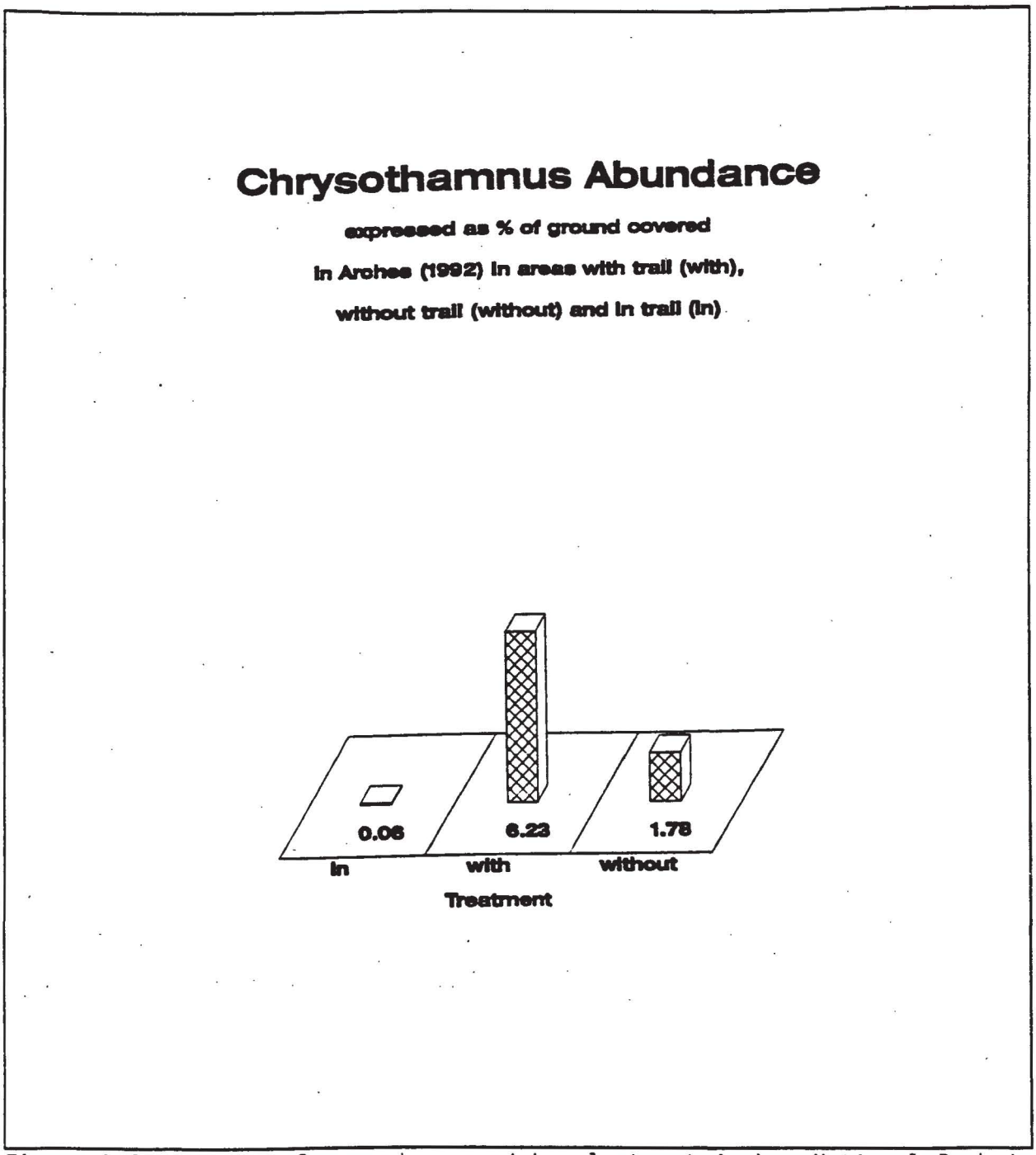

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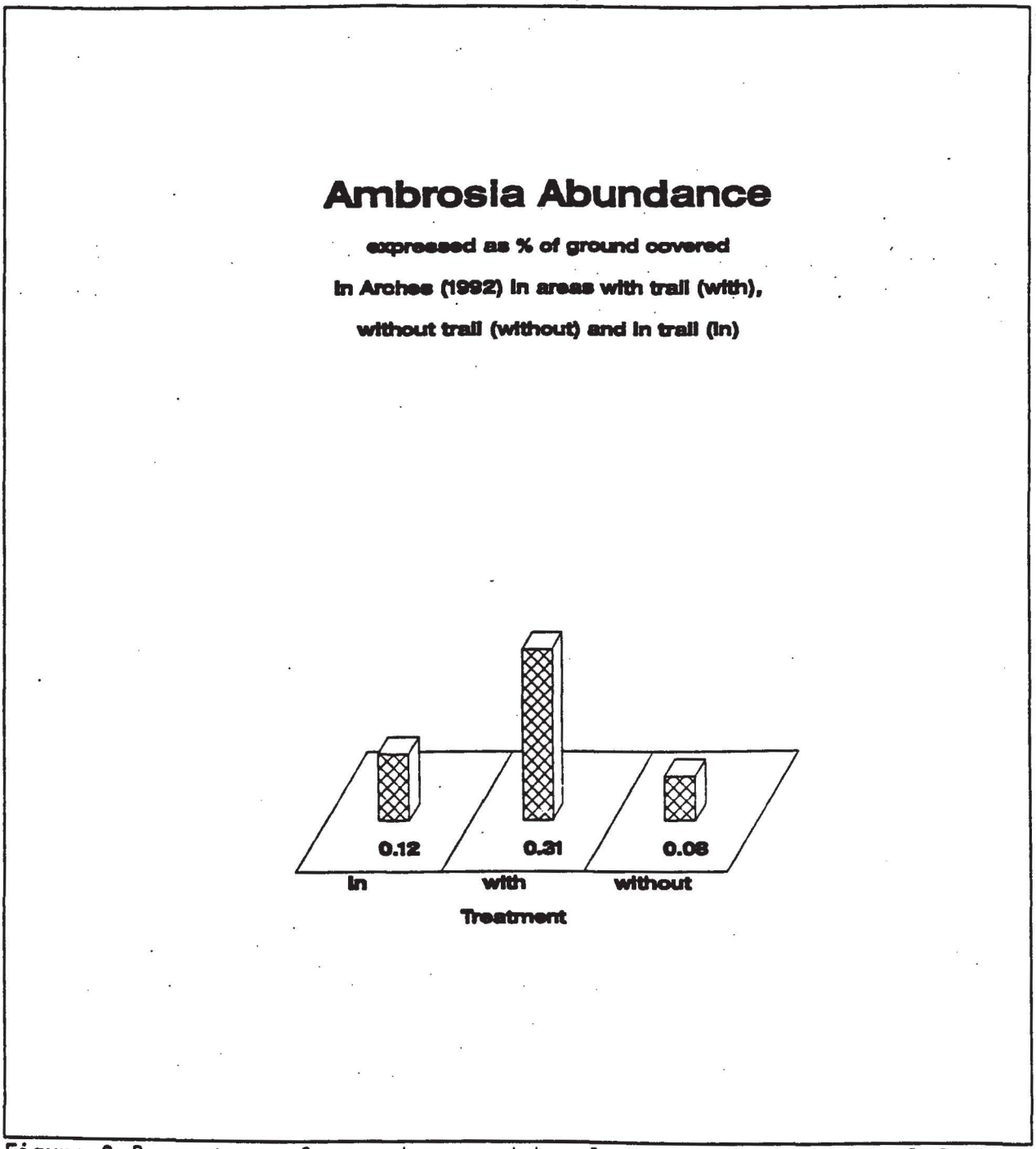

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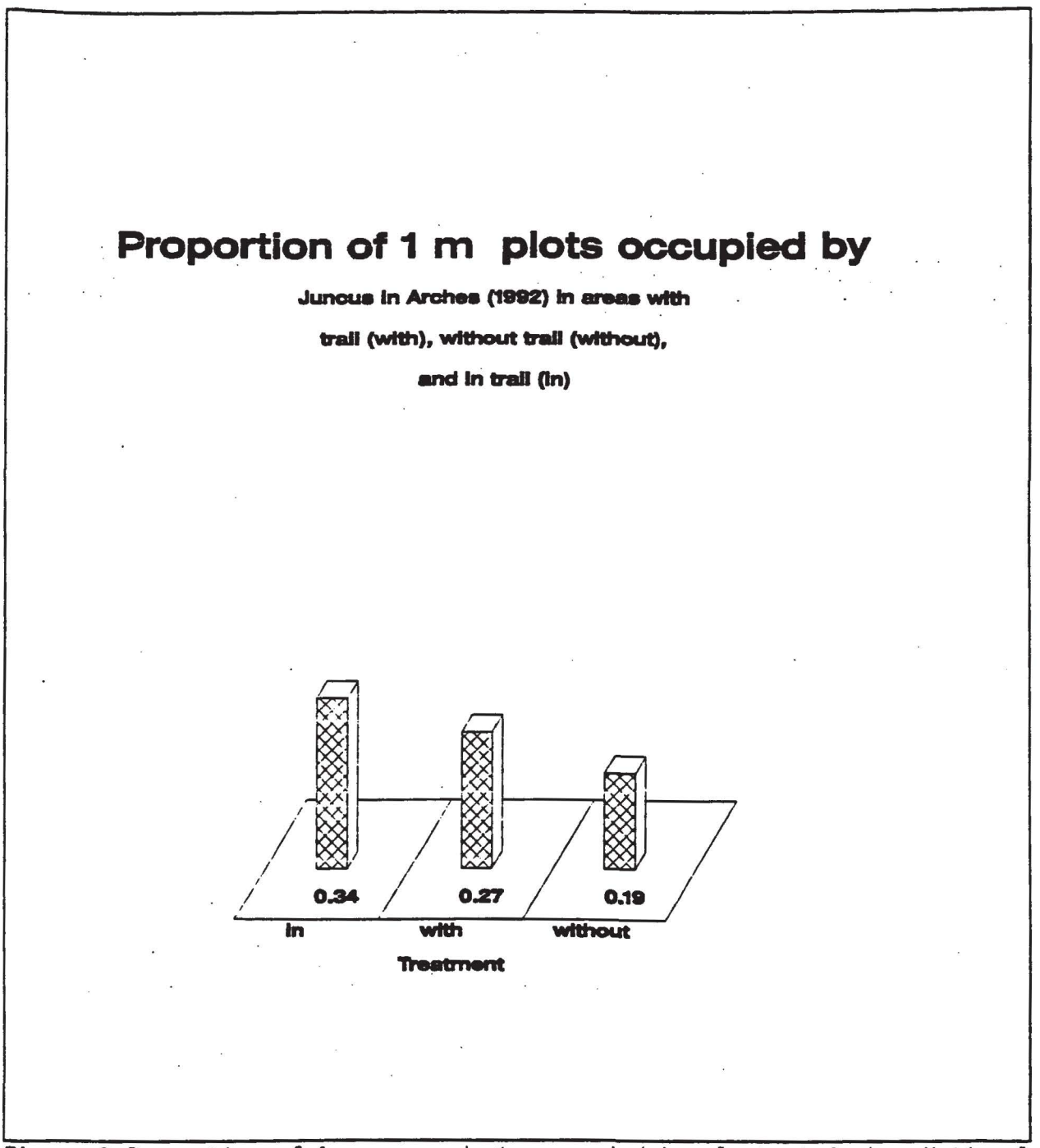
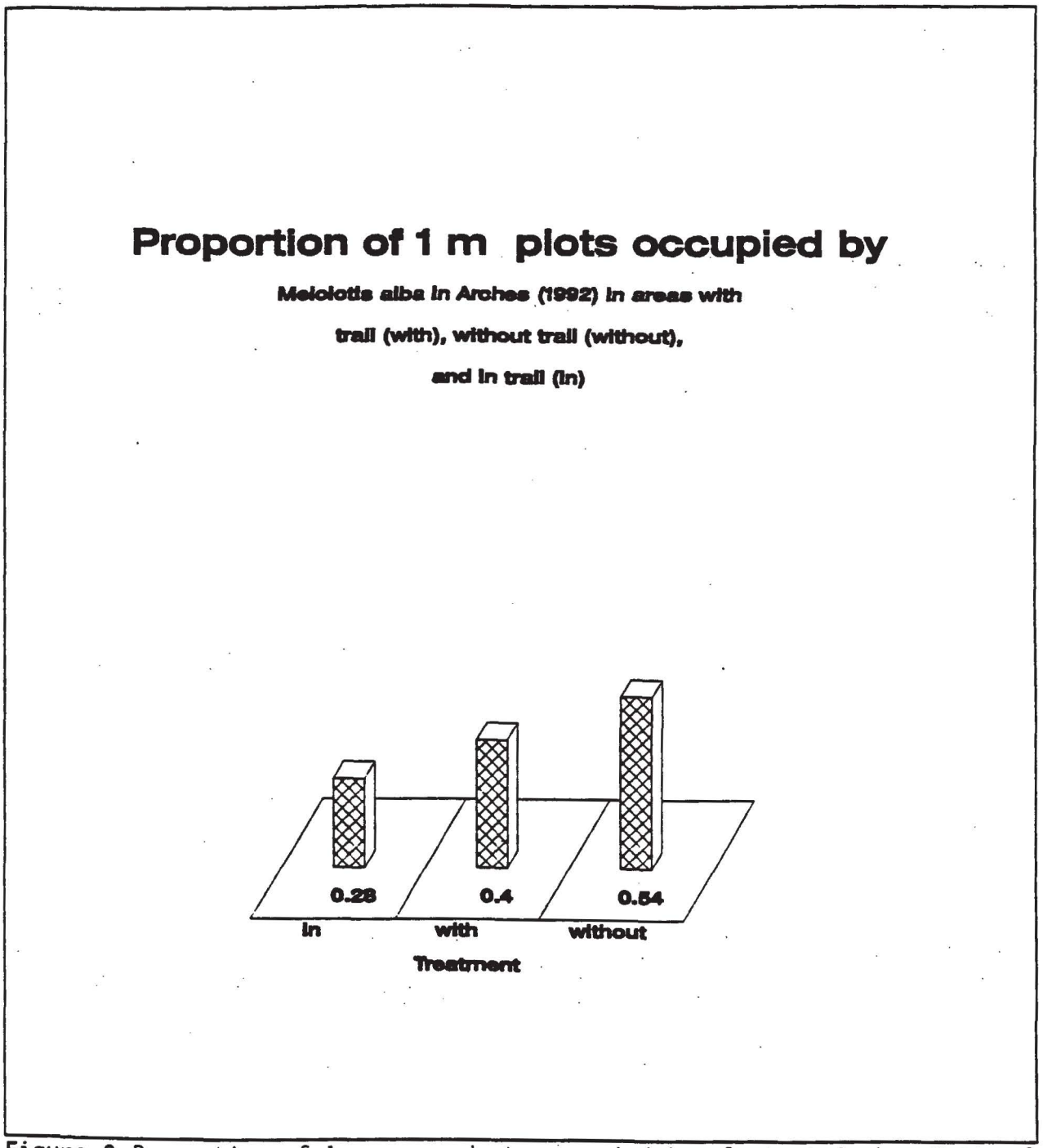


Figure 9 Proportion of 1 m sq quadrats occupied by plant at Arches National Park in 1992.



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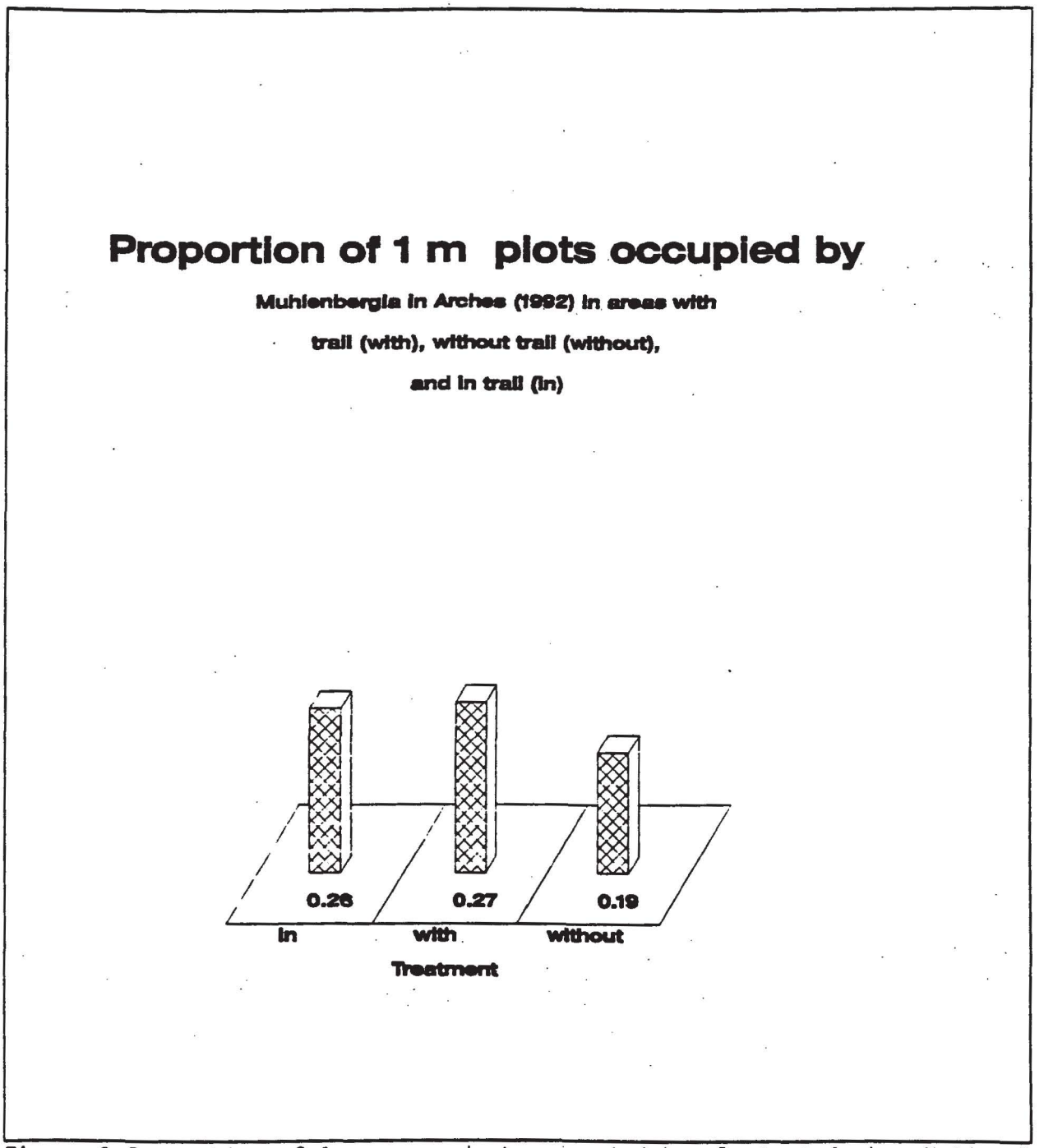

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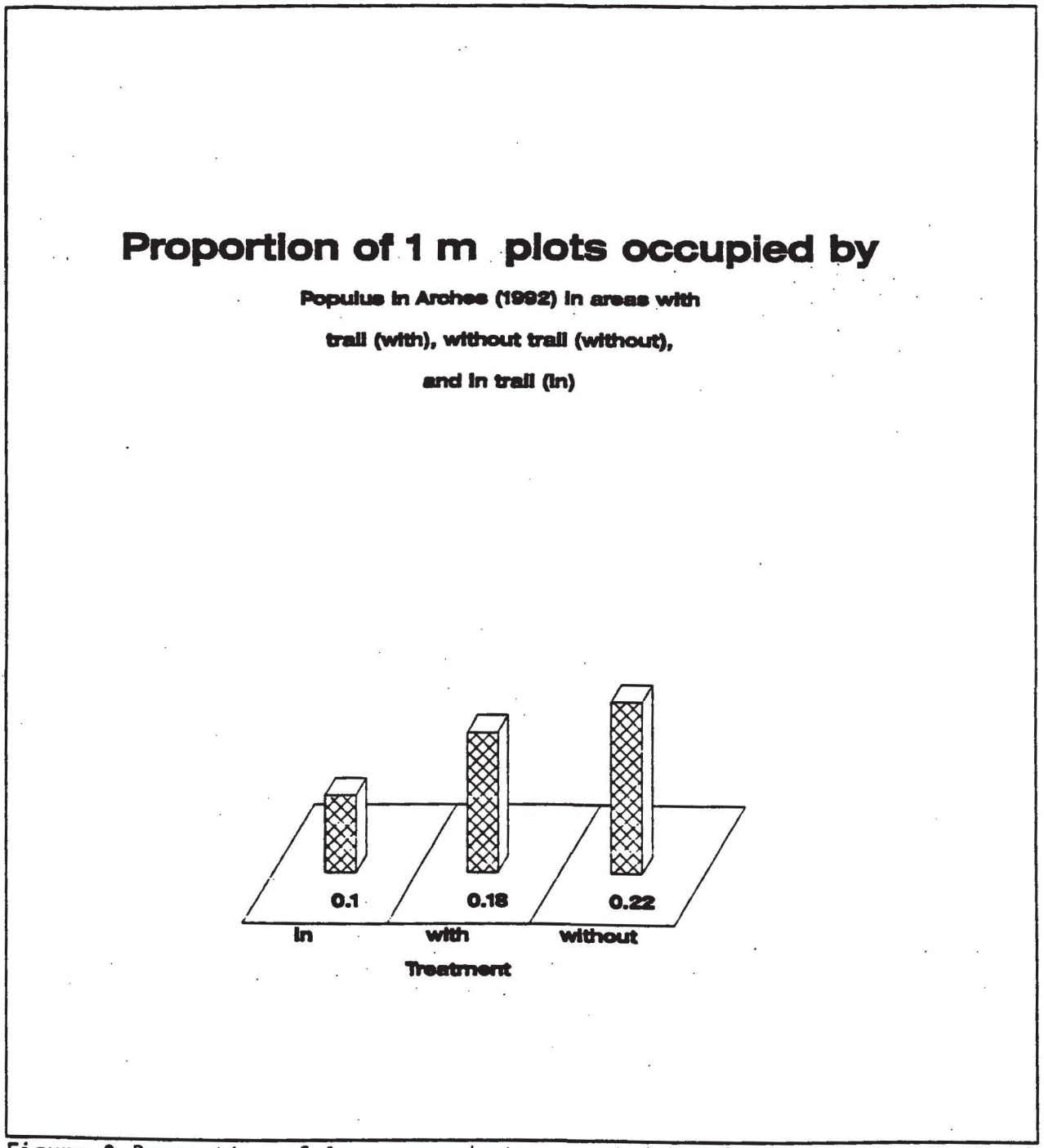

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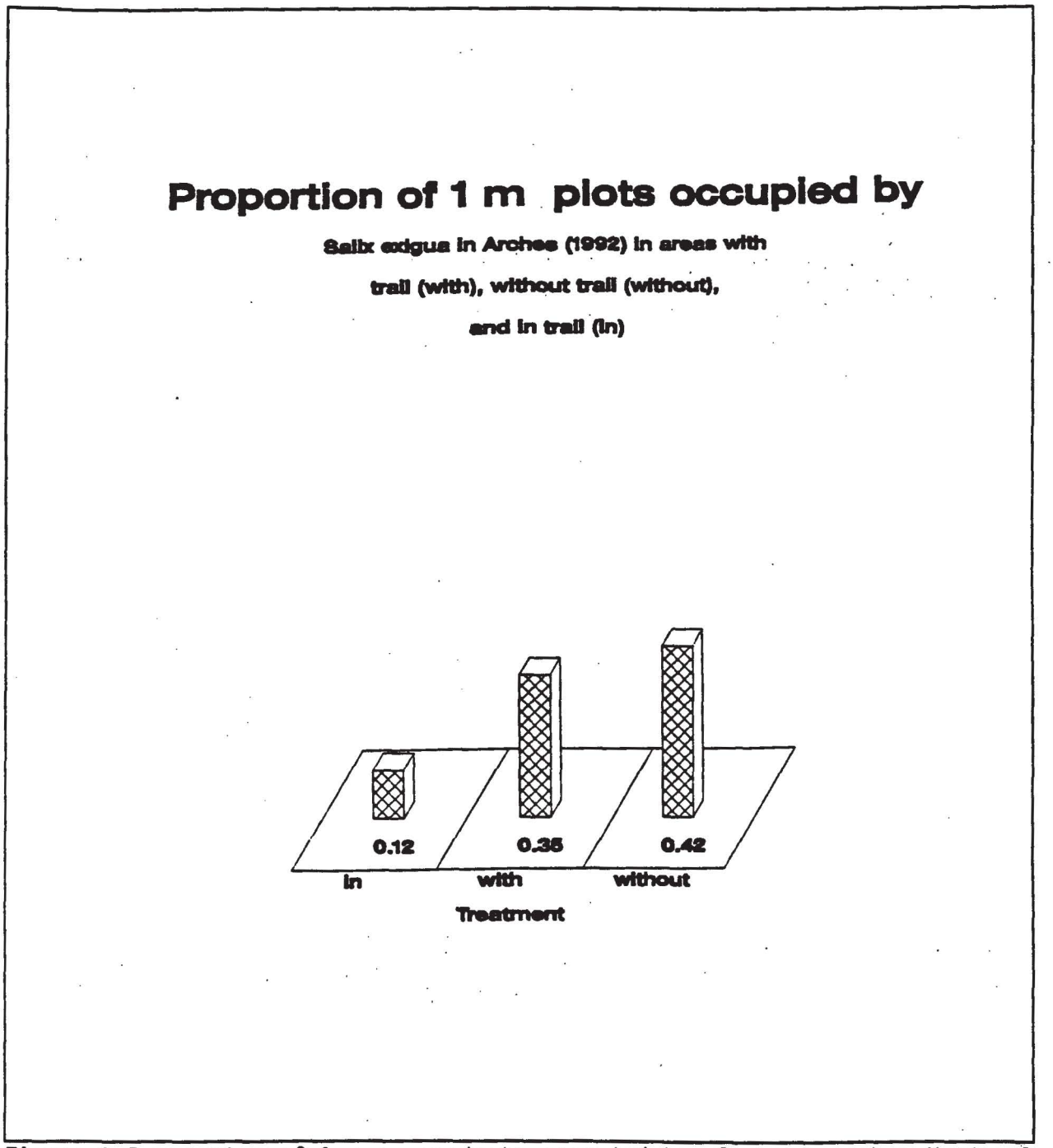

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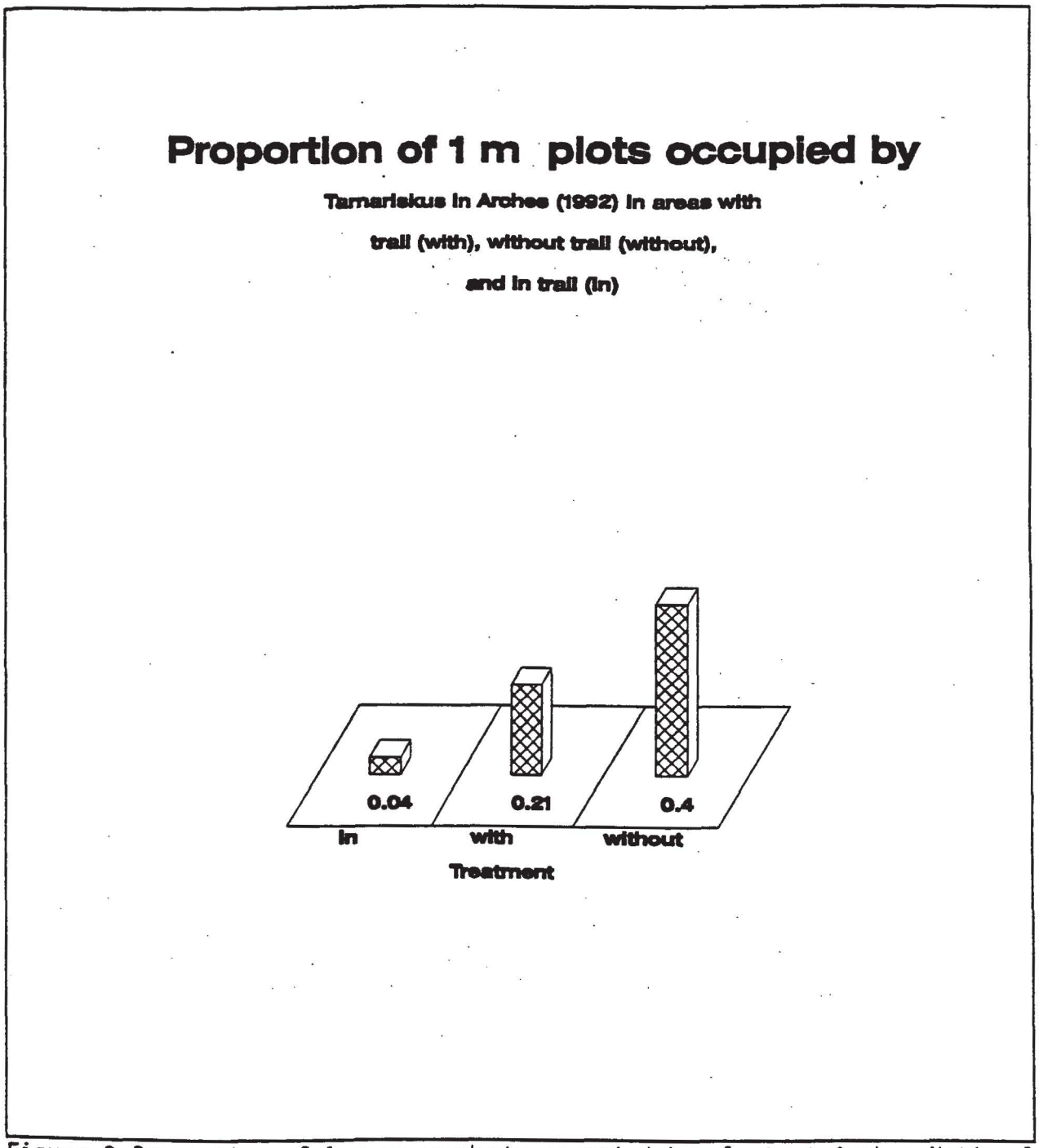

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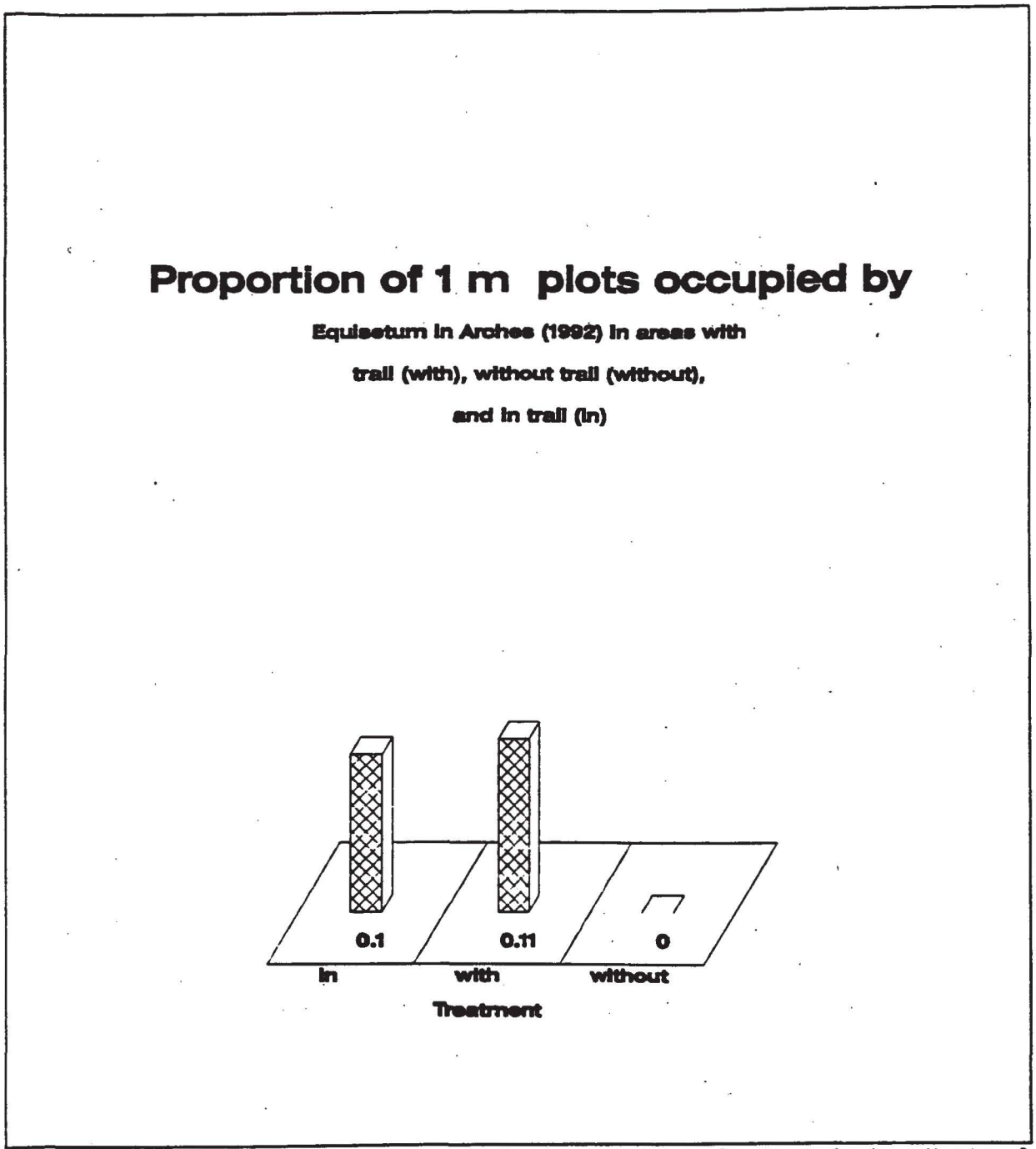

