Technical Report No. 248

POPULATIONS AND TROPHIC STRUCTURE OF A DESERT GRASSLAND INVERTEBRATE COMMUNITY

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GRASSLAND BIOME

U.S. International Biological Program

April 1974

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ABSTRACT

Invertebrate populations and biomass were measured on the Jornada desert grassland study site, United States International Biological Program, Grassland Biome, over a period from July 1970 to October 1972. Samples were taken at approximately monthly intervals from both grazed and ungrazed treatments using randomly placed quick traps and a D-Vac vacuum insect collector.

During 1970 numbers and biomass generally followed parallel trends, although overall numbers and biomass for the season were greater on the grazed treatment. Numbers and biomass on both treatments declined gradually until July 1971, at which time increases correlated with the onset of growing season precipitation were noted. Rainfall was below normal during 1971, acting as a likely causative factor in the low numbers of insects captured during that season. Following a further decrease in the winter populations, numbers and biomass again showed general upward trends associated with growing season precipitation during 1972.

No discernible between-treatment differences in numbers or biomass were detected in 1971 or 1972 due to significant population fluctuations among treatments between sampling dates. Sampling error, incurred by the

chance sampling of larger but more sparsely distributed shrubs, was responsible for the large-scale number and biomass variations encountered between adjacent sampling dates.

In terms of numbers, herbivores made up the bulk of the community during the period of study. Homoptera (Cicadellidae) and Hemiptera (Lygaeidae) were the most prevalent representatives of the herbivore compartment. Blattidae and adult Tenebrionidae, captured when sampling yucca, occasionally caused the scavenger biomass to exceed that of the herbivores. Predators occurred in low numbers, represented primarily by the Araneida. Occasionally predator biomass exceeded herbivore biomass when larger specimens (Lycosa sp.) were sampled.

Supplementary sampling with the sweep net, pitfall trap, and light trap revealed that quick trap sampling was inefficient for some taxa. At least five invertebrate families which were taken by supplementary methods were entirely absent from quick trap samples.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Rex D. Pieper whose suggestions were well appreciated throughout the course of this study. The Grassland Biome Laboratory, Colorado State University, is acknowledged for financial support as well as data summarization and analysis which made this study possible.

Appreciation is extended to Mr. Martin Connaughton who collected data for this study during the initial 1970 field season, and to Mr. Larry Teuber who aided in field sampling and counting.

INTRODUCTION

The complex interactions of biotic and abiotic variables within an ecosystem have confounded even the most ambitious ecologist. Laudable efforts have been made to relate abiotic, driving variables to primary productivity, and aspects of community interactions and population dynamics have been examined as well. The attempted modelling of an ecosystem, however, requires multidisciplinary involvement with the participation of numerous scientists and investigators. It is this realization that spurred the development of the International Biological Program (IBP).

This study was conducted as a part of the United States' participation in the IBP Grassland Biome. The overall objective of the IBP is to study organic production on a worldwide basis in order to acquire the necessary information for the development and testing of ecological theory (Van Dyne 1971). More precisely, the aim is toward a greater understanding of ecosystems, including energy flow, nutrient cycling, biotic, and abiotic variables as they affect the system.

In order to accomplish these goals, a network of Grassland Biome study sites was established extending across a spectrum of grassland types. The site chosen

for intensive study was the Pawnee, located in northern Colorado; several other sites were chosen as representatives of varying grassland types. The Jornada site, near Las Cruces, New Mexico, was designated as a representative desert grassland in the Biome Comprehensive Network.

Rangeland is an important constituent of our ecosystem. It provides valuable forage for domestic stock and supports considerable wildlife, including various game species. Consequently, in the desert grassland, as well as within any other grassland, one of the major man-imposed problems is overgrazing. A basic question, then, is how much do insects contribute to this herbivory. Smith (1940) reported that in an overgrazed mixed-grass prairie in Oklahoma, insect populations were as much as four times greater than the norm. Likewise, Hayes (1927) and Crawford and Harwood (1964) indicated the effects of overgrazing and burning of grasslands on insect populations. Invertebrate populations were consistently higher on overgrazed plots, while populations of false chinch bugs were drastically reduced in burned pastures.

The necessity of understanding the biology of insects associated with grasslands was noted by Hanson and Vorhies (1938). They pointed out that many insect

pests are native species whose behavior, life histories, and interrelationships with the environment must be known before efficient control measures can be applied. The grasshopper is probably the only insect herbivore for which sufficient information on life history and ecology is available to judge its impact on grassland (Blocker 1969), although conflicting reports on species and food preferences have made the task difficult even for this group (Mulkern et al. 1964).

While the grasshopper is a chewing insect which has been observed, during outbreak periods, to contribute to the reduction of primary productivity in grasslands, it has been noted that some herbivorous insects may actually serve to stimulate production (McDaniel 1971). Some of the sucking insects, for example, may accelerate and prolong the synthesis of starches in a plant due to their feeding activity.

The ability to judge the impact of the insect community on grasslands is of obvious importance. How much influence does the community exert on the reduction of primary productivity? Do latent populations of potentially harmful pests exist now, and could they reach epidemic level? Answers to these questions as well as others are prerequisites to the implementation of more effective range management policies. Hence, the need

for more concentrated research on the invertebrate grassland community is apparent.

The objectives of this study were 1) the measurement of aboveground invertebrate populations and biomass on an intraseasonal (and interseasonal) basis; 2) the delineation of trophic levels for major taxa; 3) the discovery of potentially important plant-insect associations, and 4) an evaluation of the selected sampling method. Ideally, the results of this study should yield a better understanding of the invertebrate community in a desert grassland and point toward areas in which future research is necessary.

LITERATURE REVIEW

Invertebrates Associated With Grasslands

A plethora of literature exists on the role of various invertebrates in grasslands. The grasshoppers and other orthopterans have probably received the most attention because of their potentially destructive capabilities (Isely 1938, Anderson 1961, Nerney 1960), yet there is abundant, although fragmentary, information on other economically important pests as well. Aside from the Orthoptera, the greatest attention probably has been directed at the following orders: Hymenoptera (mainly ants) (Race 1966, Cole 1932, Lavigne and Fisser 1966), Homoptera - Hemiptera (Blocker 1969, Blocker et al. 1972, Hayes 1927, Dietz and Harwood 1960), Coleoptera (Arnett 1968, Schwitzgebel and Wilbur 1942), and Lepidoptera (Borror and DeLong 1971, Walkden 1943, Ainslie 1930).

An attempt to discuss the pertinent literature on these as well as other important groups could readily consume an entire volume. For a more satisfactory overview, the reader is referred to Blocker (1969), Rivnay (1964), or Reed (1972).

Despite the abundance of literature on economically important insects, there is a paucity of syneco-

logical, community approaches to the study of insects in grasslands. Early works discussed faunal composition of grasslands (Hayes 1927, Smith 1940) but only in the past few years have advances been made in the understanding of community structure.

A recent example is the long-term study carried out by Evans and Murdoch (1968) on an old-field grassland in Michigan. Results of the study have yielded some insight to taxonomic composition, trophic structure and seasonal patterns of the community. Over a period of several years 1584 species of invertebrates representing 179 families and fifteen orders were collected. The dominant orders were the Hymenoptera, Diptera, Lepidoptera, and Coleoptera, to which 86 percent of the species belonged. Moderate success was achieved in classifying the food habits and seasonal occurrences of the dominant species.

In another approach to community analysis Van Hook (1971) used radioisotopes to measure energy and nutrient dynamics of invertebrates in an eastern Tennessee grassland. Initially, energy flow was monitored only as it passed from primary producers to a herbivore (grasshopper) and then to a secondary consumer (wolf spider). Population dynamics, energy budgets, and nutrient concentrations were measured and a model for compartmental energy flow and nutrient fluxes was constructed.

Comprehensive studies on grassland invertebrates in New Mexico are generally lacking. Massey and Pierce (1960) examined the effect of the leaf beetle, Trirhabada nitidicollis LeConte, on rabbitbrush, and Romney (1945) has measured populations of the beet leafhopper on Salsola kali and Lepidium alyssoides. Watts (1965) attributed the poor seed set of black grama (Bouteloua eriopoda) to the presence of large numbers of Chirothrips falsus Priesner in the seed heads. Larvae of these thrips are reported to feed on and destroy the developing caryopsis.

Watts (1963) provides some enlightening background information to a community study of invertebrates in New Mexico grasslands. Sampling black grama over a three-year period, he catalogued 120 species of insects representing 9 orders and 55 families. The Coleoptera contained the most species, but four species of Thysanoptera accounted for more than 50 percent of the total insect numbers. In contrast to Hayes' (1927) study of insects on the Kansas prairie, in New Mexico the Hemiptera were never abundant; however, certain Homoptera (e.g., mealybugs and leafhoppers) occasionally occurred in large numbers.

Sampling

To conduct a quantitative study of invertebrate populations through time requires reliable and consistent methods of measurement. Southwood (1966) has outlined many of the problems involved and reviewed some possible solutions, with particular reference to sampling.

Nonetheless, a great deal of discussion has been generated among insect ecologists as to what actually constitutes a sufficient sample for means of estimating populations. A fundamental problem has been the design or selection of an appropriate device which will yield suitable quantitative data (Southwood 1966, Morris 1960). Many such devices have been proposed, but field tests have often revealed their limited usefulness.

Assuming that a reliable device has been chosen, additional problems are encountered in the field when attempting to use the device. Many insects, such as the long-horned grasshoppers (Tettigoniidae), will elicit a flight response upon sensing vibrations caused by the footsteps of an investigator several meters away (Chauvin 1967). Other insects, like the Colza weevil, will drop to the ground at the slightest disturbance, thus avoiding capture in many cases (Chauvin 1967). Insect micromigrations to various strata of the plant

being sampled will also affect the catch and hence, its quantitative value (Lowrie 1971, Chauvin 1967).

Sweep Net. The sweep net has long been regarded as the entomologist's primary collecting tool and is perhaps best adapted to use in grasslands where a fairly uniform growth exists. It has been used repeatedly, despite its inherent shortcomings and biases (Turnbull and Nicholls 1966, DeLong 1932, Hughes 1955). Its primary value has been cited in autecological work (Chauvin 1967), yet numerous attempts have been made to justify using it as a quantitative tool.

DeLong (1932) discussed the effectiveness of the sweep net in measuring leafhopper populations. He noted that the proportion of nymphal stages represented in a sample was much lower than actually existed in the field. Sampling technique and weather conditions were listed as influencing factors in determining the comparative size of the population sample.

Gray and Treloar (1933) examined the usefulness of the sweep net in alfalfa. Their study was constructed in such a manner that the principal variable was the distribution of insects in the sampling area. In commenting on the net's limited value, they pointed out that from 124 to 1079 collections of 25 sweeps each would be necessary to reduce sampling error to the 10 percent level.

Beall (1935) estimated the number of sweep strokes required to measure populations of Lygus pratensis L. in alfalfa. He calculated that from 6 to 9 strokes of 100 inches would represent the population present on 1 m^2 of vegetation. In accord with other investigators he found considerable variation in numbers between sweeps. Menhinick (1963) conducted a similar study and found that 2.3 to 10.8 sweeps were required to estimate populations on a 1 m^2 basis, depending on species and weather conditions.

A later work calculated the number of sweeps required for specific taxa (Menhinick 1967). It was stated that 17.5 sweeps were required to estimate the density of adult Tettigoniidae, Acrididae, Odonata, and butterflies. Other 1 m^2 sweep-stroke equivalents were 3.2 for Curculionidae and Lygaeidae, 4.5 for Formicidae, 2.7 for Asilidae, 7.7 for Membracidae, and 6.5 for other Homoptera.

The effect of weather on sweep net sampling has been considered by several investigators (Menhinick 1963, DeLong 1932). Hughes (1955) found that an increase in wind speed was associated with a reduction in the catch of Meromyza variegata Meigen. Lowrie (1971) obtained similar results when sampling spiders. Romney (1945)

found that populations of the beet leafhopper were underestimated during windy conditions and that higher temperatures resulted in a greater catch of both nymphs and adults. He indicated that corrections for these factors could give a reliable population estimate.

In discussing various types of sampling apparatus, Turnbull and Nicholls (1966) stated that the sweep net could be used for grasshoppers, Heteroptera, Hymenoptera and Diptera, but that large proportions of many groups were missed. Collembola and mites were considered the most poorly represented in their sample.

Despite the apparent shortcomings of sweep net sampling, the relative ease of sampling effort has resulted in its continued widespread use. Ruesink and Haynes (1973) recently devised a model for the estimation of populations of the cereal leaf beetle, Oulema melanopus (L.), based on sweep net catch. Crop height, wind speed, air temperature, and solar radiation were found to have a great effect on catch, and an index was generated relating these factors to absolute density. The index, based on a regression equation, was multiplied by the actual field catch to obtain an accurate population estimate.

Theoretically, this technique could be expanded to a variety of insect species by the construction of a

regression model for each species of interest, thus greatly enhancing the validity of sweep net sampling. The major difficulty would be the initial collection of data relating species response to the important environmental variables.

Pitfall Trap. Pitfall traps have been found valuable in the study of various surface dwelling organisms such as beetles, spiders, Collembola, and mites (Barber 1931, Doane 1961, Schmoller 1970, Meijer 1971). Their best application has been indicated in the study of daily activity patterns, seasonal incidence, and the dispersal of a single species in one type of vegetation (Southwood 1966).

Doane (1961) used the funnel pitfall to study the activity of adult Ctenicera aeripennis destructor (Brown) in a continuously cropped wheat field. Other organisms collected included Tettigoniidae, Acrididae, Formicidae, Carabidae, Silphidae, Curculionidae, and Arachnida.

Williams (1958) devised a pitfall which separated the catch into 6 activity periods during the day. Of the 17 taxa examined, only oribatid mites and parasitic Hymenoptera were underestimated. It was felt that the pitfall gave a good indication of seasonal abundance and qualitative differences among habitats.

Schmoller (1970) found that the pitfall was an adequate tool for monitoring life histories of Alpine tundra Arachnida, provided an adequate number of specimens were taken on each sample date. Meijer (1971) used a modification of the pitfall to measure immigration of arthropods into recently reclaimed marsh land. Over a four week period 17 species of carabids, 27 species of spiders, and numerous cicadas were collected.

Limitations of the pitfall trap have been cited by several investigators (Southwood 1966, Greenslade 1964, Mitchell 1963). Greenslade (1964) discussed its limited value in quantitative studies, although he felt it could still be used in mark-recapture studies. Mitchell (1963) found evidence of predation on Carabidae by birds and larger species within the trap; this problem could be overcome by placing a small amount of killing preservative in the bottom of each trap. The general habitat surrounding the trap, as well as the amount of moisture in the soil were listed as factors influencing its efficiency (Mitchell 1963).

Greenslade (1964) found that diurnal species were not as susceptible to capture as the nocturnal ones. In addition, it was found that both the level of the mouth of the trap and the amount of vegetation surrounding the trap affected the catch quantitatively and qualitatively.

Vacuum Collectors. A variety of vacuum collectors have been described, many with modifications for specialized use. The D-Vac (Dietrick 1961) is the most readily available and widely used.

Hills (1933) described a portable, electric-powered device which was used in conjunction with a counting cage to estimate populations of insects present on plants growing on one square foot of ground. The counting cage was mounted on a 4.5 foot long pitchfork handle and was forcibly placed over the area to be sampled. A sleeve on one side of the cage allowed the operator to introduce the suction hose with which the invertebrates were removed.

Kennard and Spencer (1955) discussed an electric suction apparatus which was used to sample insects in a mango orchard. Collections could be made as high as 20 feet, but versatility was limited because of the need for a 110 volt power supply. It was mentioned that thrips were sampled more accurately with this device than with the sweep net.

Dietrick et al. (1959) used a high-speed motor and fan to suck arthropods from one square foot areas in alfalfa. The organisms collected, along with some trash, were refrigerated until extraction could take place, thus preventing predation and general exhaustive activity.

A lightweight portable sampler with a gasoline engine was later described (Dietrick 1961). Used extensively for the study of beneficial insects on cotton, the collector was found most useful in sampling Trichogrammatidae and Mymaridae. It was felt that the vacuum collecting method gave a more complete and accurate estimate of the total insect population than earlier methods. A larger proportion of immature stages, small caterpillars, and eggs were found in these samples than in sweep net samples.

A hand-operated suction apparatus was described by Southwood and Pleasance (1962). A crank, which drove a fan through a gear box, could be turned fast enough to develop an air speed of 60 m.p.h. at the collecting nozzle. It was felt that the air speed of 60 m.p.h. was the minimum necessary to pick up representatives of all groups in a consistent manner (Southwood 1966).

Extraction rates of the vacuum collector are variable, but usually high. Johnson et al. (1957) obtained rates of 95-100 percent for Hemiptera, adult Diptera, adult Hymenoptera, and surface-dwelling Collembola. The lowest rates were obtained for larval Diptera and Coleoptera, varying from 70-75 percent. An extraction rate of 87 percent was obtained by Whittaker (1965) when sampling Auchenorrhyncha.

Turnbull and Nicholls (1966) reported various figures for the efficiency of a vacuum collector designed after Dietrick's model. In using modified Berlese funnels to extract above-ground arthropods, 96.2 percent were found to be removed by the collector. They reported that Araneida, Lepidoptera, adult Hemiptera, Thysanoptera and Orthoptera were picked up; 97.7 percent of the Acarina and 96.2 percent of the Collembola were sampled. The collector missed 12.1 percent of the Homoptera, 12.5 percent of the Hemiptera nymphs, 6.9 percent of the Coleoptera, and 10 percent of the Diptera larvae.