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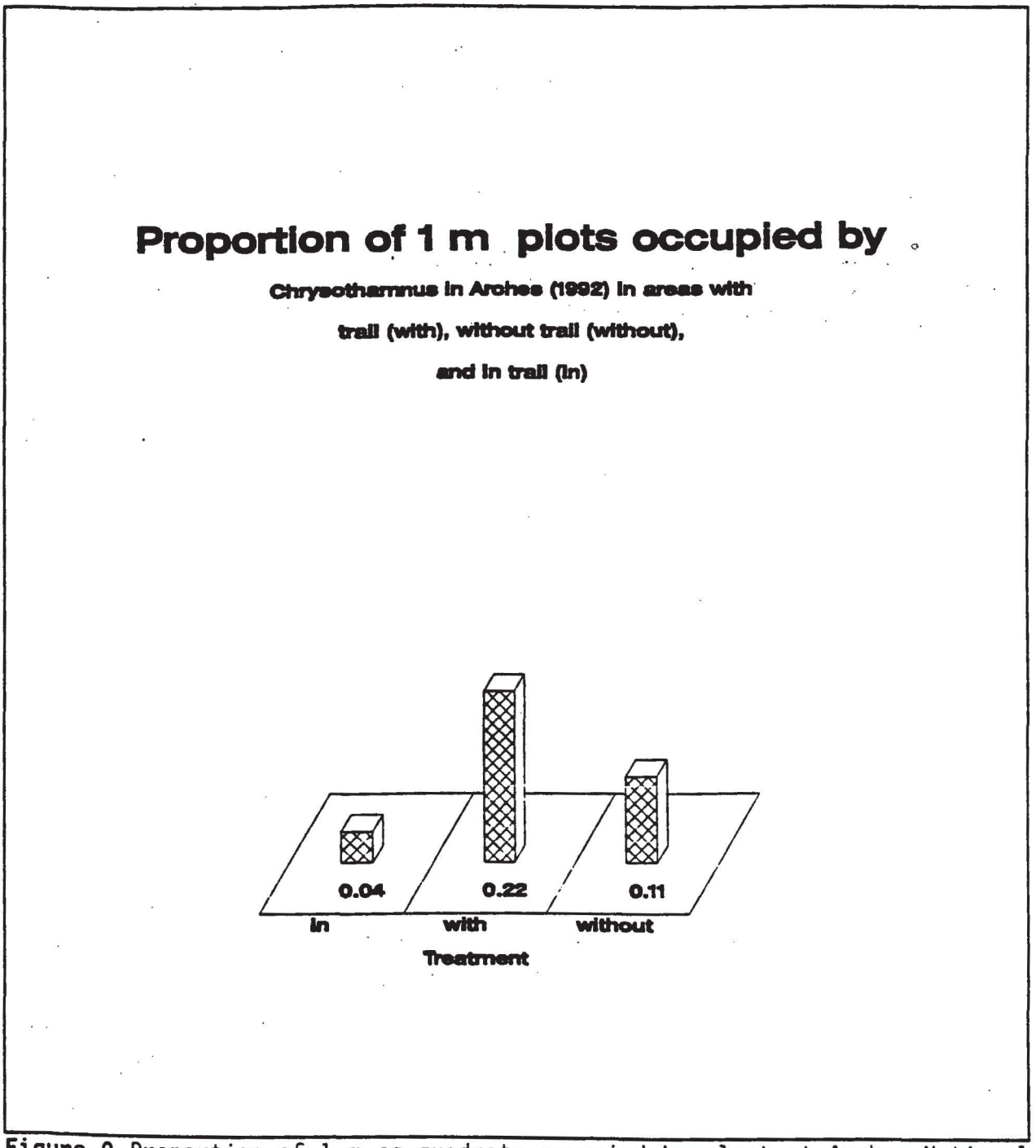

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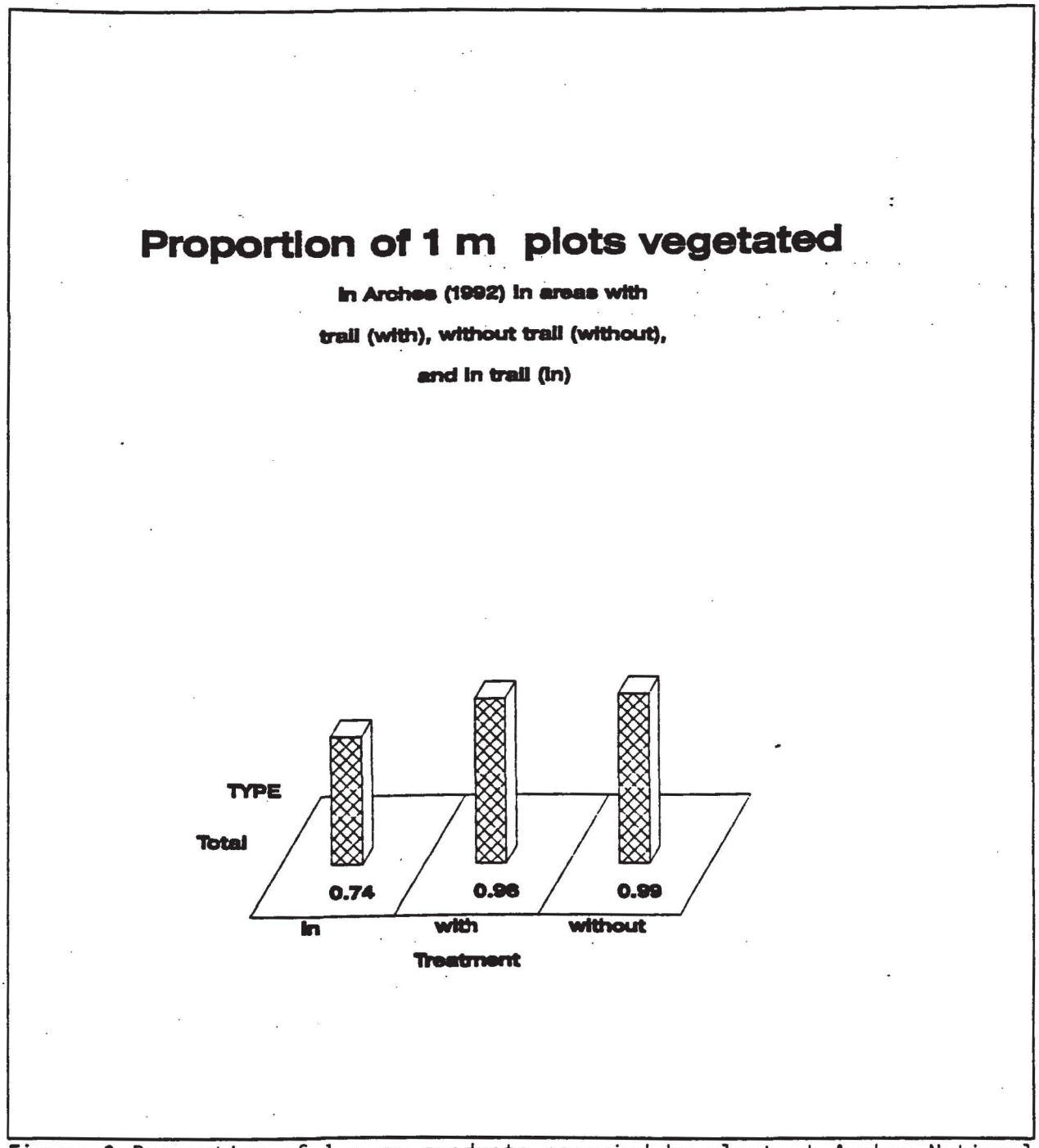

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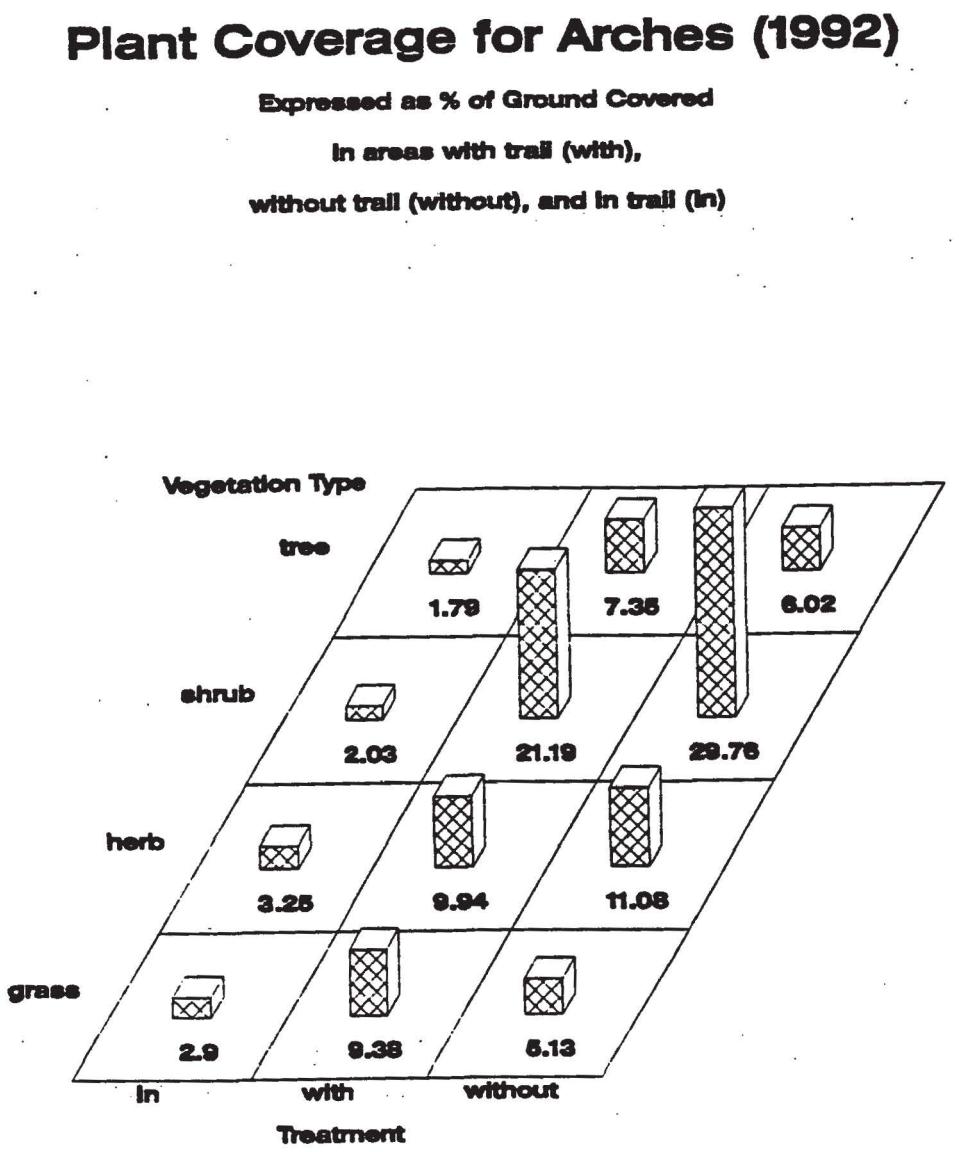
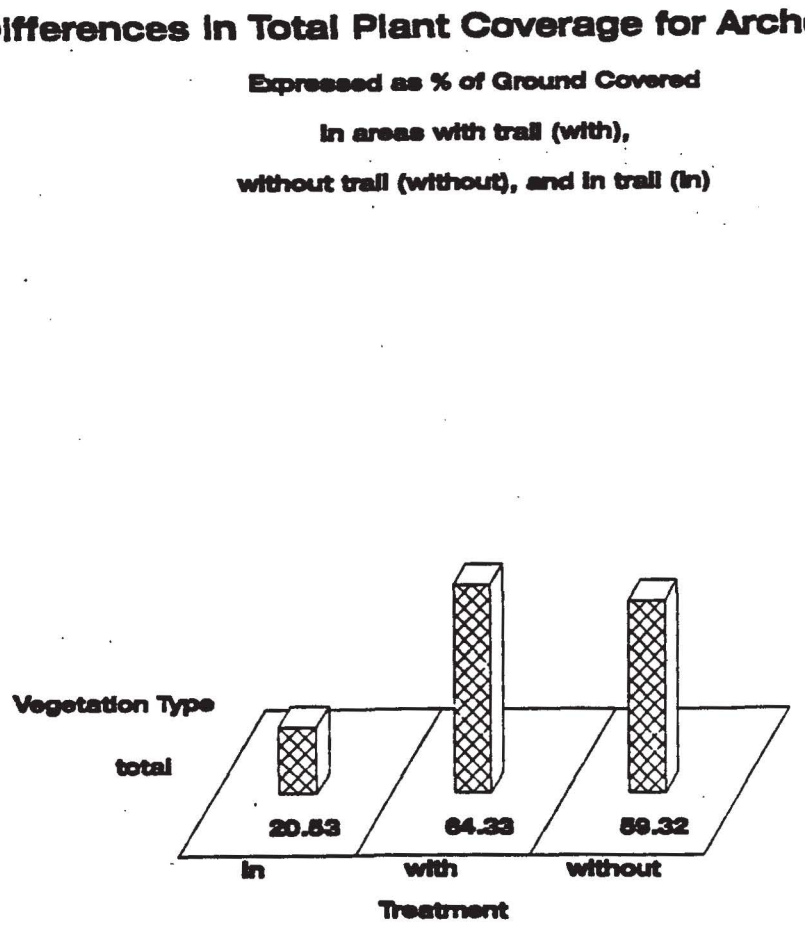


Figure 10 Percentage of ground covered by ecological plant groups at Arches National Park in 1992.



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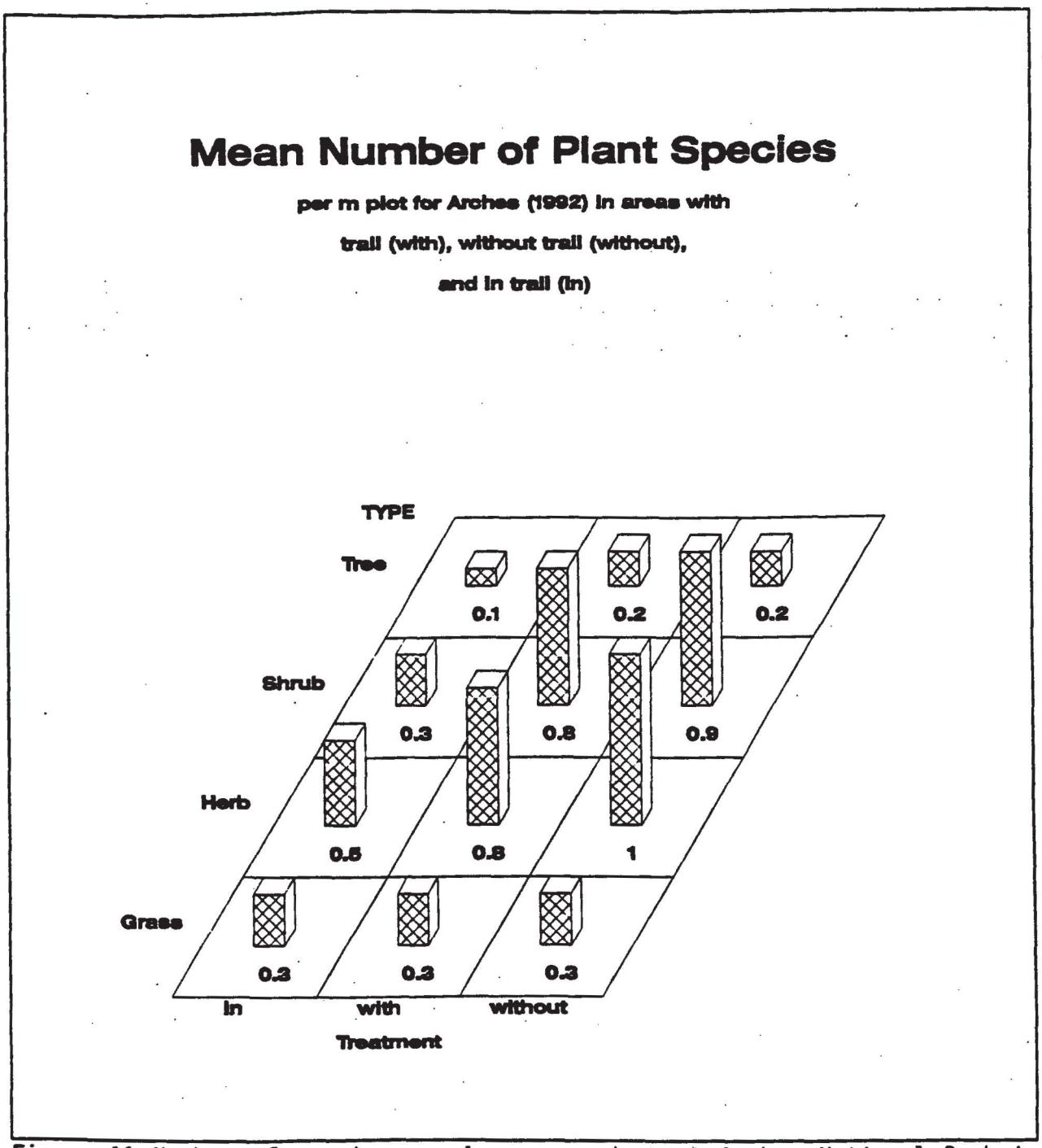
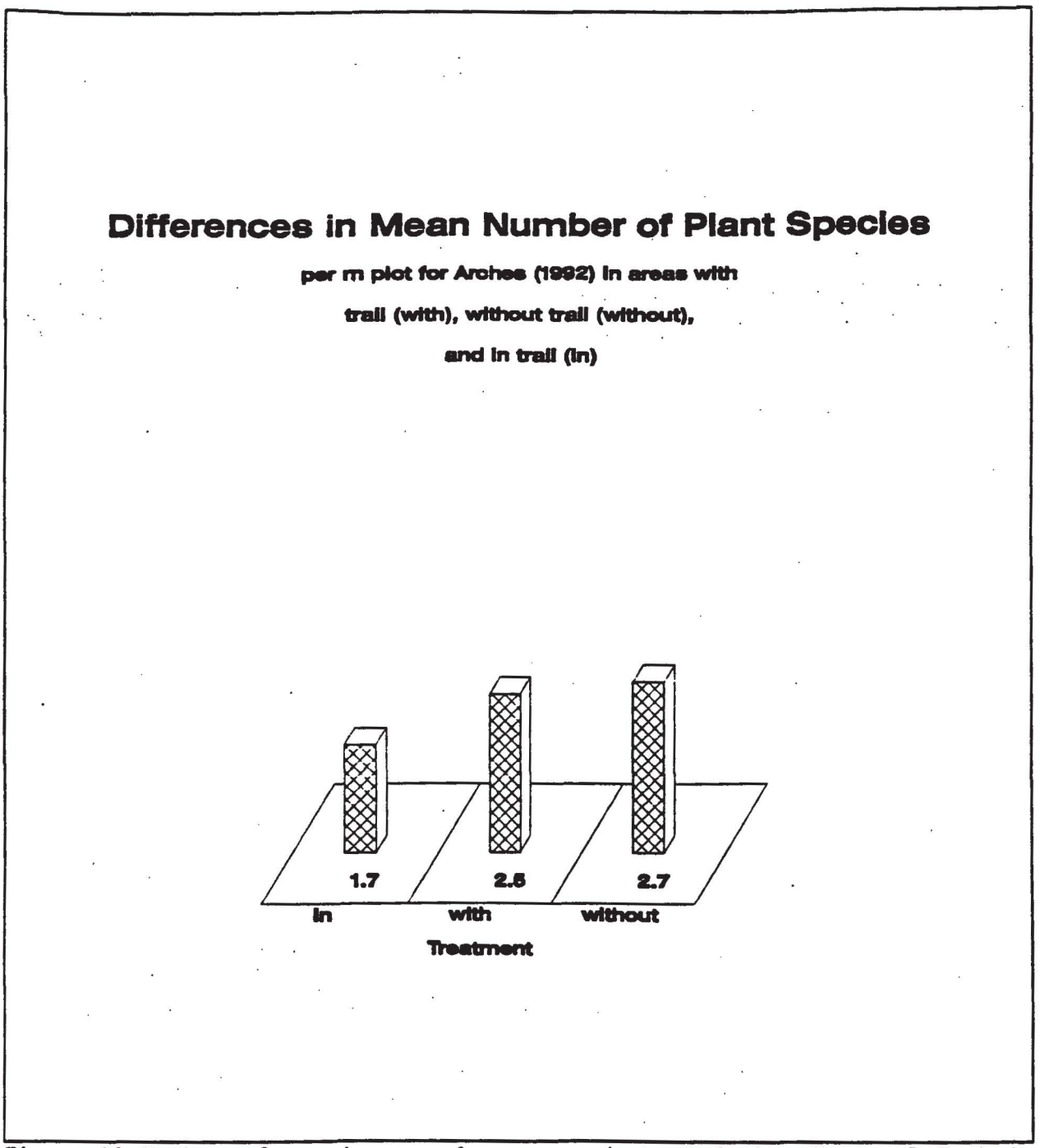


Figure 11 Number of species per 1 m sq quadrat at Arches National Park in 1992.



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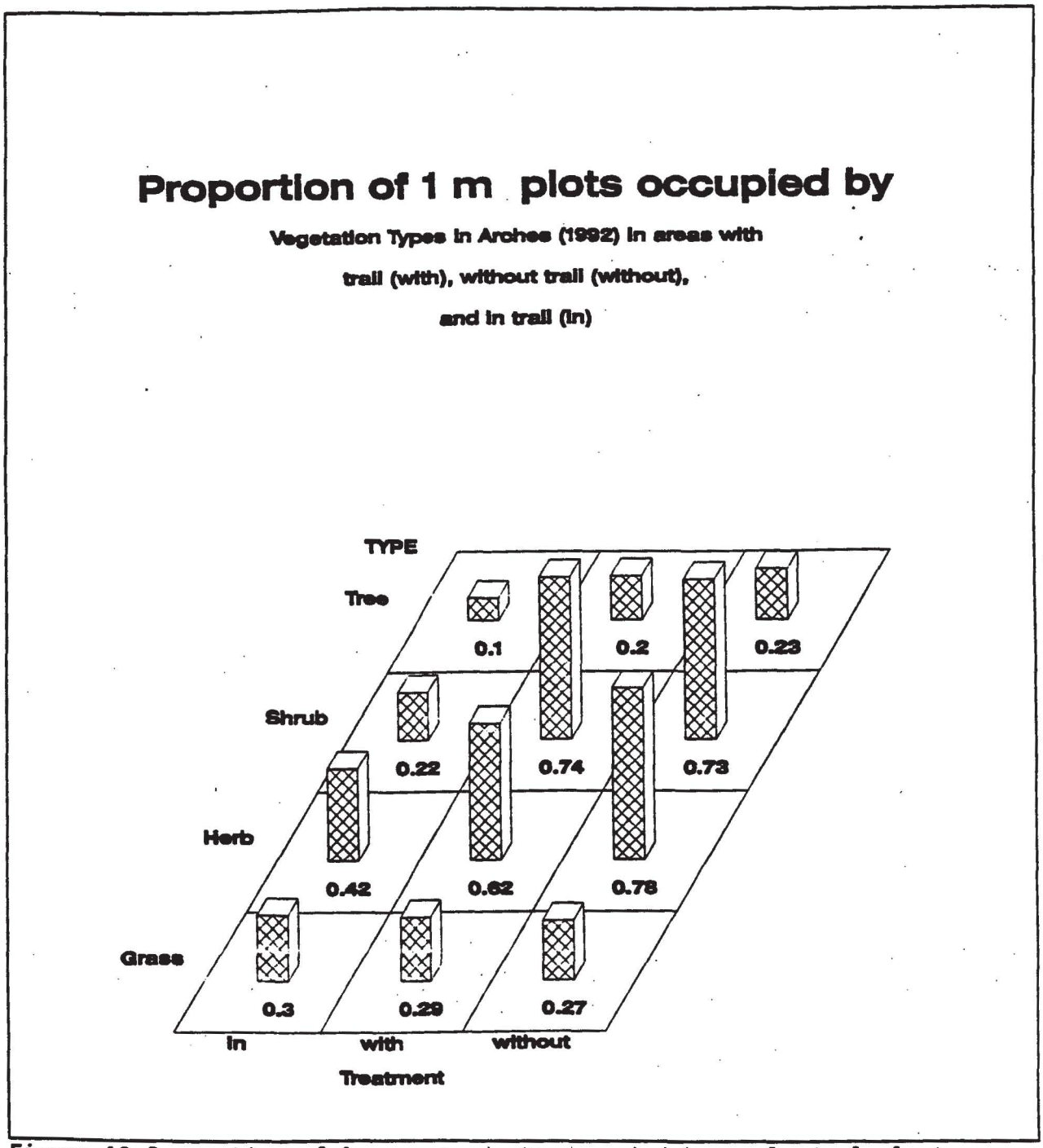
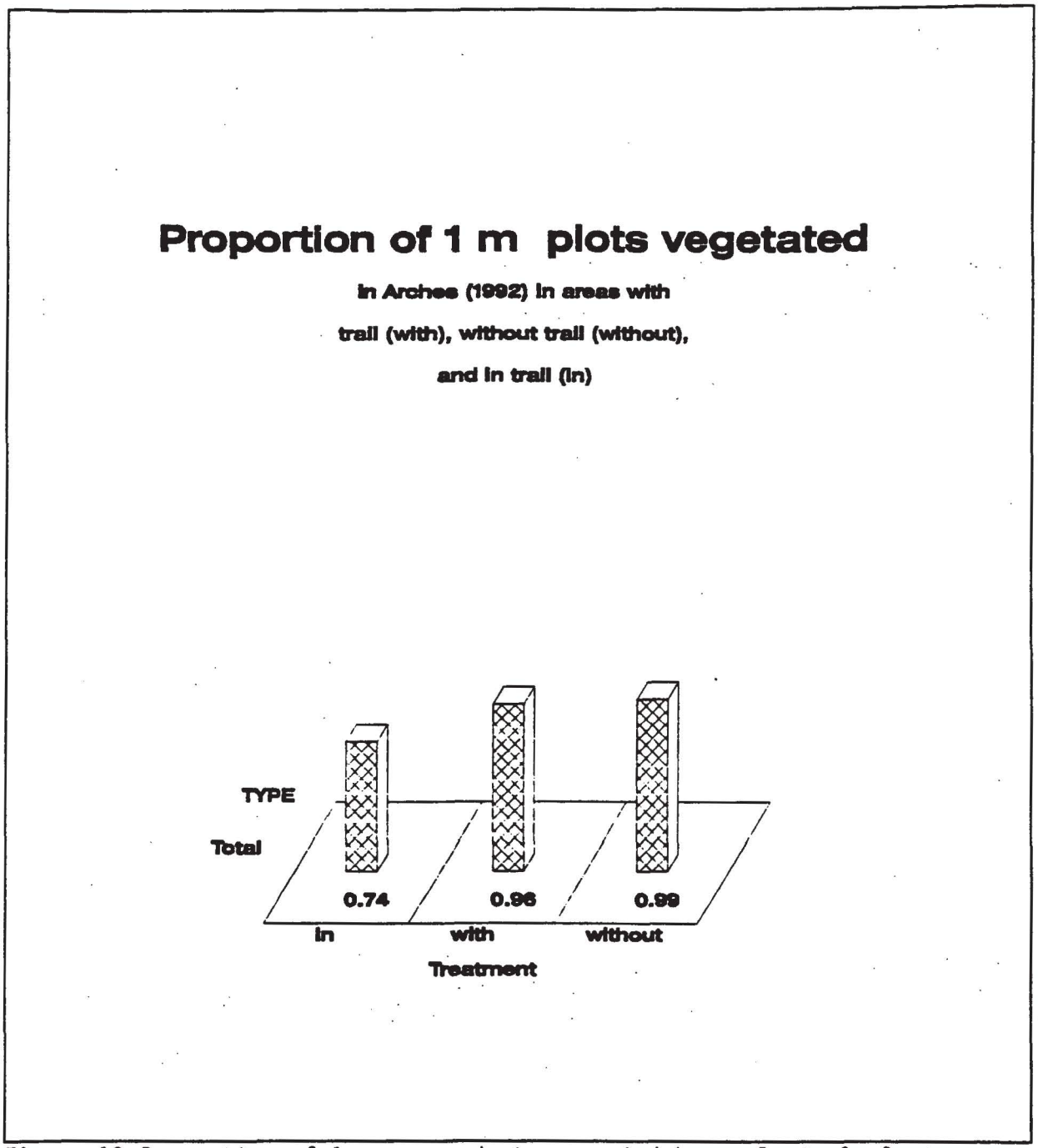


Figure 12 Proportion of 1 m sq quadrats occupied by ecological plant groups at Arches National Park in 1992.



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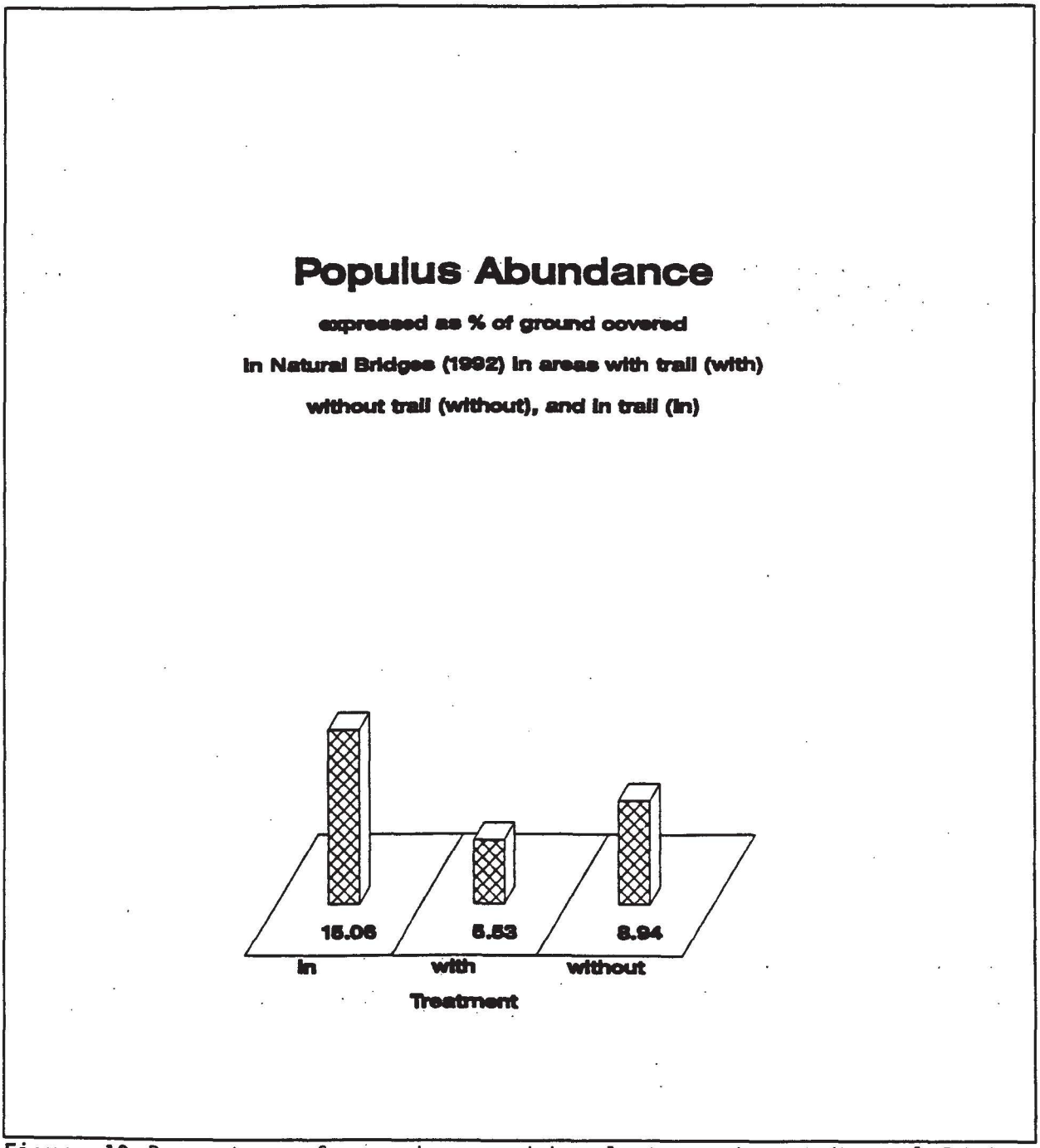
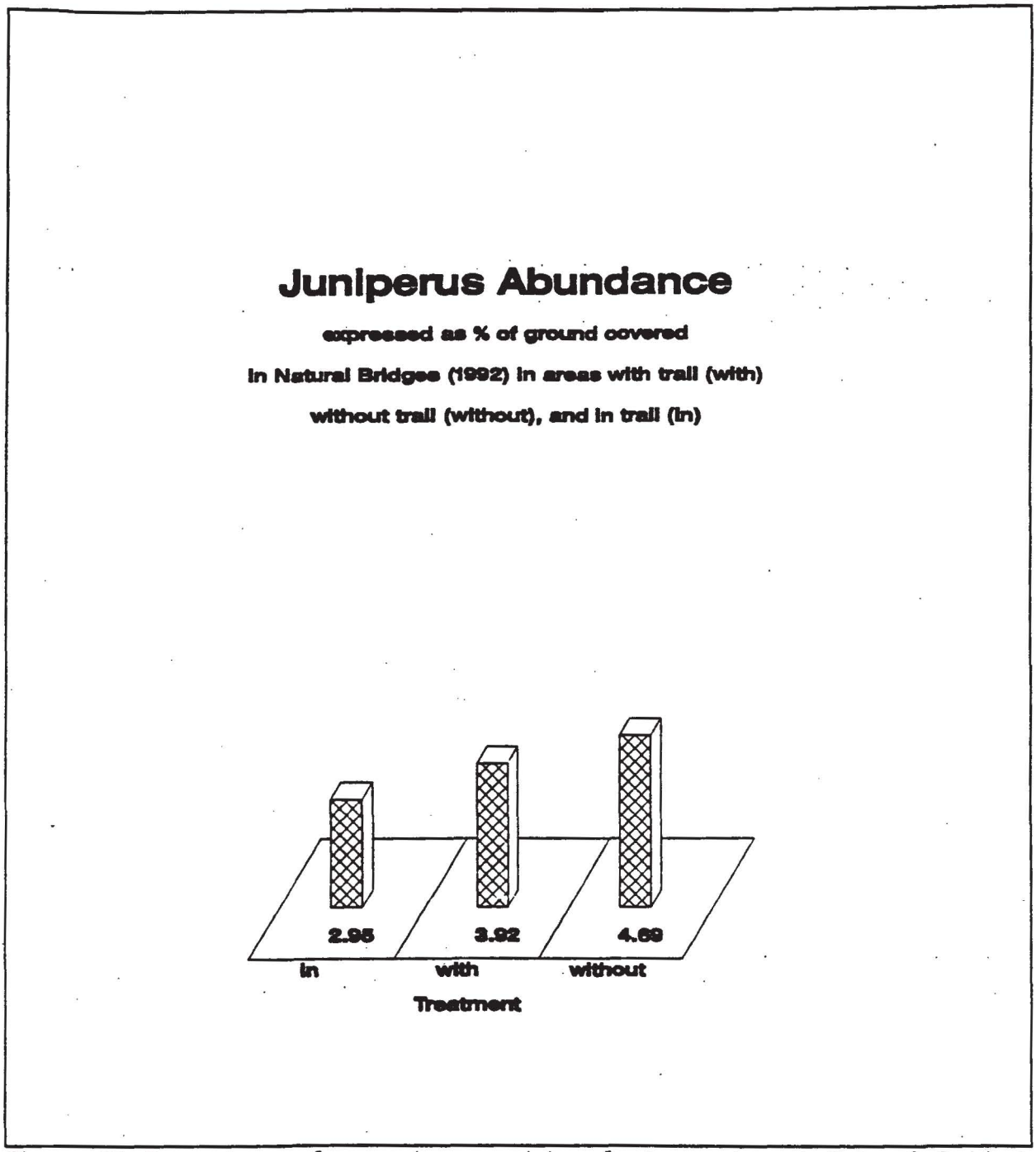


Figure 13 Percentage of ground covered by plant species at Natural Bridges National Monument in 1992.