Sampling Cages. Numerous cages have been designed with the aim of sampling a specific area of herbage within the habitat. Beall (1935) used a metal cylinder which was forced into the ground, followed by the application of an anaesthetic. Insects were removed by hand. Hill's (1933) cage, mounted on the end of a pitchfork handle, was covered with cloth. The rim of the cage was constructed of steel which was ground to a sharp "knife edge", thus allowing it to easily sink into the soil. Both manual suction-pipette and battery-powered vacuum collectors were used to remove the insects.

Wiegert (1961) constructed an apparatus for sampling density of adult meadow spittlebugs and the device later proved applicable for use on other insects

which jump or fly in a manner similar to the spittlebug. The cage, constructed of a strap iron frame covered with cloth, was quickly placed over a plant. Masonite was slipped under the cage, and the insects were shaken into a collecting jar mounted on one end of the cage. Accuracy within one percent was measured for spittlebug populations.

Smalley (1960) used a 1 m^2 cage covered with a fine mesh screen to sample grasshoppers. The device was carried by two men who ran across the field, dropping the cage on signal. Captured insects were removed manually.

Smith and Stewart (1945) used a cage and trap combination to sample field populations of grasshoppers. The cage was thrown 10 to 15 feet, a tray slid under the cage, and the grasshoppers were counted by hand. The apparatus was less efficient over dense herbage than sparse cover.

Turnbull and Nicholls (1966) described a quick trap for area sampling of arthropods in grassland communities. The trap was set up 24 hours before the sampling was to occur in order to allow the fauna to become redistributed. Remote spring actuation was used to drop the trap from its suspended position to the ground. The arthropods thus trapped were confined in the sampling area until removal by vacuum collector was accomplished.

Turnbull and Nicholls found that the quick trap method demonstrated a high degree of efficiency for most groups sampled. More recently, however, doubts as to the trap's effectiveness have been raised by several authors. Blocker et al. (1971) noted that many taxa were able to escape capture by flying away before the trap was dropped or by crawling through the mesh screen before the D-Vac operation was completed. In addition, Lavigne and Kumar (1972) noted that many apparently common groups were completely missed or underestimated by the quick trap method of collection.

Extraction. The most commonly used behavioral method of extracting arthropods from soil or herbage is the Berlese funnel (Southwood 1966). A heated copper funnel was designed by the Italian entomologist, A. Berlese, in the early 1900's and subsequently modified by the Swedish entomologist, A. Tullgren, who used a light bulb as a heat source (Southwood 1966).

Haarlov (1947) made further modifications on the Berlese-Tullgren extractor and used it to extract mites and Collembola from soil cores. Sample extraction was more efficient if the formation of dew inside the funnel was prevented and if sudden changes of temperature did not occur. Best extraction efficiencies were demonstrated when the temperature in the funnel was raised

slowly, not exceeding the maximum encountered in the field.

Dietrick et al. (1959) used a Berlese funnel which was designed to overcome the deficiencies of earlier funnels that used a light bulb as a source of heat. A 75-watt glocoil was substituted for the heat source which was slowly brought up to maximum temperature over an 8-hour period. A 75-watt spotlight was placed below the collecting jar and turned on and off at 15-minute intervals to insure the extraction of positively phototropic organisms. Sample extraction was very efficient for most taxa, provided that trash in the sample was kept to a minimum and dispersed enough to allow penetration of light from below.

A Berlese-Tullgren funnel was described by Dondale et al. (1971) which efficiently extracted grassland arthropods from coarse plant matter. A 600-watt heating element served as the heat source, and ventilating screens were installed to prevent the condensation of moisture within the funnel.

Summary of Sampling. A variety of sampling and extraction techniques have been discussed. In considering the best method to use in an ecological study in which area sampling of all taxa is the prime consideration, several factors are of importance. First, the technique

should be unbiased. All groups should be sampled with the same degree of efficiency, ideally 100 percent. Secondly, the element of time should be considered. A particular method of sampling should not be so involved that the investigator becomes overburdened with minute procedural details. Ideally, the method should be relatively quick, yet accurate.

Neither the sweep net nor the pitfall trap satisfy all of these conditions. Methodologically, they are easy to implement, but the inherent biases of both methods are legend. The quick trap and D-Vac are efficient and possibly less biased than other methods, but a greater amount of time is consumed in sampling. The Berlese funnel, likewise, is an efficient sample extractor when used with care in a consistent manner. Thus, the quick trap, D-Vac, and Berlese funnel extractors are perhaps the best tools to use in a study of this nature. Use of these methods minimizes experimenter-induced error; when used across network sites, the element of consistency is present, and data becomes comparable. A joint effort among Biome scientists came to this conclusion at the inception of the program in 1969 and 1970. Their results and suggested procedures are summarized in French (1971) and Swift and French (1972).

MATERIALS AND METHODS

The Study Area

The study area is located on the Jornada Experimental Range, a tract which was set aside for rangeland research in 1912 by Presidential proclamation. The U.S. Forest Service administered the land from 1915 to 1953 at which time control was transferred to the Agricultural Research Service (ARS). The Range consists of 105,700 acres under direct control of the ARS and an additional 85,000 acres under lease to the White Sands Missile Range (Herbel and Pieper 1970).

Specifically, the study area is located in Section 4, Range 1 East, Tonwship 20 South, at an elevation of 1350 m. Mean annual precipitation, measured at the Jornada headquarters, is 22.85 cm for a 57-year period. More than 50 percent of the total occurs between July 1 and September 30, but great fluctuations are observed among years and seasons within years (Appendix I). June is the hottest month, maximum temperatures averaging 36°C, and January is the coldest month with a mean low of 13°C (Herbel and Pieper 1970).

The main soil type on the study site is a Simona-Palma complex. Buffington and Herbel (1965) described the soil as a fine, loamy sand, calcareous to very near

the surface, and underlain with fractured, indurated caliche at depths of 25 to 60 cm. Caliche gravels and fragments have been mixed throughout the soil profile by rodents in most areas.

The experimental design consisted of both an ungrazed and a grazed plot. The ungrazed plot was a 10 ha fenced enclosure, while the grazed area consisted of the adjacent pasture. A fence was placed around the grazed study area and moved each year prior to the beginning of the growing season. Thus, the grazed area was actually a "grazed previous year, ungrazed current year" situation.

Bouteloua eriopoda (black grama) and Sporobolus spp. (dropseed) comprise the most important grass species on the plots. Forbs are represented primarily by Salsola kali (Russian thistle), while the most important shrubs include Yucca elata (yucca), Prosopis juliflora (mesquite), and Gutierrezia sarothrae (snakeweed). Table 1 gives a list of plant species recorded to date at the Jornada site.

Vegetational cover may vary greatly between seasons depending on precipitation. Perennial shrubs normally constitute a large portion of the overall plant biomass, while early spring precipitation may have a decided effect on the presence of forbs and annual grasses. Likewise, limited growing season rainfall has

Table 1. List of plant species recorded at the Jornada site and species symbols used for purposes of data logging.[a]

Grasses	
Aristida adscensionis	Arad
Aristida longiseta	Arlo
Bouteloua aristidoides	Boar
Bouteloua barbata	Boba
Bouteloua eriopoda	Boer
Enneapogon desvauxii	Ende
Erioneuron pulchellum	Erpu
Muhlenbergia porteri	Mupo
Panicum hirticaule	Pahi
Setaria macrostachya	Sema
Sporobolus airoides	Spai
Sporobolus contractus	Spco
Sporobolus flexuosus	Spfl
Tridens pulchellus	Trpu
Forbs	
Allionia incarnata	Alin
Aster leucelene	Asle
Amaranthus blitoides	Ambl
Amaranthus retroflexus	Amre
Aphanostephus ramosissimus	Apra
Applopappus gracilis	Apgr
Applopappus spinulosus	Apsp
Asclepias galioides	Asga
Astragalus allochrous	Asal
Astragalus nuttallianus	Asnu
Bahia absinthifolia	Baab
Baileya multiradiata	Bamu
Boerhaavia torreyana	Boto
Cassia bauhinoides	Caba
Chamaesaracha coronopus	Chco
Chenopodium incanum	Chin
Circium ochrocentrum	Cioc
Corispermum nitidum	Coni
Croton corymbulosus	Crco
Cryptantha circumsissium	Crci

Table 1, continued

Forbs	
Cryptantha crassisepala	Crcr
Cucurbita foetidissima	Cufo
Dalea nana	Dana
Dithraea wislizeni	Diwi
Dyssodia papposa	Dypa
Eriogonum abertianum	Erab
Eriogonum annum	Eran
Eriogonum rotundifolium	Erro
Erigonum trichopodum	Ertr
Euphorbia albomarginata	Eual
Euphorbia parryi	Eupa
Evolvulus pilosus	Evpi
Franseria acanthicarpa	Frac
Gaillardia pinnatifida	Gapi
Gutierrezia sphaerocephala	Gusp
Helianthus canus	Heca
Hoffmannseggia densiflora	Hode
Hoffmannseggia jamesi	Hoja
Hymenopappus robustus	Hyro
Kallstroemia hirsutissima	Kahi
Lepidium eastwoodiae	Leea
Lesquerella fendleri	Lefe
Linum australe	Liau
Melapodium leucanthum	Mele
Mentzelia albicaulis	Meal
Nama hispidum	Nahi
Oenothera runcinata	Oeru
Othake sphacclatum	Otsp
Pectis papposa	Pepa
Perezia nana	Pena
Petalostemum compactum	Peco
Phacelia intermedia	Phin
Plantago purshi	Plpu
Portulacta oleracea	Pool
Portulacta pilosa	Popi
Proboscidia jussieui	Prju
Psitostrophe tagentinae	Psta
Salsola kali	Saka

Table 1, continued

Forbs	
Selinocarpus chenopodioides	Sech
Senecio longilobus	Selo
Solanum elaeagnifolium	Soel
Sphaeralcea coccinea	Spco
Sphaeralcea subhastata	Spsu
Stephanomeria pauciflora	Stpa
Talinum angustissimum	Taan
Tidestromia lanuginosa	Tila
Tribulus terrestris	Trte
Zinnia grandiflora	Zigr
Shrubs	
Ephedra trifurca	Eptr
Gutierrezia sarothrae	Gusa
Krameria secundiflora	Krse
Opuntia engelmanni	Open
Prosopis juliflora	Prju
Yucca elata	Yuel

[a]Data provided by Dr. Rex D. Pieper, New Mexico State University, Department of Range Science.

been observed to retard or greatly reduce the production of perennial grasses. Under unfavorably hot and dry growing seasons, bare ground has been observed to constitute more than 70 percent of the surface area of the study site (R. D. Pieper, unpublished data).

Sampling

Collections were made over a period beginning July 14, 1970 and extending to October 29, 1972. Samples were taken at approximately monthly intervals, except during the growing season when they were taken every 10 to 14 days. Sampling dates were designed to correspond as closely as possible with the activities of other investigators gathering data on primary productivity.

Collecting traps modified after the Turnbull-Nicholls apparatus were used for area sampling of arthropods. The design of the quick trap allowed removal of all above-ground invertebrates in a .5 m^2 area with a high degree of efficiency. Placement of the traps was predetermined by an APL random number generating computer program.

Two replicates in both the grazed and ungrazed treatments were used. Primary productivity investigators generated a series of random numbers which corresponded to distance in feet across the width of the plot. Numbered stakes were placed in locations given by the

random number generator, some of which were designated as invertebrate sampling points. Plant species composition and biomass estimates for a .5 m^2 area were made at these points 24 to 48 hours prior to invertebrate sampling. This enabled plant-insect correlations to be made at a later time. Generally, five quick trap collections were made per replicate, although the number was increased to ten per replicate from September 1971 to January 1972 in an attempt to reduce sampling error.

Construction of Traps

Quick traps were constructed of a strap iron frame having a diameter of .8 m and circumference of approximately 2.5 m. Height of the traps was 60 cm (Figure 1). The cages were originally covered with a 16-mesh hardware cloth but later modified by covering with a 32-mesh Lumite® fabric obtained from Chicopee Manufacturing Company, Cornelia, Georgia. It was felt that the finer mesh fabric would prevent the escape of minute insects such as the Chalcidoidea which may otherwise have avoided capture. A cloth entry sleeve, 18 cm in diameter, located at the top of the trap allowed introduction of grass clippers and the D-Vac hose for sample removal.

A tripod standing 2 m tall was used as a support for the trap. A 10 m long nylon rope attached to the top-center of the trap served as the release mechanism.

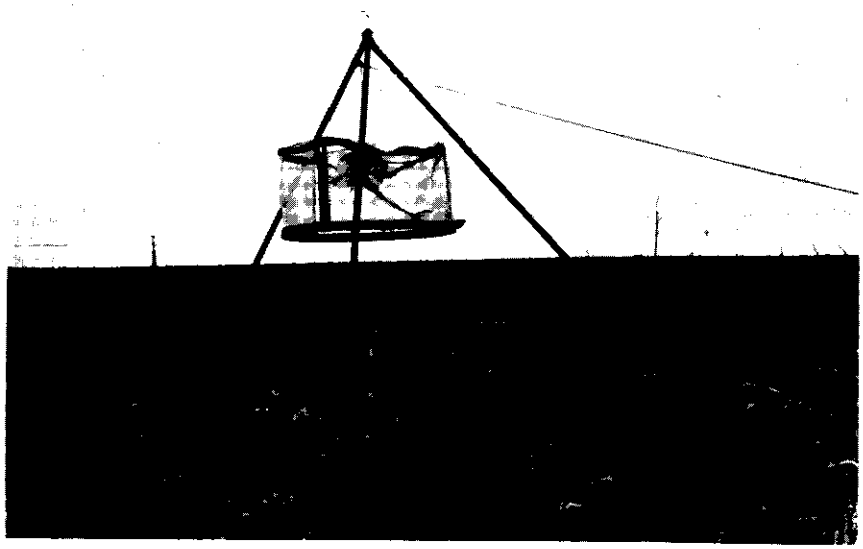

Figure 1. Quick trap apparatus showing tripod, release rope and suspended trap.

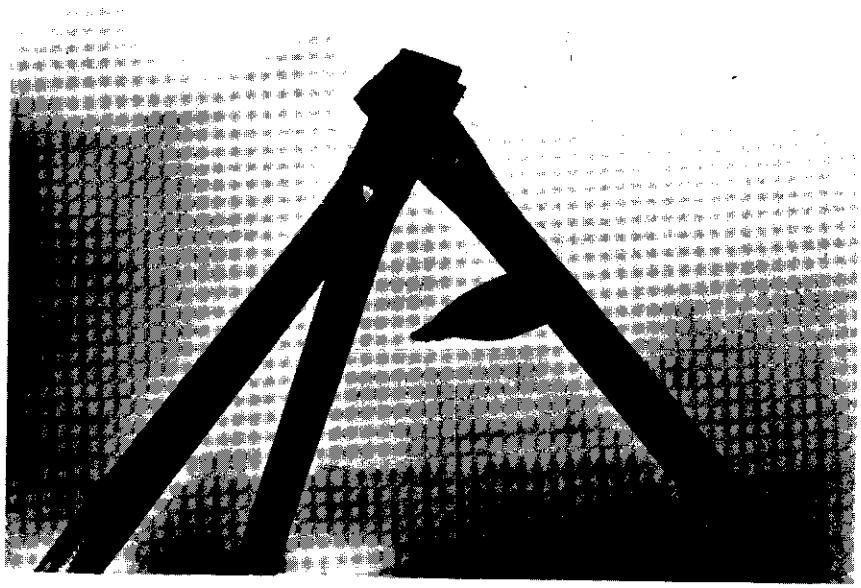

Figure 2. Closeup of apex of tripod from which quick trap was suspended. When the rope was inserted into the forked structure welded to one leg of the tripod, the trap could be suspended and released when desired.

The rope was knotted, the knot being inserted into a fork-like structure projecting from one leg of the tripod and serving as the suspension mechanism (Figure 2). The remaining length of rope was stretched away from the trap and tied to a nearby stake, thus allowing relatively quick, remote actuation (Figure 1).

All traps were set in this manner on the day preceding sampling. The intervening 18-24-hour period between the setting of the traps and the sampling process allowed any disturbed fauna to become redistributed over the sampling area.

Sample Removal: D-Vac

Sample removal was accomplished by the use of a modified D-Vac vacuum insect collector, supplied by the D-Vac Company, Riverside, California. Following the first field season of use, the two-cycle Tecumseh engine was replaced with a four-cycle Briggs and Stratton lawn mower engine. The newer engine added additional weight to the sampler, but proved invaluable in its greater dependability.

To compensate for the added weight of the four-cycle engine, a carrying frame was constructed on which the D-Vac was strapped. Two investigators could then easily transport the D-Vac along with all necessary sampling paraphernalia.

tin reducing cone to the 34 cm fiberglass collecting cylinder. An automobile heater hose, 10 cm wide and 2 m long, was attached to the small end of the reducing cone (Figure 3). The distal end of the hose was reinforced with duct tape to provide rigidity when suctioning arthropods from dense root crowns. Primary advantages of the smaller hose included increased wind velocity and hence, increased suction power.

Sampling took place between 10 a.m. and 4 p.m. on all occasions. Quick traps in close proximity (15 m or less) were released simultaneously before the D-Vac engine was started. After a trap had been dropped, hand-powered grass clippers were introduced through the entry sleeve, and all vegetation was clipped to within 1 cm of the soil surface. If little vegetation was present, it was simply placed in the D-Vac bag in which the sample would be collected; otherwise, the clipped material was put in paper sacks and saved for extraction. This clipping procedure was not performed during the first field season.

After clipping, the D-Vac engine was started and the nylon collecting bag was inserted and attached to the fiberglass collecting chamber. The reducing cone was placed over the collecting chamber and the operator

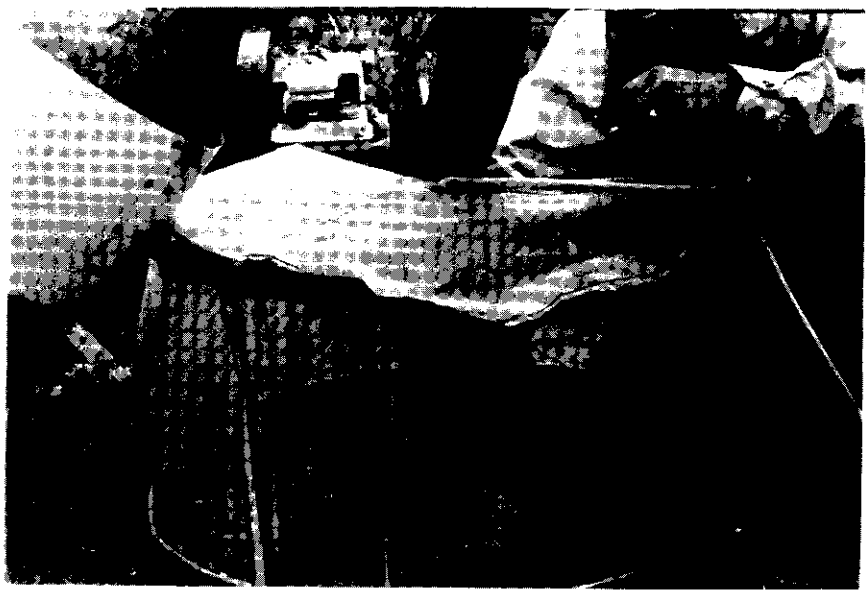

Figure 3. D-Vac apparatus in operation showing collecting hose, tin reducing cone and fiberglass collecting chamber.

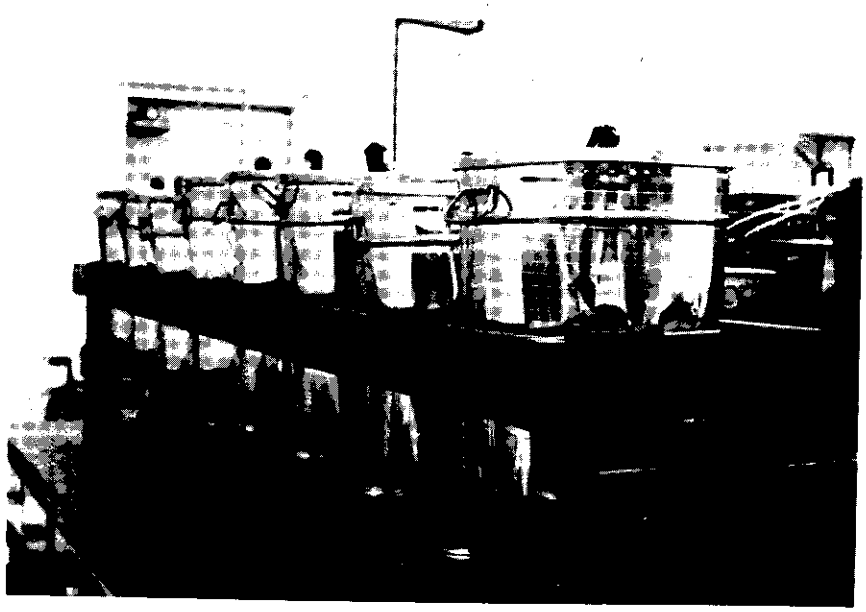

Figure 4. Berlese funnel bank. Twenty such funnels were constructed permitting simultaneous extraction of all samples.

introduced the hose into the quick trap. The end of the hose was moved from side to side in the trap at 1-2 cm above the soil surface. Root crowns were scoured gently but thoroughly to dislodge any animals that might be clinging to the remaining vegetation. After the soil surface had been vacuumed completely, the sides and top of the cage were suctioned to remove flying insects. The entire D-Vac process took between three and five minutes, depending on the amount of residual plant matter in the trap.

To prevent the escape of flying insects, the engine was kept running as the reducer cone was removed. A tag indicating sample date, treatment, replicate, and quadrat number was placed in the bag with the sample. The D-Vac bag was then removed from the collecting chamber, knotted, and placed in a plastic container which was then transferred to a large Thermos ice chest. A 6 cm layer of cubed ice at the bottom of the chest had sufficient cooling capacity to immobolize the sampled arthropods (preventing predation) until extraction could take place.

Sample Processing

Samples were returned to the laboratory in Las Cruces and extracted in modified Berlese funnels. The Berlese funnels were constructed from 30 lb. lard cans, 40 cm tall and 32 cm in diameter (Figure 4). A hole was

cut in the center of the cover to accommodate a light fixture and a 75-watt bulb. The bottom of the can was removed and a tin reducing cone was soldered in its place. To the small end of the reducer cone a Mason jar lid was soldered, thus enabling easy change out of collecting jars.

A large mesh screen mounted inside the funnel at the joint of the reducing cone served as the sample support. A circular cardboard baffle, 16 cm in diameter, rested on top of the supporting screen (Figure 5). The sample was poured onto this baffle to minimize the accumulation of loose sand in the collecting jar. Sufficient open area remained for invertebrates to crawl away from the baffle and fall through the screen, into the collecting jar below.

Twenty such funnels were constructed, permitting simultaneous extraction of invertebrates from all quadrats sampled.

Extraction time was 48 hours; invertebrates were collected in pint Mason jars containing 70 percent ethanol. Following extraction, the vegetation from each sample was hand sorted for any macroscopic invertebrates that had not made their way to the collecting jar. Organisms found in this manner were added to the Berlese sample and treated as part of the total count.

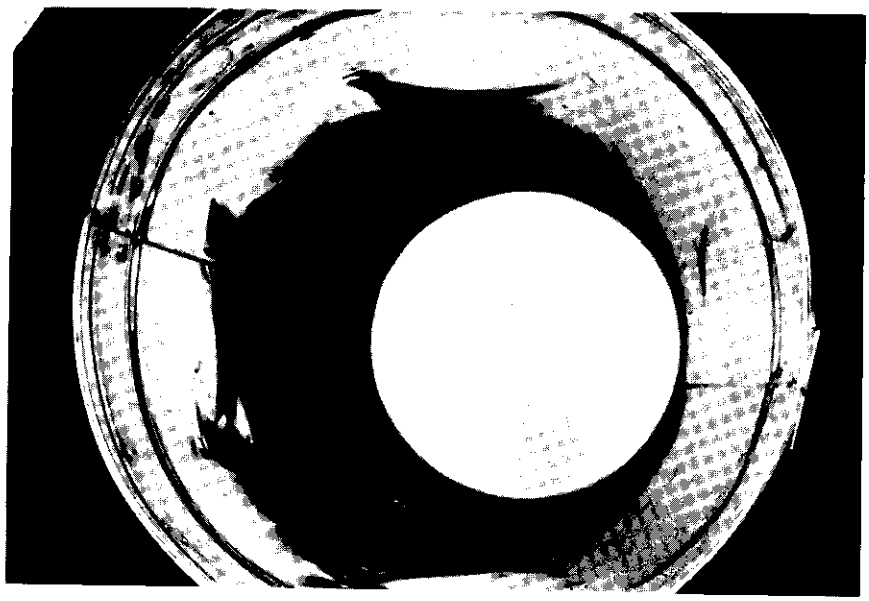

Figure 5. Interior view of a Berlese funnel showing cardboard sample baffle and retaining screen.

Each sample was examined under a Bausch and Lomb binocular dissecting microscope at 10x. Insects were identified to family, counted, and separated. Taxa were placed in separate vials containing 70 percent ethanol.

The arthropods were later dried at 60°C for 48 hours and weighed on a Cahn Gram Electrobalance.® All weights were recorded to the nearest ten-thousandth of a gram.

Supplementary Sampling

In addition to quick trap samples, which were used primarily for population estimates, several other sampling techniques were employed as efficiency checks. Sweep net sampling, carried out intermittently during the growing season, provided specimens which were pinned and placed in Cornell trays to make up a representative collection of the area. Many of the pinned specimens were sent to specialists for species determinations.

A transect of 25 pitfall traps was placed in the ungrazed treatment in the spring of 1971 and 1972. Each trap had a mouth opening of 8 cm and was placed 1.5 m from the next closest trap. Water containing a fungicide was used as a preservative, and a small amount of kerosene was poured on top of the water to retard evaporation. Samples were collected at approximately weekly intervals. On return to the lab, the pitfall catches were separated by family and preserved in KAAD.

Nocturnal activity was monitored on eight occasions with various types of light traps. Initially, a Coleman lantern was suspended from a quick trap tripod and the D-Vac collecting cylinder placed immediately below the light source. The D-Vac was turned on and sample bags changed out at fifteen minute intervals. This procedure yielded a large catch, but many insects were badly damaged. Later attempts utilized the Coleman lantern as a light source, and insects were captured by hand as they landed on a white linen sheet, suspended vertically near the lantern.

RESULTS AND DISCUSSION

A total of 118 families representing 19 invertebrate orders were collected between July 1970 and October 1972. Most of these arthropods were collected by means of the quick trap and D-Vac; however, some taxa were taken by other methods (Table 2). Specialists have further determined a number of genera and species of prominent taxa (Table 3).

Quick trap samples were utilized for the estimation of populations, biomass, and trophic structure, while other sampling methods were used as checks on the general efficiency of the quick trap. Data pertaining to community trophic structure is presented for the 1972 field season only. A lack of, as well as confusing, information on some taxa and problems in specimen identification curtailed satisfactory trophic delineation in the early part of this study.

Insect populations were generally lower than those measured at other grassland sites. Data for the Osage site during 1971 showed a peak density of 4410 insects/m^2 (Reed 1972), approximately 40 times greater than the peak density recorded at the Jornada. Similarly, insects at the Pantex site during 1970 peaked at 750/m^2 (Huddleston et al. 1972), 7.5 times greater than the Jornada peak for the same year.

Table 2. List of orders and families collected at the Jornada site from 1970 to 1972.

Order	Family	Trophic Level[a]	Method of Collection[b]
Thysanura	Lepismatidae	SC	
Collembola	Entomobryidae	HB or SC	
	Poduridae	HB or SC	
	Sminthuridae	SC	
Thysanoptera	Phloeothripidae	HB or PR	
	Thripidae	HB	
Neuroptera	Chrysopidae	PR	
	Myrmeleontidae	PR	
Isoptera	Termitidae	OM or SC	
Orthoptera	Acrididae	HB	
	Blattidae	SC	
	Gryllacrididae	HB or OM	P
	Gryllidae	HB or OM	
	Mantidae	PR	H
	Phasmidae	HB	H
	Tettigoniidae	HB	H
Homoptera	Aphididae	HB	
	Cercopidae	HB	
	Cicadellidae	HB	
	Cicadidae	HB	
	Cixidae	HB	
	Coccidae	HB	
	Fulgoridae	HB	
	Membracidae	HB	
	Psyllidae	HB	
Hemiptera	Coreidae	HB or PR	
	Corimelaenidae	OM	H
	Corizidae	HB	
	Cydnidae	OM	H
	Lygaeidae	HB or PR	
	Miridae	HB	
	Nabidae	PR	
	Pentatomidae	HB	

Table 2, continued

Order	Family	Trophic Level[a]	Method of Collection[b]
	Phymatidae	PR	
	Reduviidae	PR	
	Tingidae	HB	
Coleoptera	Bostrichidae	HB	H
	Bruchidae	HB	
	Buprestidae	HB	H
	Cantharidae	HB	
	Carabidae	PR	P
	Cebrionidae	U	L
	Cerambycidae	HB	H
	Chrysomelidae	HB	
	Cicindelidae	PR	L
	Cleridae	PR	H
	Coccinellidae	PR	
	Curculionidae	HB	
	Elateridae	HB	P
	Erotylidae	SC	H
	Histeridae	PR	P
	Meloidae	PR;HB	
	Mordellidae	SC or PR	
	Nitidulidae	HB or SC	
	Phalacridae	HB	
	Pselaphidae	SC	
	Scarabaeidae	HB or SC	P
	Silphidae	SC	P
	Tenebrionidae	HB or SC	
	Trogidae	SC	P
Diptera	Anthomyidae	OM	
	Asilidae	PR	
	Bombyliidae	HB	
	Calliphoridae	SC	
	Chloropidae	OM	
	Muscidae	OM	
	Mycetophilidae	HB or SC	
	Pipunculidae	PA	
	Sarcophagidae	PA or SC	
	Sciaridae	HB or SC	
	Syrphidae	OM	
	Tachinidae	PA	

Table 2, continued

Order	Family	Trophic Level[a]	Method of Collection[b]
Lepidoptera	Arctiidae	HB	H
	Geometridae	HB	
	Lycaenidae	HB	H
	Noctuidae	HB	
	Nymphalidae	HB	H
	Pieridae	HB	H
	Pyralidae	HB	
	Pyromorphidae	HB	H
	Sphingidae	HB	
	Tortricidae	HB	
Hymenoptera	Andrenidae	HB	
	Apidae	HB	
	Braconidae	PA	
	Ceraphronidae	PA	
	Chalcididae	PA	
	Chrysididae	PA	P
	Cynipidae	PA	
	Encyrtidae	PA	
	Euchartidae	PA	
	Eulophidae	PA	
	Eurytomidae	HB or PA	
	Formicidae	OM	
	Ichneumonidae	PA	
	Mutillidae	PA	P
	Pompilidae	PA	
	Sphecidae	PR	
	Tiphiidae	PA	L
	Vespidae	PR	
	Xylocopidae	HB	H
Acarina	Caeculidae	HB	
	Oribatidae	HB	
	Tetranychidae	PA	
	Trombidiidae	HB	H
Araneida	Agelenidae	PR	
	Argiopidae	PR	
	Dictynidae	PR	
	Gnaphosidae	PR	
	Linyphiidae	PR	
	Lycosidae	PR	
	Salticidae	PR	

Table 2, continued

Order	Family	Trophic Level[a]	Method of Collection[b]
	Theraphosidae	PR	H
	Theridiidae	PR	
	Thomisidae	PR	
Phalangida	Phalangiidae	OM	
Chelonethida	Chermetidae	PR	
Solpugida		PR	P
Scorpionida	Buthidae	PR	P
Scolopendromorpha		PR	
Class Diplopoda		HB	P

[a]Taken from observations as well as literature. U=Unknown; HB=Herbivore; PR=Predator; PA=Parasite or Parasitoid; OM=Omnivore; SC=Scavenger. A trophic level such as HB;PR refers to feeding habits of the immature and adult.

[b]Most specimens were regularly collected by quick-trap. Otherwise, P=pitfall; L=light trap; H=by hand (e.g., sweep net).

Table 3. List of species identified to date from various collecting procedures at the Jornada site, 1970 to 1972.

TAXON

Order Thysanoptera
- Family Phloeothripidae
  - *Haplothrips halophilus* Hood
- Family Thripidae
  - *Chirothrips simplex* Hood

Order Hemiptera
- Family Lygaeidae
  - *Lygaeus kalmii kalmii* Stal
- Family Miridae
  - *Lygus* sp.
- Family Pentatomidae
  - *Chlorochroa sayi* Stal
  - *Chlorochroa ligata* Stal
- Family Tingidae
  - *Gargaphia opacula* Uhler
  - *Corythucha morilli* Osborn & Drake
  - *Corythaica venusta* (Champion)

Order Homoptera
- Family Cicadellidae
  - *Cuerna arida* Oman & Beamer
  - *Aceratagallia uhleri* (Van Duzee)
  - *Deltocephalus* sp.

Order Neuroptera
- Family Myrmeleontidae
  - *Brachynemerus peregrinus* (Hag.)

Order Coleoptera
- Family Bostrichidae
  - *Amphicerus cornutus* (Pallas)
- Family Carabidae
  - *Calosoma peregrinator* Guerin-Meneville
  - *Euryderus grossus* Say

Table 3, continued

Family Cebrionidae
Selonodon sp.
Family Cerambycidae
Ergates sp.
Family Chrysomelidae
Gratiana pallidula (Boheman)
Family Cicindelidae
Cicindela cuprascens LeConte
Cicindela limniscata LeConte
Family Coccinellidae
Hippodamia convergens Guerin-Meneville
Family Curculionidae
Ophryastes tuberosus LeConte
Sapotes longipilosus Van Dyke
Smicronyx profusus Casey
Sibinia setosus LeConte
Epimechus gracilis Fall
Family Elateridae
Neotrichophorus arizonensis (Schaeffer)
Hemicrepidius carbonatus LeConte
Lanelater schotti (LeConte)
Family Erotylidae
Cypherotylus californicus Lacordaire
Family Histeridae
Saprinus discoidalis LeConte
Family Meloidae
Megetra cancellata (Brandt & Erichson)
Pyrota akhurstiana Horn
Pyrota palpalis Champion
Cystodemus wislizeni LeConte
Negalius marmoratus Casey
Family Scarabaeidae
Canthon imitator Brown
Canthon ebenus (Say)
Canthon puncticollis LeConte
Diplotaxis sp.