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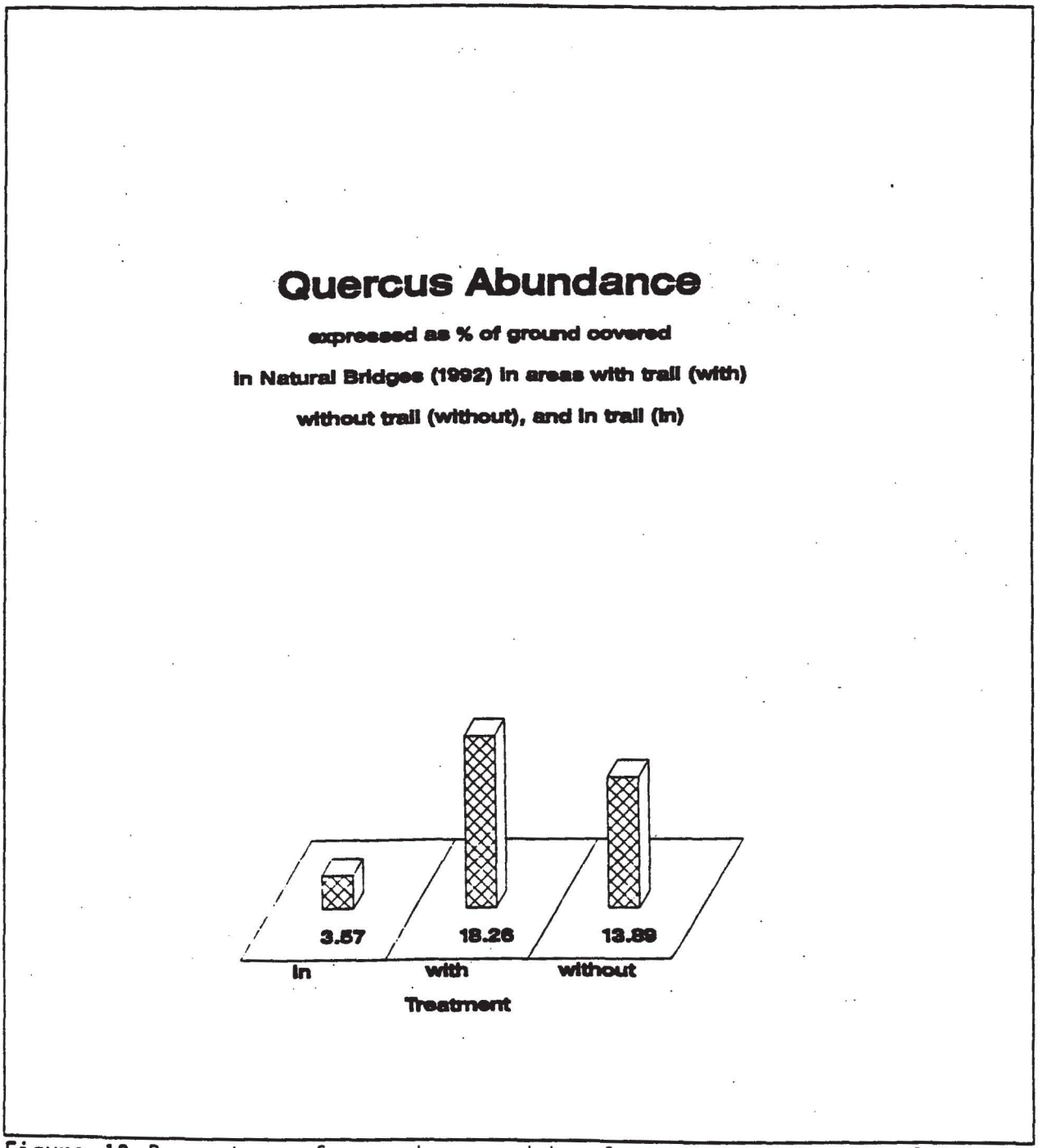

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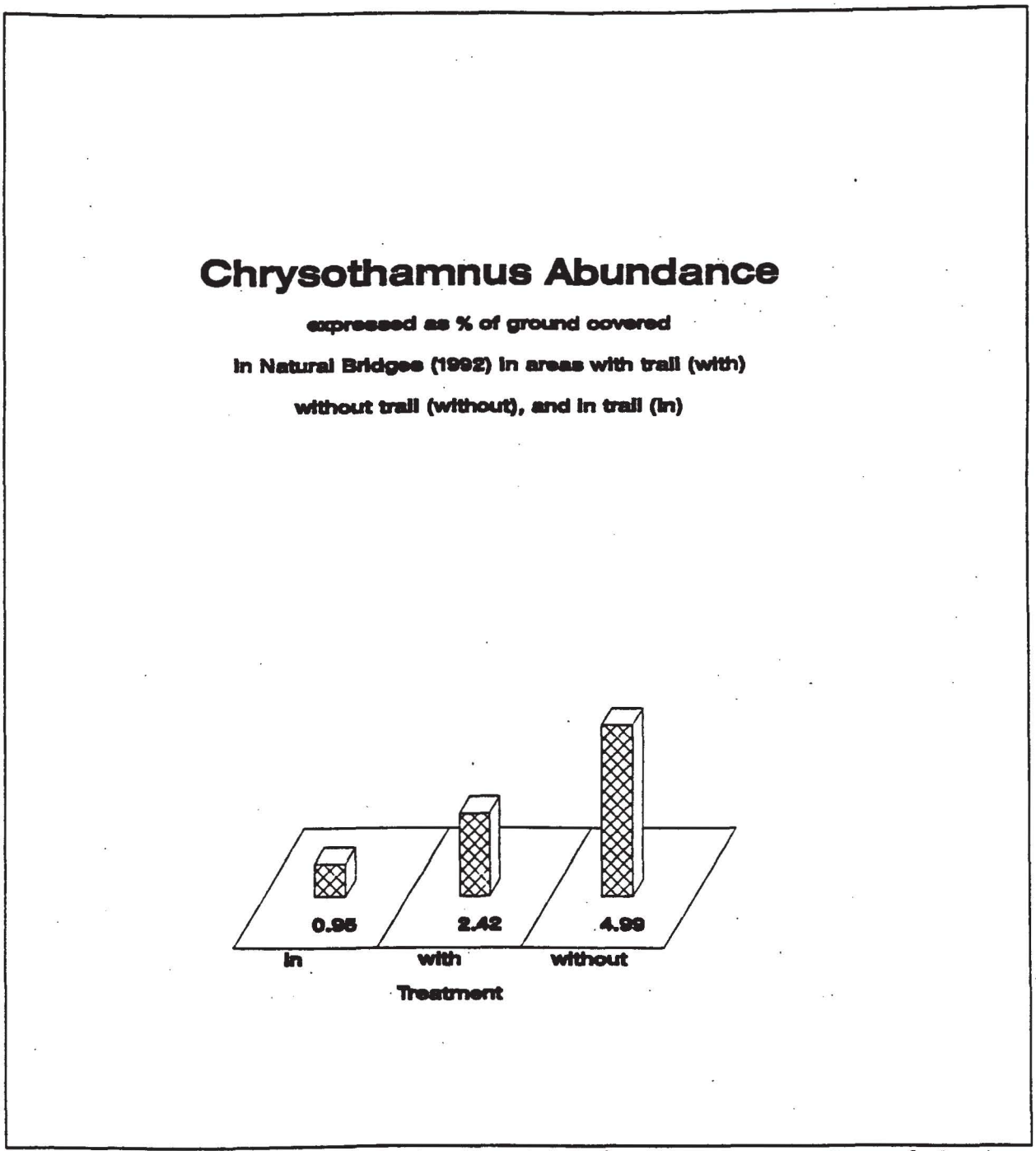

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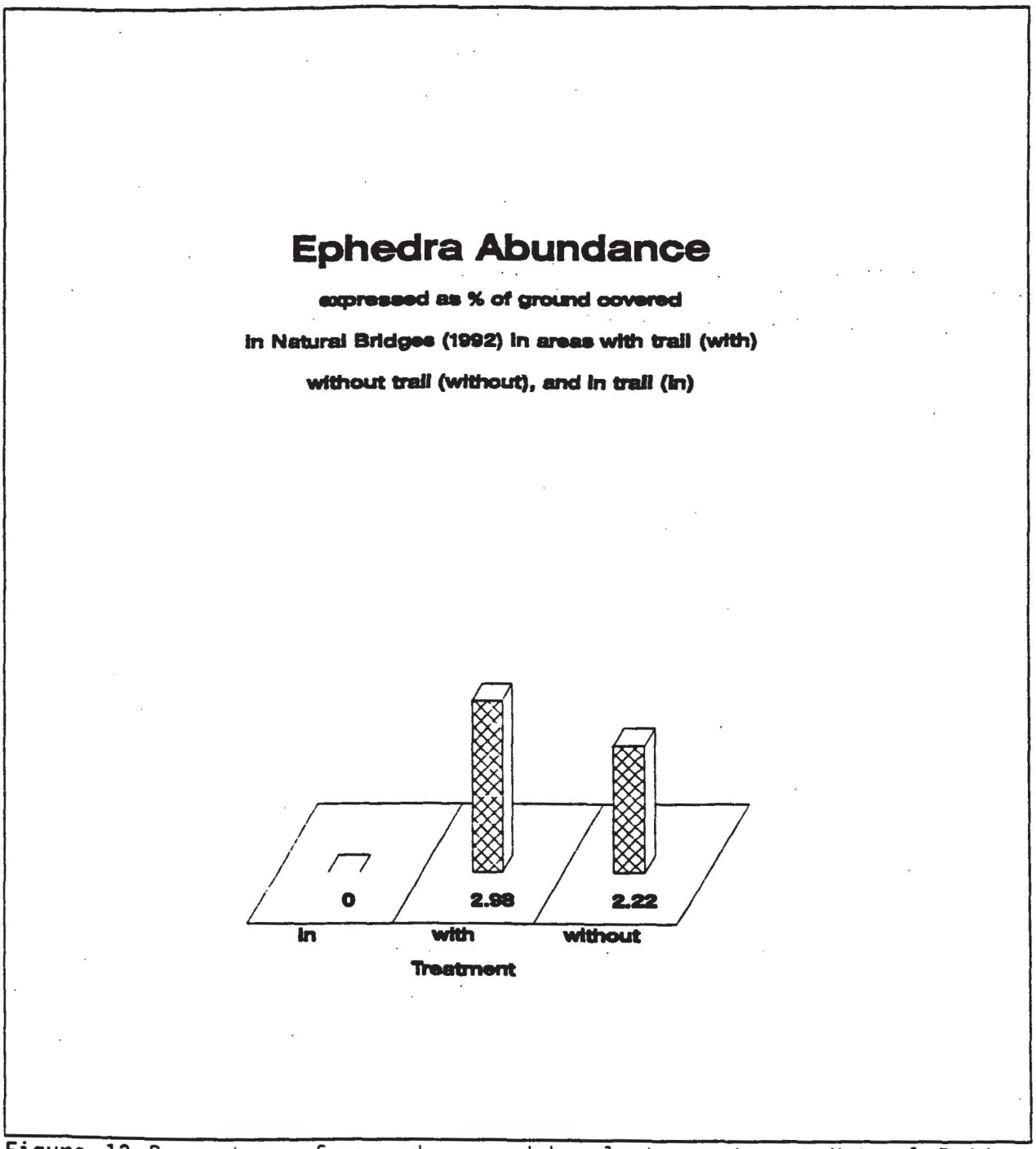

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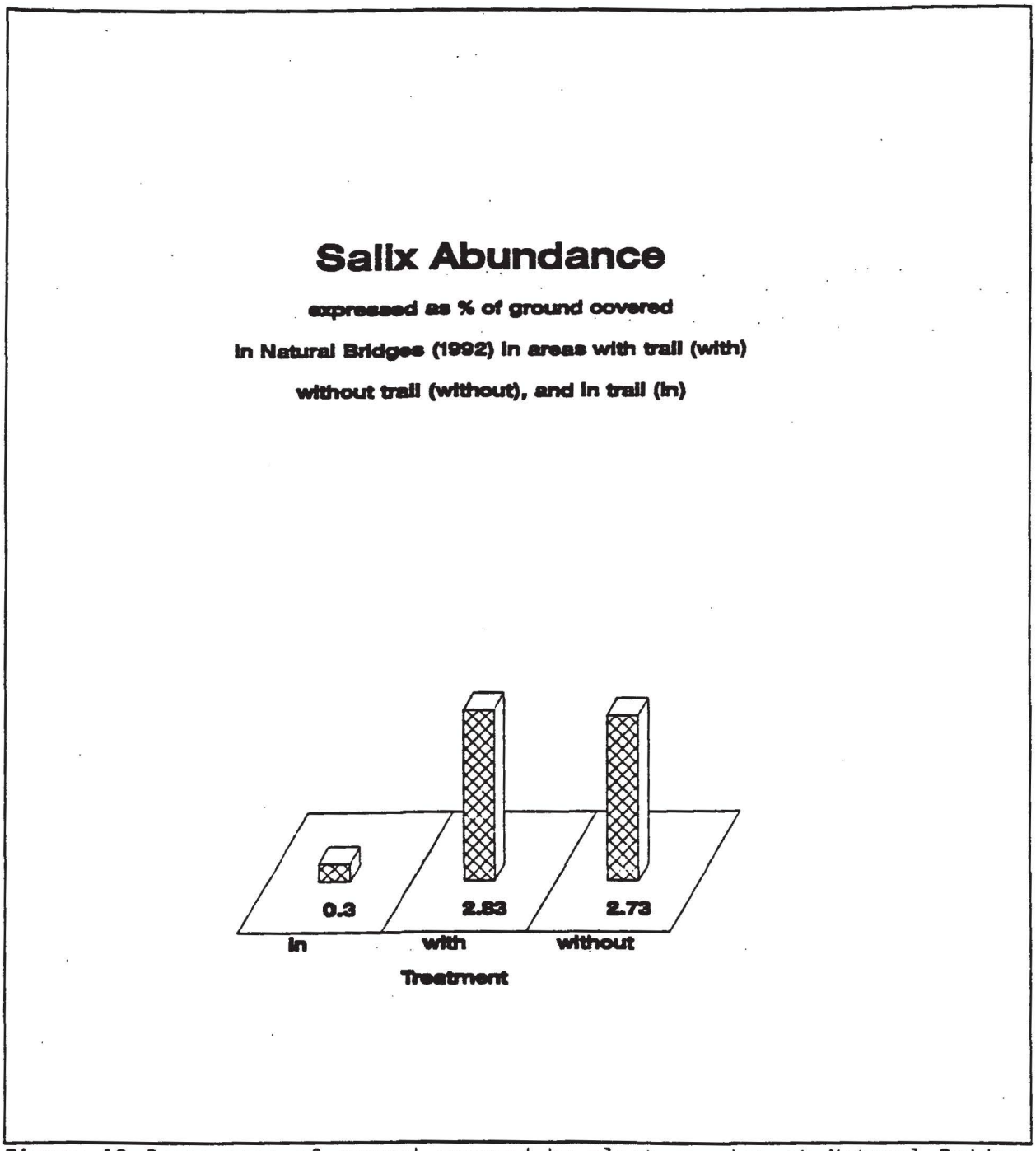

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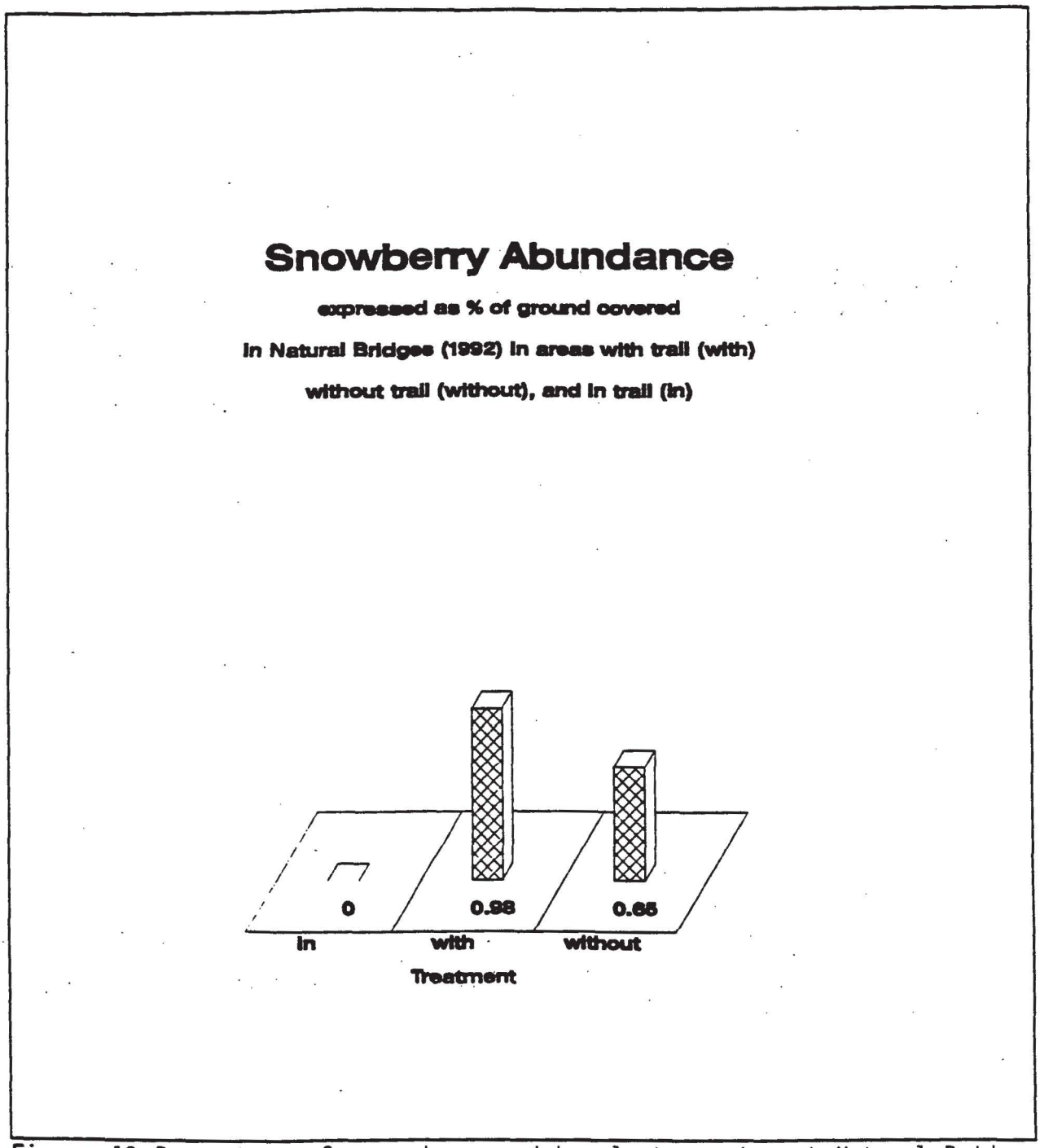

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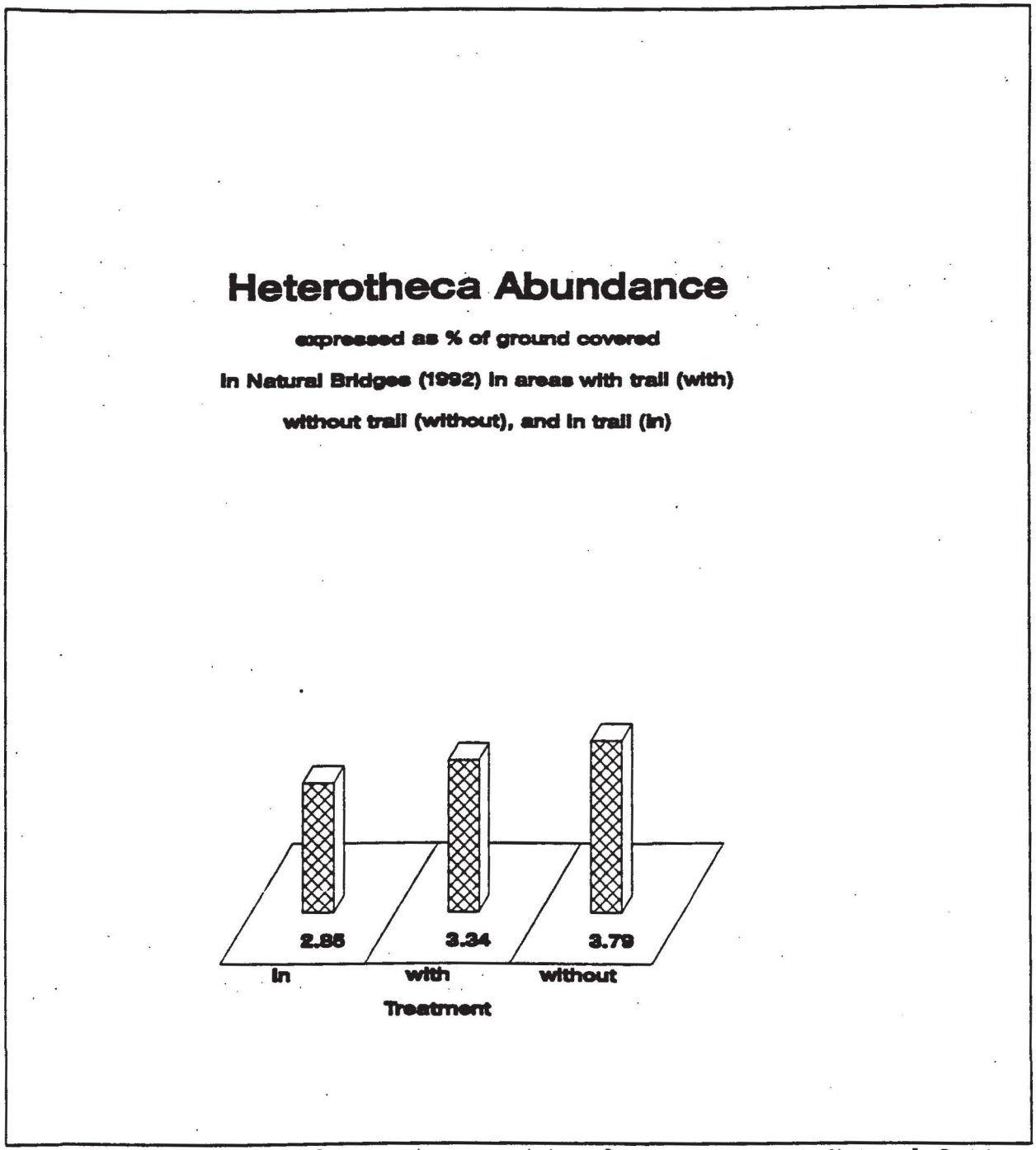

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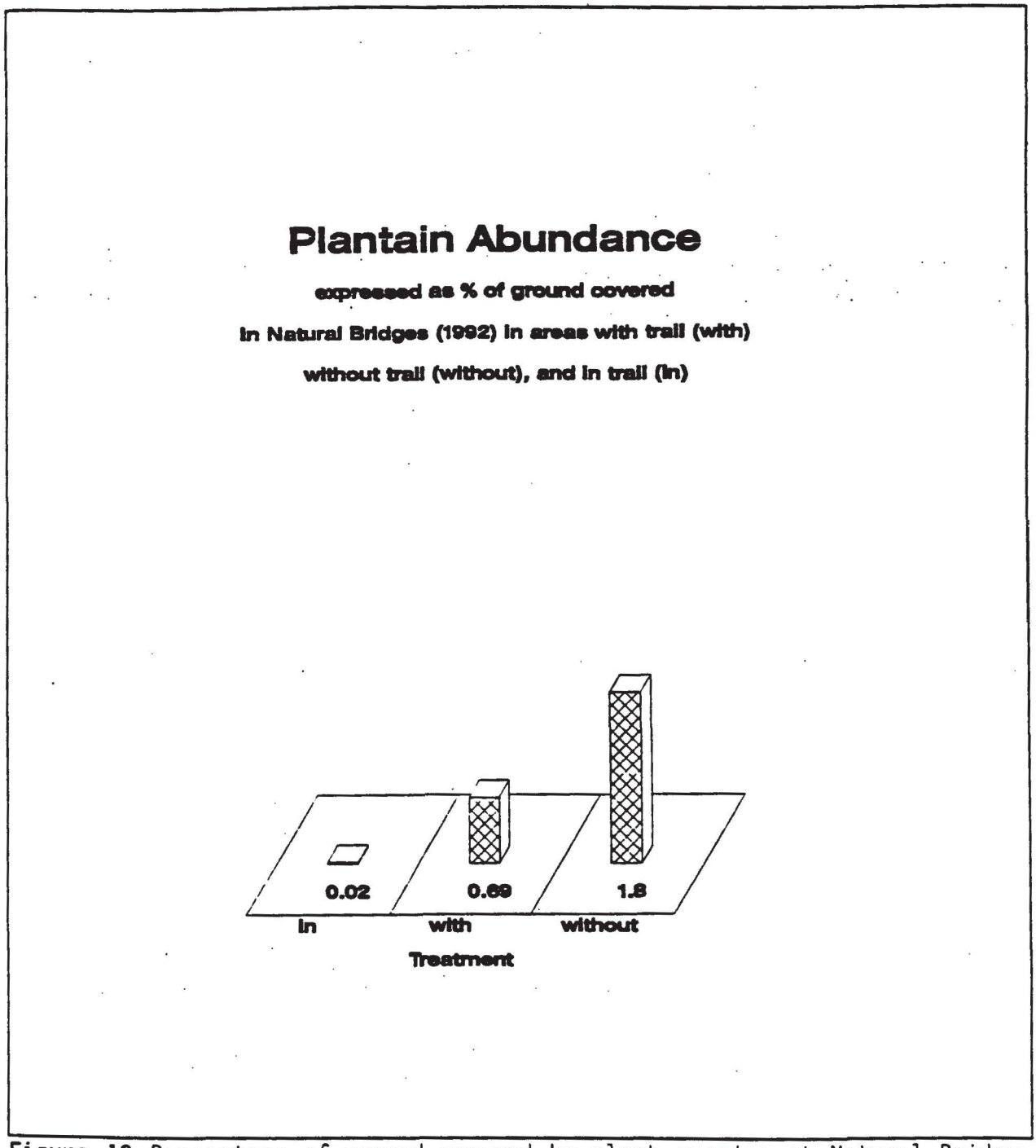

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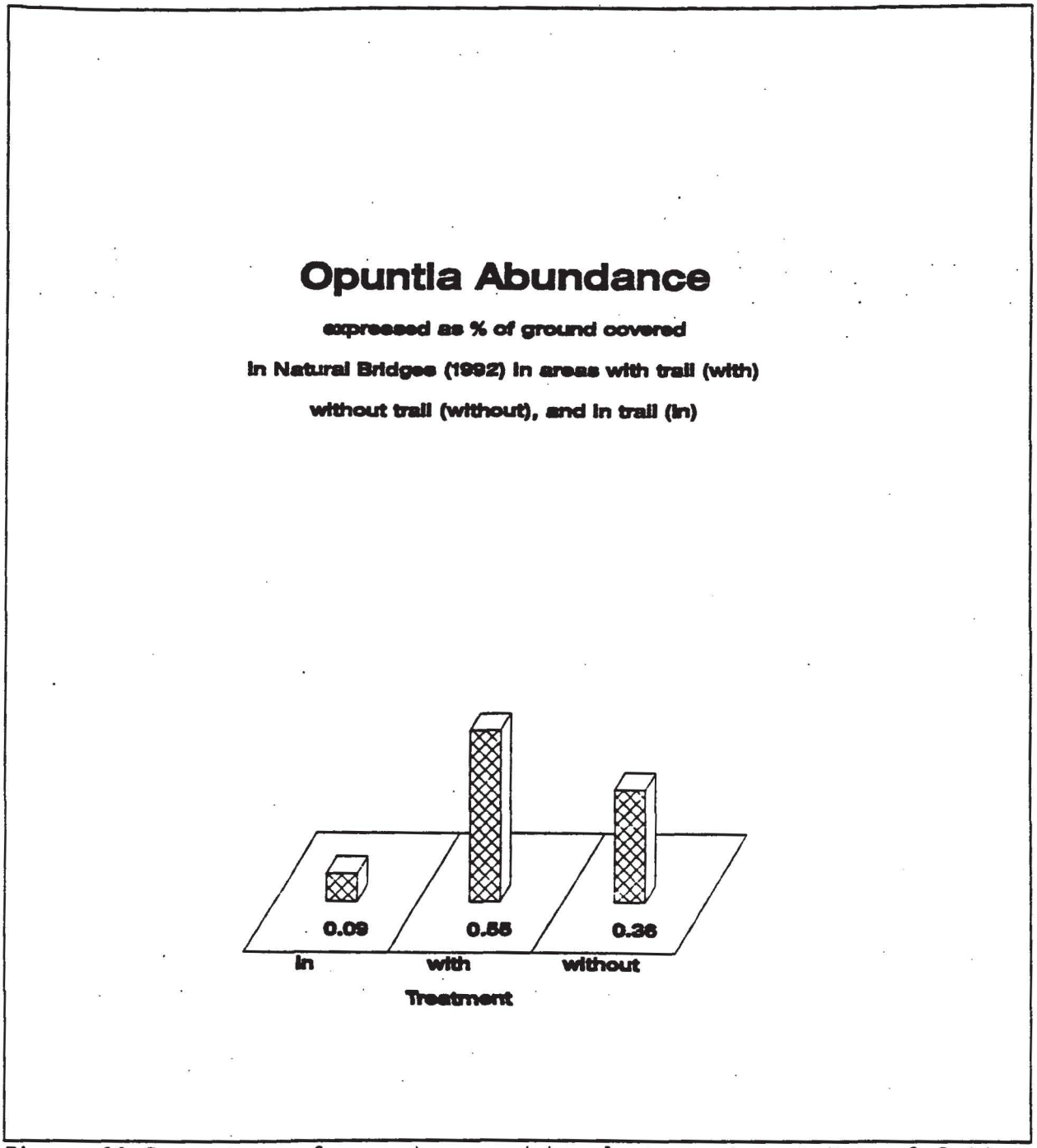

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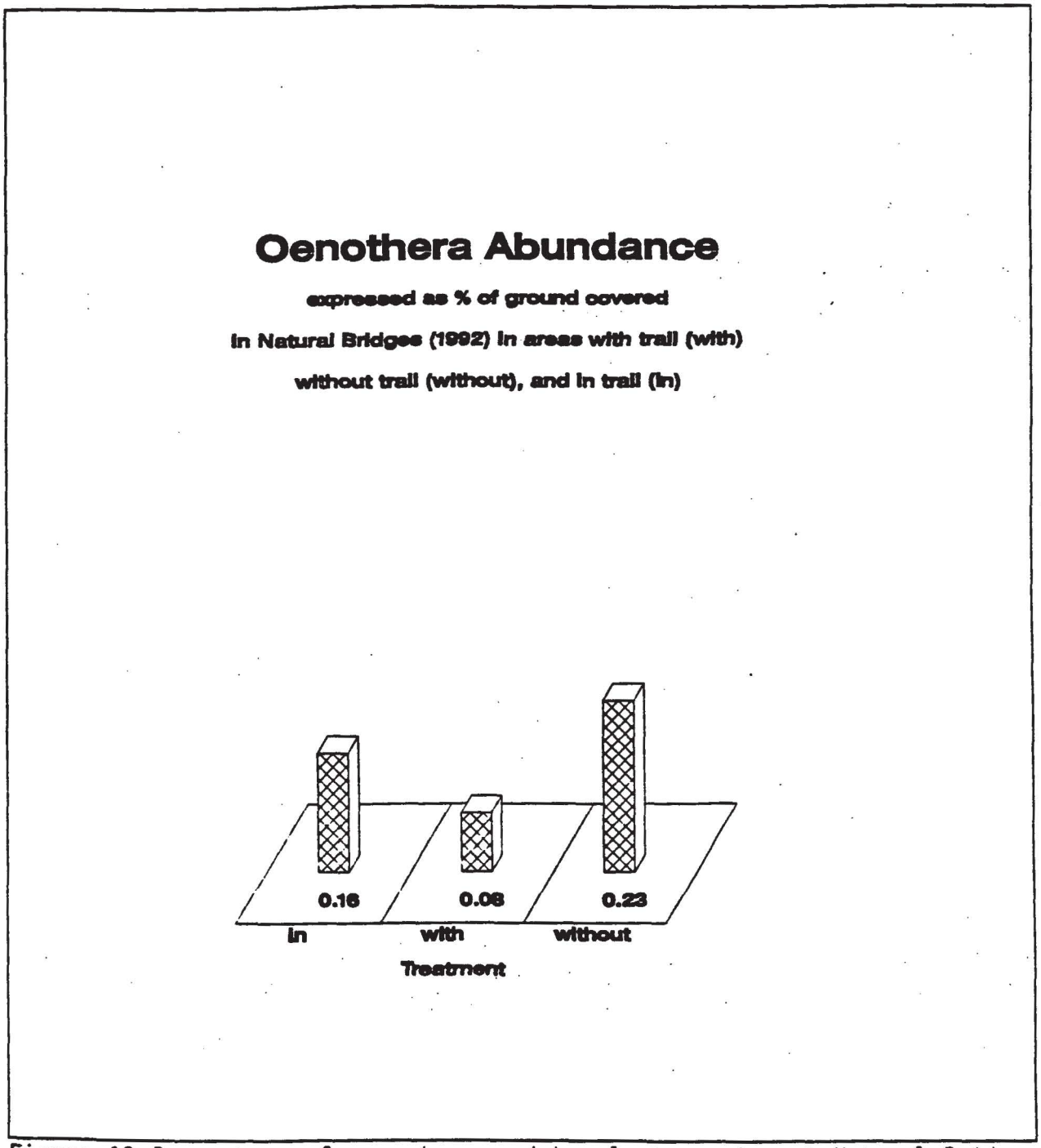

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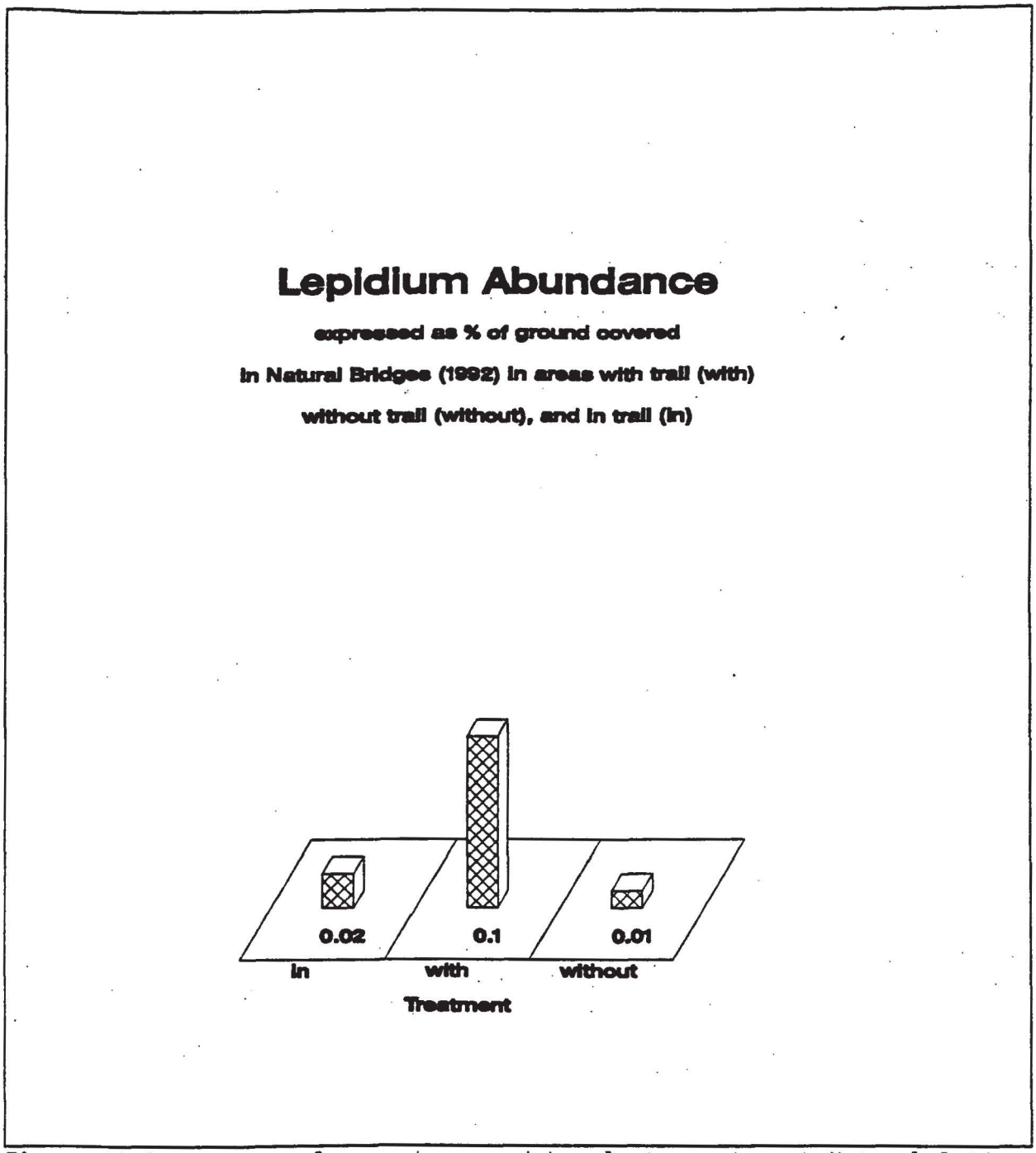

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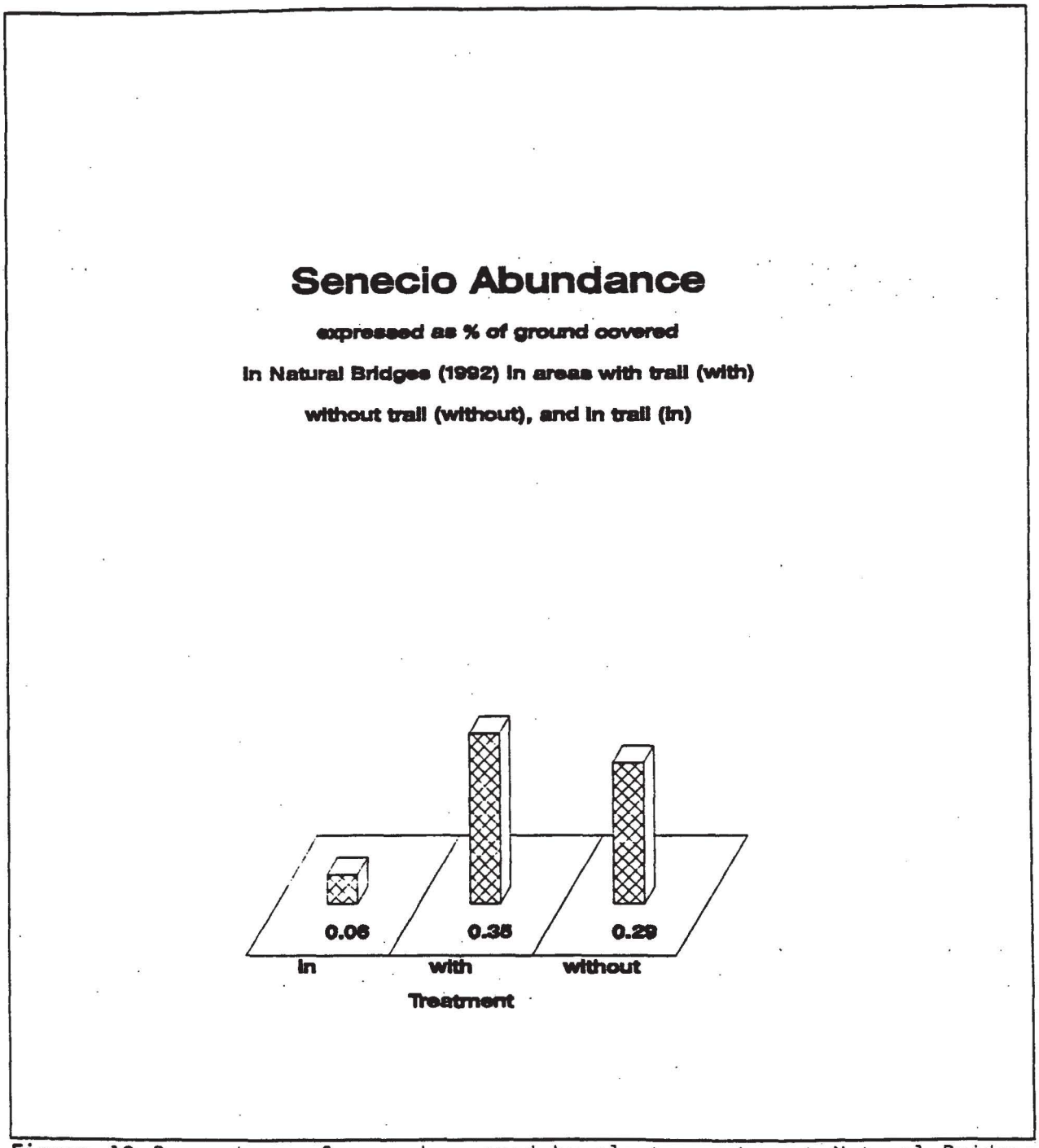

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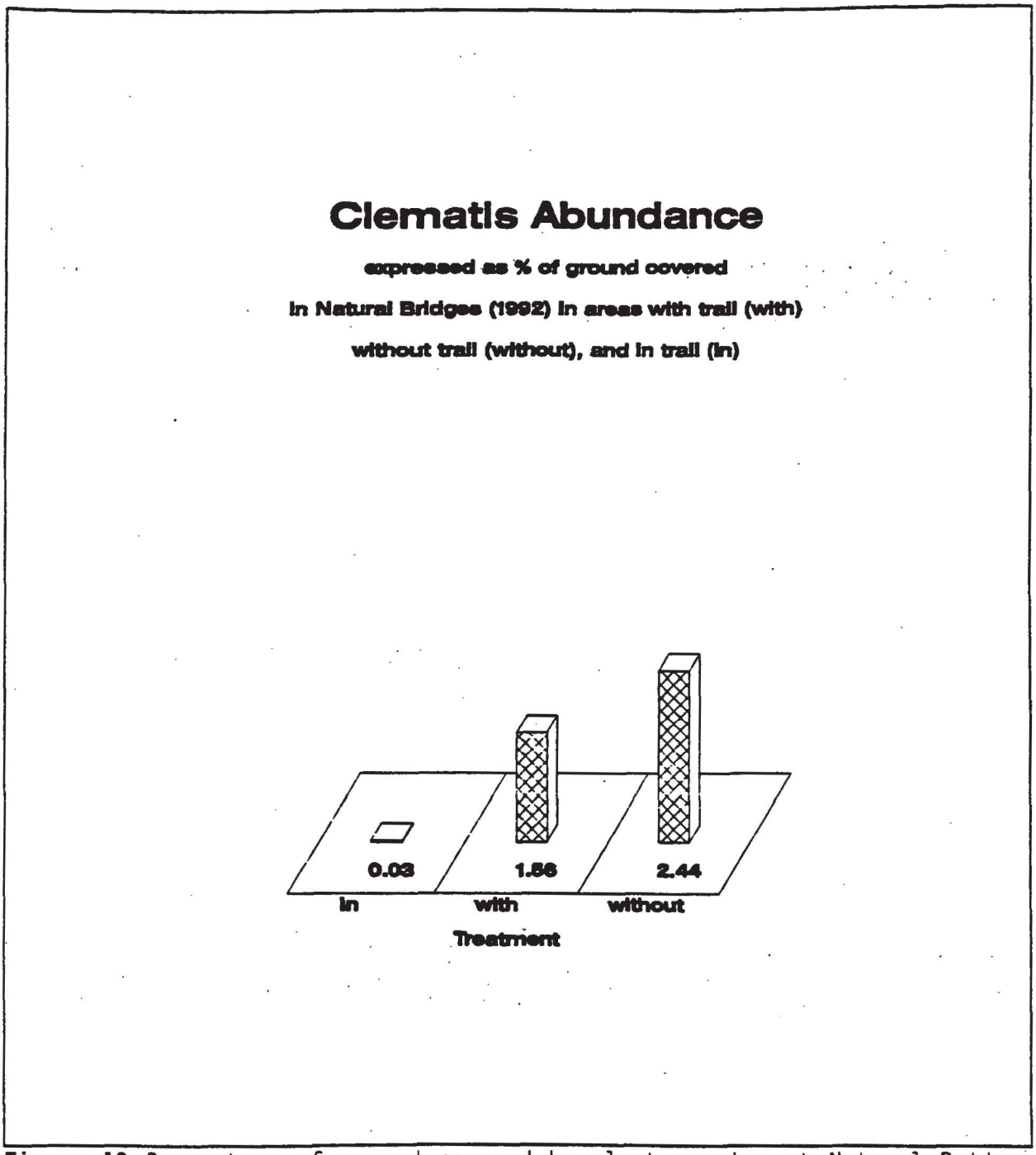

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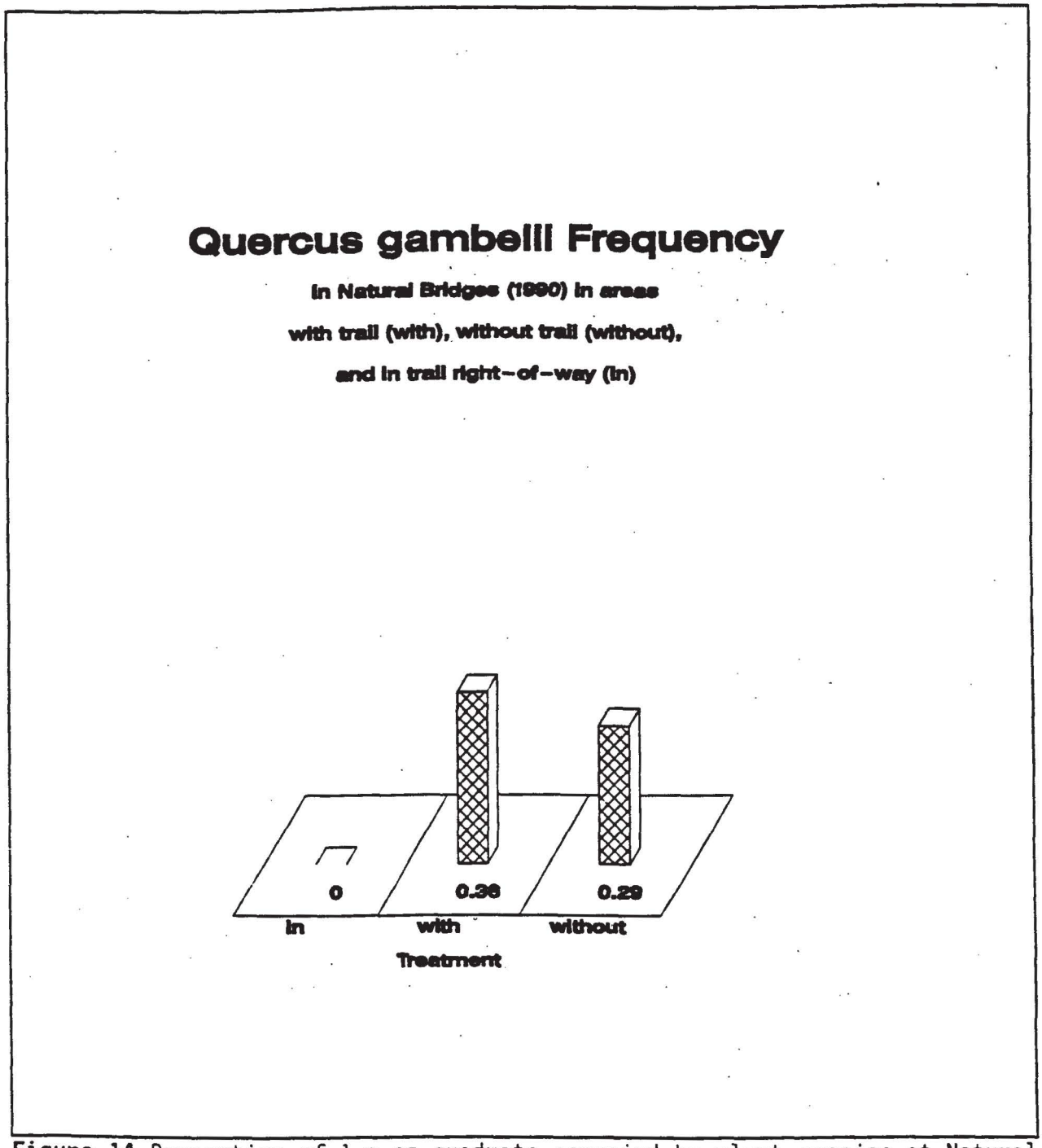
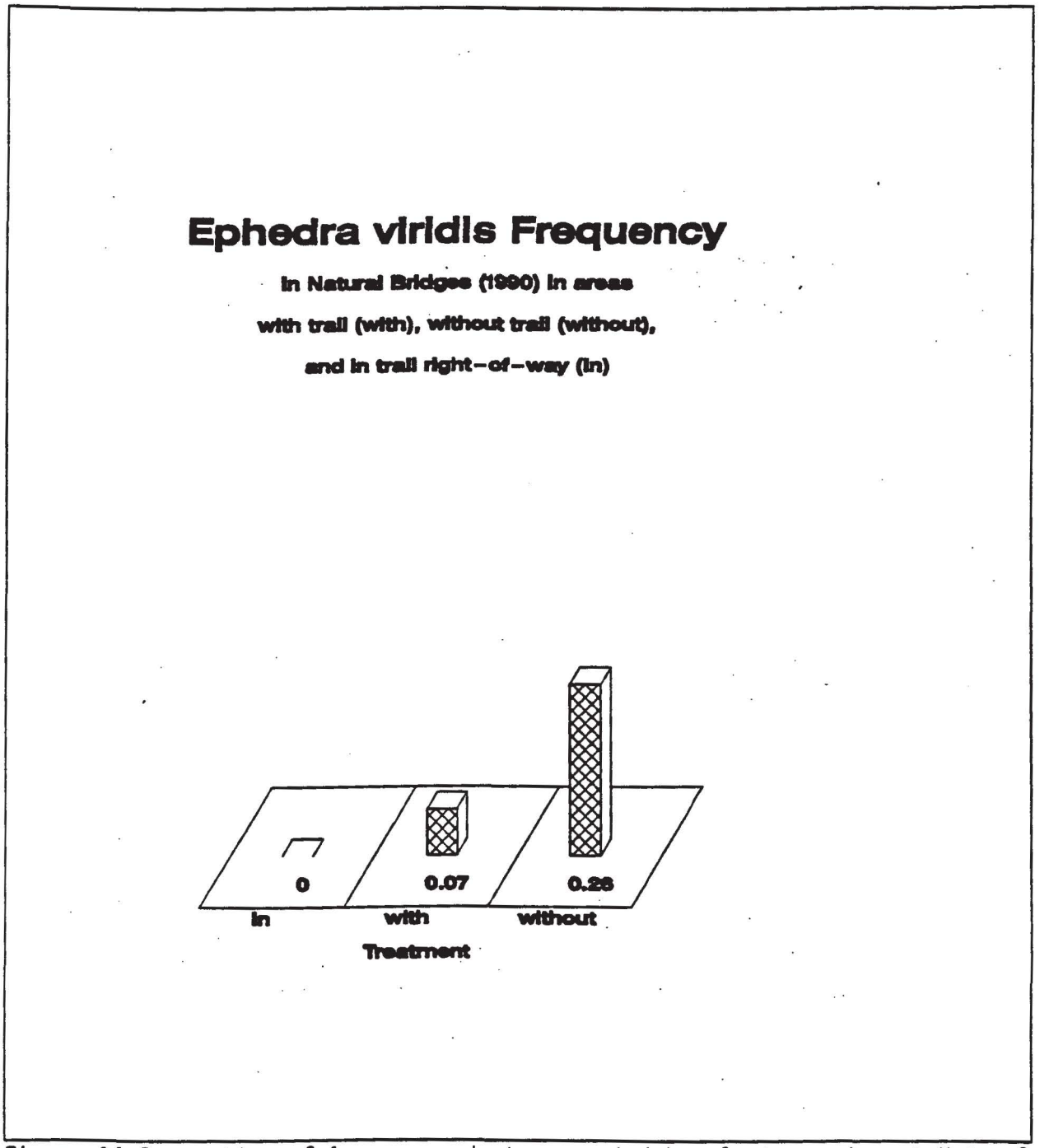


Figure 14 Proportion of 1 m sq quadrats occupied by plant species at Natural Bridges National Monument in 1990.



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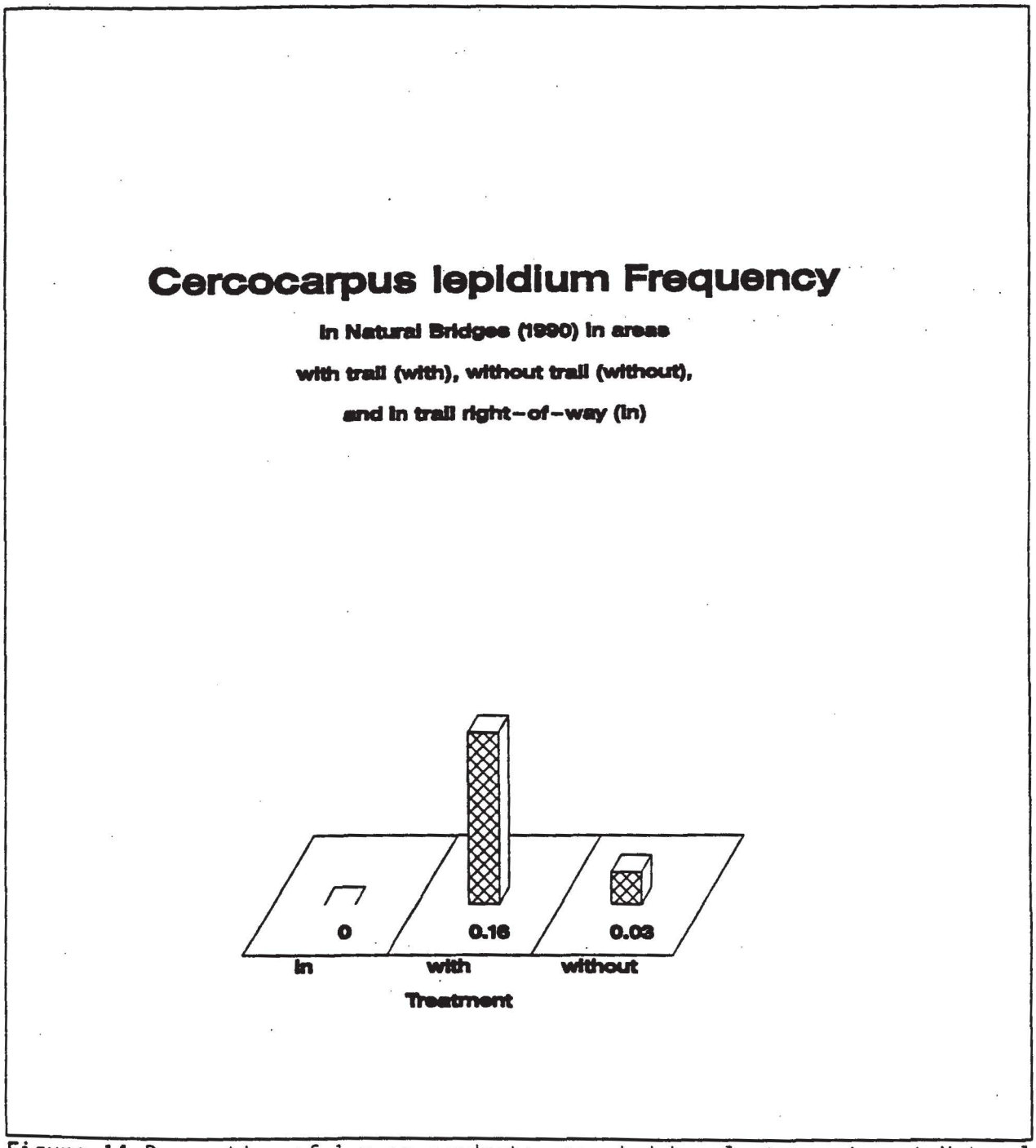

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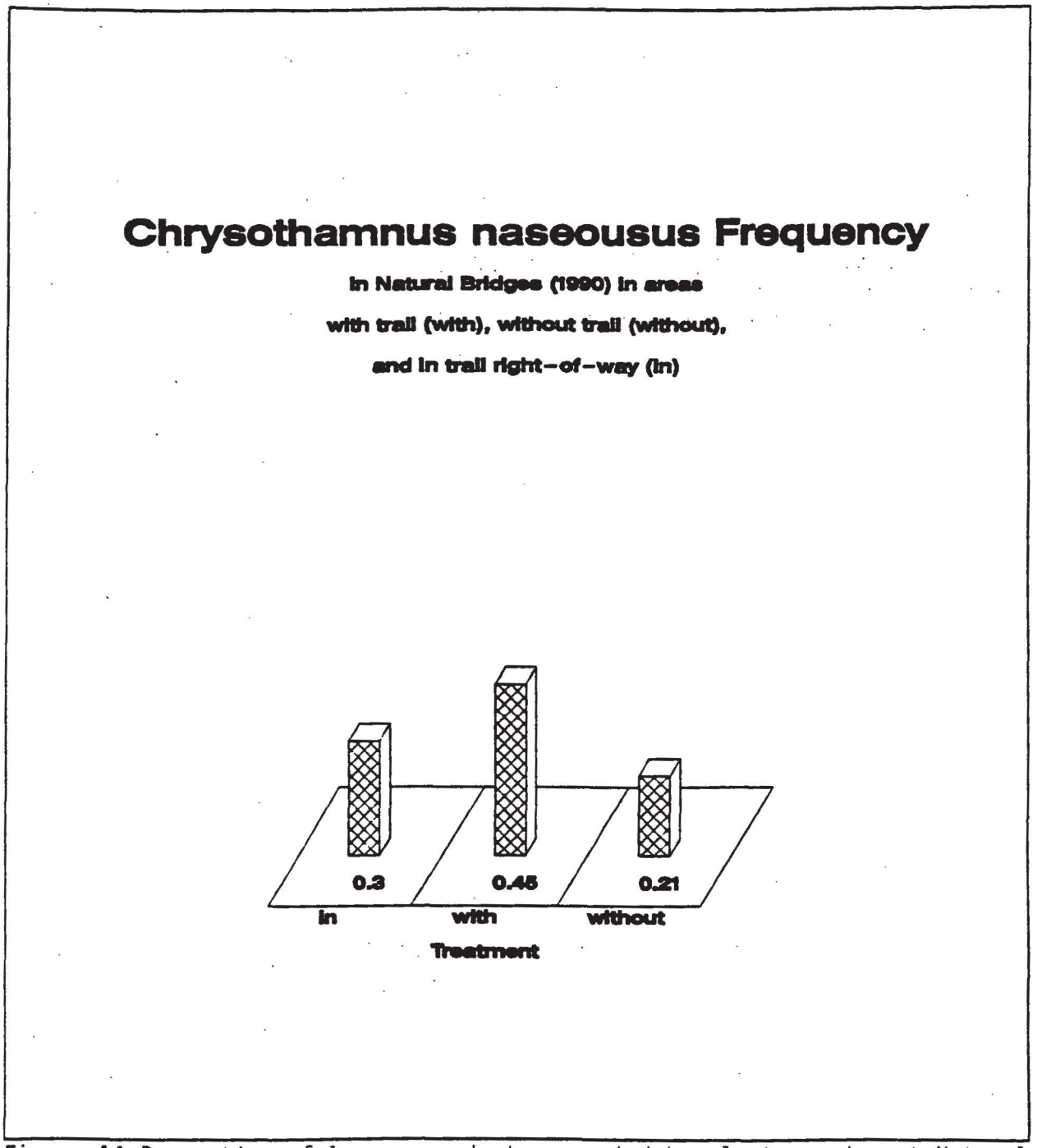

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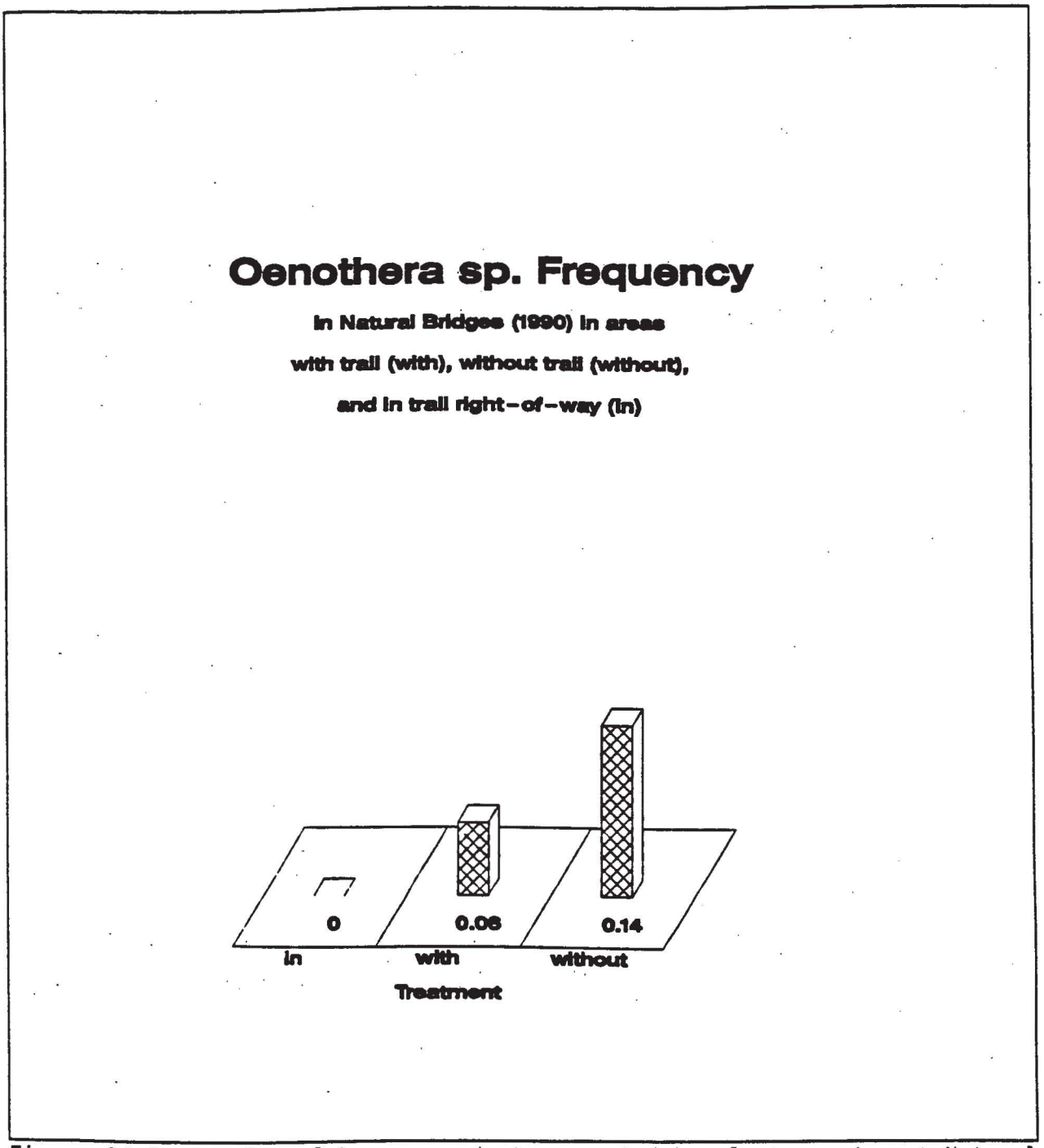

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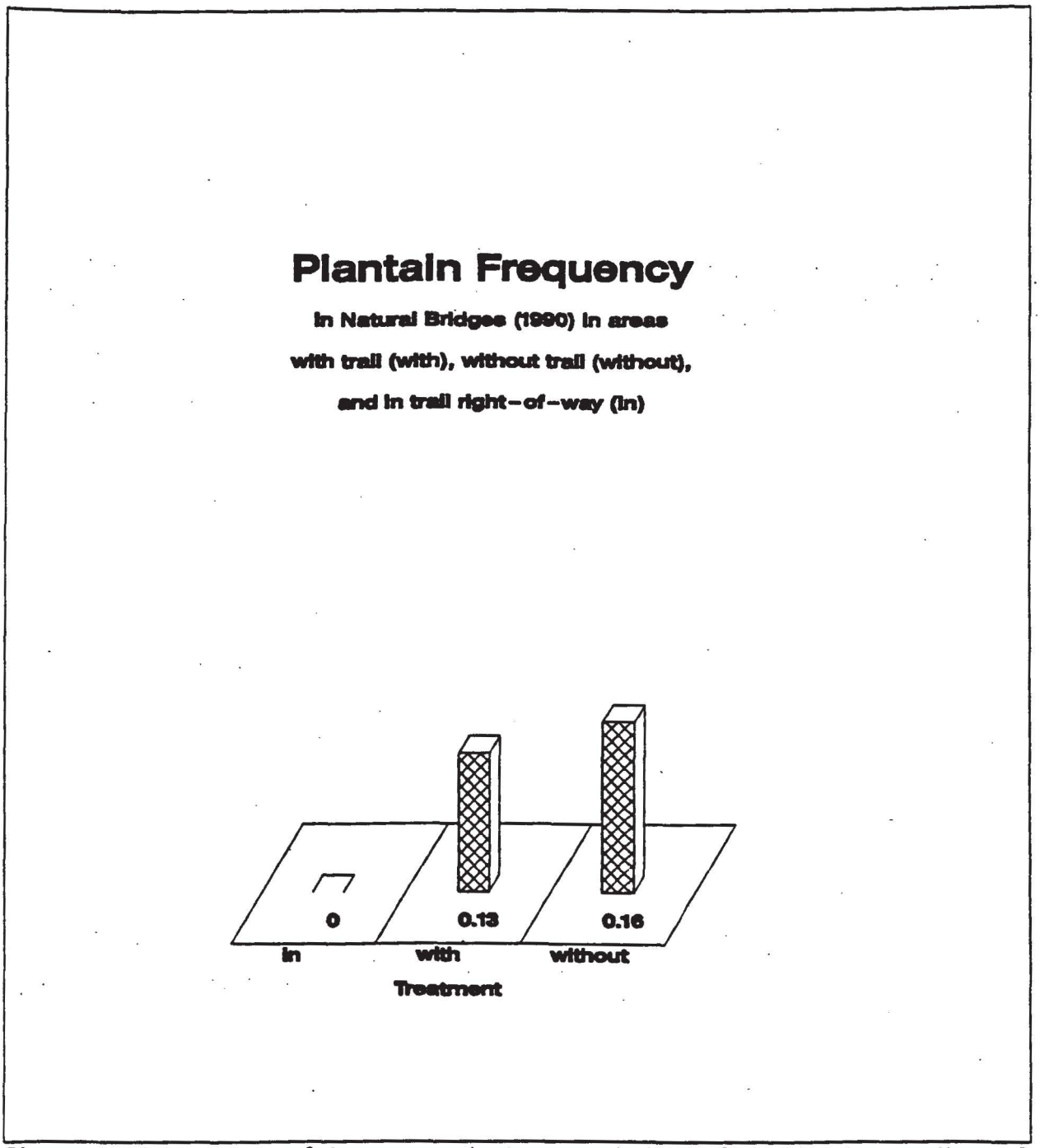