Table 3, continued

Rhombonalia cavifrons (LeConte)
Bothynus gibbosus (DeGreen)
Family Tenebrionidae
Eleodes gracilis LeConte
Eleodes carbonaria (Say)
Glyptasida sp.
Eleodes hispilabris (Say)
Eleodes extricata (Say)
Eusattus subvelutinus Casey
Family Trogidae
Trox nodosus Robinson
Order Lepidoptera
Family Nymphalidae
Speyeria sp.
Family Pieridae
Pieris rapae (L.)
Family Sphingidae
Clerio lineata (Fabricius)
Order Diptera
Family Asilidae
Mallophorina pulchra Pritchard
Epheria subarida (Bromley)
Epheria pallidula (Hine)
Protocanthus nr. *nearno* Martin
Family Bombyliidae
Heterostylum croceum Painter
Family Chloropidae
Sarcotinia sp.
Family Sarcophagidae
Blaesoxipha plinthopyga (Wiedemann)
Family Tachinidae
Euphorocera tachinomoides Townsend

Differences in precipitation and consequent plant productivity may partially account for the widespread variation in insect numbers between sites. Total rainfall at the Osage for 1971 was 60 cm compared to only 21 cm for the Jornada. The resulting low ground cover and vegetative growth on the desert grassland site yielded similarly lower numbers of invertebrates. Sparsely distributed perennial shrubs were observed to harbor many insects but were only rarely sampled, another factor contributing to the lower numbers at the Jornada site.

Major invertebrate orders were determined for each field season by mean numbers and biomass. The most common groups on the ungrazed treatment during 1972, in descending order of frequency, were the Homoptera, Collembola, Hymenoptera, Hemiptera, and Acarina. Similarly, the common groups on the grazed plot were the Hemiptera, Hymenoptera, Homoptera, Collembola, and Acarina. Coleoptera and Thysanoptera were occasionally taken in large numbers on both treatments.

Of the foregoing orders, the most commonly encountered families were the Cicadellidae, Sminthuridae, Formicidae, Lygaeidae, Tingidae, and Caeculidae (Acarina). In comparison, Reed (1972) determined the major groups of a tallgrass prairie to be the omnivorous Formicidae,

followed by the herbivorous Thysanoptera, and Entomobryidae. The fact that the Entomobryidae are commonly found in leaf litter and under bark probably accounts for their lower numbers in the desert grassland. Other groups occurring in large numbers on the tallgrass prairie were Sminthuridae, Coccoidea, Nitidulidae, Cicadellidae, Delphacidae, Lygaeidae, and Carabidae. At the family level the dominant fauna for both the grazed and ungrazed sites are actually quite similar. The majority of the frequently occurring invertebrates are herbivorous in the tallgrass prairie as well as in the desert grassland.

In 1970, as well as in 1971, dominant orders by numbers were similar for both the grazed and ungrazed treatments. In 1971 the dominant orders, in descending order, were the Hymenoptera, Coleoptera, Acarina, and Hemiptera; in 1970, the Acarina, Homoptera, Hemiptera, and Hymenoptera were the most prevalent. Using comparable sampling methods in 1971, Lavigne and Kumar (1972) reported the Coleoptera, Diptera, Hemiptera, and Homoptera to be the most commonly occurring insect orders on shortgrass prairie in northern Colorado. The Acarina were occasionally abundant but were extremely variable between sample dates. Herbivores thus dominated both sites at the order level, although scavengers were frequently sampled in both areas.

The shift in dominance of the Acarina from 1970 to 1972 can be explained by the gradual decline of the caeculid mite population. The caeculids peaked on July 14, 1970 at 30.8/m^2 on the ungrazed treatment and 35.0/m^2 on the grazed treatment. Their numbers later reached a low point on June 26, 1971, never again building up to their former peak. It is possible that the abnormally dry growing seasons of 1970 and 1971 induced a high mortality on these fungal-feeding organisms.

Major contributors to biomass for 1972 were the Coleoptera (most notably Tenebrionidae), Araneida, Homoptera (Cicadellidae and Cicadidae), and Orthoptera on the ungrazed treatment, while the grazed treatment was dominated by the Coleoptera, Orthoptera, Araneida, and Hemiptera, respectively. During 1970 and 1971 the Hymenoptera (primarily Formicidae), Hemiptera, Coleoptera, and Acarina contributed the greatest biomass.

The difference in biomass vs. number dominance resulted from the intermittent collection of larger stout-bodied invertebrates such as spiders and grasshoppers. The dry weight of these organisms was observed to exceed that of a leafhopper by a factor of 1000 or more, thus accounting for the relatively large biomass. Except for the Araneida, the major groups according to

biomass were, as with the density data, chiefly herbivorous. Reed (1972) found that the Formicidae, Cicadellidae, and Curculionidae were the greatest contributors to biomass at the Osage grassland during 1971. In contrast, the curculionids of the desert grassland contributed substantially to biomass only during 1970.

Data for overall invertebrate density (mean number/m^2), 1970 to 1972, is found in Figures 6-8. Numbers for the grazed treatment were at an all-time high on July 30, 1970 when the invertebrate density reached 99.4/m^2. The Formicidae and Caeculidae made up 82 percent of the specimens taken on that date. The highest densities observed on the ungrazed treatment were on August 8 and August 30, 1972 when numbers reached 81.4/m^2 and 78.2/m^2 respectively, the Termitidae and Formicidae accounting in part for these peaks.

With the exception of the July 30 sample, numbers for both the ungrazed and grazed treatments followed similar trends during 1970 (Figure 6). Although overall densities gradually declined as the season progressed, the grazed treatment had higher populations on all sampling dates with the exception of November 4. The majority of the arthropods sampled were herbivores. Growing season precipitation was below average for 1970; peak numbers appear to be correlated with the rains which occurred in mid-July. Only a slight increase in numbers

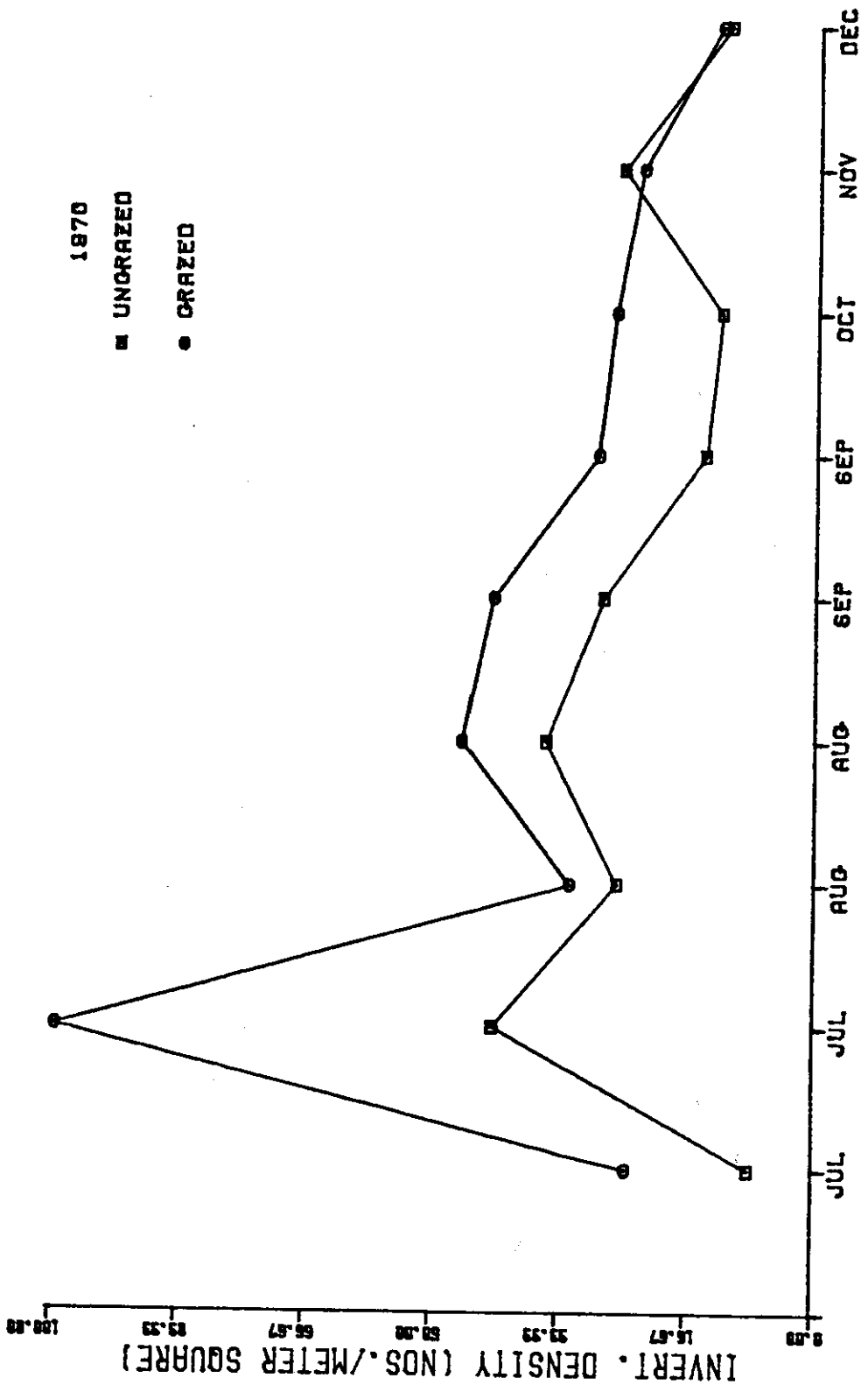

Figure 6. Mean density (nos./m^2) of invertebrates sampled from July 14, 1970 to December 8, 1970.

was associated with peak plant biomass measured by primary producer investigators in late August.

Populations continued to decline gradually at the close of 1970 and through June 26, 1971, at which time densities of invertebrates reached an all-time low of $1.6/m^2$ on the ungrazed and $.4/m^2$ on the grazed (Figure 7). Precipitation between October 1970 and May 1971 was 4.5 cm. The abnormally dry conditions perhaps more than low-temperature effects during the winter, probably contributed to the decline of invertebrate numbers during this period.

Invertebrate numbers on both treatments once again showed an increase on July 22, 1971 and exhibited a general upward trend through the remainder of the season. Total precipitation up to July 22 was 1.7 cm; .5 cm fell on July 22, marking the beginning of the "rainy" season which yielded a total of 16.35 cm by October 26, the last recorded rainfall of the year. It seems reasonable to conclude that the apparent increase in invertebrate numbers was somehow either a direct or indirect response to this increased precipitation.

Lavigne and Kumar (1972) described an increase in invertebrate populations which corresponded with days on which rainfall occurred. The response could be behavioral, the arthropods becoming more active and hence more susceptible to capture under more "favorable" micro-

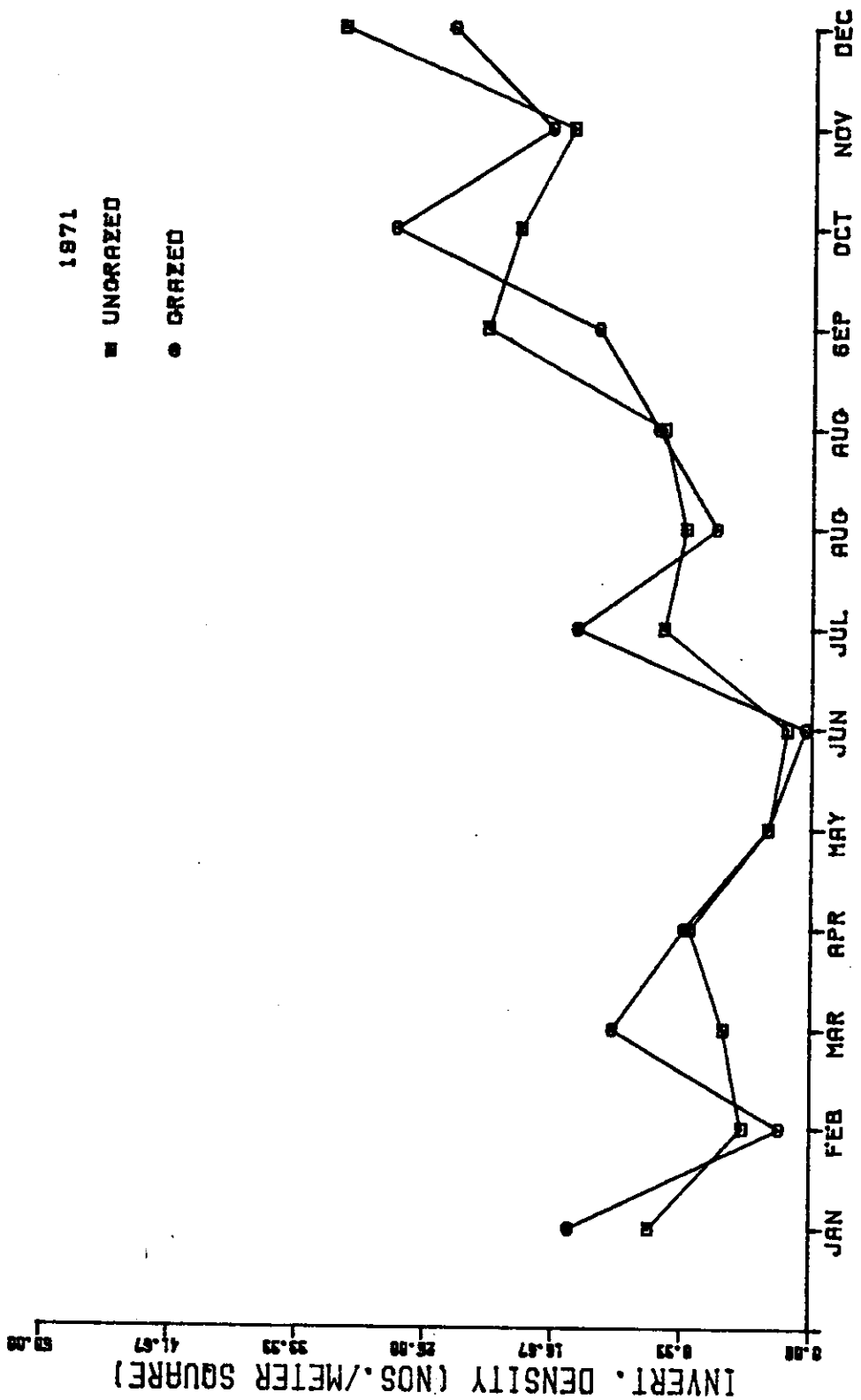

Figure 7. Mean density (nos./m^2) of invertebrates sampled from January 28, 1971 to December 30, 1971.

climatic regimes. On the other hand, indirect responses, exhibited as lag effects, could be interpreted as an onset of reproduction initiated by increased precipitation. The development of a reproductive population would be closely correlated with plant productivity and would help insure the success of the insect community in the desert grassland (Odum 1971).

Trends for invertebrate numbers in 1972 are less discernible than for previous years (Figure 8). January populations dropped from the December 1971 level, although a general increase occurred as the season progressed. Peak density of 81.4/m^2 was measured on the ungrazed treatment on August 8; on this same date, populations on the grazed treatment were only 32.73/m^2. On July 7 the opposite was true; while populations on the grazed were 55.2/m^2, the ungrazed treatment had a density of only 27.4/m^2. It is likely that these discrepancies are attributable to sampling error, a topic to be discussed in a later section.

Mean invertebrate biomass (g/m^2, dry weight) is summarized in Figures 9-11. Biomass trends for 1970 generally follow the trend of populations (numbers) for that season (Figure 9). Although numbers on the grazed treatment exceeded the ungrazed on July 30, biomass on the ungrazed plot was greater due to the presence of several large hymenopterous species in the samples.

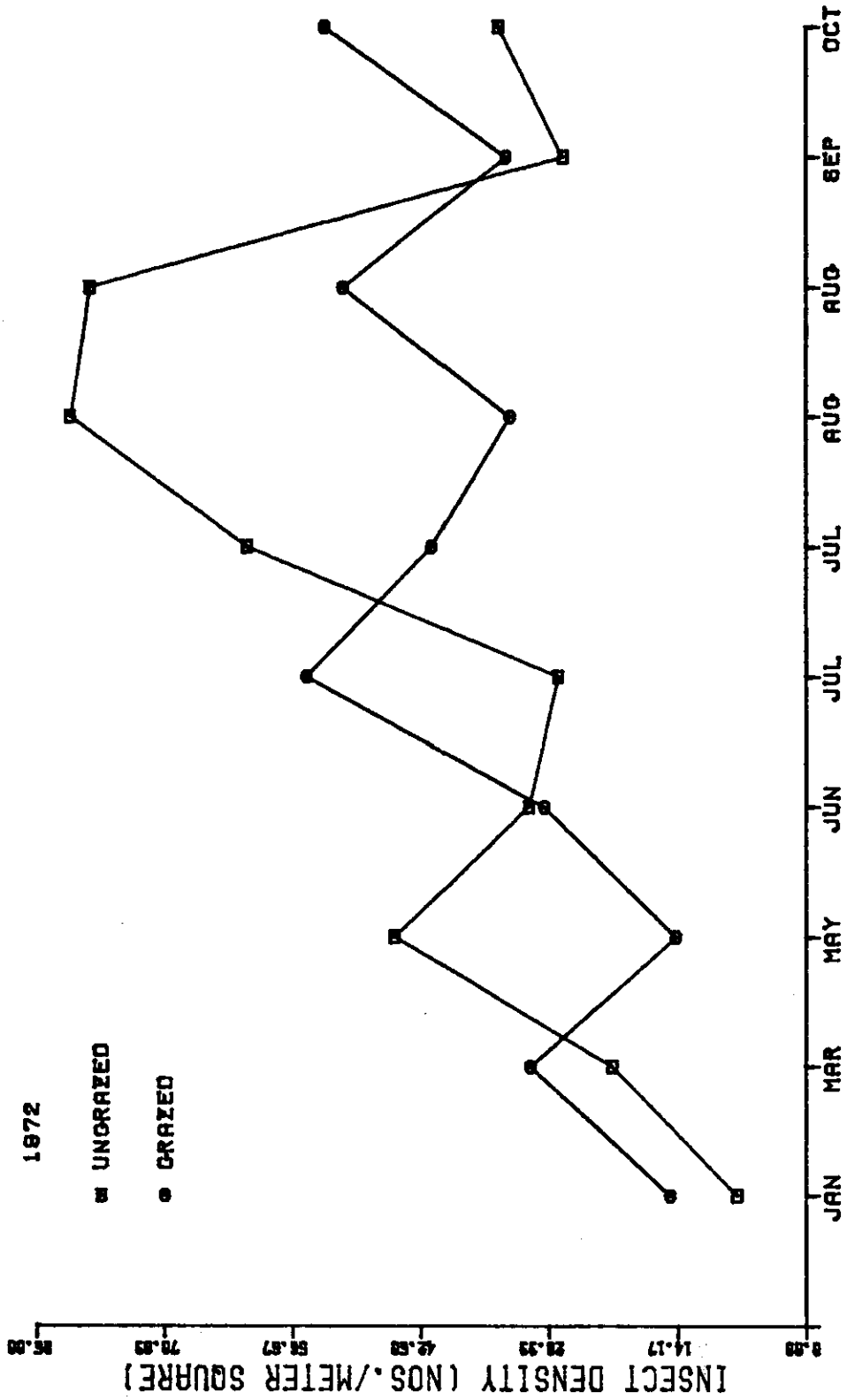

Figure 8. Mean density (nos./m^2) of invertebrates sampled from January 21, 1972 to October 29, 1972.

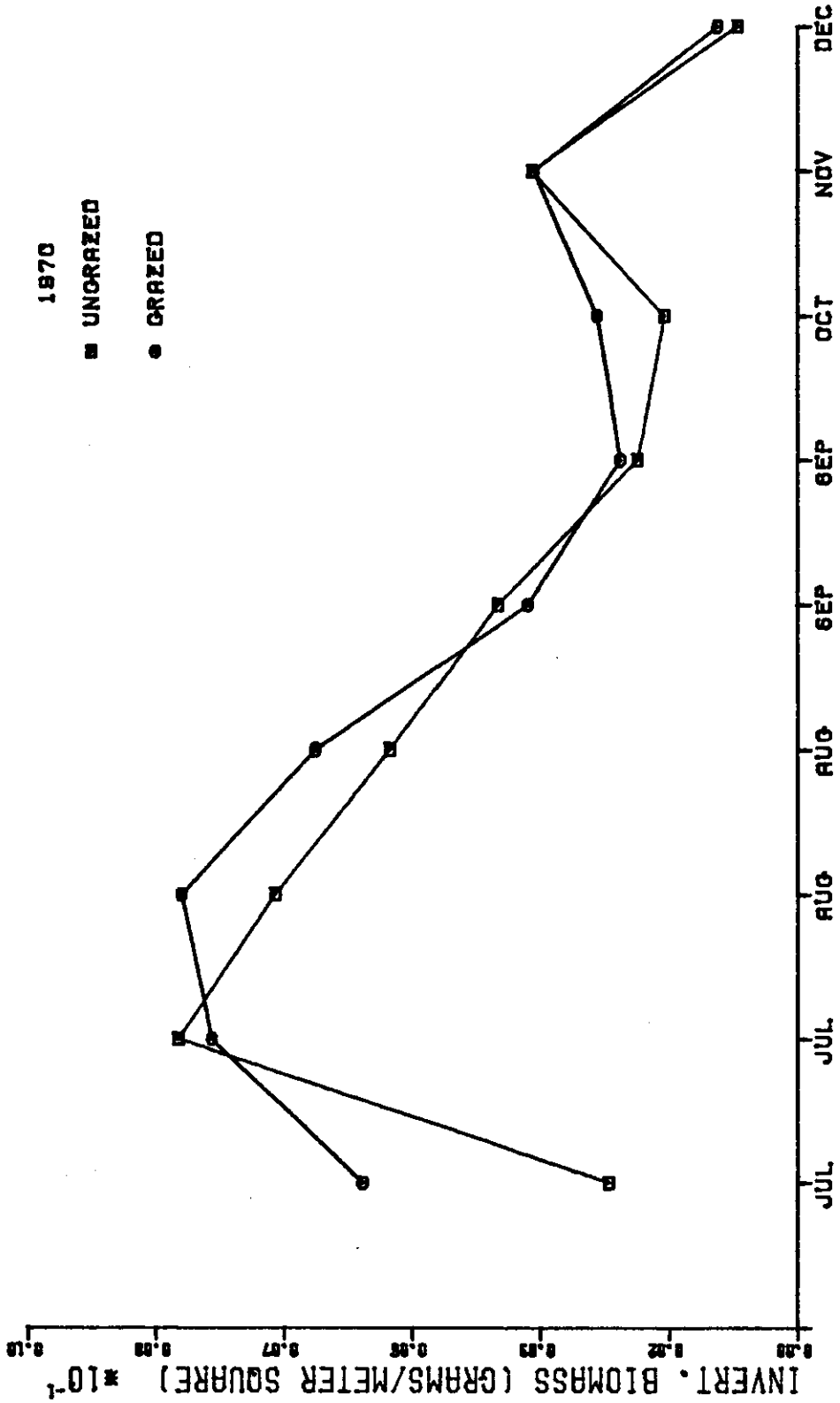

Figure 9. Mean invertebrate biomass (g/m^2) of samples taken from July 14, 1970 to December 8, 1970.

Biomass peaked for the season at .00804g/m^2 on this date. A gradual decline occurred after the peak until the low on both the grazed and ungrazed treatments was reached on December 8 at .00104g/m^2 and .00078g/m^2 respectively. Low biomass coincided with an expected drop in overall invertebrate activity during the cooler winter season.

During 1971 numbers were too low for the extraction of biomass until July (Figure 10). Peak biomass on the ungrazed treatment occurred on October 12 at .0213g/m^2, while the peak on the grazed occurred nearly a month later, on November 9, at .02784g/m^2. By this time however, biomass on the ungrazed had dropped again to .0034g/m^2. These apparent discrepancies are attributable to chance sampling of larger but infrequently caught arthropods. For example, on November 9, numbers on the grazed and ungrazed were nearly equal, but an adult Tettigoniid was captured on the grazed plot, yielding an unexpectedly high biomass. Similarly, on October 12 the presence of a large asilid and a grasshopper (Acrididae) on the ungrazed treatment caused biomass to be high.

In 1972, as in 1971, there is little apparent correlation between trends of numbers and biomass. However, biomass did peak at an all-time high coinciding with peak insect density on the ungrazed treatment on August 8 (Figure 11). The record-high biomass of .782g/m^2 was a

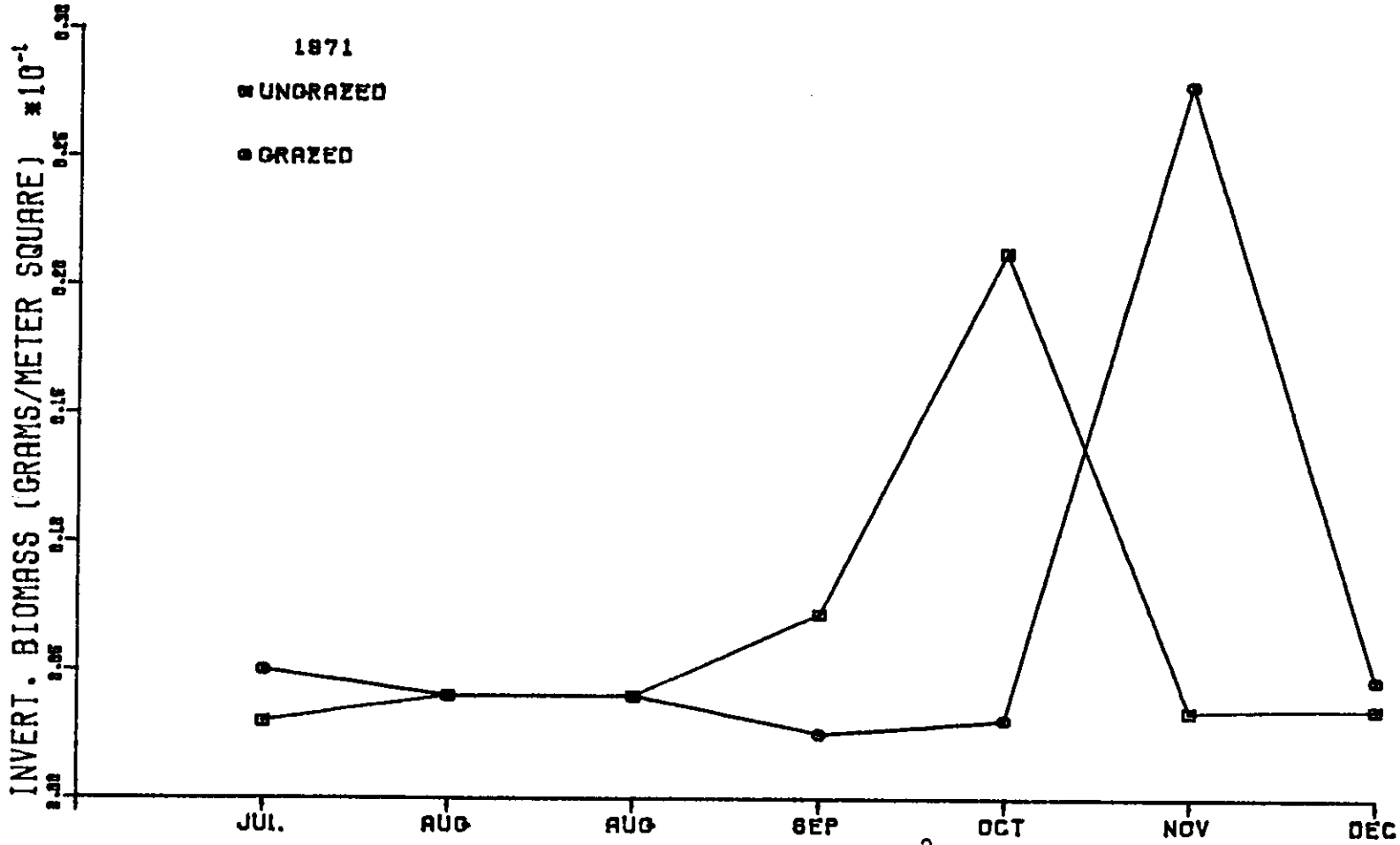

Figure 10. Mean invertebrate biomass (g/m^2) of samples taken from July 22, 1971 to December 30, 1971. No biomass data is available prior to July due to extremely low numbers of arthropods captured.

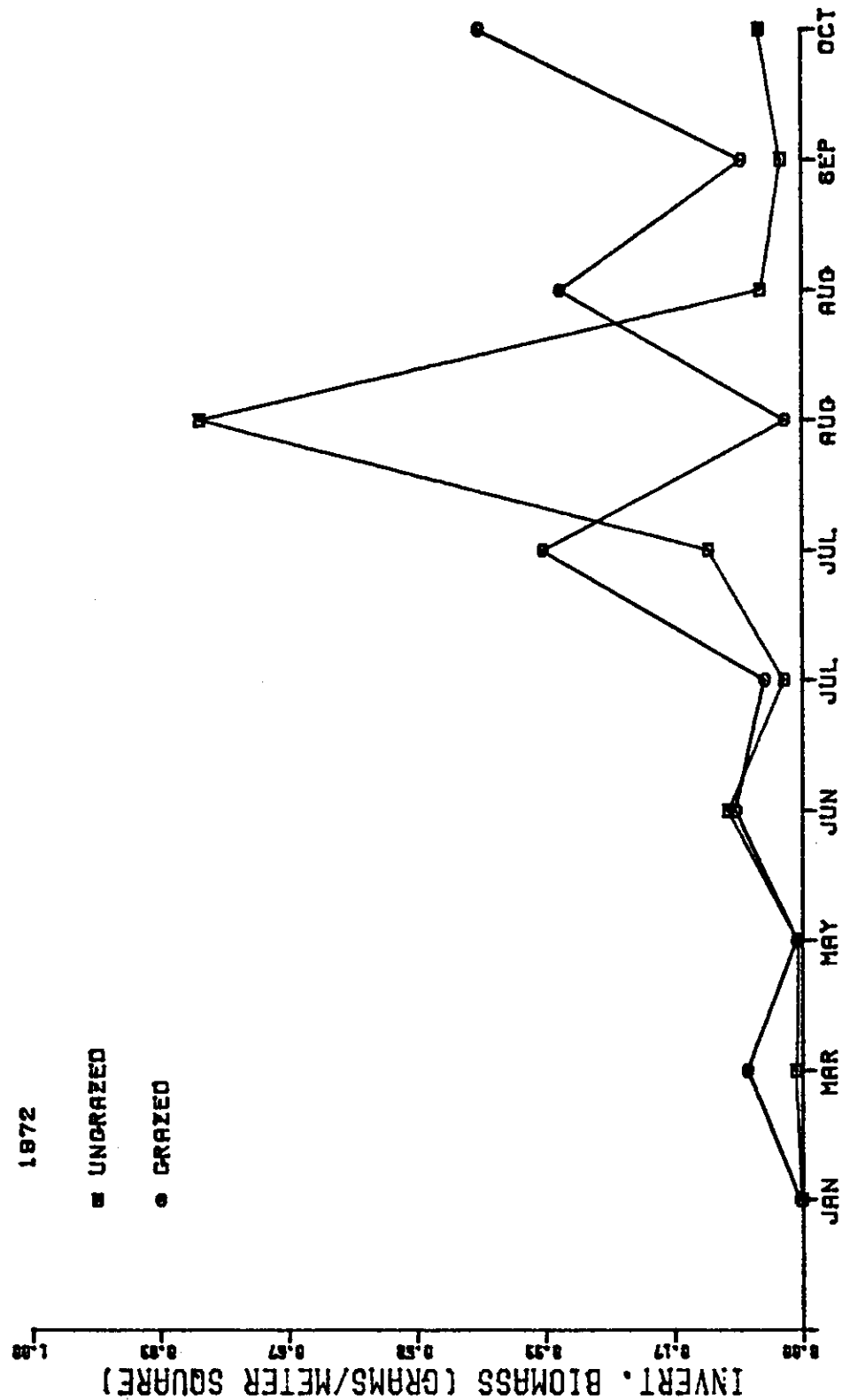

Figure 11. Mean invertebrate biomass (g/m^2) of samples taken January 21, 1972 to October 29, 1972.

result of a large number of Eleodes sp. (Tenebrionidae) and Lygaeus sp. (Lygaeidae) which were collected from a sample taken over yucca.

Blocker et al. (1971) indicated that an index of leafhopper numbers was not necessarily a good predictor of biomass because of the wide variation in weight between species, sexes of the same species, and size of the life stages. Similarly, Reed (1972) reported varying number-biomass relationships with Araneida. During one part of the season there was an inverse relationship between numbers and biomass; later both followed parallel trends. Without any apparent direct relationship between overall numbers and biomass, it appears that both parameters must be measured if an evaluation of population dynamics and energy flow of the insect community is to be undertaken.

The feeding habits of about 75 percent of the invertebrate taxa were determined for 1972 (Figures 12-15). Direct observation supplemented with reports from the literature provided the trophic level for most groups. Feeding habits were broken down to herbivore, omnivore, predator, scavenger, and parasite. An initial division of the herbivore compartment into plant-chewing and plant-sucking later proved inconvenient due to the frequent absence of any chewing herbivores in the samples. Similarly, the parasite category was often vacant, except for an occasional parasitic tachinid or hymenopteron.

A summary of trophic categories at the family level is given in Table 2.

The herbivores made up the bulk of the community on the ungrazed treatment in 1972 (Figure 12), but their numbers fluctuated widely through time. The peak, occurring on May 18, resulted from a large number of coccids which were extracted from the root crowns of Bouteloua spp. and Sporobolus sp. Following the May sample, these insects were only infrequently collected; on the grazed treatment they were rarely captured, probably because of the lower density of grass species on that plot.

Later in the season the Cicadellidae, Tingidae, Lygaeidae, and Thysanoptera dominated the herbivore compartment. Several species of leafhoppers were collected from Bouteloua eriopoda, Sporobolus flexuosus, and Salsola kali. Three genera of tingids, Corythucha sp., Corythaica sp., and Gargaphia sp., were commonly taken on Gutierrezia sarothrae, Salsola kali, and Bouteloua eriopoda, although nymphs were encountered only on G. sarothrae and on S. kali. The lygaeids were not observed feeding, but quick trap captures revealed their presence in association with Salsola kali and Yucca elata.