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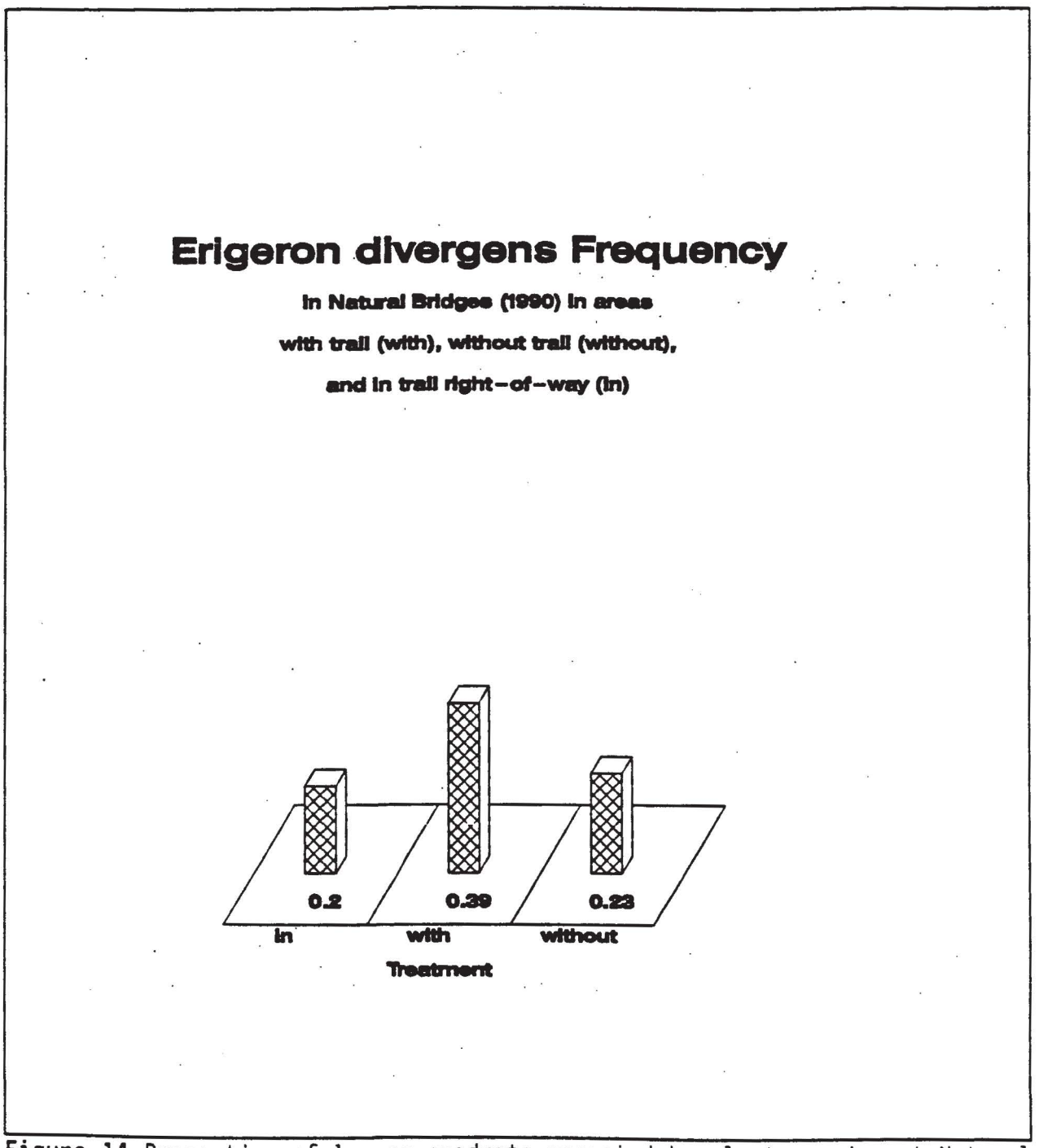

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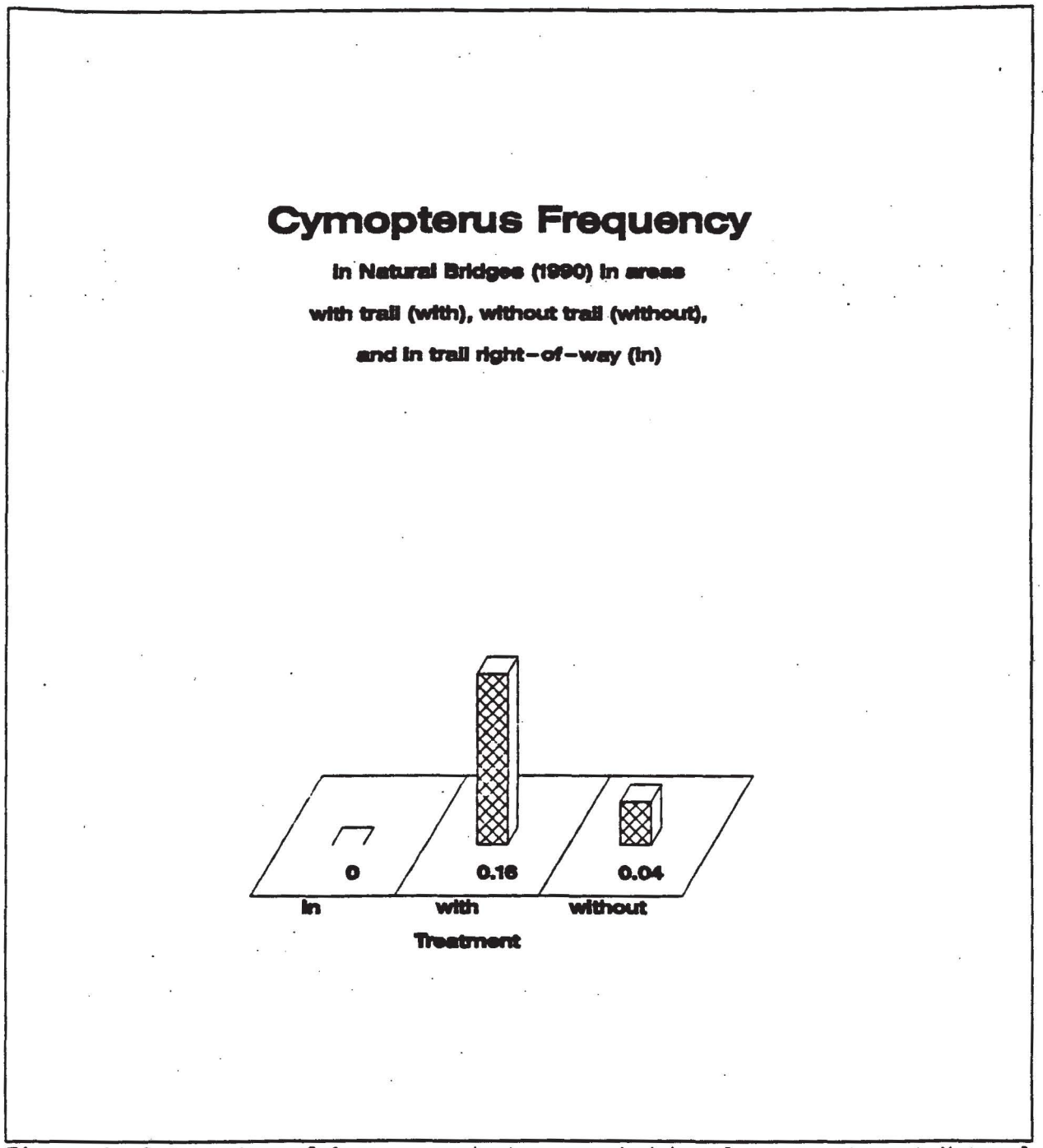

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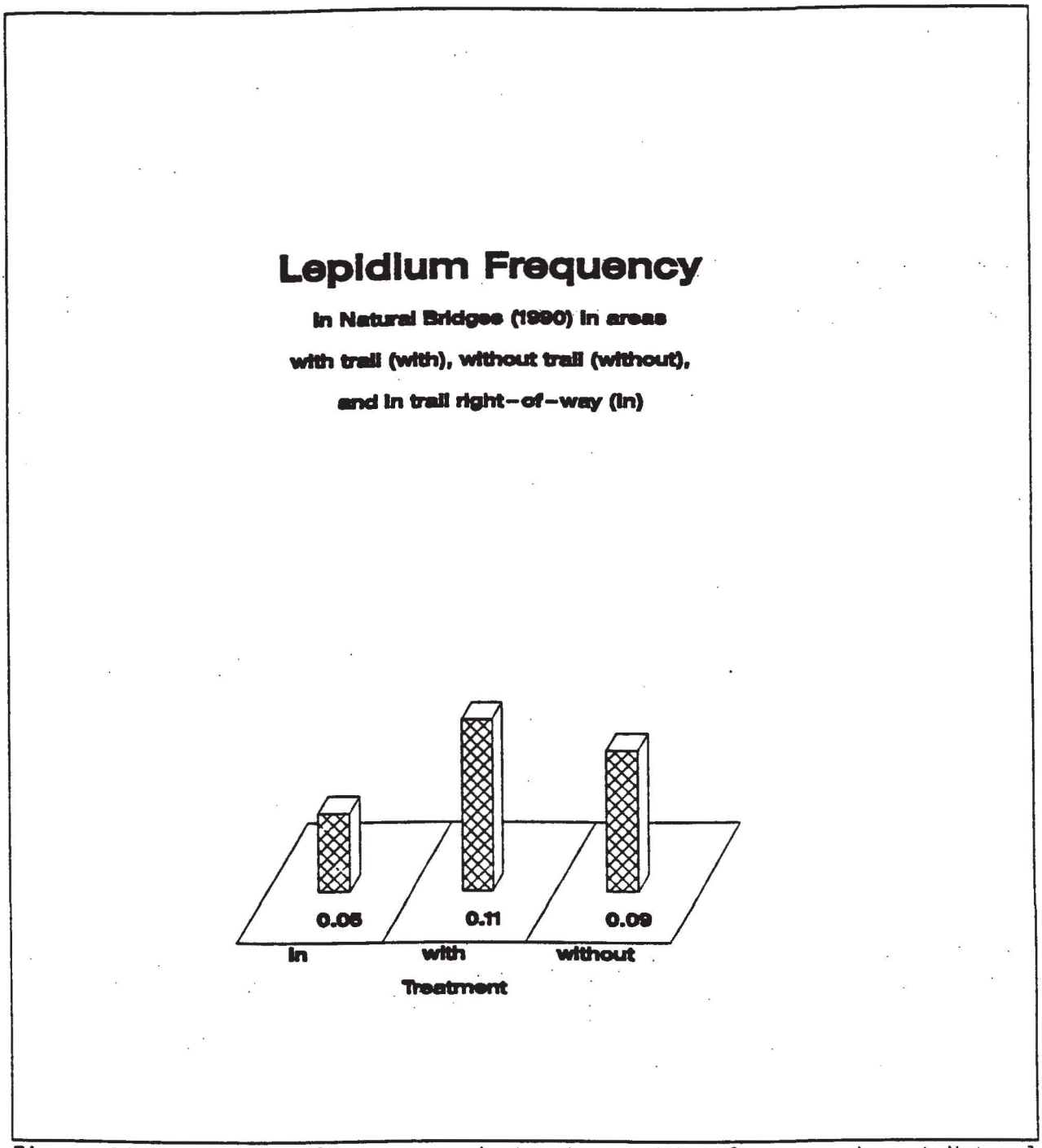

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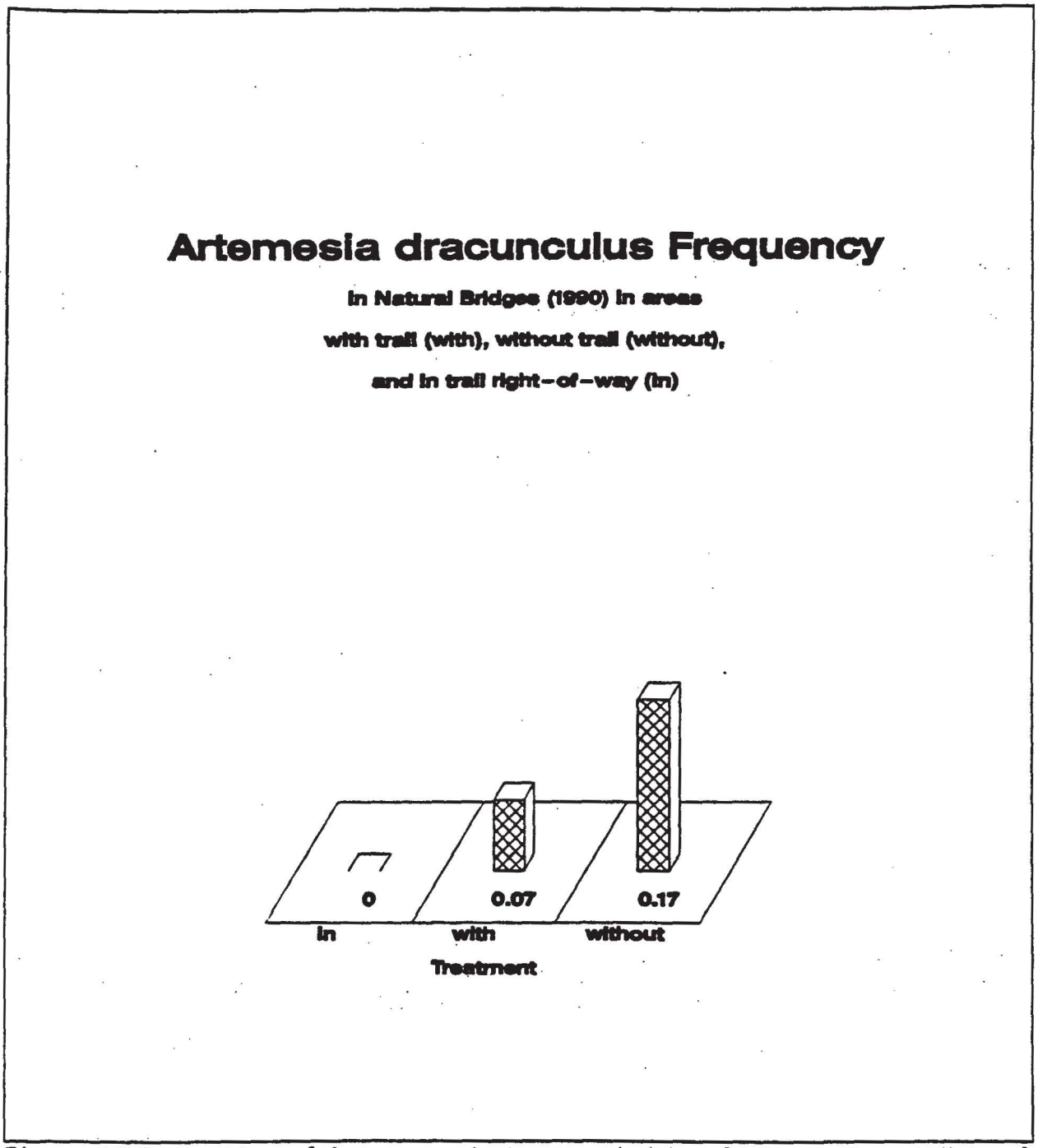

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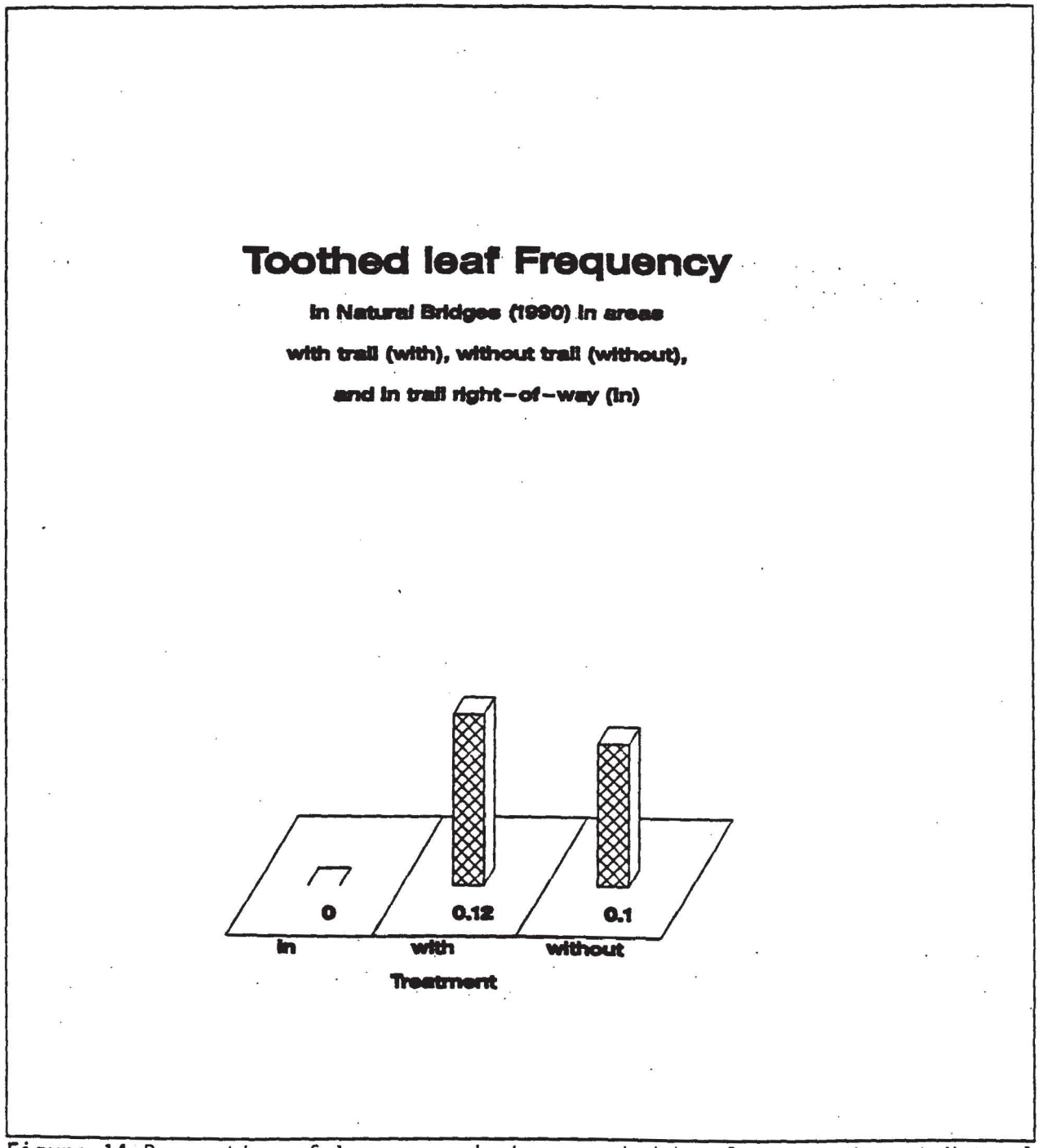

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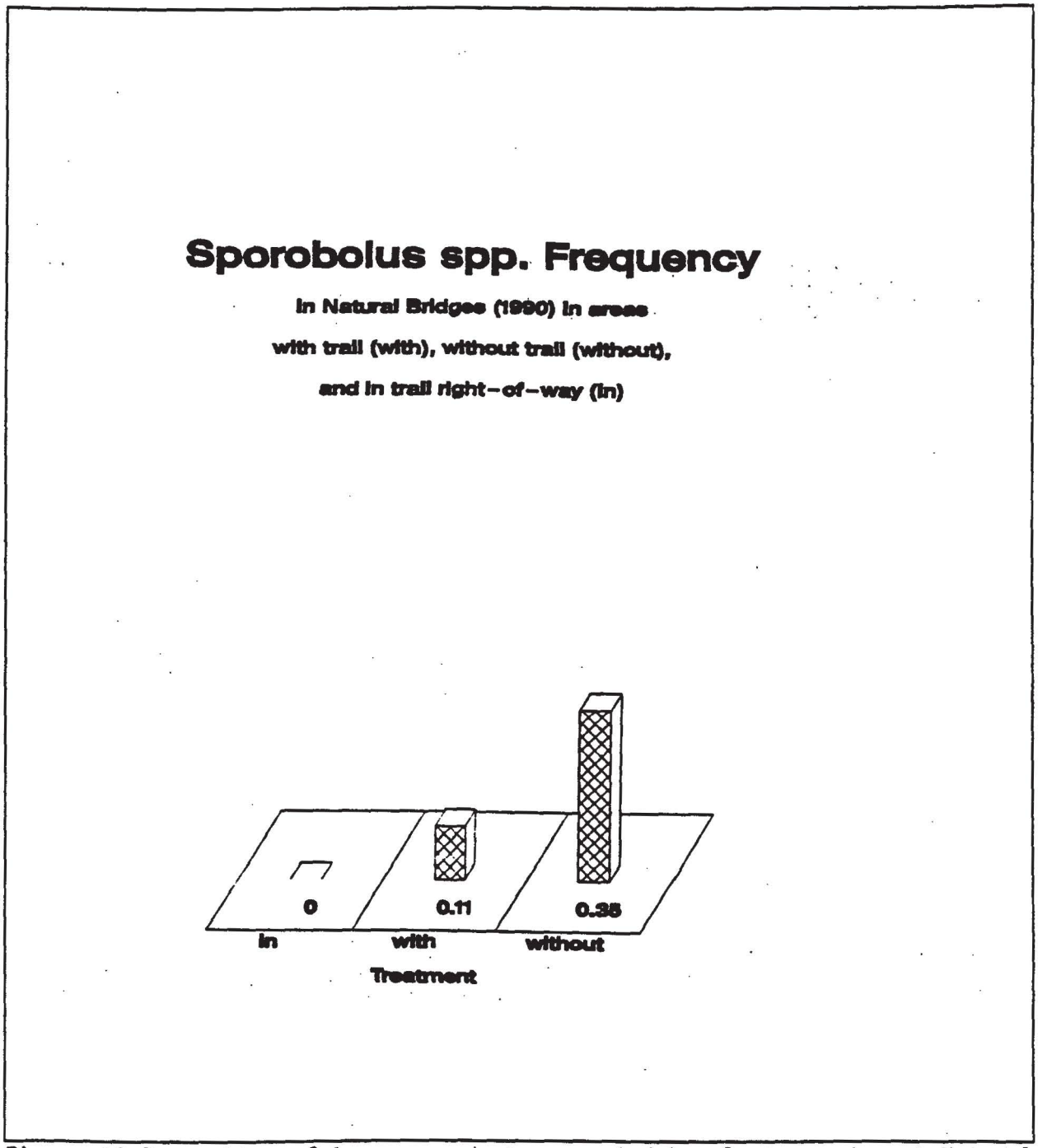

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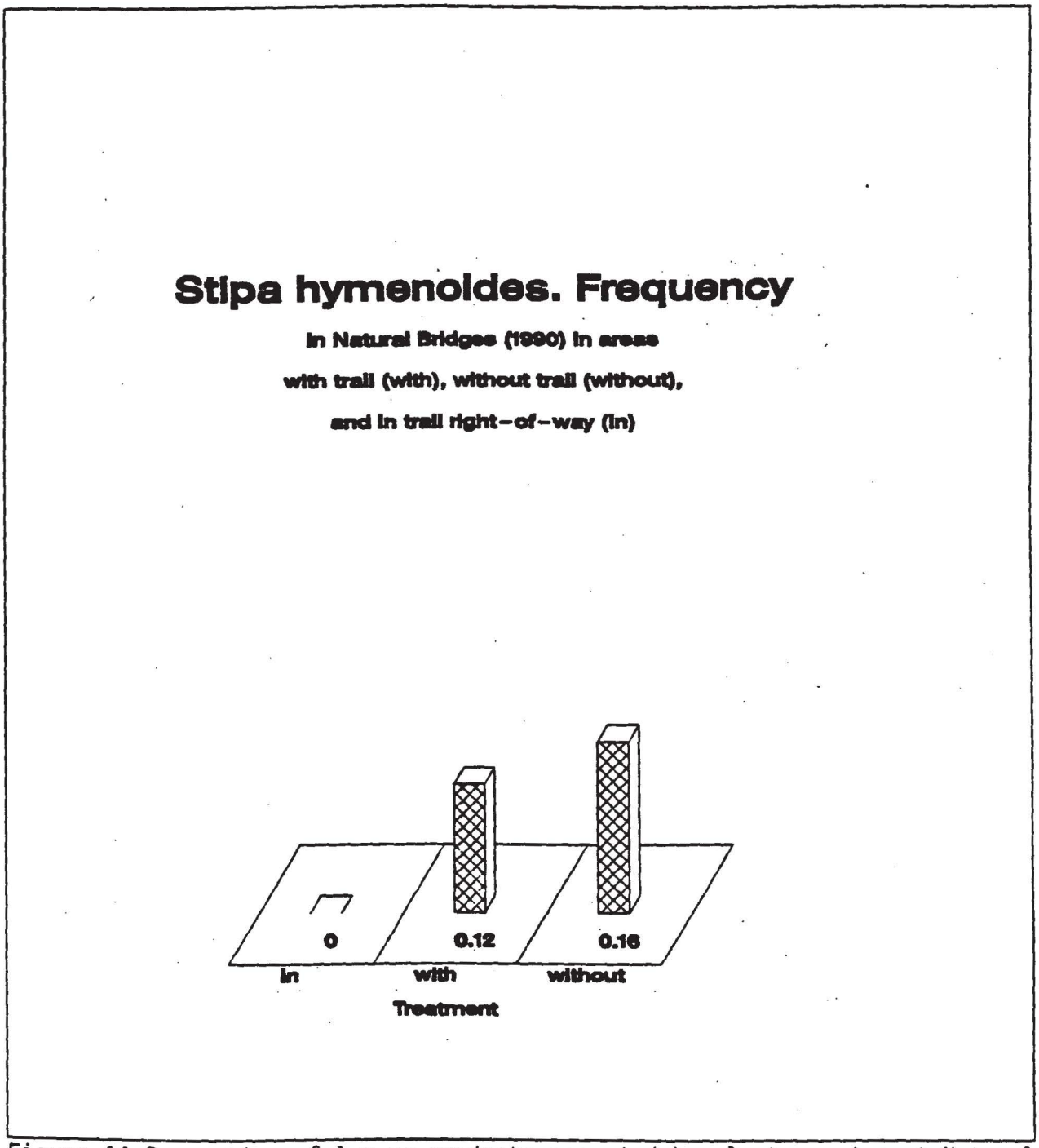


Figure 14 Proportion of 1 m sq quadrats occupied by plant species at Natural Bridges National Monument in 1990.

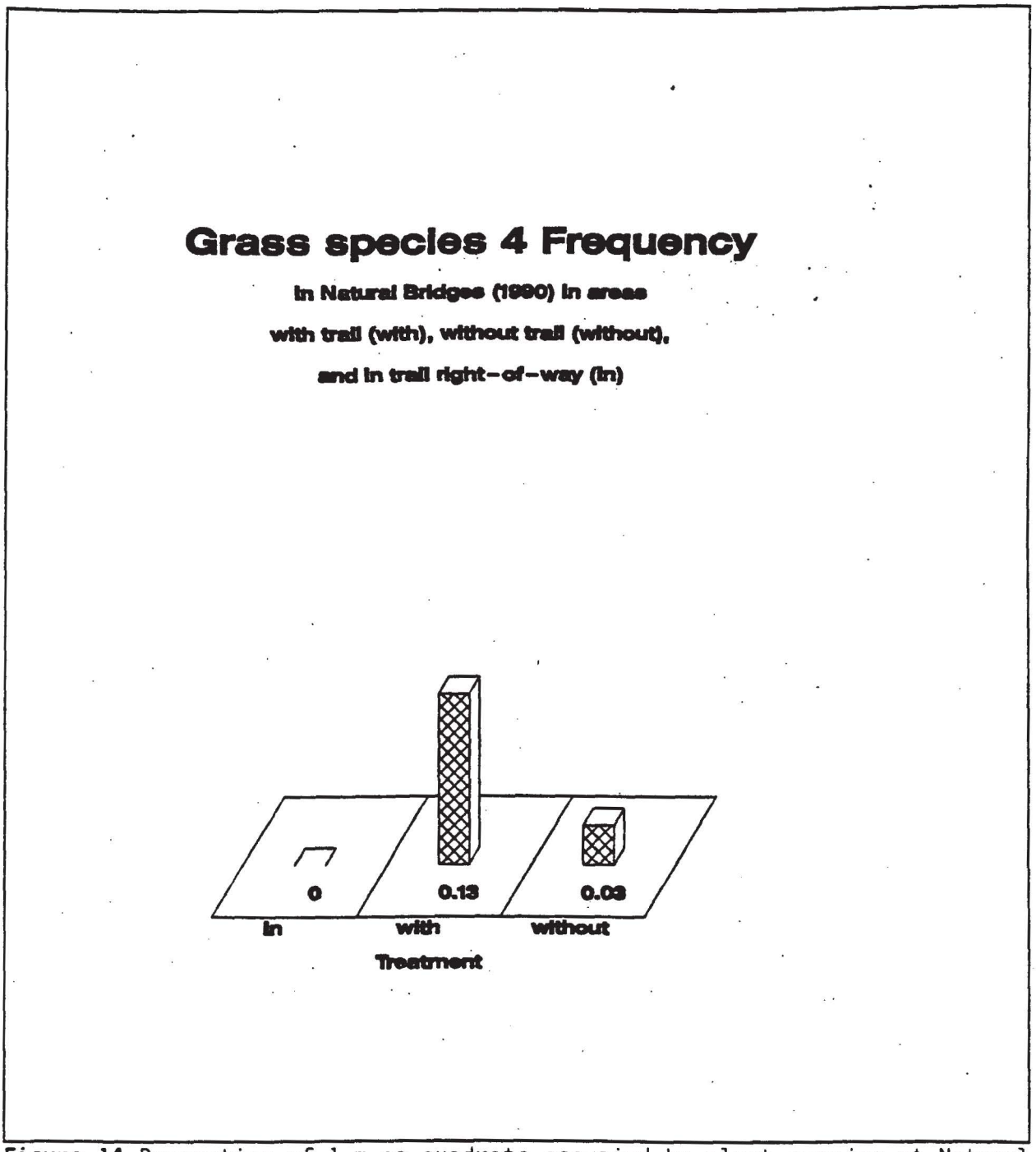
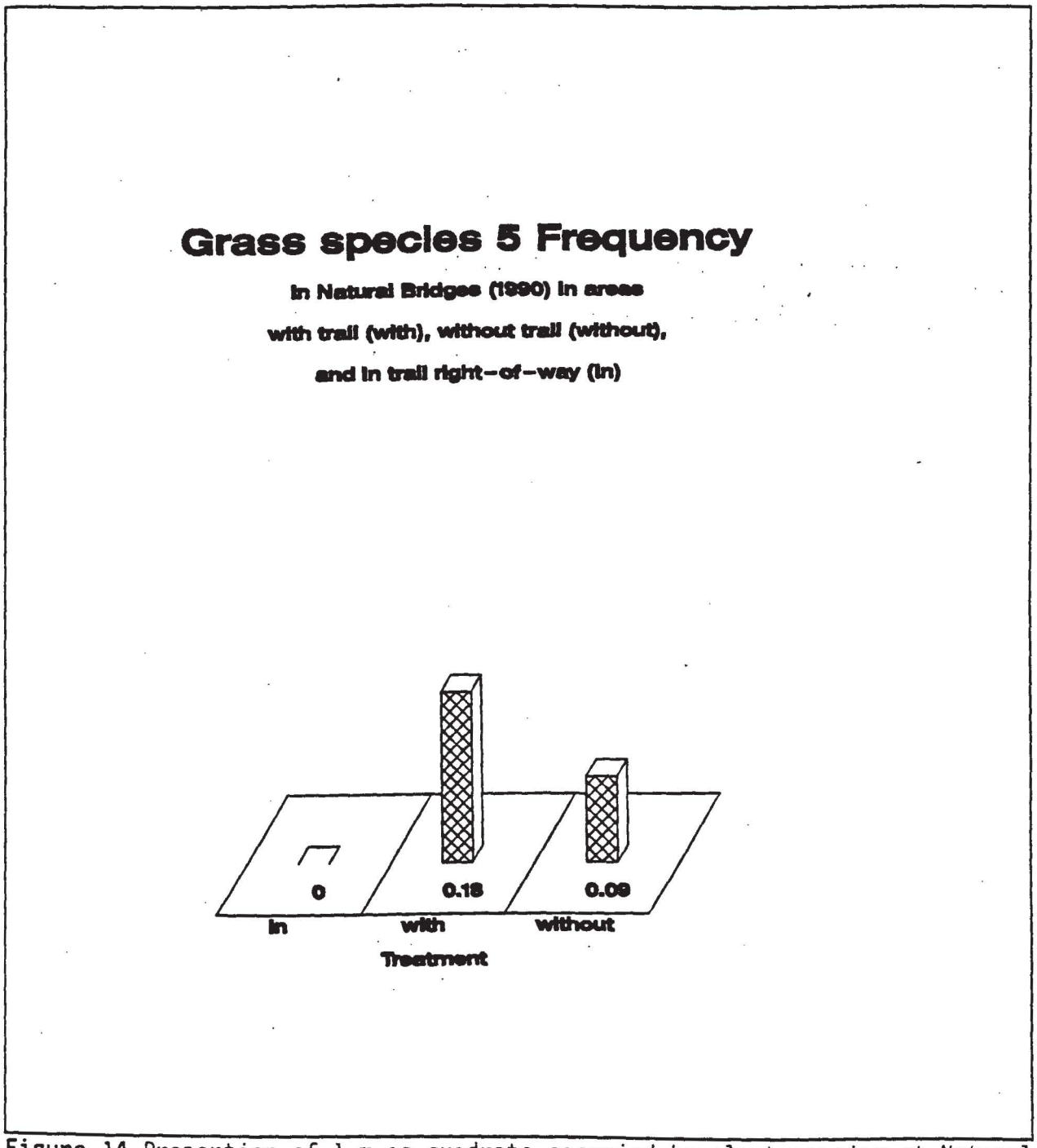


Figure 14 Proportion of 1 m sq quadrats occupied by plant species at Natural Bridges National Monument in 1990.