Herbivores on the grazed treatment (Figure 13) were consistently more abundant than other trophic components throughout the season, yet their numbers were not as high as the herbivores on the ungrazed treatment

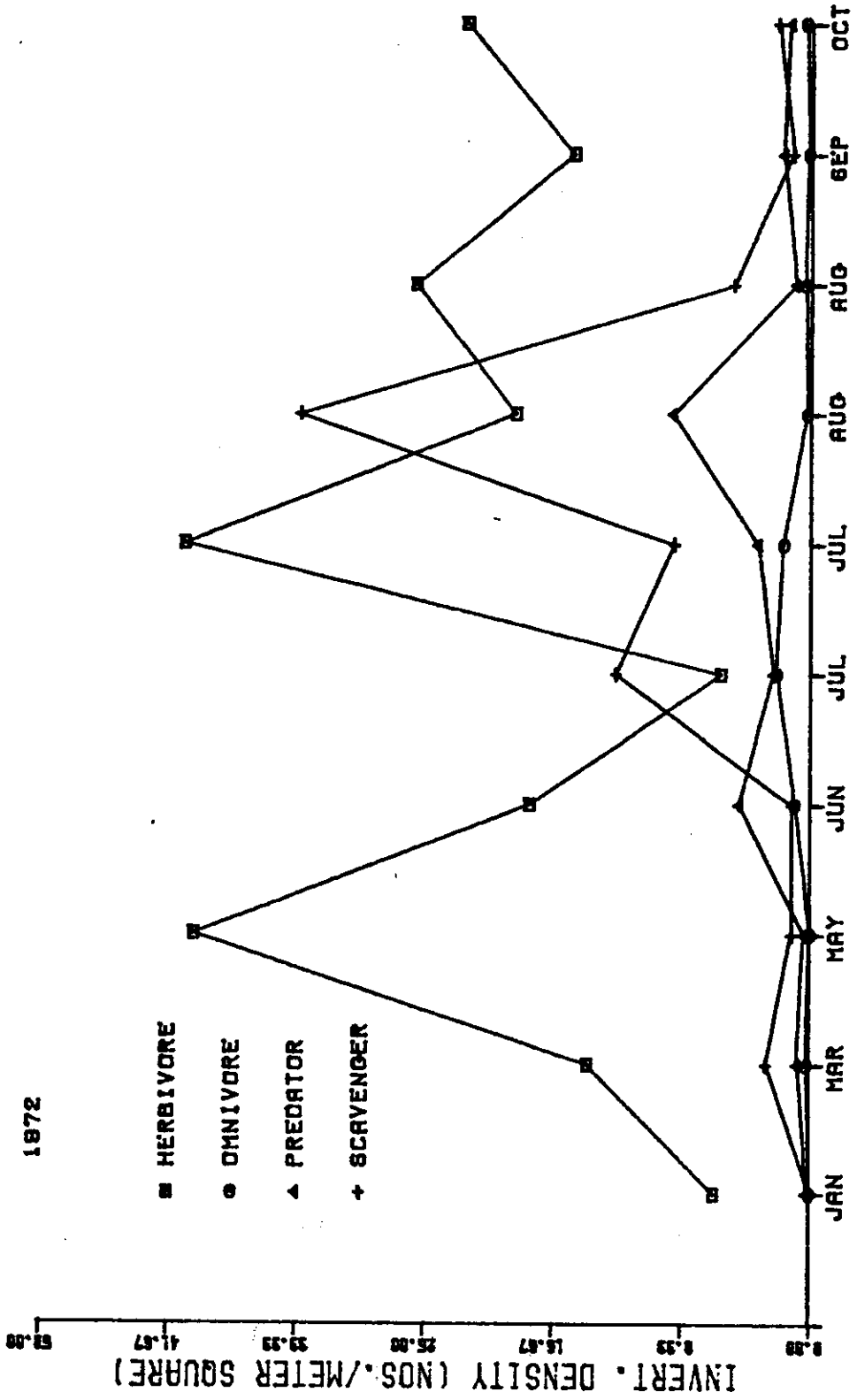

Figure 12. Mean invertebrate density (nos./m^2) by trophic level for the ungrazed treatment, 1972.

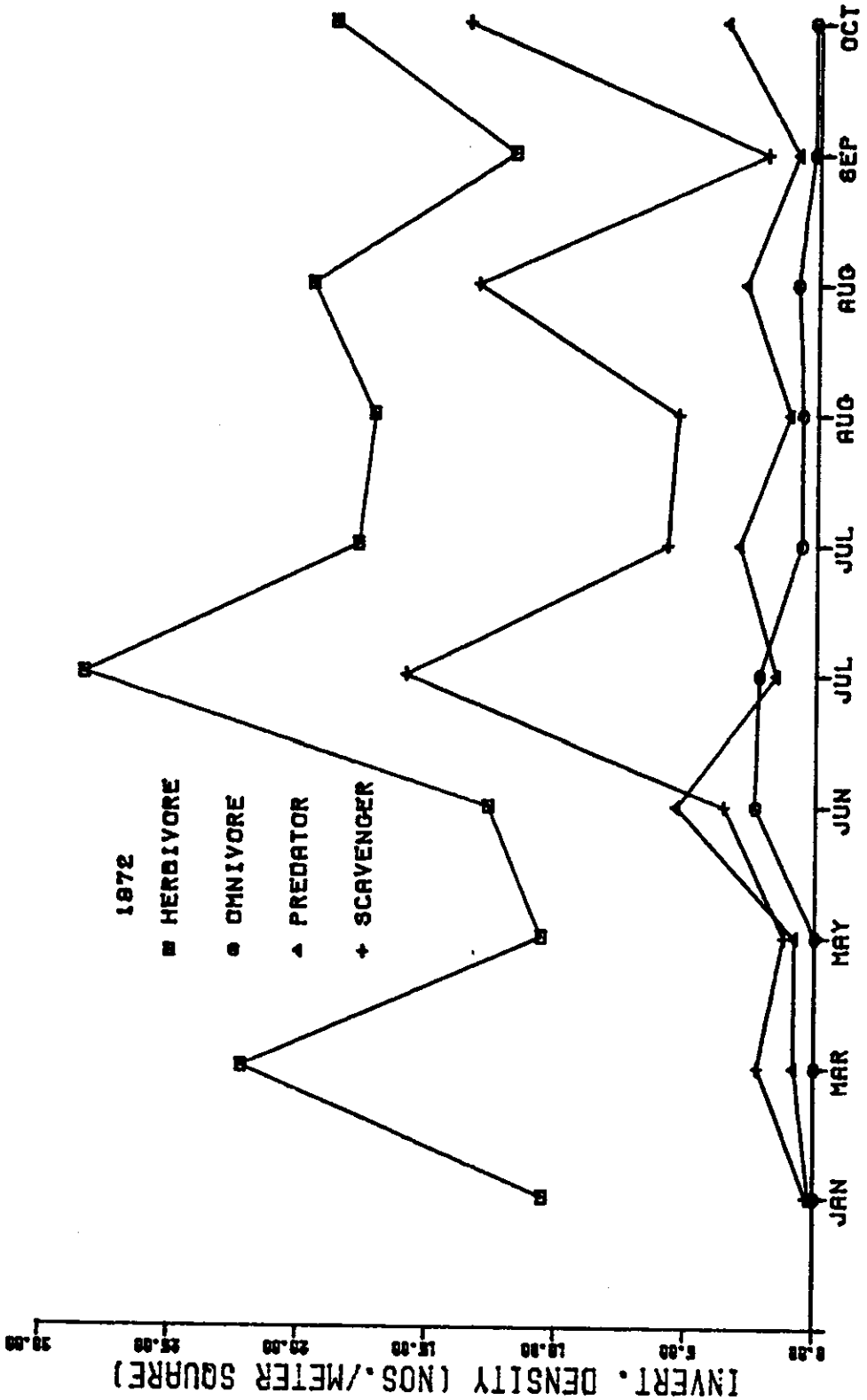

Figure 13. Mean invertebrate density (nos./m^2) by trophic level for the grazed treatment, 1972.

(Figure 14). Although herbivore numbers were greater than other trophic levels, their biomass was often exceeded by the scavenger component. Scavengers accounting for this biomass (Figure 15) were chiefly the Blattidae and Tenebrionidae (adult Eleodes sp.).

In contrast, results of a similar study found the scavengers to contribute a much lower biomass. Reed (1972) found the herbivorous invertebrates of a tallgrass prairie to comprise 59 and 66 percent of the mean biomass over a two-year period. No tenebrionids were collected on the tallgrass prairie. Evans and Murdoch (1968), restricting their study to insects, found that 85 percent of the species in a Wisconsin grassland were herbivorous as adults and 41 percent as larvae. The disparity between these data and that of the desert grassland needs further investigation. A partial explanation can be offered: the August 8 ungrazed treatment, scavenger biomass is high because of the number of tenebrionids captured in one sample over yucca. Repeated observations indicate that as many as 50 of these organisms may be found on any given yucca plant. They are found clustered around the dead portion of the stalk and leaves near the ground, where they may be feeding or seeking shelter. The distribution of yucca on the plot is such that the actual tenebrionid biomass is probably much lower. Secondly, the saw-tooth shape of the scavenger

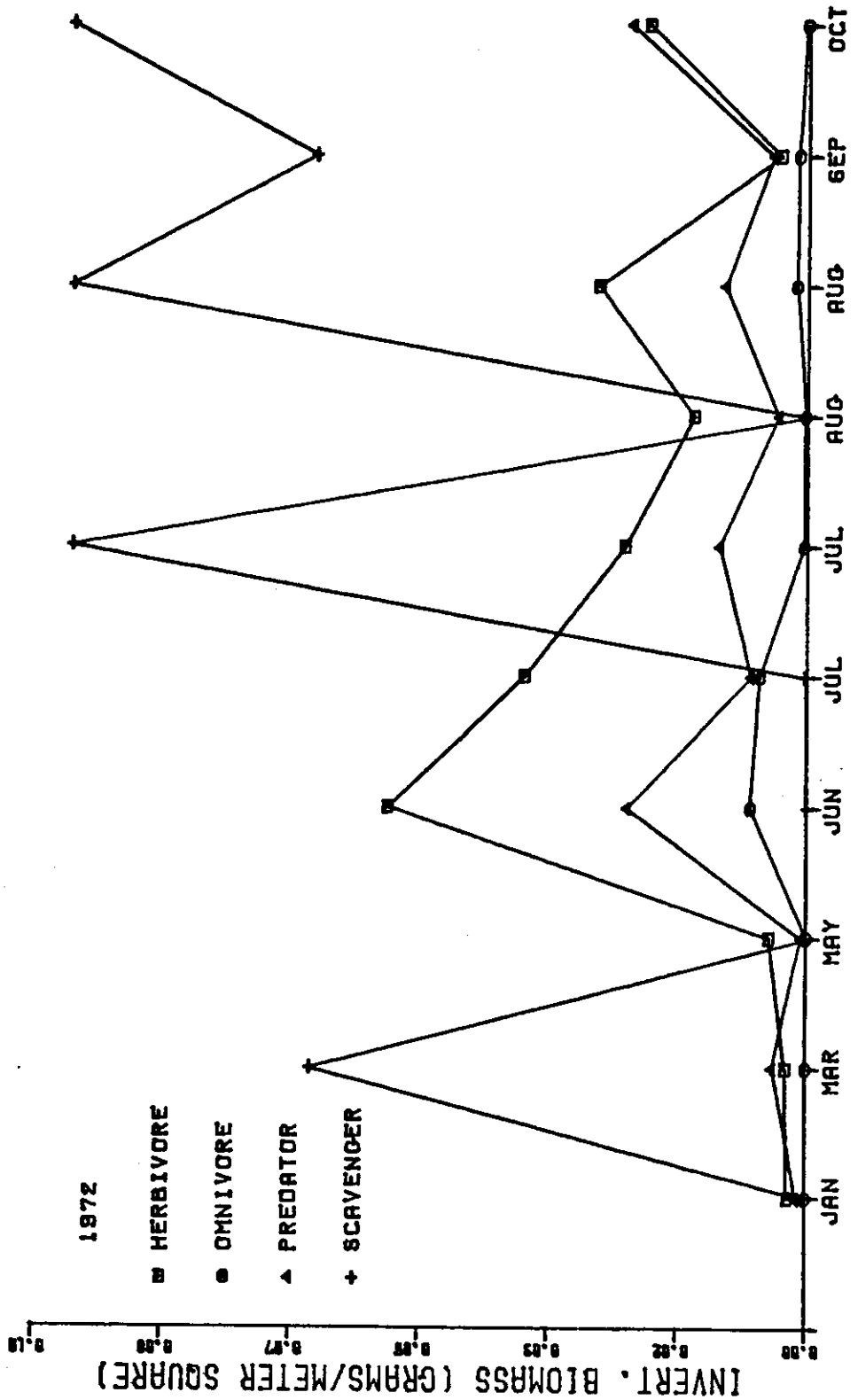

Figure 14. Mean invertebrate biomass by trophic level for ungrazed treatment, 1972.

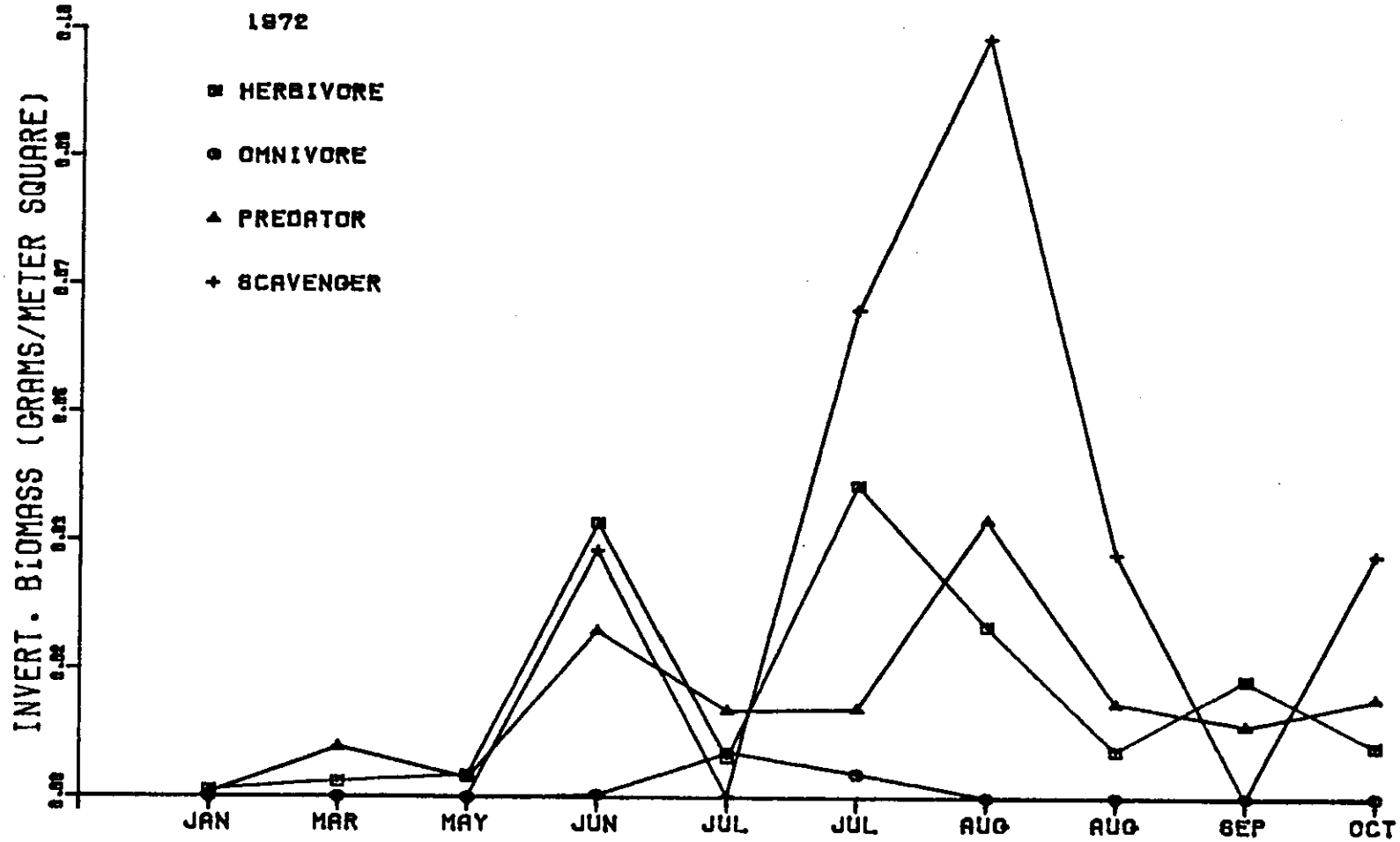

Figure 15. Mean invertebrate biomass (g/m^2) by trophic level for grazed treatment, 1972.

data for the grazed treatment (Figure 15) hints that chance sampling error may be involved. There is no logical reason to suspect that biomass fluctuations of this magnitude would occur naturally.

Omnivore and predator numbers remained low throughout the season. Omnivorous ants were never captured in great quantity despite the existence of numerous nests on the plots. The harvester ants, Pogonomyrmex sp., were sampled only twice during 1972. The most commonly taken predators were the Araneida (Lycosidae, Thomisidae, and Theridiidae). The black widow spider, Latrodectus mactans Scheffer, was captured frequently between August and October. Other common predators were the Myrmeleontidae and the Coccinellidae. Predator biomass on both treatments generally tracked population numbers throughout the 1972 season.