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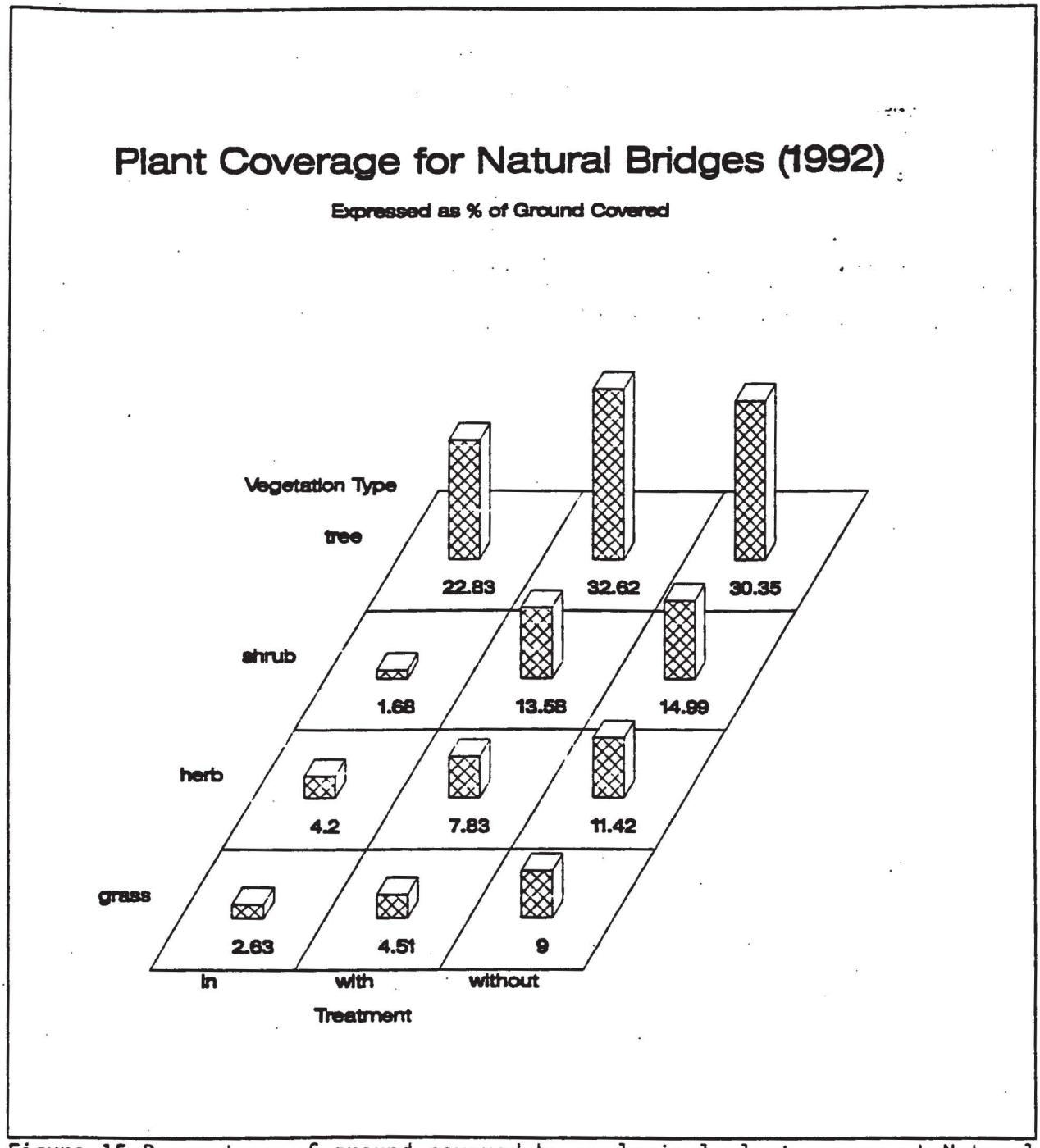
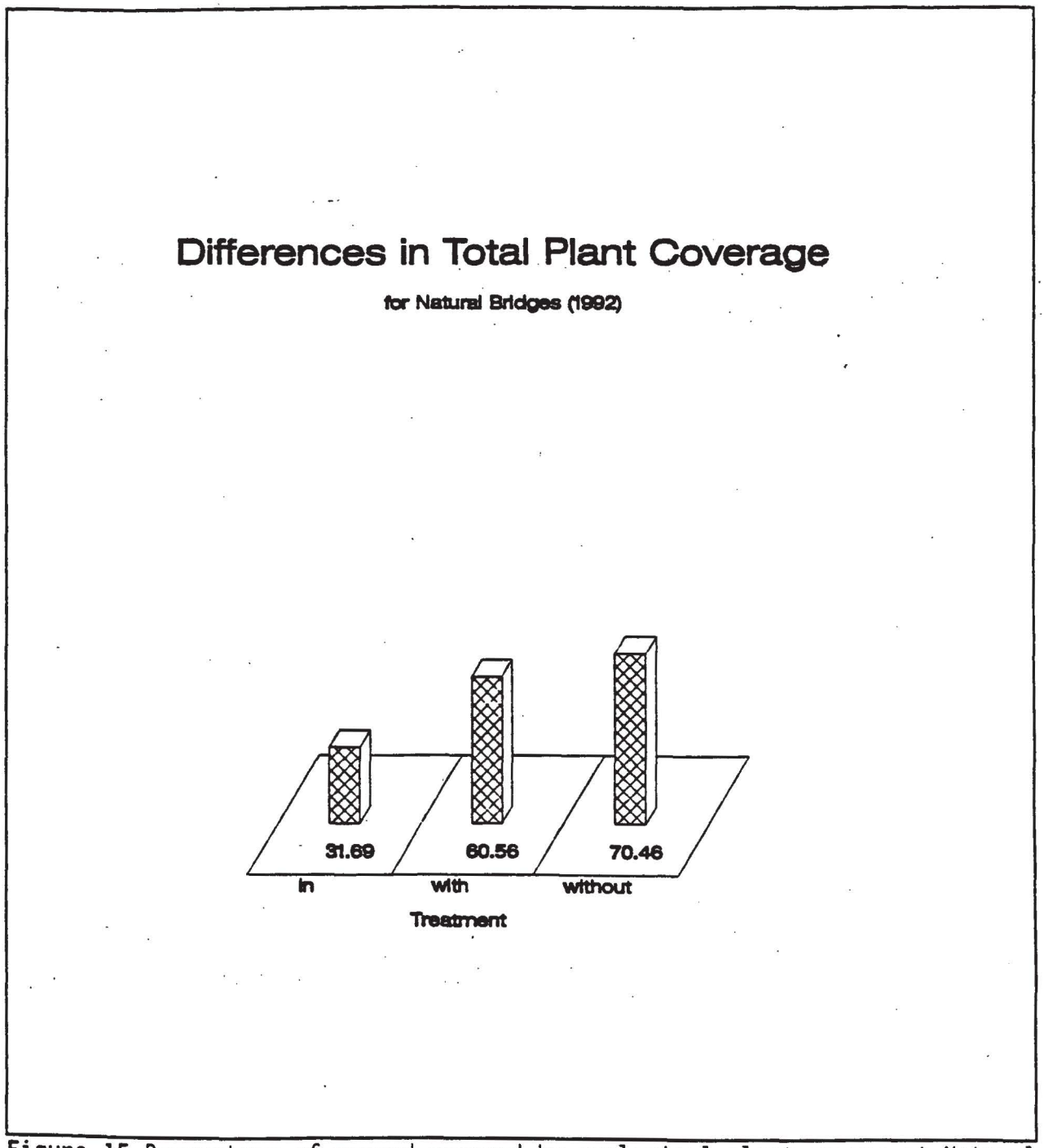


Figure 15 Percentage of ground covered by ecological plant groups at Natural Bridges National Monument in 1992.



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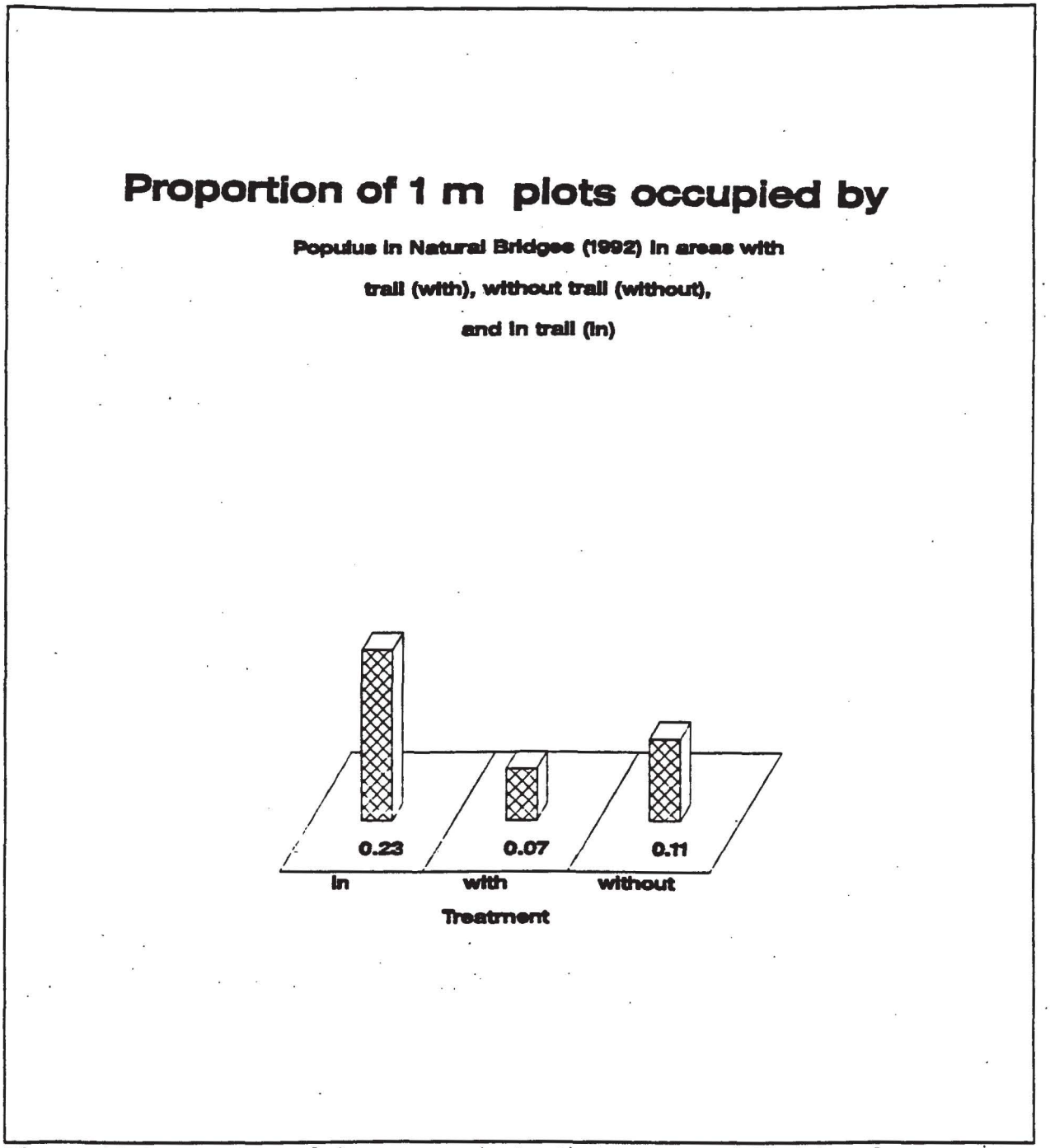
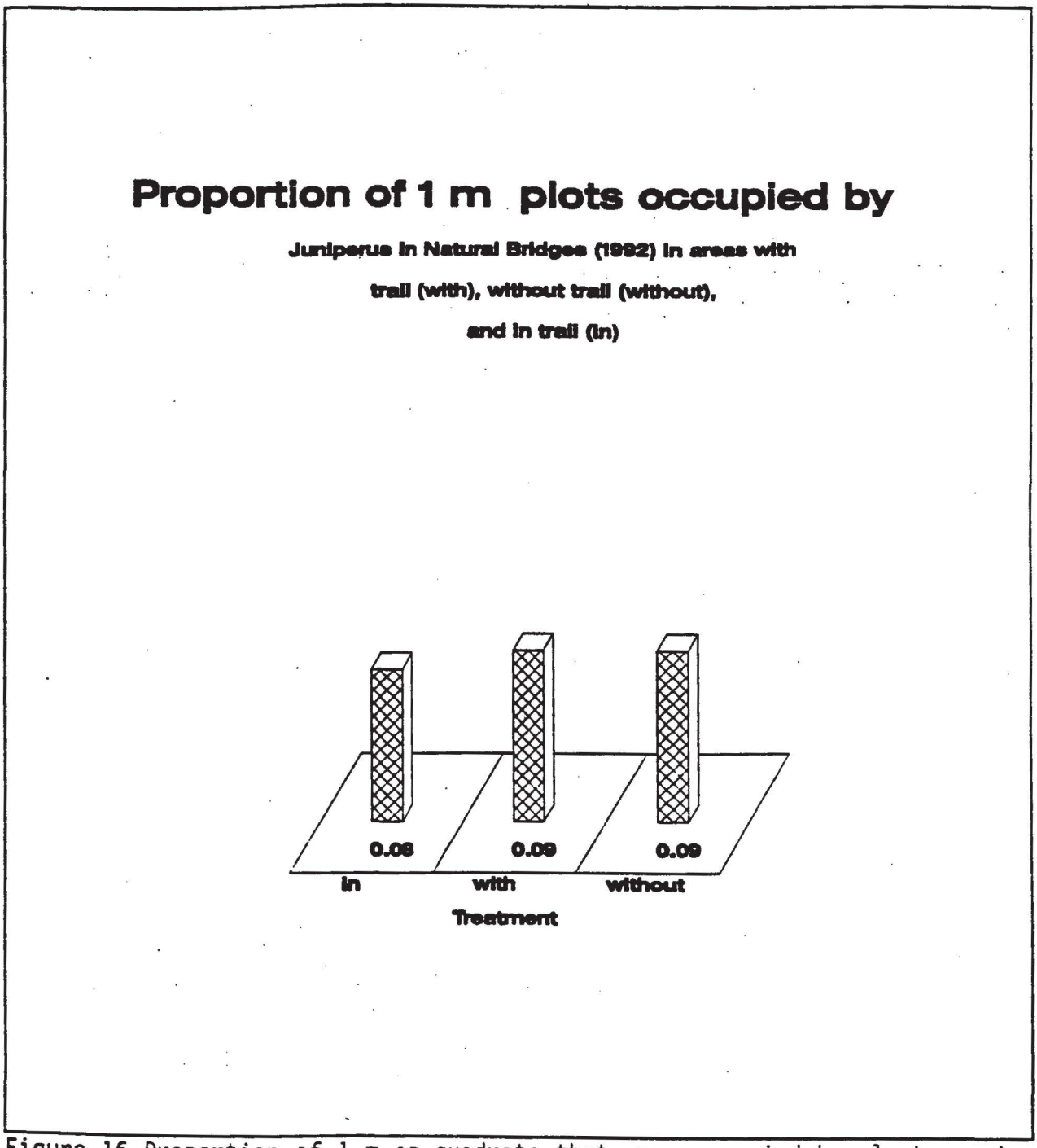


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.



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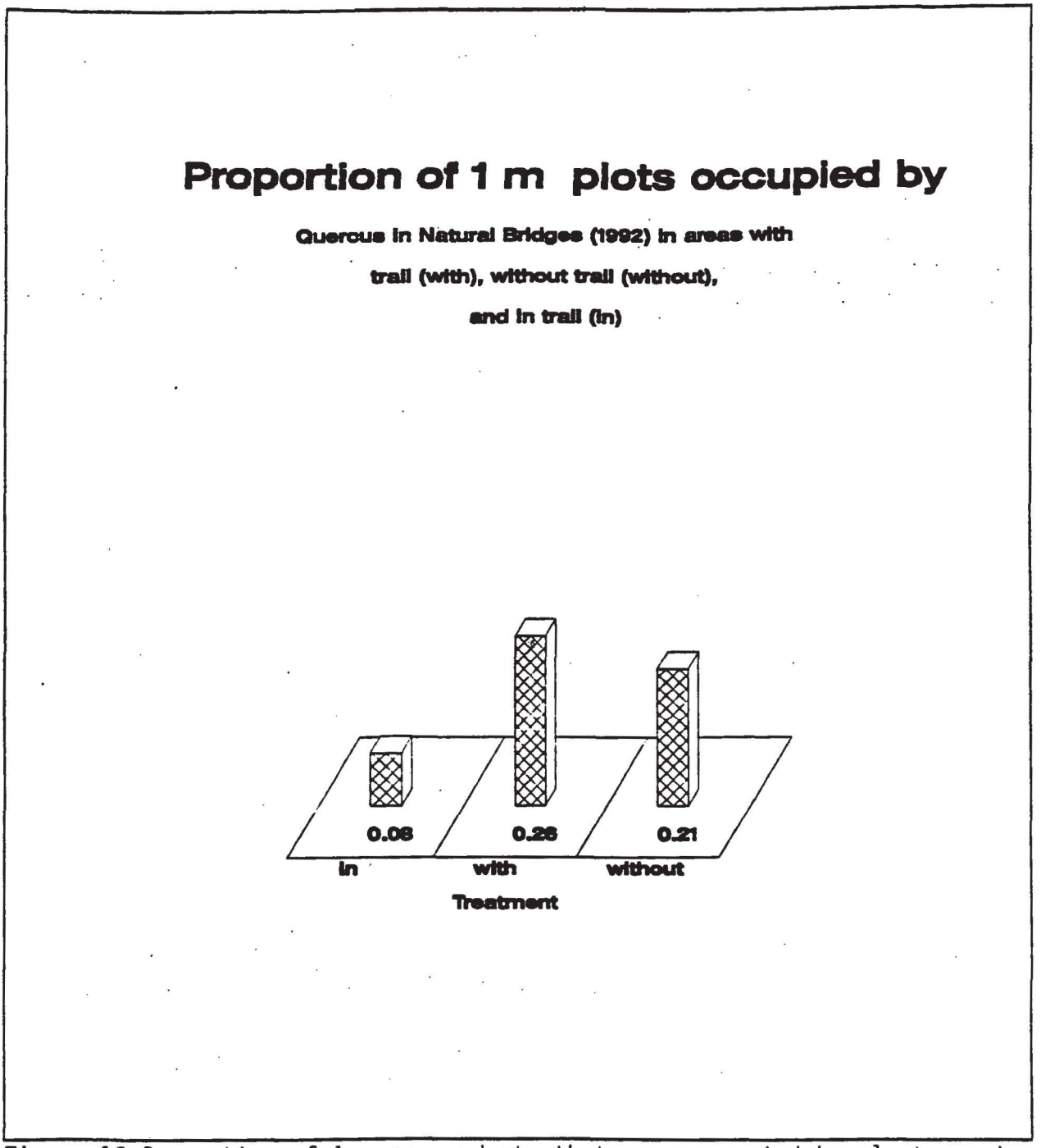

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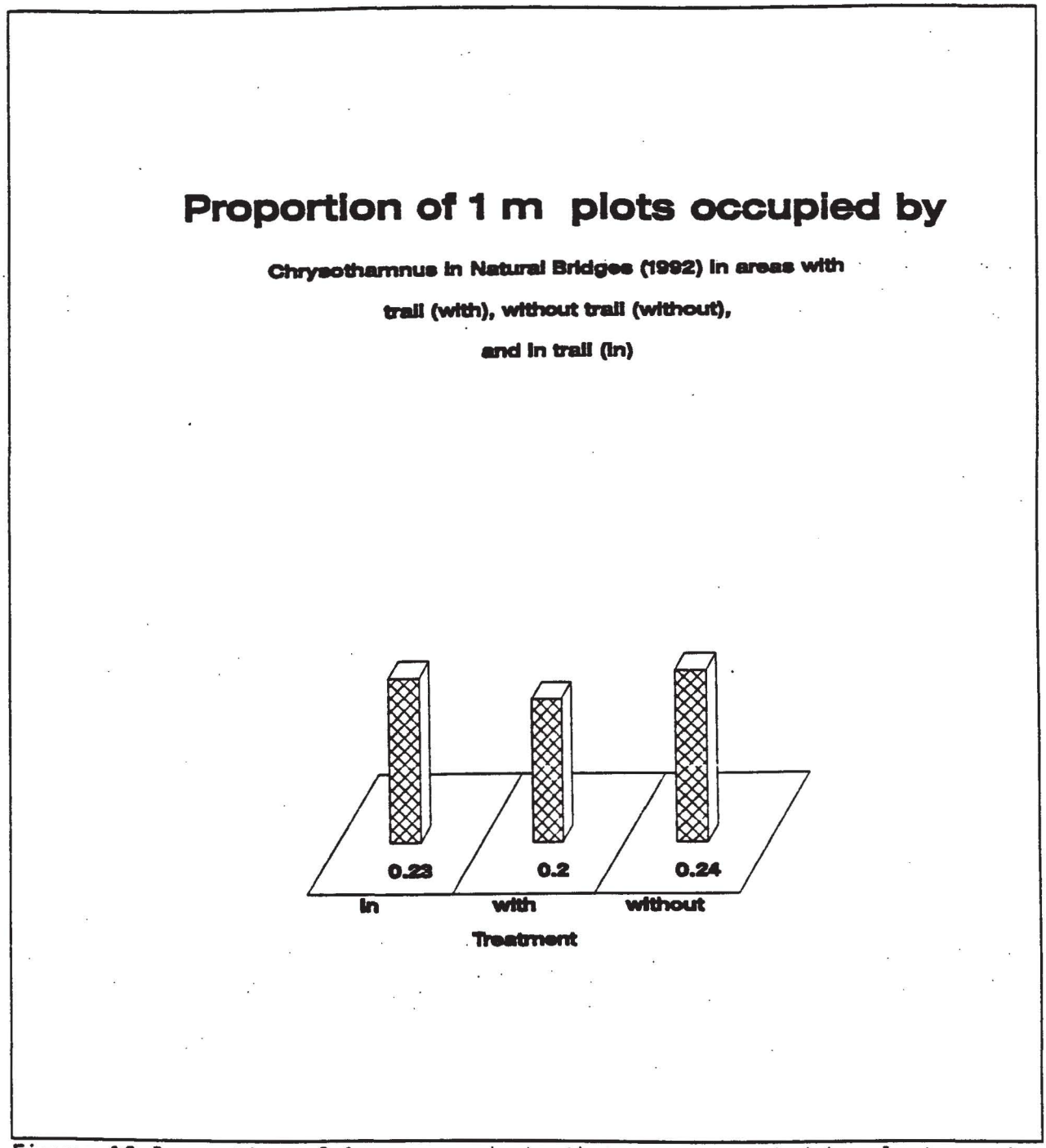

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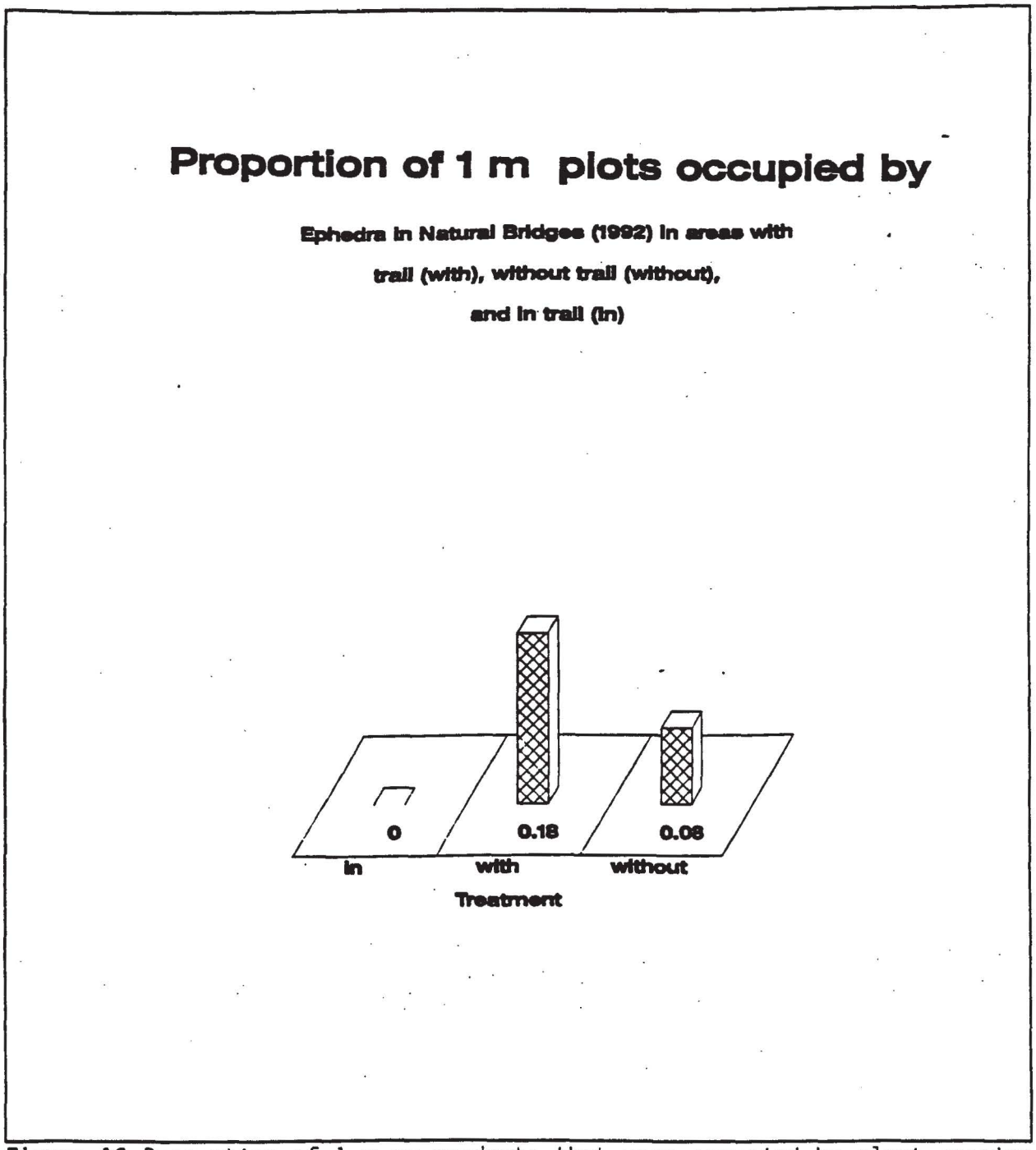
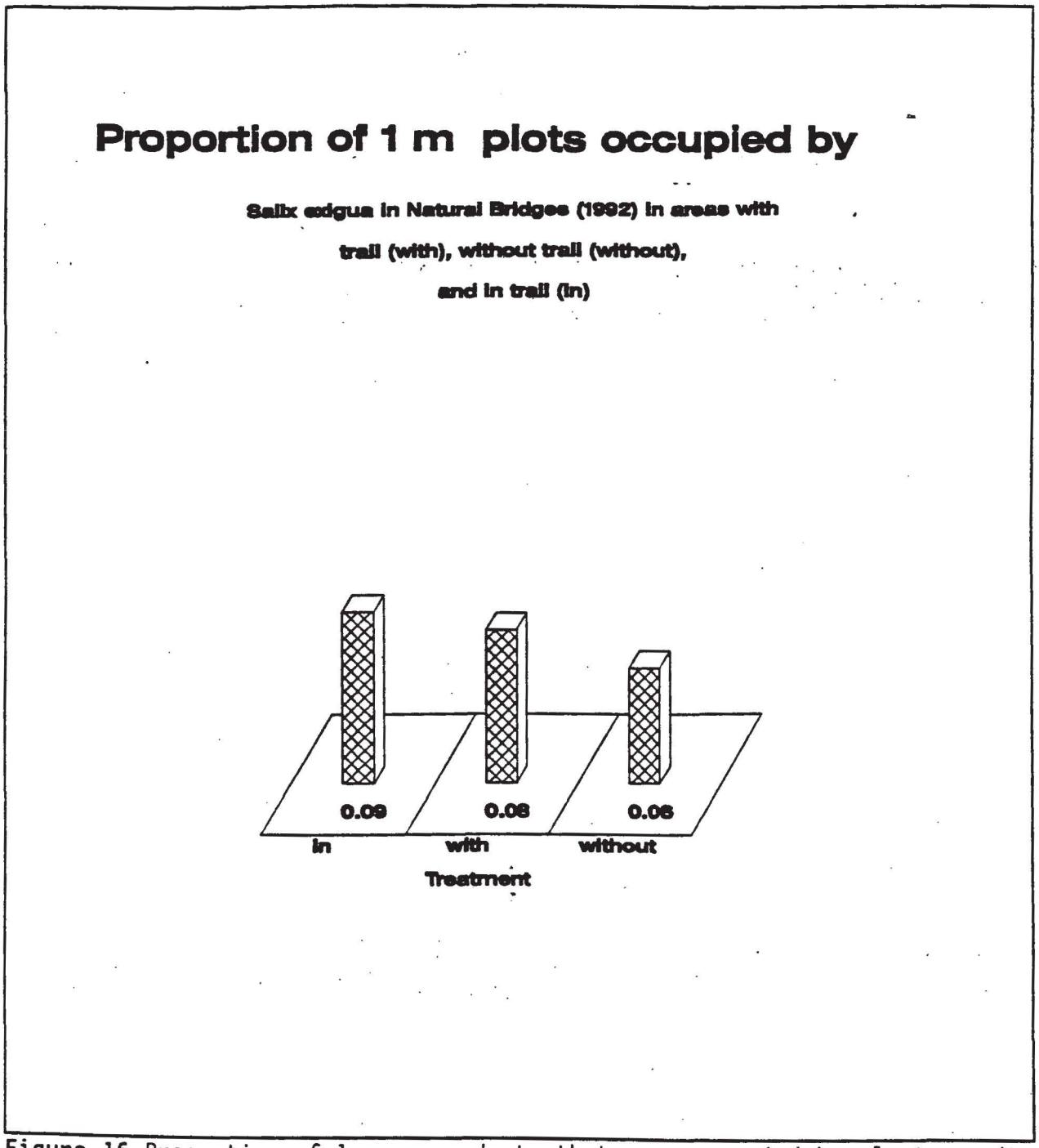


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.



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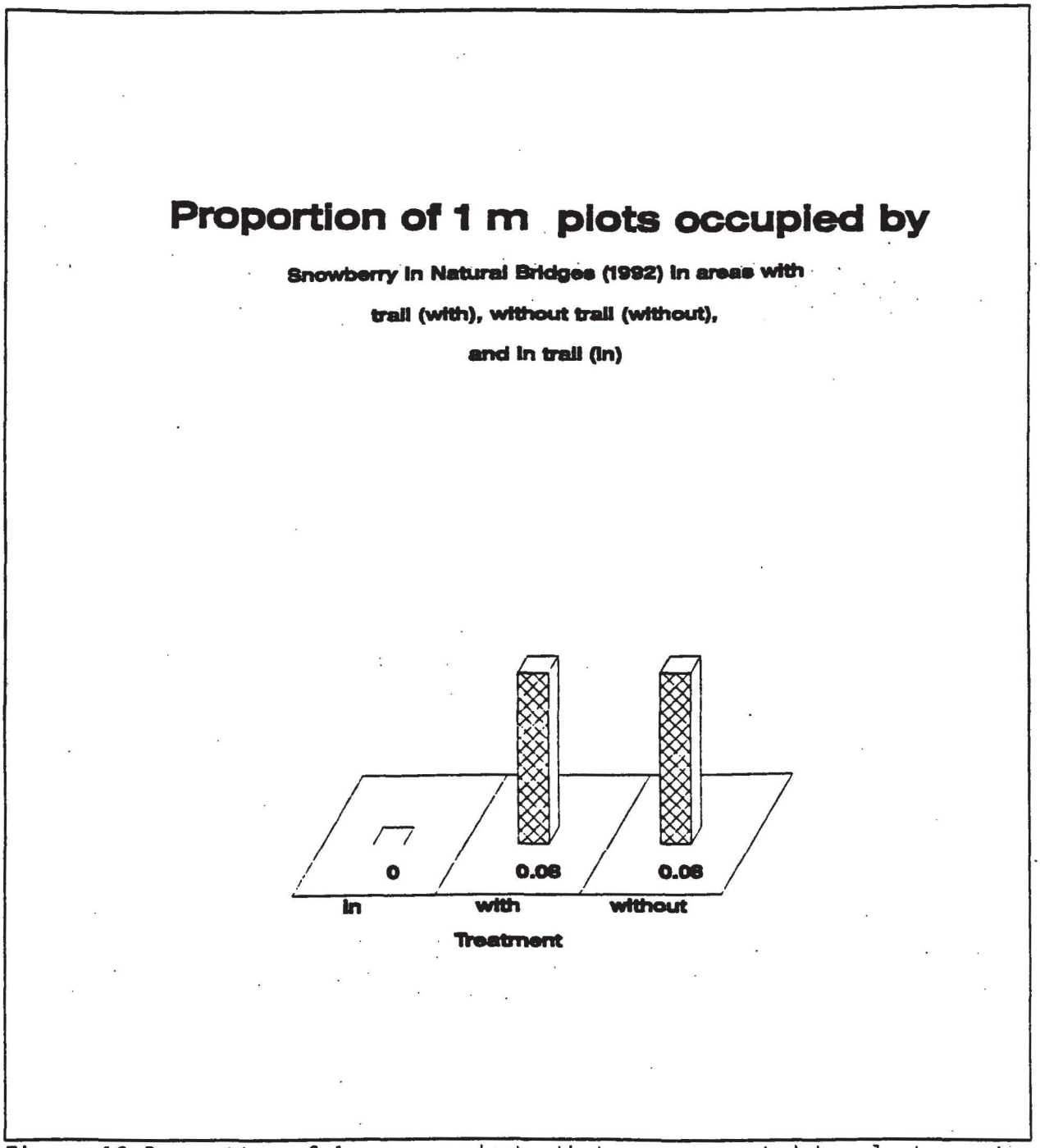

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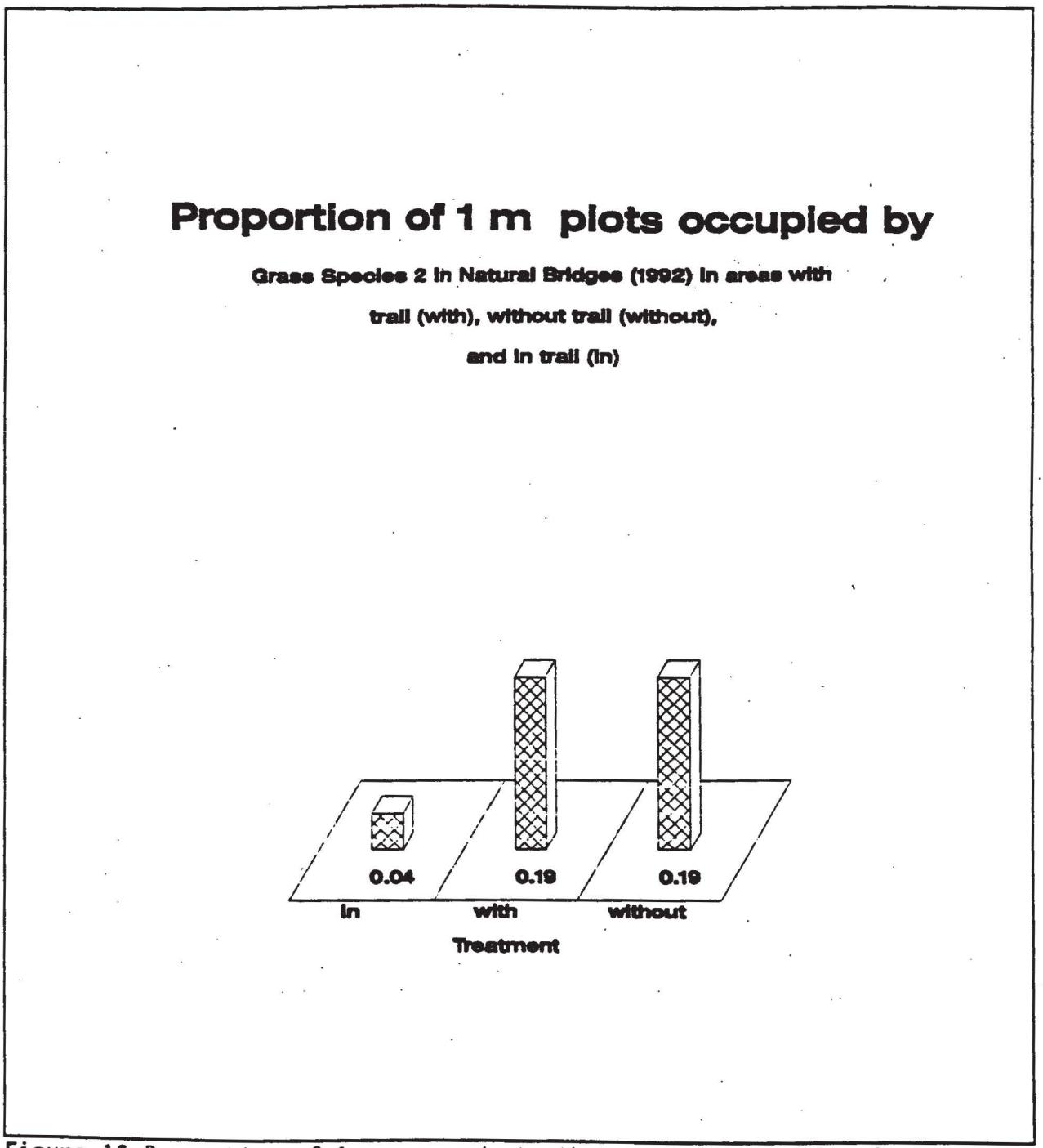