As it was not possible to observe the habits of many of the invertebrates considered in this study, comparisons of plant species and insects occurring in the same quadrats were undertaken in hope of elucidating potentially important plant-insect relationships. Three 1972 sample dates were chosen for an analysis of these possible relationships: June 23, August 8, and August 30. Estimated plant species biomass and invertebrates were tabulated for each quadrat, comparisons being made across quadrats yielding the results in Table 4. A simple chi-

Table 4. Inter-quadrat comparison of plant species and invertebrates for three sampling dates in 1972. Chi-square values are included only for associations significant at the 95 percent confidence level. Larger chi-square values are indicative of stronger species associations.

Invertebrate Taxa	Plant Species[a]							
	Yuel	Spfl	Saka	Trpu	Gusa	Crcr	Boer	Crco
Lygaeidae	28.9	--	8.5	--	--	--	--	--
Aphididae	28.9	--	--	--	--	--	--	--
Blattidae	28.9	--	--	--	--	--	--	--
Termitidae	28.9	--	--	--	--	--	--	--
Cicadellidae	--	13.5	10.5	9.3	4.3	--	7.7	--
Tingidae	--	4.3	13.2	6.2	12.6	6.3	--	--
Phloeothripidae	--	5.4	9.7	4.2	5.2	--	5.4	--
Sminthuridae	--	7.6	6.4	6.4	--	--	--	8.3
Coccinellidae	--	5.2	--	--	--	6.3	--	--
Curculionidae	--	5.4	--	--	--	--	--	--
Thripidae	--	--	--	--	9.3	--	--	--
Formicidae	--	--	--	6.3	--	--	--	--
Myrmeleontidae	--	--	--	--	--	4.8	--	--

[a]List of Jornada plant species and species codes is found in Table 1 (on page 23).

square technique, often used by plant ecologists and based on the presences and absences of species pairs, was used to detect departures from randomness (Pielou 1969). Chi-square values exceeding the 95 percent confidence level were regarded as significant plant-insect associations. Generally, stronger associations occur in the upper-left corner of the table, decreasing diagonally to the lower right. The data reveal several interesting points: some taxa, such as the Blattidae and Termitidae, are invariably found in association with a particular plant. Other insects, such as the tingids, are strongly associated with Salsola kali and Gutierrezia sarothrae and weakly associated with Sporobolus flexuosus and Tridens pulchellus. It is possible that if this association analysis had been carried to the species level, stronger associations resulting from species differences would have been revealed.

Other plant-insect associations were revealed when sampling specific plants or parts of plants. Table 5 summarizes the families collected by D-Vac on mesquite on July 16 and August 16, 1971. All of these families were taken at least one time during normal quick trap sampling, but several taxa were extremely abundant on mesquite while relatively uncommon on other plants. The herbivorous Psyllidae, Membracidae, and Cercopidae were taken in large numbers, and the Mantidae and Phasmidae,

Table 5. List of families collected on mesquite, July 16 and August 16, 1971.

Order	Family
Homoptera	Cercopidae
	Cicadellidae
	Fulgoridae
	Membracidae
	Psyllidae
Orthoptera	Mantidae
	Phasmidae
Hemiptera	Tingidae
Neuroptera	Chrysopidae
	Myrmeleontidae
Diptera*	Asilidae
	Phoridae
	Tachinidae
Lepidoptera*	Geometridae
	Tortricidae
Coleoptera	Bruchidae
	Cerambycidae
	Curculionidae
	Nitidulidae
	Tenebrionidae
Thysanoptera	Phloeothripidae
Collembola	Sminthuridae
Hymenoptera*	Cynipidae
	Formicidae
	Pompilidae
Acarina*	Caeculidae
Araneida	Argiopidae
	Lycosidae
	Salticidae
	Thomisidae

*Not all specimens were taken to family.

while rarely taken by quick trap, were not uncommon in the mesquite samples. Although smaller cerambycids were taken in quick trap samples, the large mesquite beetles (Ergates sp.) were taken only in mesquite samples. Likewise, small pompilids were occasionally captured with the quick trap, but the large tarantula hawk (Pepsis sp.) was taken only on mesquite.

Yucca blooms were first sampled in 1972 by placing a 32-mesh Lumite bag over the flower stalk and later placing the flower in a Berlese funnel for extraction. Table 6 summarizes the results for samples taken on May 24 and June 21. Although aphids were predominant, it is expected that thrips, particularly Frankliniella occidentalis (Pergande), would have paralleled them in numbers had the blooms been fully open (J. G. Watts, personal communication*). Since yucca blooms had never been sampled by quick trap or included in population estimates, it was obvious that the randomized sampling scheme was causing certain important biological relationships to be ignored. It is reasonable to assume that half of the more than 300 yucca on the 10 ha ungrazed plot bloomed during a season and that each had an average population of 3,000 aphids, yielding a population of about 45,000 aphids per ha which were not being included in quick trap population counts. Additionally, there would be numerous Thysanoptera unaccounted for, as well

(*May 1972.)

Table 6. Summary of invertebrates captured on yucca flowers on May 24 and June 21, 1972.

Order	Family	Stage[a]	Total Catch May 24	Total Catch June 21
Thysanoptera	Thripidae	A	228	187
		N	17	43
Homoptera	Aphididae	N	3000+	3500+
Hemiptera	Miridae	A	6	14
		N	2	3
	Pentatomidae	A	0	6
Diptera		A	1	5
Lepidoptera[b]		A	7	10
Hymenoptera	Formicidae	A	33	65
Coleoptera	Coccinellidae	A	5	12
		N	0	15
	Mordellidae	A	0	1
	Nitidulidae	A	2	0
Araneida	Salticidae	A	1	1
	Thomisidae	A	0	1

[a]A=adult; N=larva or nymph.

[b]At least two families of microlepidoptera were collected.

as a significant number of ants deriving starches from aphid honeydew and an unknown population of lady beetles thriving on the herbivorous aphids. With the present sampling system, a substantial amount of energy flow would be entirely overlooked. The fact that this situation was actually observed in the field gives cause to question the accuracy of a strictly randomized sampling scheme for invertebrates in the desert grassland.

Other data suggest further deficiencies in the sampling method. Pitfall and light trap data indicate that a number of taxa are either being missed entirely or are underestimated by the quick trap. Table 2 indicates a variety of groups that were collected by these methods as a check on quick trap efficiency. The Gryllacrididae, while taken only once in the quick trap, were abundant in pitfalls. The spring of 1971 and 1972 yielded as many as 200 camel crickets per week in 25 pitfall traps. Likewise, the Solpugida, Chrysididae, and Scorpionida were common in pitfalls while rare or absent in quick trap samples. Three dung-feeding species of Scarabaeidae, Canthon puncticollis, Canthon imitator, and Canthon ebenus, one silphid, Nicrophorus sp., a trogid, Trox nodosus, and a histerid, Saprinus discoidalis, were numerous in pitfalls but were never captured by means of the quick trap. It is likely that some of

these were attracted to dead and decaying invertebrates in the traps, yet their complete absence from quick trap samples is indicative of another shortcoming of the sampling method.

Light trapping also revealed several taxa that were either completely missed or underestimated by the quick trap. Some of the poorly represented Coleoptera were the Cicindelidae, Cebrionidae, and Scarabaeidae (Phyllophaga sp.); yet all of these were commonly taken by light trapping. Among the lepidopterous representatives at light were the sphingids, noctuids, and pyralids. None of these groups were frequent representatives in quick trap samples.

Lavigne and Kumar (1972) discussed further discrepancies in a similar sampling technique in use at the Pawnee site. It was stated that of 42 grasshopper species recorded on the Pawnee, 25 of which were common, only 7 had been taken with the quick trap and D-Vac. Cicadellidae and Thysanoptera were cited as being grossly underestimated; furthermore, the western harvester ant had never been taken by the D-Vac despite the presence of 25 colonies per ha with an average of 2676 ants per colony.

Groups efficiently collected as indicated by the number of families represented were the Collembola, Hemiptera, Homoptera, and Neuroptera. Only half of the

families of Coleoptera, little more than a fourth of the families of Lepidoptera, and only a third of the families of Orthoptera present on the Pawnee site were taken by the D-Vac.

Some of the factors contributing to the inadequacy of the sampling system were pointed out by Lavigne and Kumar (1972) as follows: 1) The mesh size of the quick trap screen is so large as to allow the escape of as many as 20 families of arthropods. This problem has partially been solved at the Jornada by changing over from a 16-mesh to a 32-mesh screen. 2) Many species being missed respond to the movement of the dropped trap and fly off before the trap hits the ground. This phenomenon has been observed frequently at the Jornada. A possible solution is to use a spring-actuated trap which would propel itself rapidly to the ground. 3) The number of samples taken is insufficient. At the Jornada, as well as at the Pawnee, standard errors of population estimates have indicated that the sampling effort should be increased by a factor of no less than five in order to obtain statistically significant estimates.

Finally, the sampling technique is not designed to collect those insects that are most important on each grassland, but is only useful in showing that some faunal differences among the various sites exist. This is most certainly true, as the Jornada desert grassland

is perhaps the most atypical of all the IBP grassland sites. It is dominated by large forbs and shrubs such as mesquite, yucca, Russian thistle, and broom snakeweed, some of which are reservoirs for large populations of a variety of insects during drought conditions or during daylight hours for nocturnal insects. During drought conditions, bare ground may constitute more than 70 percent of the surface area of the site (Pieper, unpublished data). Thus, isolated pockets, or reservoirs, of insects, clustered across a large area of bare ground, have caused unique sampling difficulties at the Jornada site.

To further investigate the effects of plant-insect associations, number of samples, and plant distribution on sampling accuracy, a FORTRAN language simulation program was written with the capability of manipulating these variables. An array, dimensioned 30 by 100, represented the desert grassland study site, which consisted of grass, forbs, shrubs, yucca and bare ground. The percent composition of these categories could be assigned in any proportion, and the array was filled in a random manner. For most cases, array composition was assigned to simulate the actual distribution as follows: grass (25 percent), forbs (10 percent), shrubs (10 percent), yucca (5 percent) and bare ground (50 percent). Due to the random manner in which the array was filled, these percentages were closely approximated but rarely

exact (Table 7). Yucca was placed in a separate category because of its apparently unique complement of invertebrates, while the shrub category was primarily represented by mesquite. Figure 16 is a map of a portion of the 3000 element array as it was stored in the computer. Blank spaces indicate bare ground, while "G" represents grass, "F" represents forbs, "S" represents shrubs, and "Y" represents yucca.

Ten hypothetical species of insects were assigned overall densities (numbers per unit area) and probabilities of being encountered in each plant category and on bare ground. Table 8 is an example of some typical data which was used in the analysis. Insect 1 had an overall distribution of 50.10 per unit area (element), while the probability of finding this insect was high only on yucca. Calculated densities for each insect species in each plant category and on bare ground for the insects listed in Table 8 is found in Table 9. Thus, insect 1 has a density of only .74 per unit of bare ground while its density per unit of yucca is 632.55.

Sampling of the array was accomplished in a random manner similar to the method being used to assign actual sampling locations in the field. One element in the array was considered a quadrat; sampling results were reported in multiples of 5 quadrats, up to 100 quadrats. With each sampling increment, the sampled den-

Table 7. Computer-generated plant cover values closely matched those requested by the programmer. Values were rarely identical due to the random manner in which the array was generated.

Category	Per Cent Cover			
	Requested	Generated*		
Grass	25	24.90	25.13	25.07
Forbs	10	9.97	10.13	9.97
Shrubs	10	10.23	9.83	9.93
Yucca	5	4.83	5.00	5.10
Bare ground	50	50.07	49.90	49.93

*Results of three separate computer runs.

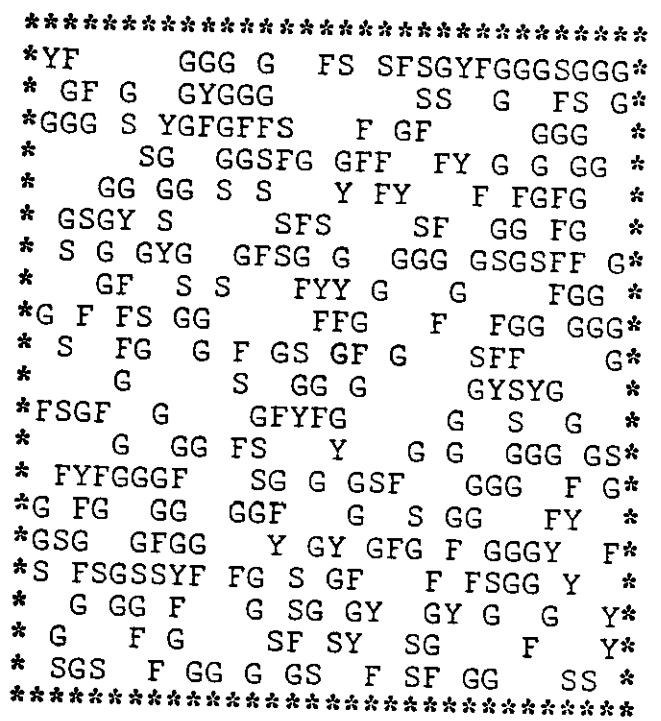

Figure 16. Map of a portion of the simulated Jornada plot, representing 16.7% of the total area. Plant distribution was assigned randomly with these approximate percentages: Grass (25%), Forbs (10%), Shrubs (10%) and Yucca (5%). Bare ground constituted about 50% of the total area.

Table 8. Typical set of input data for ten hypothetical insects, indicating overall insect density, and probability of occurrence on bare ground, grass, forbs, shrubs and yucca.

INSECT	OVERALL DENSITY	PROBABILITY OF ENCOUNTER				
		BARE GROUND	GRASS	FORBS	SHRUBS	YUCCA
1	50.10	.001	.012	.019	.200	.850
2	45.20	.001	.100	.150	.880	.450
3	68.20	.630	.500	.410	.380	.470
4	2.70	.200	.001	.002	.180	.650
5	4.20	.001	.110	.200	.790	.130
6	35.70	.190	.270	.090	.070	.580
7	14.00	.150	.195	.175	.188	.340
8	27.60	.003	.680	.240	.270	.138
9	22.80	.002	.753	.721	.630	.650
10	1.96	.260	.012	.001	.272	.740

Table 9. Computed densities of ten hypothetical insects based on overall density and probability of occurrence data (Table 8). Insect 1 has a density of .74 per unit of bare ground and 632.55 per unit of yucca.

	CALCULATED DENSITIES				
INSECT	BARE-GROUND	GRASS	FORBS	SHRUBS	YUCCA
1	.74	8.93	14.14	148.84	632.55
2	.30	30.19	45.29	265.71	135.87
3	79.20	62.86	51.54	47.77	59.08
4	3.59	.02	.04	3.23	11.67
5	.03	3.49	6.34	25.03	4.12
6	32.70	46.46	15.49	12.05	99.81
7	11.86	15.42	13.84	14.87	26.89
8	.36	81.69	28.83	32.43	16.58
9	.13	48.05	46.01	40.20	41.48
10	2.59	.12	.01	2.71	7.38

sity of each insect species was printed out (Table 10). Relative sampling error for each species was thus available, as was root-mean-square (RMS) error for the entire sample. RMS error, a measure of error based on the squares of the percent deviation of the sampled values from the true values, was used most frequently for this analysis.

Figure 17 indicates the results of sampling without replacement; each data point is a composite average of the previous point plus five additional quadrats. No element in the array was sampled more than once. Figure 18 used identical initial plant and insect distribution data, but replacement sampling was permitted; each data point represents a new set of elements in the array, but it is possible to have successively sampled the same element more than once. Standard error bars for all lines on each graph were obtained from five successive runs of each data set using differing seeds for the random number generator.

Although both graphs follow similar trends, sampling with replacement yields a larger standard error, primarily because averaging of successive samples does not occur. Generally, sampling accuracy increases with an increase in sample size, yet the effect is more pronounced in an environment containing higher plant-insect associations or host specificities.

Table 10. Typical set of simulated data generated when sampling twenty quadrats (elements) with high plant-insect associations. The relative sampling error on individual insect species as well as overall error is included in the computer print out.