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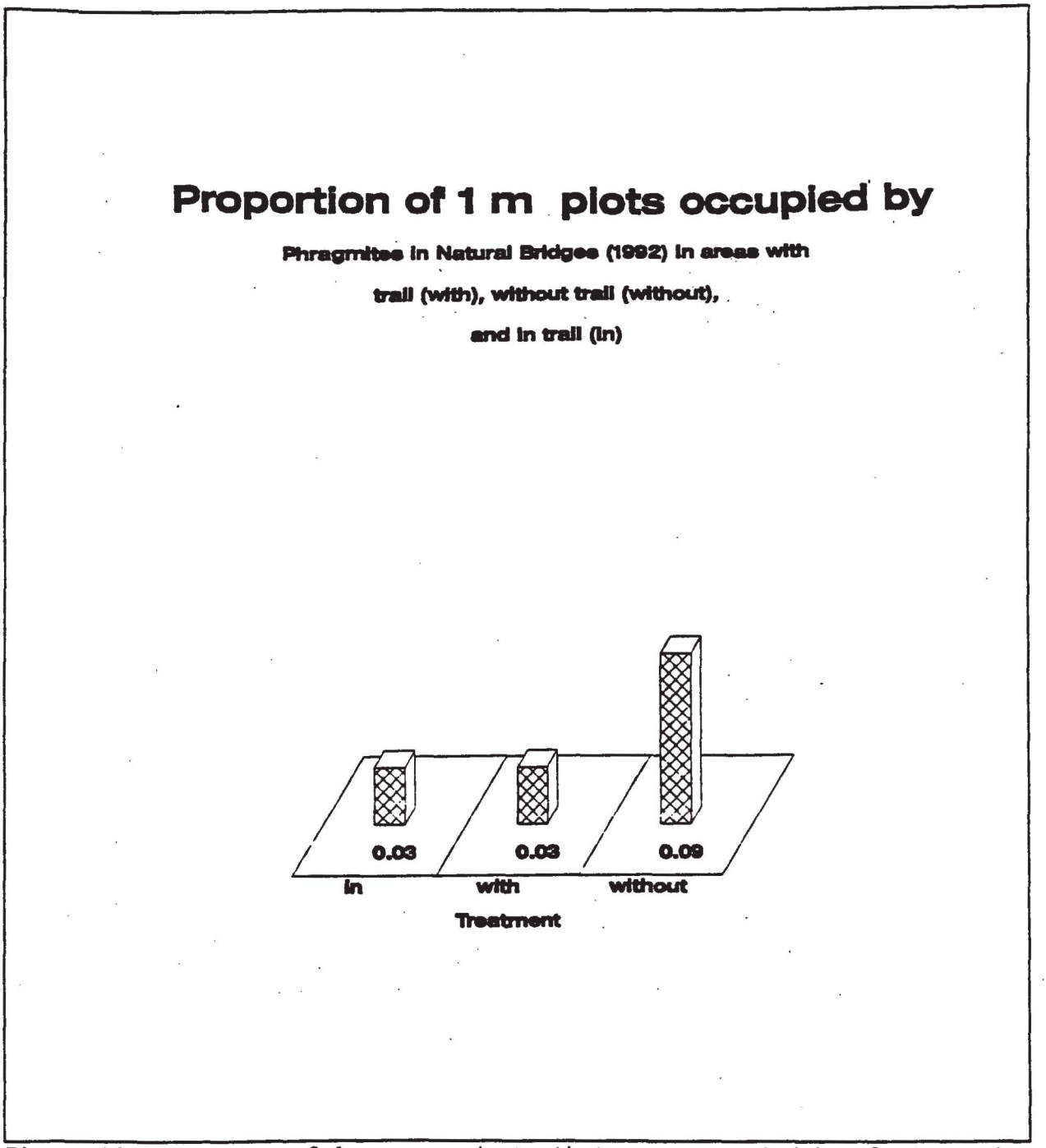

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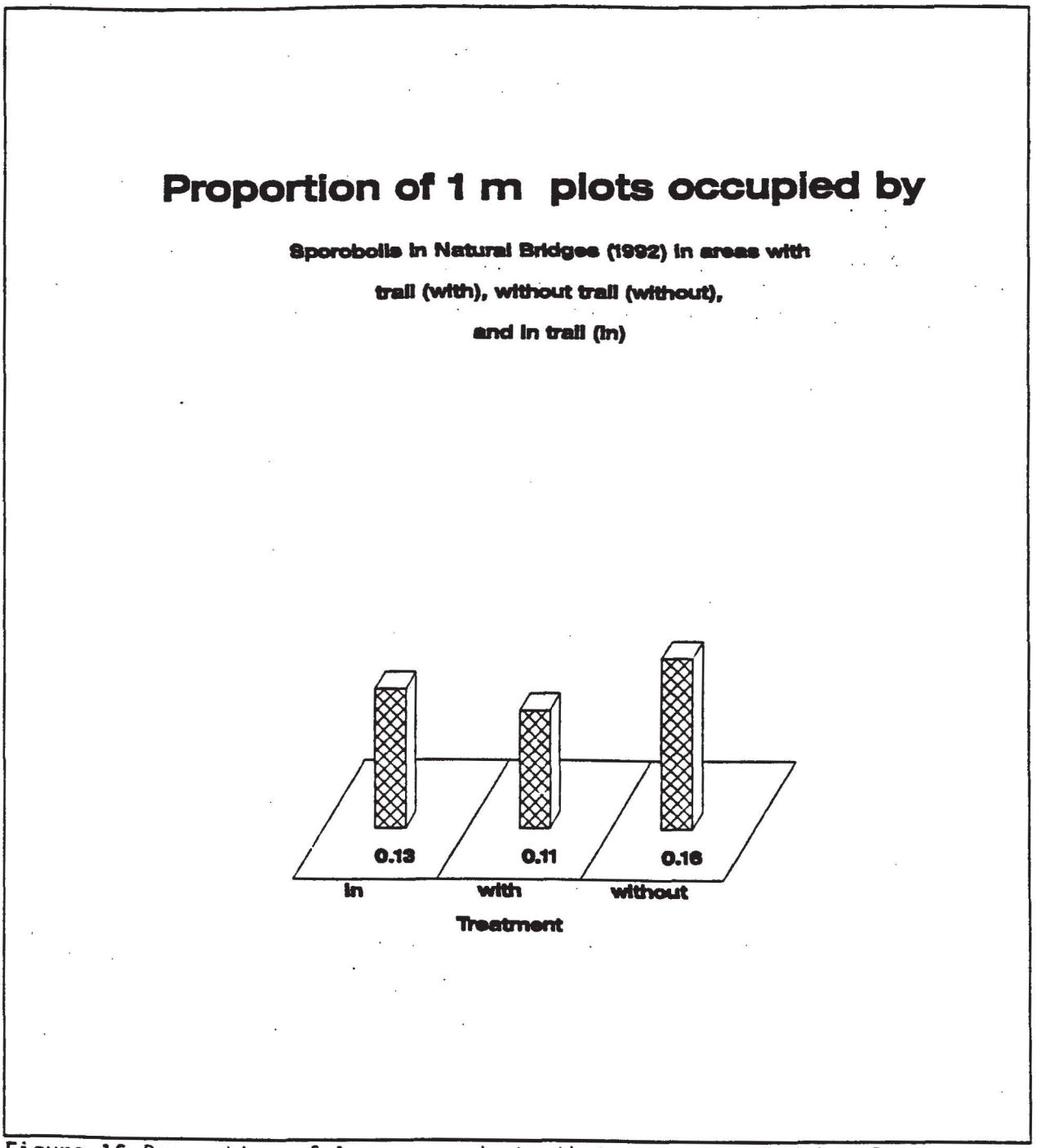

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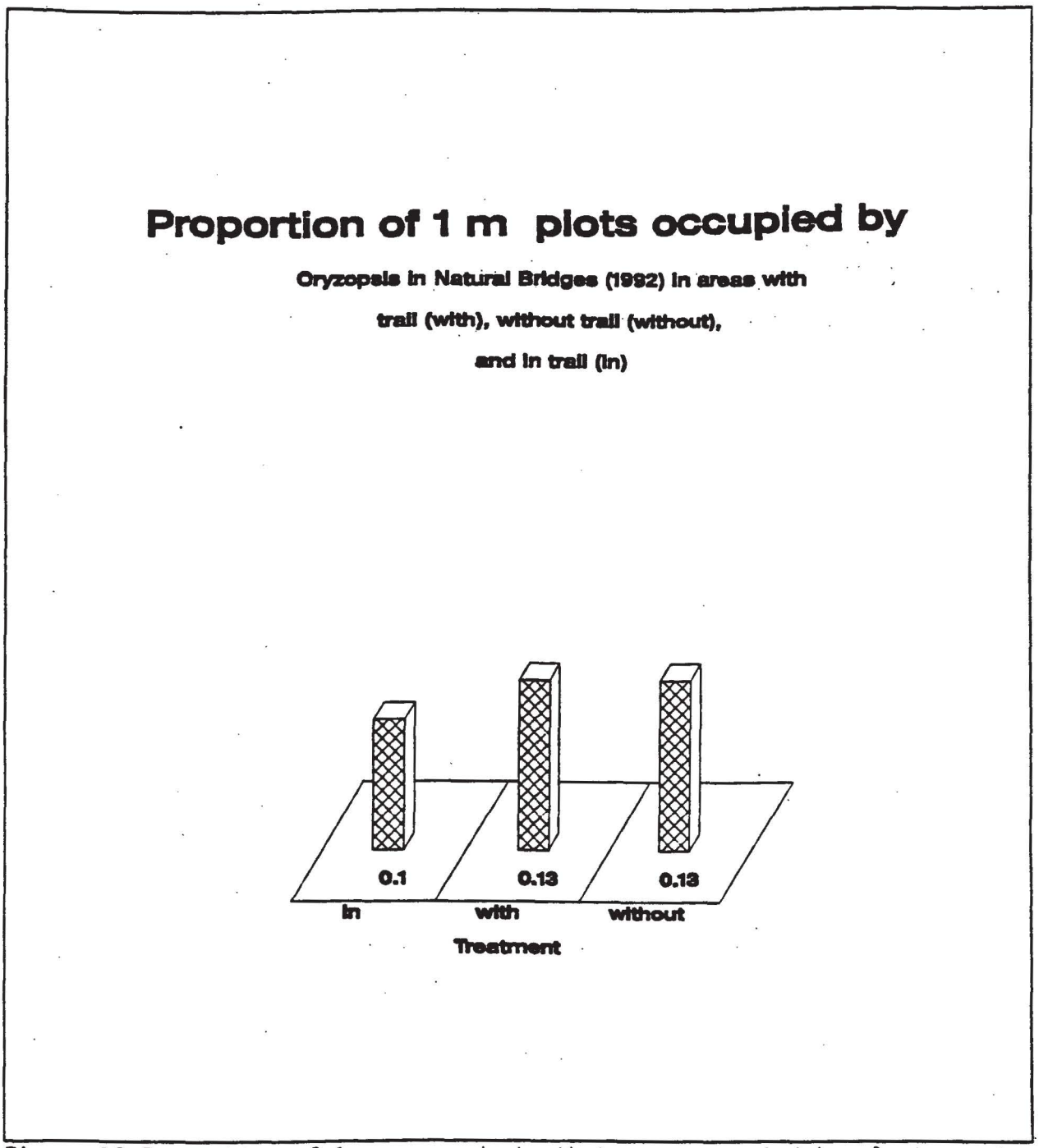

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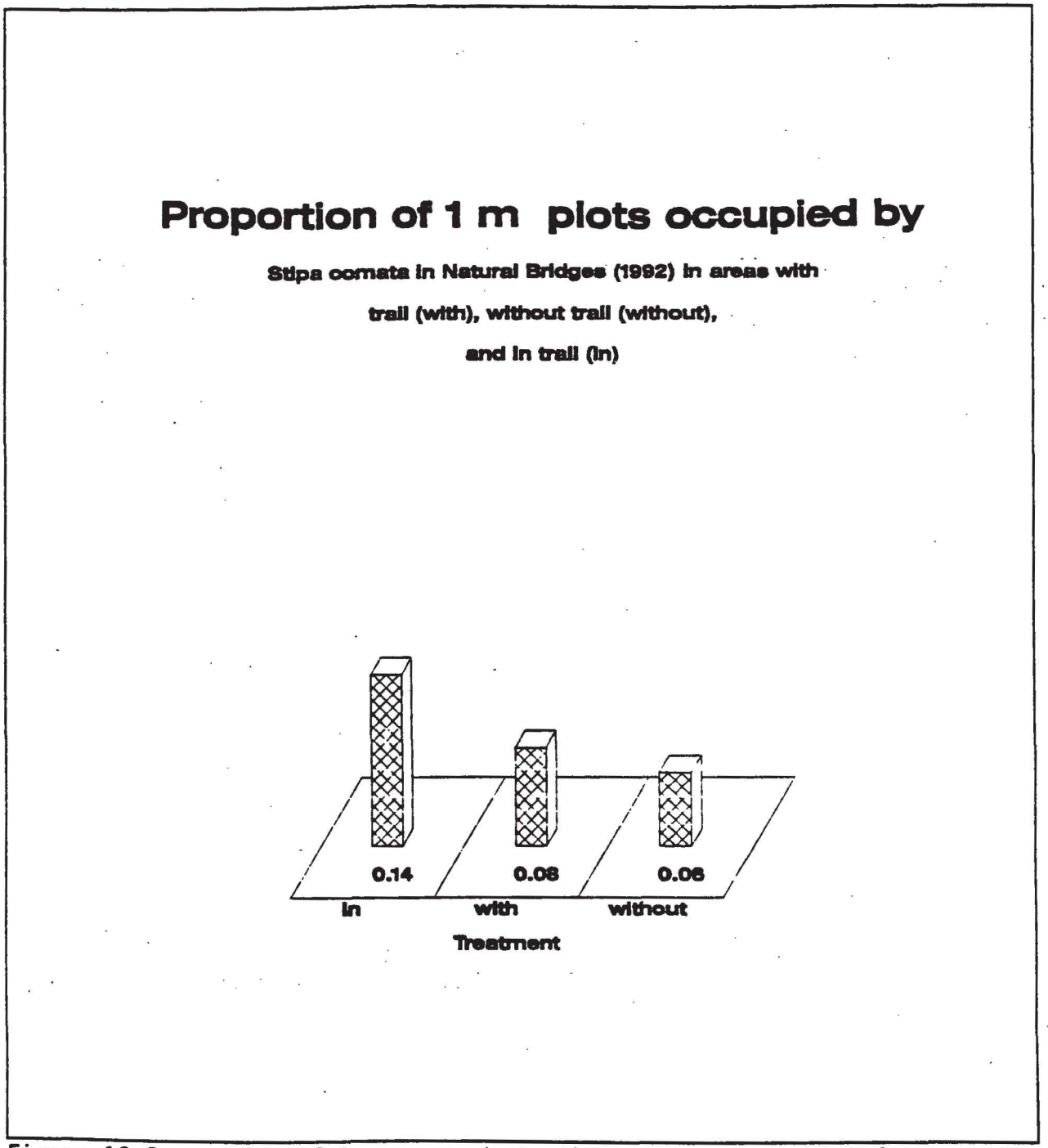


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.

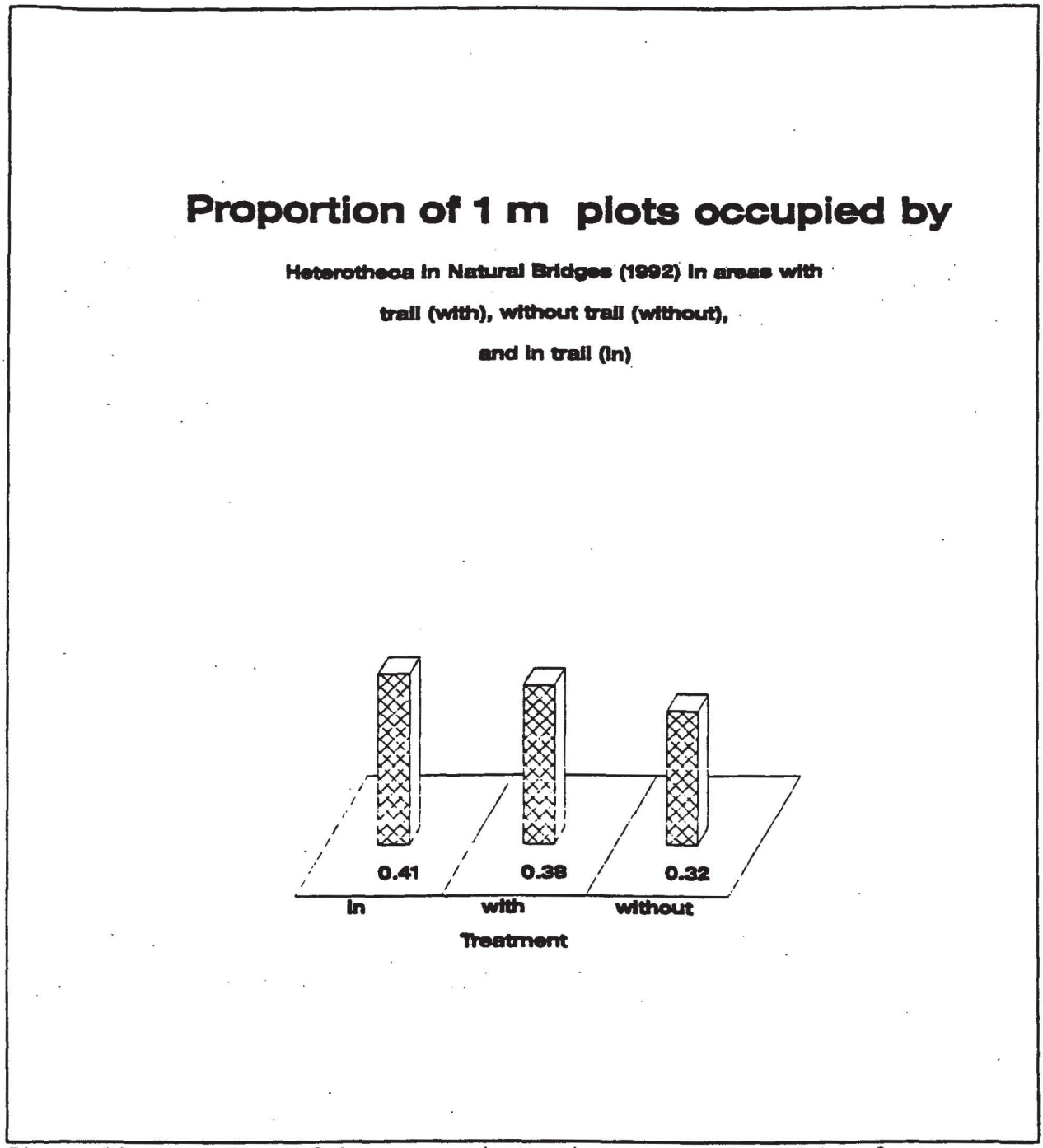


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.

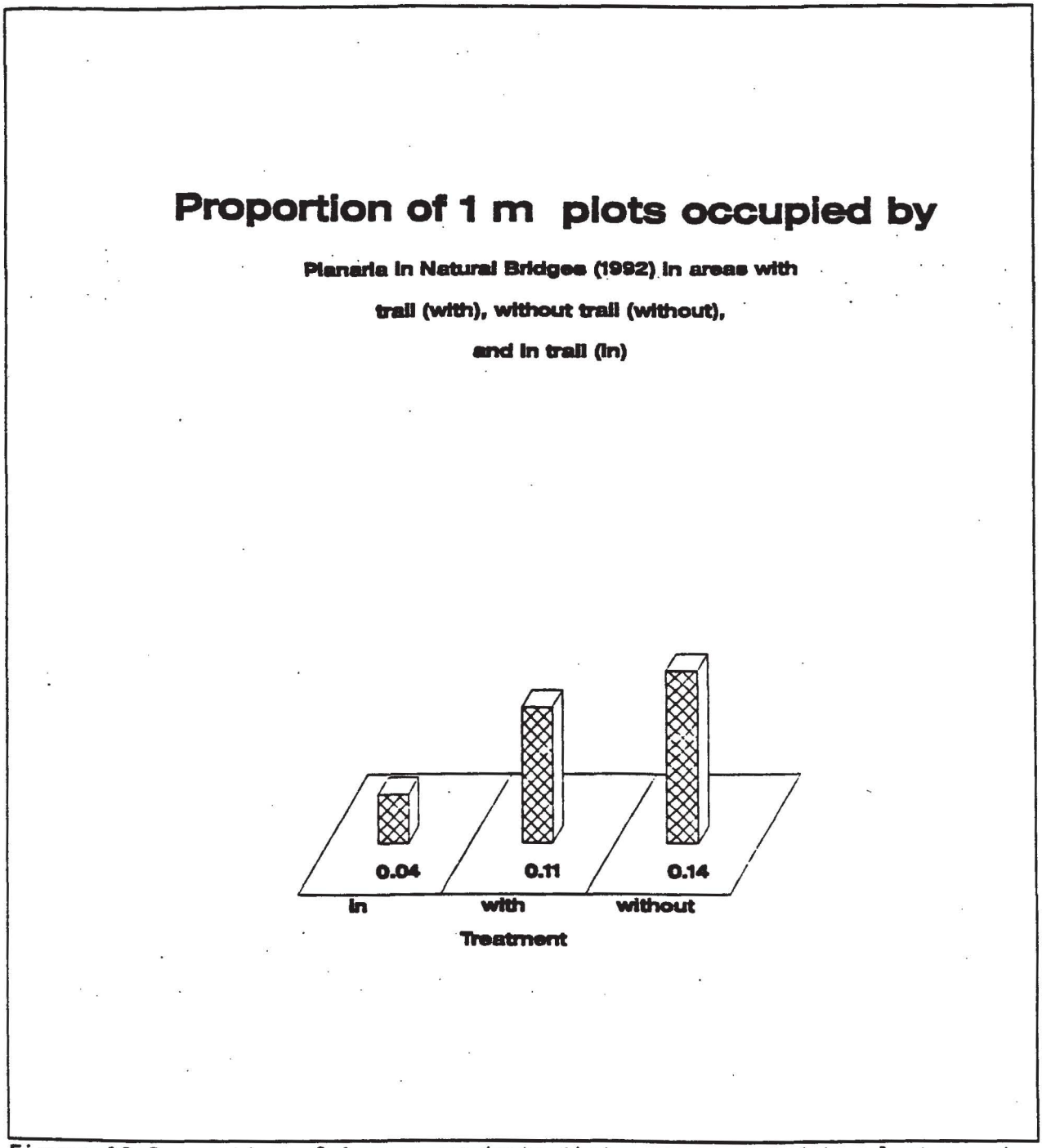


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.

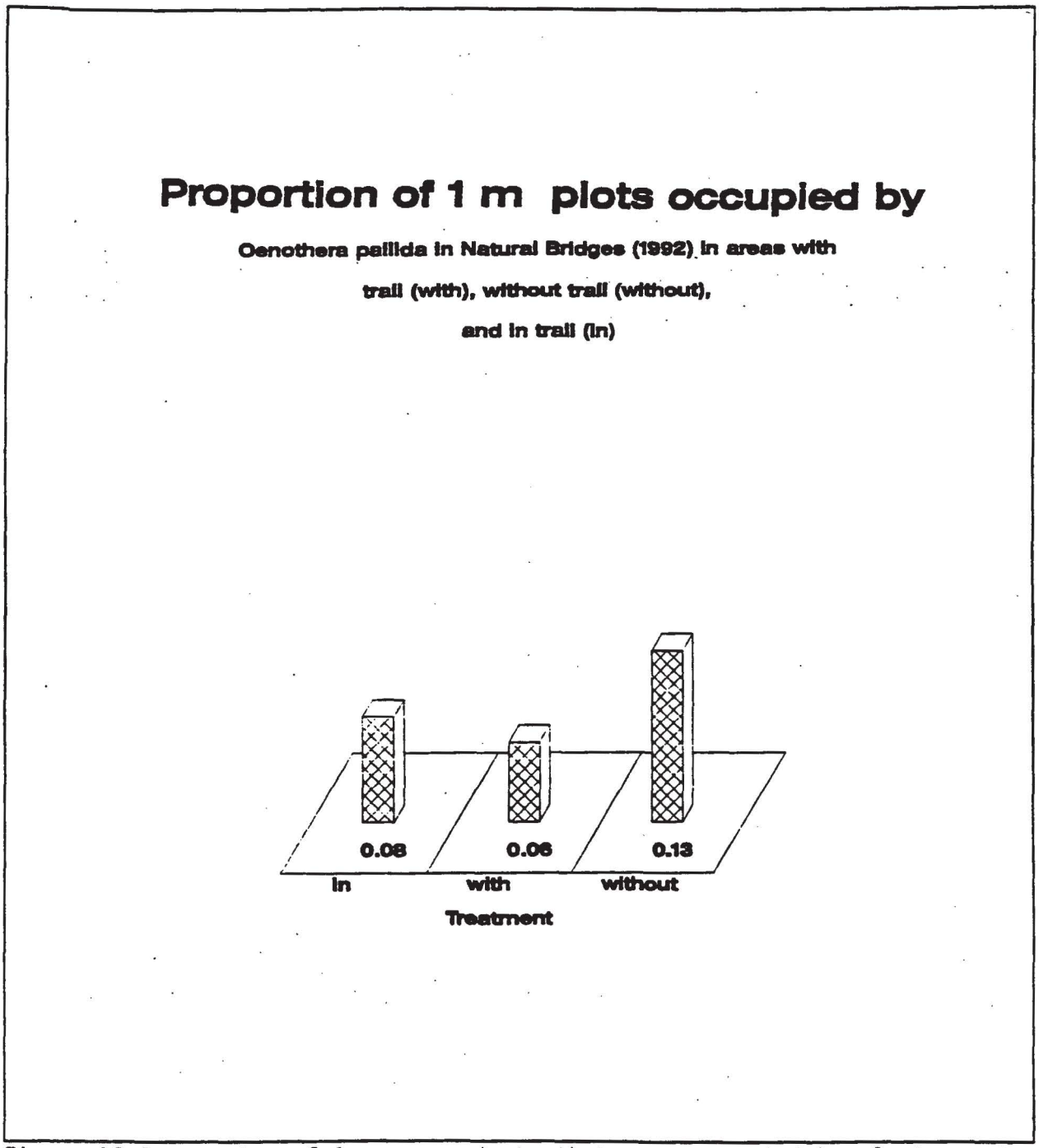


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.

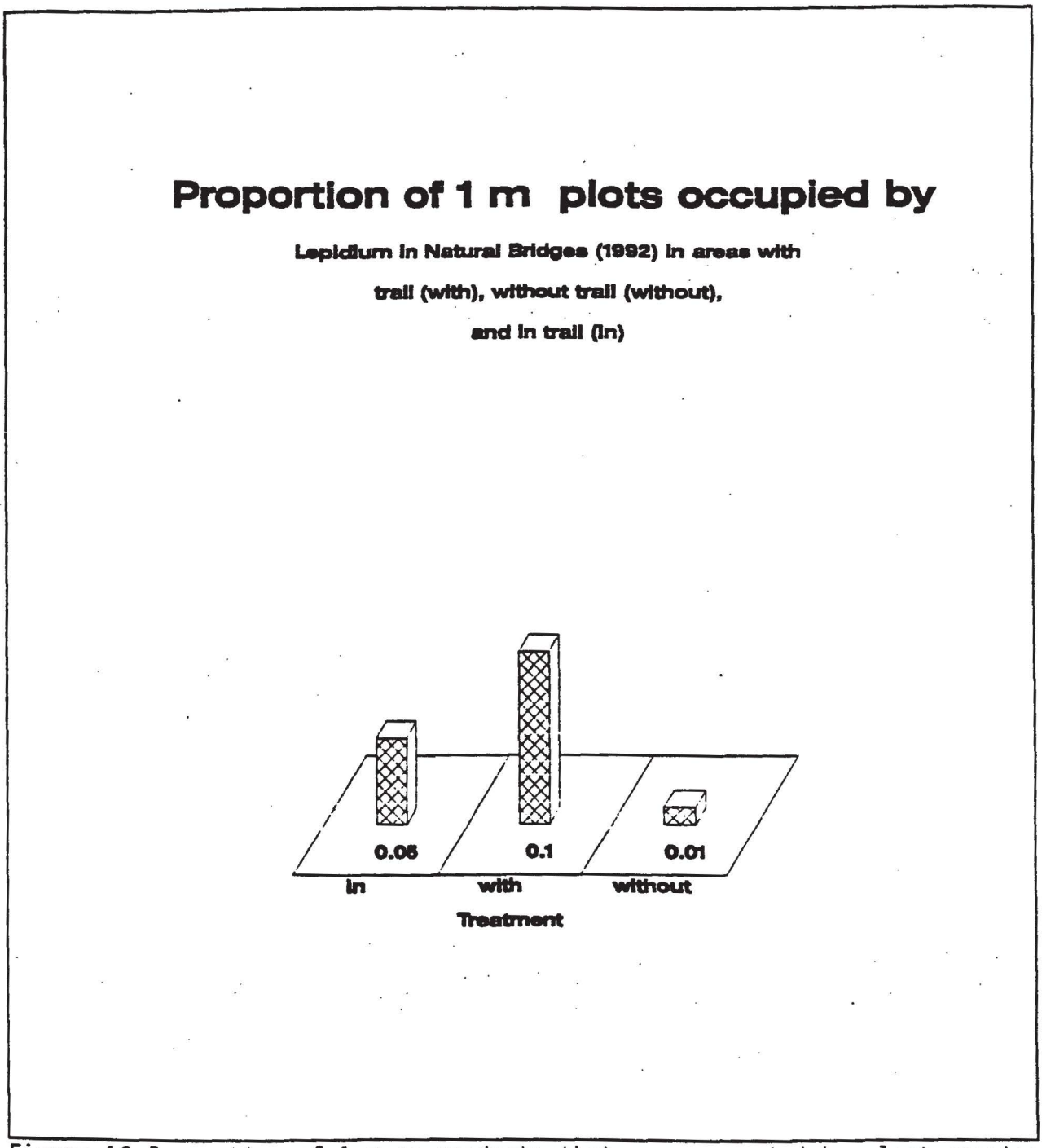
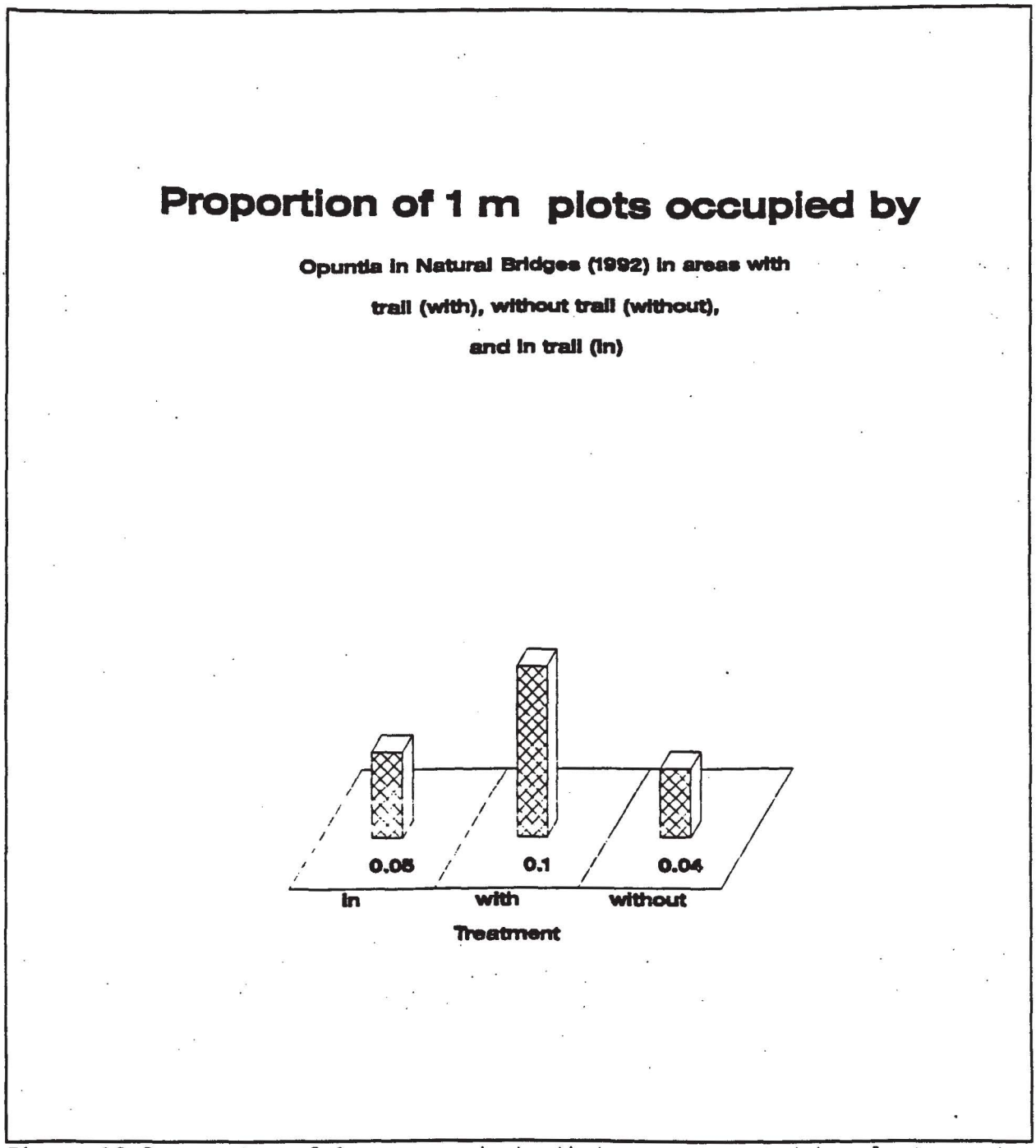


Figure 16 Proportion of 1 m sq quadrats that were occupied by plant species at Natural Bridges National Monument in 1992.



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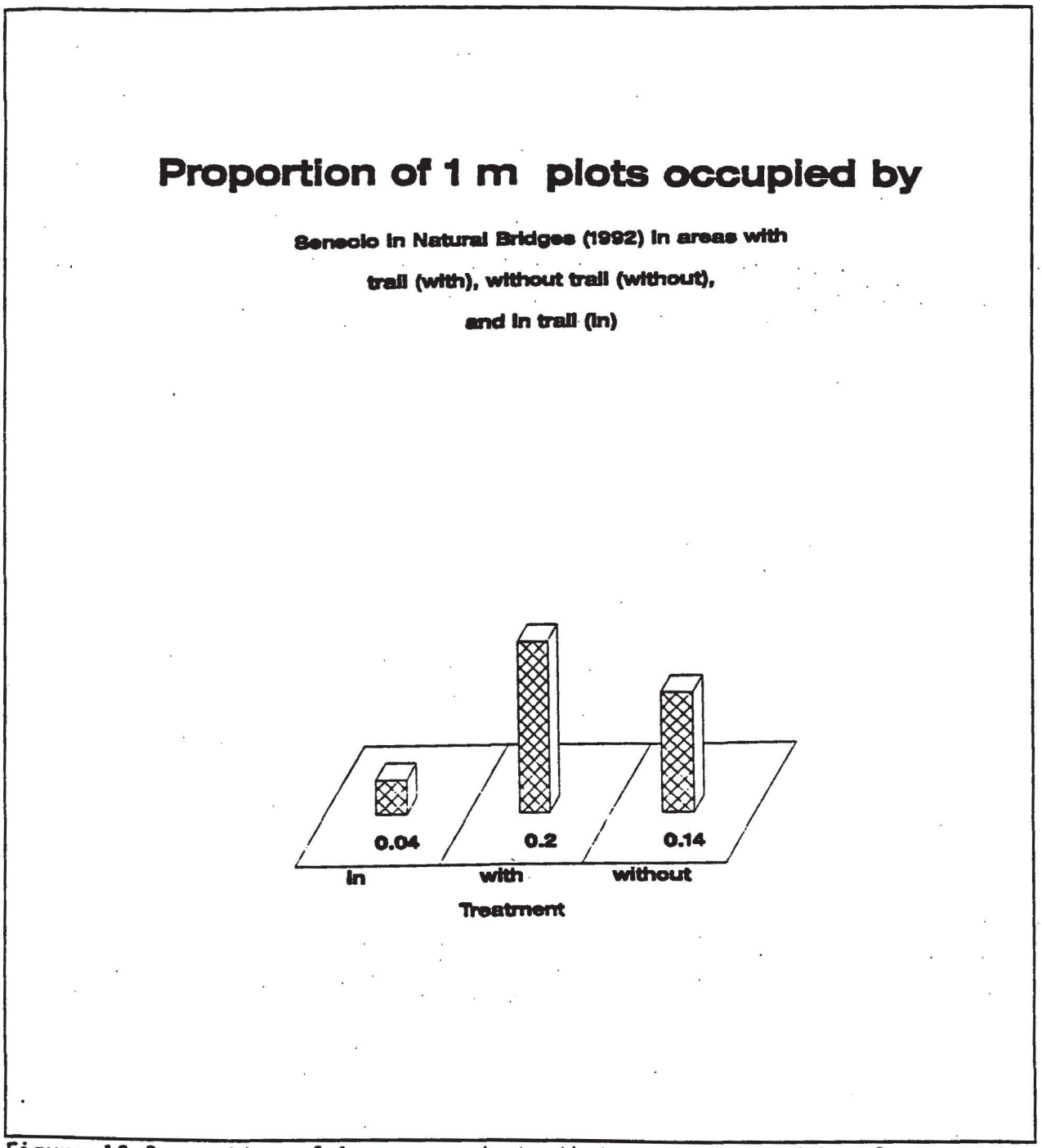

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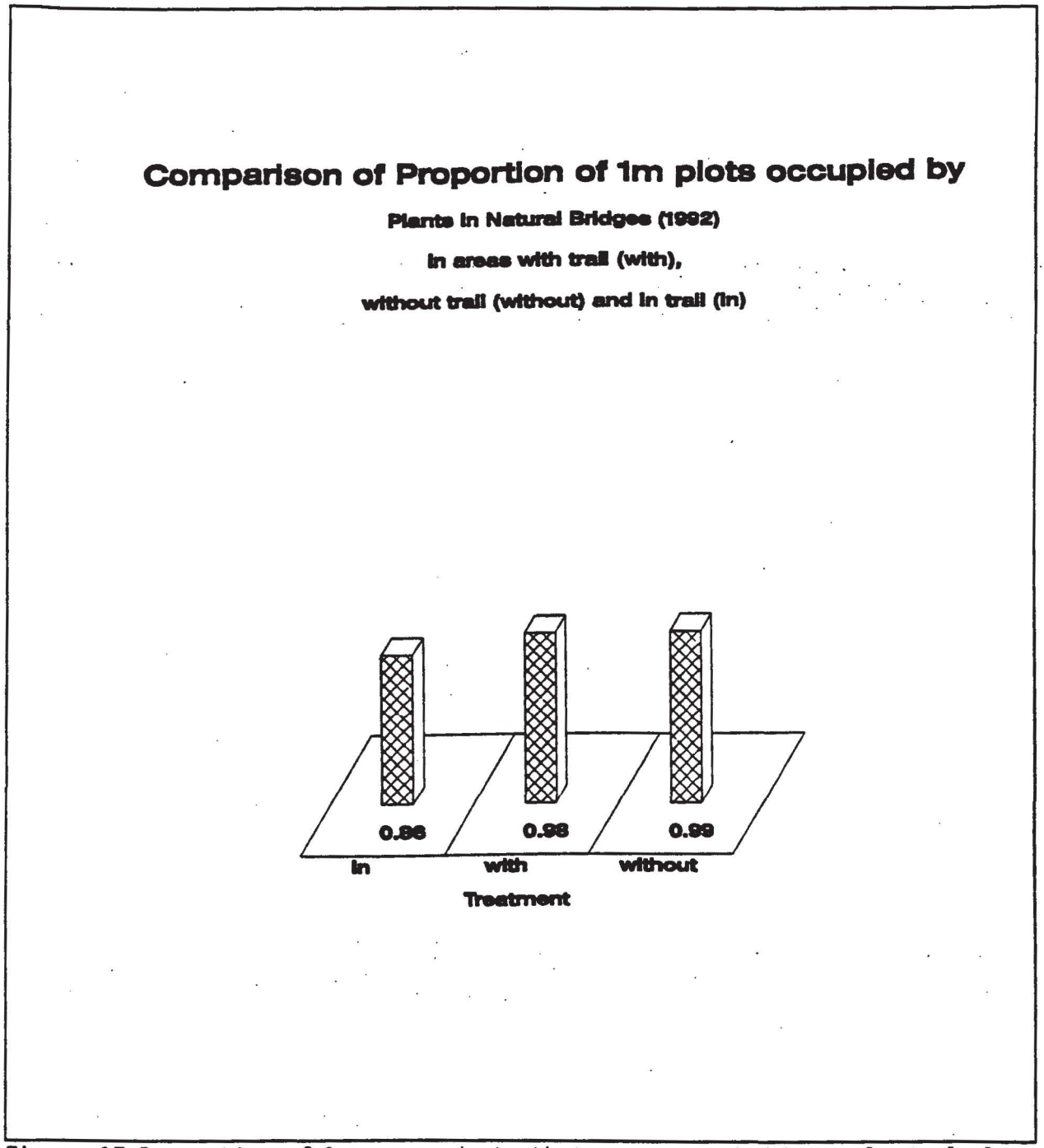

Figure 17 Proportion of 1 m sq quadrats that were occupied by ecological plant groups at Natural Bridges National Monument in 1992.

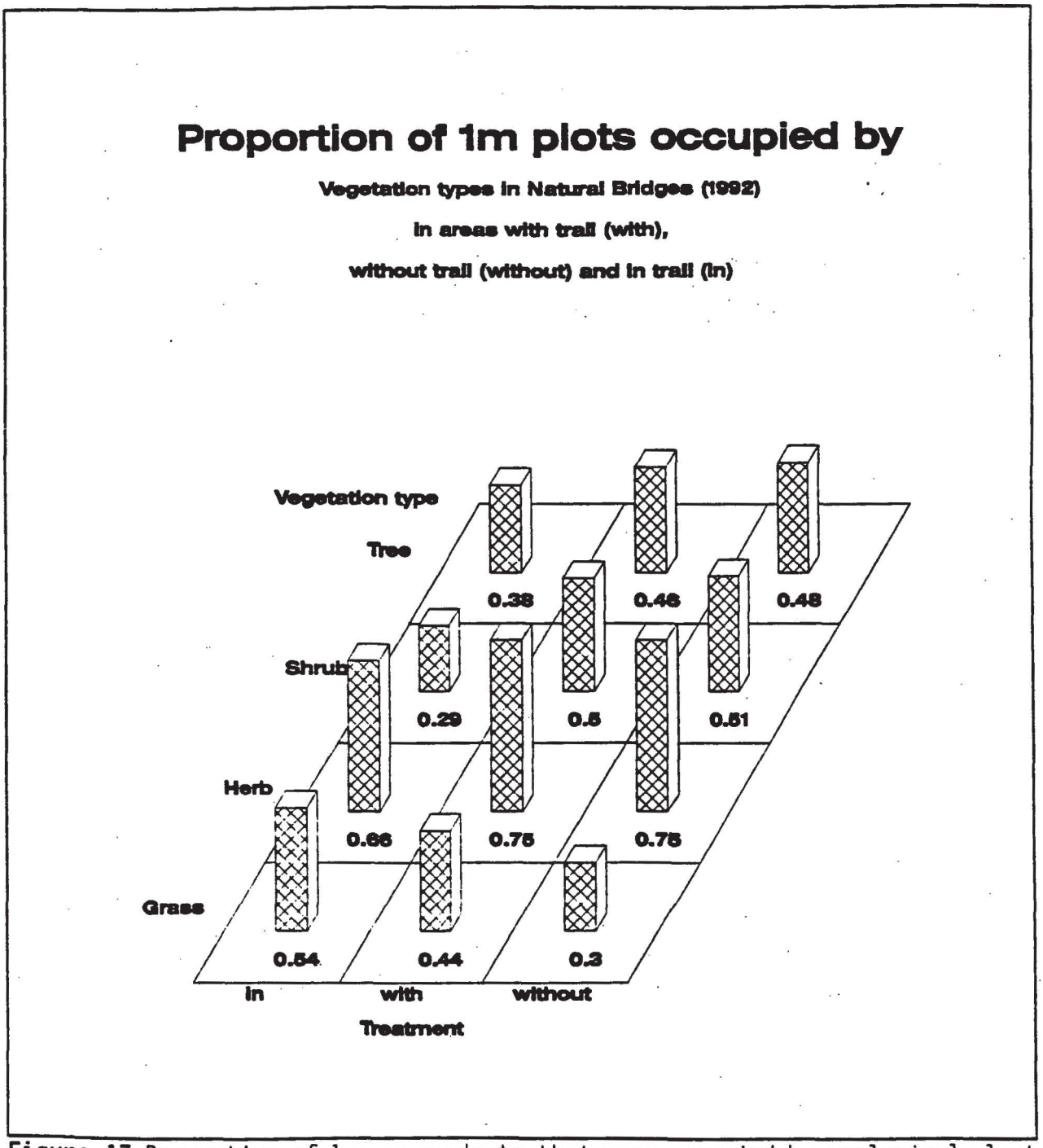

Figure 17 Proportion of 1 m sq quadrats that were occupied by ecological plant groups at Natural Bridges National Monument in 1992.

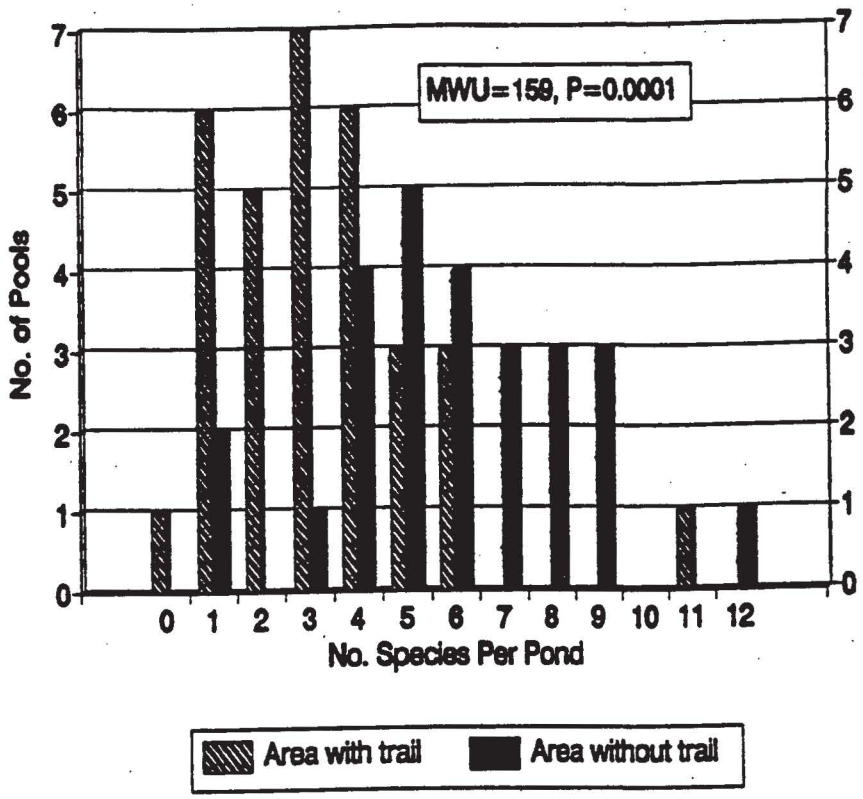

Figure 18 Number of species per pool at Natural Bridges in 1991.

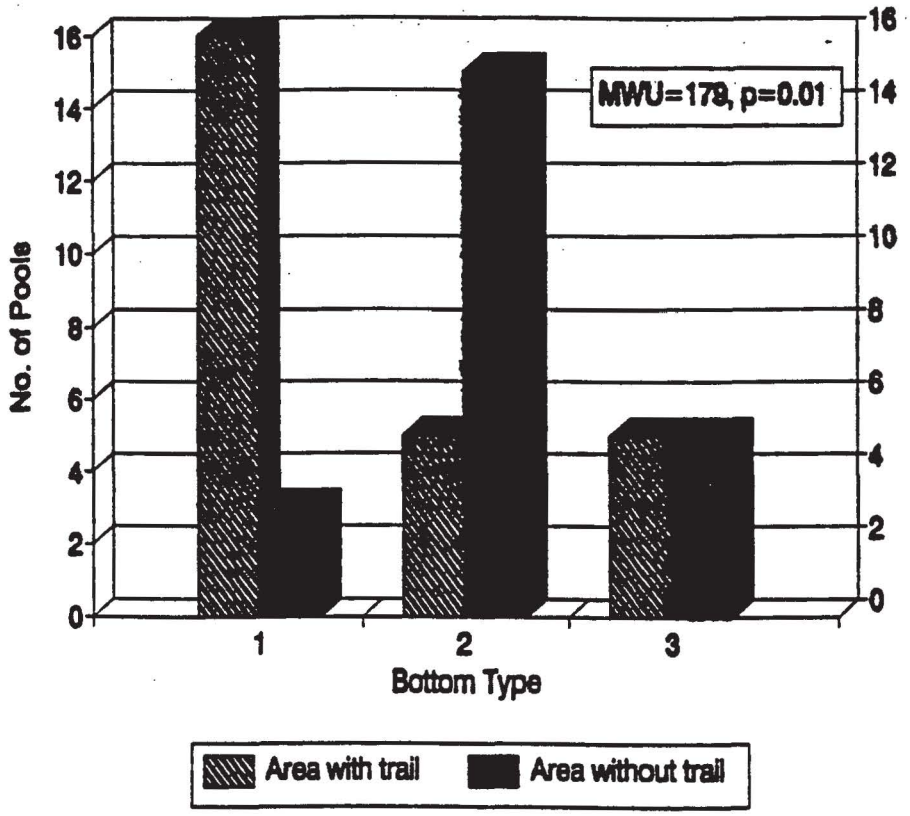

Figure 19 Distribution of pool substrate types at Natural Bridges.

Appendix I. Lists of species observed at Canyonlands in 1990 and 1991, with comments on our confidence in our identifications.

Plants

Identification	Comments on Identification
Trees	
Populus fremonti - Cottonwood	1
Tamarix ramosissima - Tamarisk	1
Pinus edulis - Pinon	1
Olneya tesota	1
Juniperus	2
Foresteria neomexicana	1
Fraxinus anomala - Single-leaf ash	1
Shrubs	
Atriplex canescens - Four-winged salt-bush	1
Artemisia tridentata - Big sagebrush	1
A. campestris	1
A. ludoviciana	1
A. filifolia - Old man sagebrush	1
Sarcobatus vermiculatus - Greasewood	1
Chrysothamnus nauseosus - Rubber rabbitbrush	1
Salix exigua - Sand bar willow	1
S. lutea	1
Ephedra	3
Herbs	
Castilleja linariifolia - Wyoming paintbrush	1
Ambrosia acanthicarpa - Bur ragweed	1
Machaeranthera canescens	1
Thelypodium integrifolium - Tall thelypody	1
Opuntia polyacantha - Pricklypear cactus	1
Sphaeralcea grossulariifolia - Globe mallow	1
Artemisia dracunculus - sagebrush	2
Melilotus alba - White-sweet clover	1
Oenothera pallida - Pale evening primrose	1
O. longissima - Tall yellow evening primrose	1
Gutierrezia sarothrae - Broom snakeweed	1
Lepidium montanum - Tall peppergrass	1
L. latifolium	1
L. fremonti	1
Suaeda torreyana - Torrey seepweed	3
Echinocereus triglochidiatus - Claretcup cactus	1
Asclepias sp - Milkweed	3
Cymopterus sp - Cymopterus	3
Erigeron sp - Daisy	3
Cirsium - Thistle	3
Chenopod (Chenopodiaceae)	4

saw-toothed dandelion (Compositae)	4
yellow bark	6
cabbage plant	6
cone flower	6
Heterotheca villosa - Golden aster	1
Hymenopappus filifolia	1
Solidago sparsifolius - Goldenrod	1
Stanleya pinnata - Prince's Plume	1
Rosa - Rose	3
Abronia fragrens	1
Astragalus - Locoweed	3
Senecio multilobus - Groundsel	1
Townsendi incana	1
Gilia longiflora	1
G. aggregata	1
Ranunculus cymbalaria	1
Theylsperma	3

Grasses

Sporobolus spp Dropseeds	3
Stipa hymenoides - Indian Rice Grass	1
S. comata - Needle and thread grass	1
Bouteloua gracilis - Blue grama	1
Distichlis spicata - Desert saltgrass	2
Muhlenbergia aspera -	2
Elymus canadensis	1
Elymus - Wildrye	3
Poa fendleriana	1
Agrostis alba	1
grass sp 2	4
grass sp 3	4
grass sp 4	4

Other species

Clematis linqusticifolia - Western virgin's bower	1
Juncus articus - Rush	1
Equisetum spp (E. hygemale and E. arvense) Horsetail	3
Scirpus - bulrush	3

Notes:
All identifications are to the level listed.
Comments on identification: 1 = species identification is certain, 2 = educated guess, 3 = Genus identification is certain, 4 family identification is certain, 5 = order identification is certain, 6 = unknown, but represents just one species.
See Table 1 for comments on species distributions across treatments.

Aquatic Animals

	1990				1991	
	proportion of pools occupied				proportion of pools occupied	
	June samples		July samples			
Canyonlands Identification	area lacking road	area with road	area lacking road	area with road	area lacking road	area with road
Notonectidae - back swimmers	0.923	0.800	0.889	0.563	0.800	0.867
Zygoptera - damselfly naiads	0.769	0.900	1.000	0.938	0.933	0.800
Gyrinidae - whirligig beetles	0.769	0.400	0.778	0.625	0.933	0.867
Gerridae - water striders	0.923	0.900	1.000	0.813	1.000	1.000
Nematomorpha - horse hair worms	0.385	0.350	0.778	0.000	0.333	0.200
Coleoptera (Hydrophilidae?) hydrophilids	0.385	0.400	0.444	0.250	0.400	0.867
Corydalidae - "helgrimites"	0.154	0.300	0.000	0.000	0.000	0.000
Trichoptera - caddisfly larvae	0.077	0.000	0.000	0.000	0.000	0.000
Culicidae - mosquito larvae	0.077	0.000	0.000	0.000	0.000	0.000
Molluscs - snails	0.000	0.200	0.556	0.813	0.867	0.867
Belostomatidae - water bugs	0.000	0.100	0.111	0.000	0.000	0.000
Anisoptera - dragonfly naiads	0.000	0.000	0.111	0.125	0.333	0.333
Bufo woodhousii - woodhouse's toad juveniles	0.000	0.000	0.333	0.063	0.000	0.000
Bufo punctatus - red spotted toad juveniles	0.154	0.000	0.000	0.000	0.000	0.000
Scaphiopus intermontanus - great basin spadefoot toad tadpoles	0.308	0.150	0.000	0.000	0.000	0.000
Bufo tadpoles - toad tadpoles	0.615	0.650	0.556	0.500	0.533	0.467
Corixids	0.000	0.000	0.000	0.000	0.067	0.067

Notes:
Bufo tadpoles include both red spotted and woodhouse's toad tadpoles as discussed above.
All taxa are identified correctly as listed.
All taxa represent one species with the possible exception of culicidae.

Small Mammals

Identification	Comment on identification
Peromyscus boylei - brush mouse	certain of identification
P. truei - pinon mouse	certain of identification
P. maniculatus - deer mouse	certain of identification
P. crinitus - rock mouse	identification likely - need skull to positively separate it from brush mouse
Reithrodontomys megalotis - western harvest mouse	certain of identification
Neotoma albigula - white-throated woodrat	certain of identification
N. mexicana - mexican woodrat	identification likely - need skull to positively separate it from desert woodrat
N. cinerea - bushy-tailed woodrat	certain of identification
Dipodomys ordii - ord's kangaroo rat	certain of identification

Notes:
see Tables 9 and 10 for distribution of species across treatments.

Birds

Canyonlands

Identification	area lacking trail	area with trail
Turdus migratorius - robin	absent	present
Aeronautes saxatalis - white-throated swift	present	present
Tachycineta thalassina - violet-green swallows	present	present
Zenaidura macroura - mourning dove	present	present
Trochilidae - hummingbird	present	present
Selasphorus playcercus - broad-tailed hummingbird	present	present
Archilochus alexandri - black-chinned hummingbird	present	absent
Selasphorus rufus - rufus hummingbird	present	absent
Fringillidae - sparrow	present	present
Melospiza melodia - song sparrow	present	absent
Zonotrichia leucophrys - white-crowned sparrow	absent	present
Spizella passerina - chipping sparrow	absent	present
Amphispiza belli - sage sparrow	absent	present
Pooecetes gramineus - vesper sparrow	absent	present
Pipilo erythrophthalmus - rufus-sided towhee	present	present
Chlorura chlorura - green-tailed towhee	absent	present
Guiraca caerulea - blue grosbeak	present	absent
Geothlypis trichas - yellow throat	present	absent
Dendroica petechia - yellow warbler	present	absent
Parulidae - warbler	absent	present
Wilsonia pusilla - Wilson's warbler	present	absent
Vireonidae - vireo	present	absent
Anas discors - blue-winged teal	absent	present
Cathartes aura - turkey vulture	absent	present
Corvus corax - raven	present	present
Gymnorhinus cyanocephalus - pinon jay	absent	present
Aphelocoma coerulescens - scrub jay	present	present
Molothrus ater - brown-headed cowbirds	present	present
Dendrocopos spp - downy or hairy woodpeckers	present	present
Colaptes sp - common flicker	present	present
Psaltriparus minimus - common bushtit	present	present
Parus inornatus - plain titmouse	absent	present
P. gambeli - mountain chickadee	present	present
Icteridae - blackbird	absent	present
Polioptila caerulea - blue-gry gnatcatcher	absent	present
Myiarchus cinerascens - ash-throated flycatcher	present	absent
Tyrannidae - flycatcher	absent	present
Salpinctes obsoletus - rock wren	absent	present

Notes:
All species are identified to the levels listed in the table.

Appendix II. Lists of species observed at our Arches study site in 1992, with comments on our identifications.

Plants

Identification	Comments
Trees	
Populus fremonti - Cottonwood	1
Tamarix ramosissima - Tamarisk	1
Shrubs	
Salix exigua - Sand bar willow	1
Chrysothamnus naseosus - Rubber rabbitbrush	1
Artemisia tridentata - Big sagebrush	1
Gutttierizzia sarothrae - Snake weed	1
Herbs	
Artemisia ludoviciana - Louisiana wormwood	1
A. campestris	1
Ambrosia acanthicarpa - Bur ragweed	1
Aster brachyactis - Aster	3
Xanthium strumarium - Cocklebur	1
Suaeda - Seepweed	3
Thelypodium integrifolium - Tall thelypody	1
Astragalus - Locoweed	3
Abronia fragrans - Sand verbena	1
Gilia aggregata - Scarlet gilia	1
Castilleja linariifolia - Wyoming paintbrush	1
Oxytenia acerosa - Copperweed	1
Haplopappus drummondii - Happlopappus	1
Hymenopappus filifolius - Hyaline herb	1
Grindelia squarrosa - Blanket flower	1
Conyza canadensis - Horseweed	1
Melilotus alba - Sweet white clover	1
Grasses	
Muhlenbergia - Muhly grass	3
Stipa humenoides - Indian rice grass	1
S. comata - Needle and thread grass	1
Aqatics	
Juncus articus - Wiregrass	1

Small mammals

Mustela frenata - Long tailed weasel	1
Peromyscus maniculatus - Deer mouse	1
P. boylei - Brush mouse	1
P. crinitus - Canyon mouse	1
Neotoma albigula (could be N. lepida)	2
N. cinerea - Bushy tailed woodrat	1
Reithrodontomys megalotis Western harvest mouse	1

Onchymys leucogaster (juv. specimen, could be O. torridus)	2
Perognathus parvus - Great Basin pocket mouse	1
Dipodomys ordii - Ord's Kangaroo rate	1

Comments categories
1 - certain of identification
2 - educated guess as to species indentification, genus certain
3 - genus certain

Appendix III. Species encountered during the systematic surveys at Natural Bridges National Monument. The species distributions are noted in 1990, and comments are made as to how certain we are of its listed identification.

Plants

1990 samples

Number of quadrats occupied per grid

Identification	Comments on ID	Plant Location (Grid) trt 1 1	trt 1 3	trt 2 2	trt 2 4
Trees					
Quercus gambelii - Gambel's Oak	1	12	17	19	17
Populus fremontii - Cottonwood	1	5	2	4	3
Juniperus osteosperma - Utah Juniper	1	1	1	0	2
Fraxinus anomala - One Leafed Ash	1	1	0	3	2
Acer negundo - Box Elder	1	0	0	1	0
Cherry	6	0	0	0	0
Shrubs					
Populus angustifolia - Narrow Leaf Cottonwood	1	0	0	1	1
Ephedra viridis - Morman Tea	1	18	8	2	5
Rhus trilobata - Squawbush	1	4	3	1	2
Salix exigua - Sandbar Willow	1	2	2	5	0
Mahonia fremontii - Fremont's Mahonia	1	1	0	1	0
Cercocarpus montanus - Alder-leaf Mountain Mahogany	1	0	1	3	4
C. ledifolius - Mountain Mahogany	1	1	2	11	5
Chrysothamnus nauseosus - Rubber Rabbitbrush	1	12	9	26	19
Rosa woodsii - Rose	1	0	1	0	7
Herbs					
Mahonia repens - Oregon Grape	1	0	0	9	0
Yucca baccata Datil Yuca	1	0	1	0	1
Sphaeralcea grossulariaefolia - Globe Mallow	1	5	0	0	0
Opuntia polyacantha - Prickly pear Cactus	1	1	6	0	2
Oenothera - Primrose	3	0	0	0	3
Erigeron divergens - Spreading Daisy	1	5	18	17	22
plantain	6	5	11	5	8
lplantain	6	0	0	1	2
pink willow	6	0	0	3	0
Cymoterus sp - cymoterus	3	3	1	5	11
Lepidium montanum - Tall peppergrass	2	1	8	3	8
Artemisia dracunculus - sagebrush	2	14	3	6	1
square round	6	0	0	4	0
hairy tongue	6	0	1	1	1
white step	6	0	1	0	0
Goldenrod (Solidago sp?)	6	0	0	0	10

Astragalus sp	3	0	1	0	1
round spinach	6	0	0	0	1
yellow spot	6	0	3	0	2
four leaf	6	0	2	0	4
Herbs (cont.)					
toothed leaf	6	0	10	0	12
Cirsium	3	0	1	0	0
celery II	6	0	12	0	0
white cherry	6	0	0	0	1
Grasses					
Sporobolus spp - Dropseed (mainly S. cryptandrus)	3	22	13	4	7
Stipa hymenoides - Indian Rice Grass	1	12	4	7	5
Hordeum jubatum - Foxtail Barley	1	4	0	2	1
Phragmites communis - Common Reed	1	1	0	0	2
Hilaria jamesii - Galleta	1	0	1	2	0
grass sp 3	6	5	0	0	0
grass sp 4	6	3	0	13	0
grass sp 5	6	0	9	3	13
Other plants					
Clematis ligusticifolia - Western Virgins Bower	1	5	2	8	7
Juncus articus - Rush	1	1	0	0	0
Equisetum spp (E. hygemale and E. arvense) Horsetail	3	0	3	4	1
total number of species	28	27	36	34	

Notes:
Ecological groupings (trees, shrubs, herbs, and grasses) listed in this table show where species are grouped for the ecological groupings analyses.
Comments on identification: 1 = species certain, 2 = educated guess, 3 = Genus certain, 4 = family certain, 5 = order certain 6 = unknown, but only one species present.

Additional plant species added in 1992

Indentification	Comment on identification
Trees	
No new species	
Shrubs	
Symphoricarpos longiflorus - Long flowered snowberry	1
Guttierizzia sarothrae - Snake weed	1
Herbs	
Senecio multilobatus - Butterweed	1
Mirabilis multiflora - Long flowered 4 o'clock	1
Linum aristatum - Yellow flax	1
Helianthella microcephala	1
Lomatium parryi - Parry biscut root	1

Chenopodium album	1
Astragalus mollissimus - Locoweed	1
Townsendia annua - Townsendia	1
Tragopogon dubius	1
Cryptantha flava	1
Smilicina stellata	1
Pachystima myrinites	1
Leptodactylon pungens - Prickly gilia	1
Sisymbrium altissimum	1
Machaeranthera grindelioides	1
Galium multiflorum - Bedstraw	1
Hymenoxys acaulis - Stemless bitterweed	1
Swertia albomarginata	1
Artemisia ludoviciana - Louisiana wormwood	1
Solidago sparsiflora - Goldenrod	1
Penstemon cyanocaulis	1
Lesquerella rectipes	1
Aster chilensis	1
Grasses	
Poa fendleriana	1
Elymus trachycaulum	1
E. smithii	1
Calamagrostis scopulorum	1
Agropyron cristatum	1
Bromus inermis	1
Plantain - unkown basal rossette, likely a mustard	6

Comments on identification key
1 = species identification certain, 6 = unknown

Aquatic Animals

Identification	Proportion of pools occupied area with no trail	area with trail
Notonectidae - back swimmers	0.275	0.231
Gyrinidae - whirligig beetle	0.250	0.103
Gerridae - water striders	0.900	0.641
Nematomorpha - horse hair worms	0.150	0.359
Coleoptera (Hydrophilidae?) - Hydrophilids	0.125	0.128
Dyticidae - dyticid beetles	0.050	0.051
Tricoptera - caddisfly larvae	0.500	0.179
Culicidae - mosquitoe larvae	0.200	0.282
Coleoptera ? - large headed worm	0.025	0.000
Anisoptera - dragonfly larvae	0.025	0.000
Corixidae - water boatman	0.050	0.051
Chironomidae - midges	0.075	0.205
Amphipoda - amphipods (scuds)	0.475	0.410
Bufo tadpoles - toad tadpoles	0.450	0.385
Ambystoma tigrinum - tiger salamander	0.025	0.000
Hyla arenicolor - canyon tree frog	0.050	0.000
Rana sp (pipiens ?)	0.000	0.026

notes:
Bufo tadpoles are mainly Woodhouse's toad tadpoles but include some Red spotted toad tadpoles, indentifying these to species requires a lot of handling and it commonly leads to death of the tadpole, we left the identification at the level of genera.
Rana sp belongs to the R. pipiens group, to determine which species it is would probably require an electrophoretic analysis.

All indentifications represent individual species (except possibly the chironomids) even though we have only labeled the taxa to family or higher grouping.

Birds

Identification	area lacking trail	area with trail
Pipilo erythrophthalmus - rufus-sided towhee	present	present
Zonotrichia leucophrys - white-crowned sparrow	present	absent
Falco sparverius - kestral	present	absent
Aeronautes saxatalis - white-throated swift	present	present
Tachycincta thalassina - violet-green swallow	present	absent
Selasphorus platycercus - broad-tailed hummingbird	present	present
S. rufus - rufus hummingbird	present	absent
Trochilidae - hummingbird	absent	present
Corvus corax - raven	present	present
Aphelocoma coerulescens - scrub jay	present	present
Parus atricapillus - black-capped chickadee	present	absent
Psaltriparus minimus - common bushtit	absent	present

notes:
All species were identified to the taxon listed in this table.

Small Mammals

Identification	Comments on identification
Peromyscus maniculatus - Deer mouse	1
P. boylii - Brush mouse	1
P. crinitus - Canyon mouse	1
P. truei - Pinon mouse	1
Neotoma albigula - White throated woodrat	1
N. lepida - Desert woodrat	2
N. cinerea - Bushy tailed woodrat	1
Mus musculus - House mouse	1
Microtus - Vole	4
Perognathus parvus - Great Basin Pocket mouse	1

Comments on Identification key
1 = species certain, 2 = genus certain (but may be N. albigula), 4 = Family certain,