INSECT	DENSITY		SAMPLE RMS ERROR
	ACTUAL	SAMPLED	
1	50.10	60.32	.6334
2	45.20	33.40	
3	68.20	106.42	
4	2.70	.51	
5	4.20	.62	
6	35.70	9.59	
7	14.00	9.77	
8	27.60	38.11	
9	22.80	1.44	
10	1.96	.50	

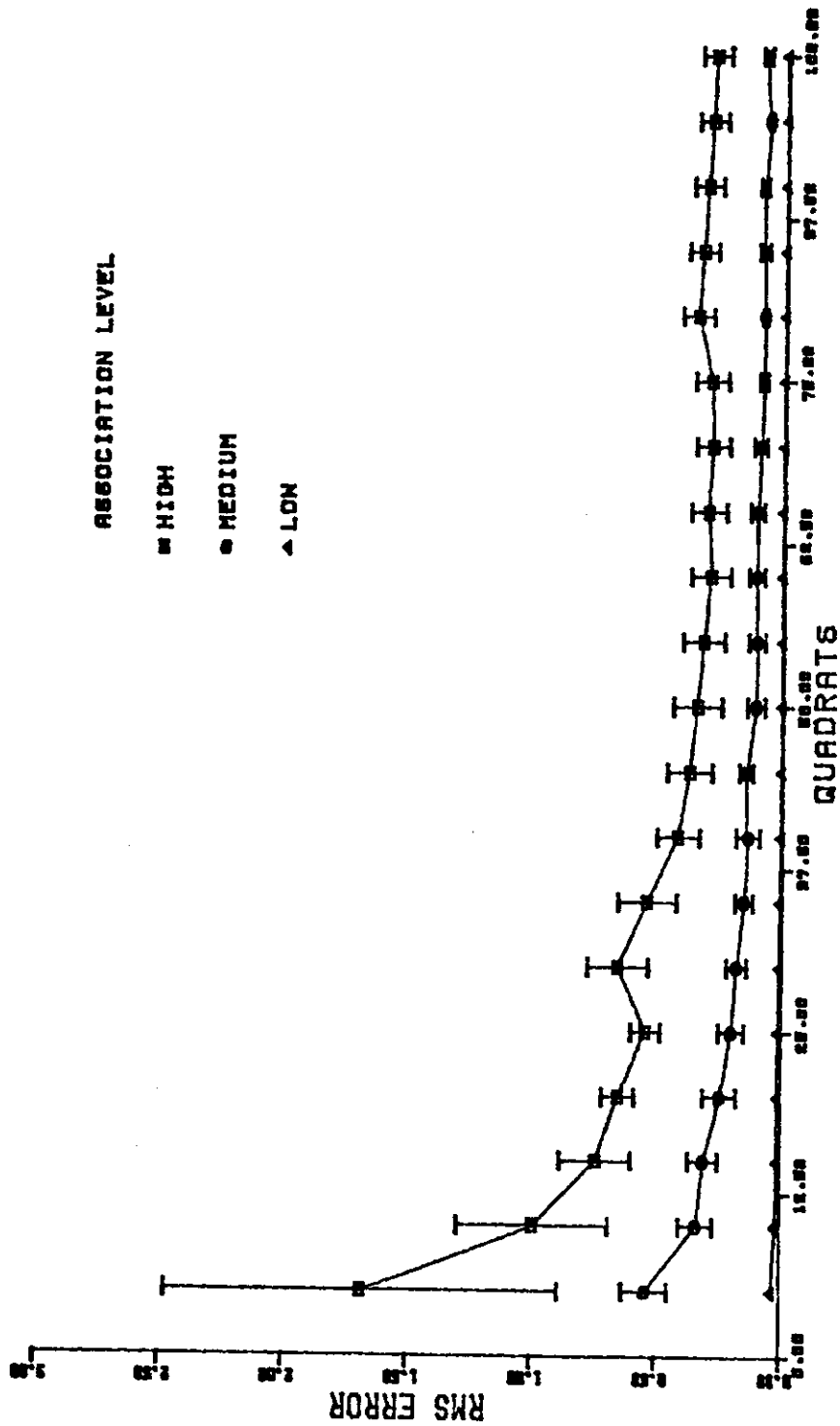

Figure 17. Results of sampling without replacement. Higher levels of plant-insect association result in greater sampling error.

In an environment with minimal host specificity, five quadrats were nearly as accurate in predicting population densities as 100 quadrats were. Similar results were obtained when increasing the plant-insect association factor while maintaining the environment at a more homogeneous level. To illustrate the effect with an example, the yucca component was normally set at five percent of the total ground cover, and two insects were assigned a high probability of encounter on yucca only. Sampling under these circumstances yielded a large standard error, but when yucca was increased to 20 percent ground cover, sampling error was negligible (Figure 18), despite the high degree of plant-insect association.

Figures 17 and 19 indicate the varying degrees of sampling accuracy that result from three different degrees of plant-insect association. Intuitively it is felt that the category designated "high plant-insect associations" is representative of the Jornada desert grassland. The high degree of sampling error associated with this category parallels observations in the field: some taxa are grossly underestimated in the analysis because a yucca plant has a low probability of being sampled, yet it has numerous insects associated with it which are uncommon elsewhere.

Likewise, many other shrub species bear their own somewhat unique complement of insects; shrub distribu-

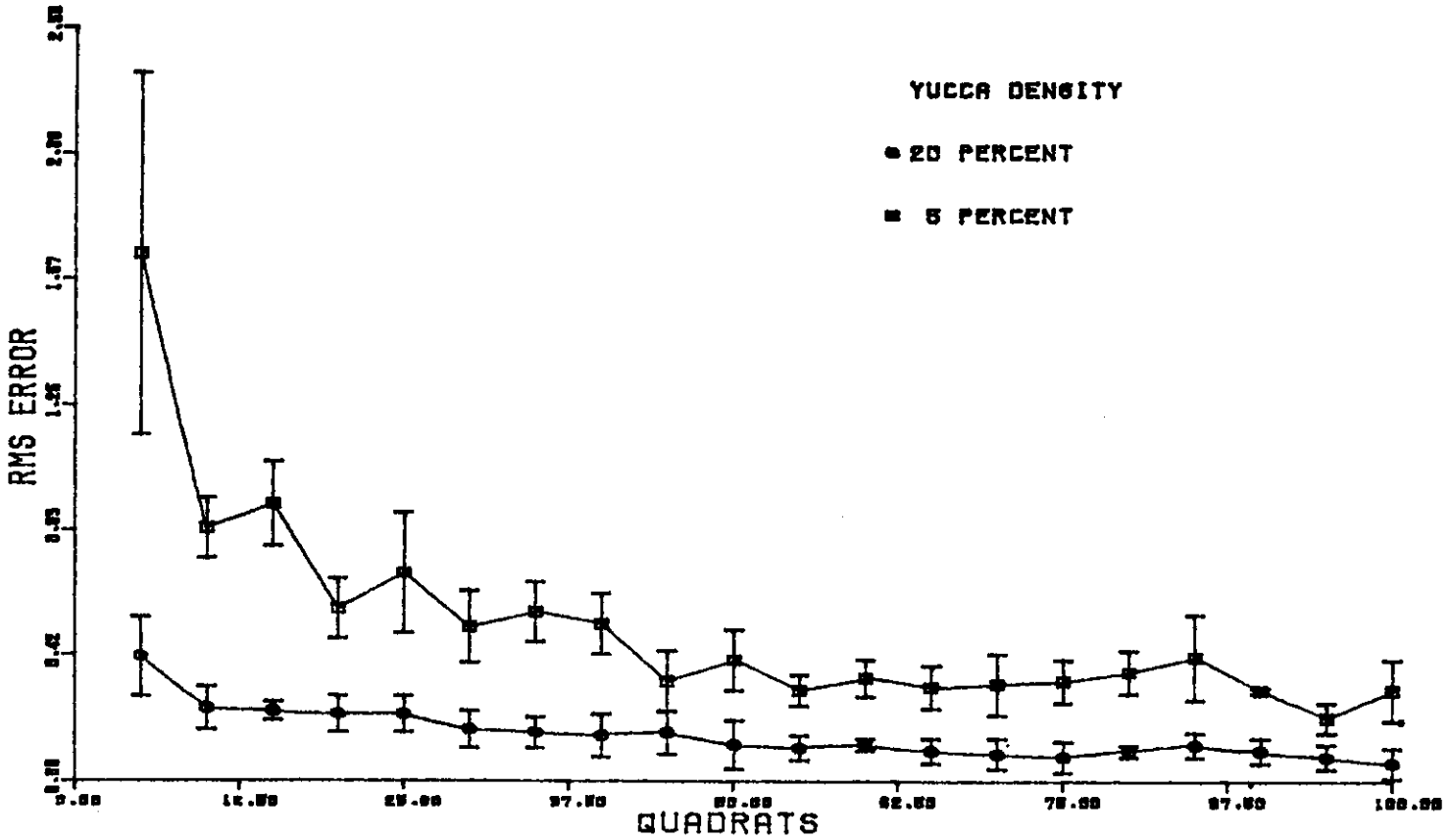

Figure 18. Comparison of sampling error under two different distributions of yucca. When yucca is sparsely distributed sampling error is greater than under a more homogeneous yucca distribution.

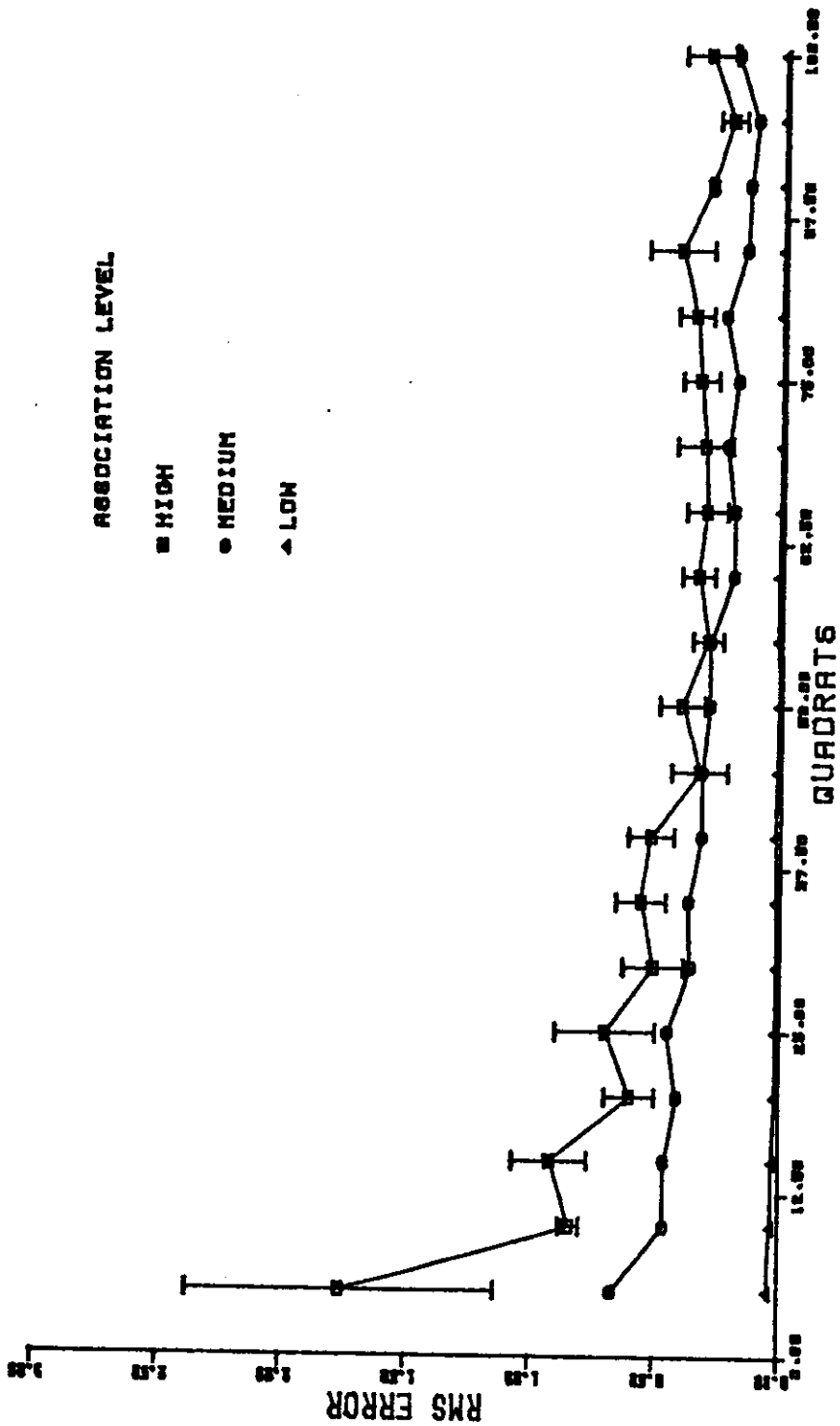

Figure 19. Results of replacement sampling under three levels of plant-insect association. Sampling error is greater with higher levels of association.

tion, especially of yucca, is clumped and nonrandom, thus curtailing the success of a randomized sampling technique which encompasses a total of only $10m^2$ surface area on any one sampling date. A sampling method which could account for the aforementioned factors is essential for a better understanding of the desert grassland invertebrates.

The most apparent strategy of reducing sampling error is to increase the sampling effort. However, if the computer model gives any indication of the actual field situation, it appears that 10 times as many quadrats would be necessary to reduce error by one-half. Economically, though, an effort of this magnitude would not be feasible.

Another possibility is to continue sampling the smaller grass and forb species with the standard $.5m^2$ quick trap, but to also include D-Vac samples of large shrubs in the population estimates. Presumably the shrubs would be sampled randomly, but in proportion to their actual distribution on the study site. A similar procedure was followed at the Desert Biome, Rocky Valley, Nevada site with apparenty good results (Turner 1972). The D-Vac sampling effort was distributed among Ambrosia dumosa (15 percent), Larrea divaricata (25 percent), Lycium andersonii (25 percent), Ephedra nevadensis (10 percent), Krameria parvifolia (15 percent) and others

(10 percent). It was possible to report invertebrate density and biomass on an area basis, and more complete information was available as to the interacting roles of insects and specific plants.

The data derived from this study have resulted in a better understanding of population dynamics and community structure of the desert grassland invertebrate community. A logical continuation of this study would encompass an attempt at an improved sampling technique and examine more closely the roles of specific organisms with their environment. During the years that this study was conducted, it appeared that invertebrates exerted little competition with cattle for forage. However, noting the diversity of herbivores, the question of potential competition, given appropriate conditions, remains to be answered.

SUMMARY AND CONCLUSIONS

Invertebrate populations and biomass were measured on the Jornada desert grassland study site, United States International Biological Program, Grassland Biome, over a period from July 1970 to October 1972. Samples were taken at approximately monthly intervals using randomly placed quick traps and a D-Vac vacuum insect collector.

During 1970 numbers and biomass generally followed parallel trends, although overall numbers and biomass for the season were greater on the grazed treatment. Numbers and biomass on both treatments declined gradually until July 1971, at which time increases correlated with the onset of growing season precipitation were noted. Rainfall was below normal during 1971, acting as a possible causative factor in the low numbers of insects captured during that season. Following a further decrease in the winter populations, numbers and biomass again showed general upward trends associated with growing season precipitation during 1972.

No discernible between-treatment differences in numbers or biomass were detected in 1971 or 1972 due to significant population fluctuations among treatments between sampling dates. Sampling error, incurred by the chance sampling of larger but more sparsely distributed

shrubs, was responsible for the large-scale number and biomass variations encountered between adjacent sampling dates. Of 32 sampling dates, density on the grazed treatment exceeded the ungrazed on 20 occasions. On 11 dates the density on the grazed treatment exceeded the ungrazed, and on one sample date treatment densities were approximately equal. These data tend to support Smith's (1940) observations of unexpectedly high insect densities in an overgrazed mixed-grass prairie.

In terms of numbers, herbivores made up the bulk of the community during the period of study. Homoptera (Cicadellidae) and Hemiptera (Lygaeidae) were the most prevalent representatives of the herbivore compartment. Blattidae and adult Tenebrionidae, captured when sampling yucca, occasionally caused the scaverger biomass to exceed that of the herbivores. Predators occurred in low numbers, represented primarily by the Araneida. Occasionally predator biomass exceeded herbivore biomass when larger specimens (Lycosa sp.) were sampled.

Supplementary sampling with the sweep net, pitfall trap, and light trap revealed that quick trap sampling was inefficient for some taxa. At least five invertebrate families which were taken by supplementary methods were entirely absent from quick trap samples.

Apparent sampling discrepancies expressed at least in part by large-scale variations in numbers and

biomass between adjacent sampling dates gave cause to question the validity of the randomized sampling technique. Results of a computer simulation model confirmed suspicions that random samples encompassing only a small area tend to neglect the more sparsely distributed population clumps which exist on the Jornada desert grassland.

Future attempts to monitor invertebrate populations at the Jornada desert grassland should probably be accompanied by a stratified sampling scheme based on the spatial distribution of the more prominent grass and shrub species. Additionally, process studies should be undertaken in an effort to further determine the impact of herbivores on primary productivity and the importance of the role of scavengers in decomposition.

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APPENDIX I

APPENDIX TABLES

Appendix Table 1. Yearly and growing season precipitation totals at the Jornada Experimental Range (cm). (From Herbel and Pieper 1970)

Year	July	Aug.	Sept.	Yearly Total	Year	July	Aug.	Sept.	Yearly Total
1916	3.57	4.87	3.95	20.71	1932	2.68	4.10	5.10	23.83
1917	2.29	2.45	1.84	17.30	1933	2.52	11.50	6.38	35.60
1918	1.45	3.88	0.64	9.19	1934	3.76	5.25	11.63	18.59
1919	3.90	7.34	0.00	26.70	1935	2.22	2.03	0.18	14.25
1920	7.98	6.43	6.50	35.69	1936	2.35	10.05	4.92	27.08
1921	3.83	8.36	2.27	24.69	1937	4.13	2.96	7.34	26.31
1922	3.83	3.20	1.86	12.24	1938	1.12	2.26	8.00	20.43
1923	0.64	4.59	2.88	23.41	1939	14.73	0.15	8.06	32.10
1924	1.73	3.90	4.44	18.93	1940	2.74	2.45	5.41	27.20
1925	8.52	0.81	0.54	15.56	1941	3.78	1.86	5.96	27.23
1926	4.27	3.03	2.27	26.62	1942	4.87	5.38	11.45	36.34
1927	12.62	0.97	8.16	34.65	1943	1.96	6.07	3.22	20.68
1928	3.80	5.92	6.43	23.09	1944	5.96	1.42	2.97	21.18
1929	3.24	6.68	0.07	26.59	1945	5.87	2.86	3.30	21.79
1930	4.97	6.96	15.70	23.14	1946	2.88	2.40	5.51	14.43
1931	3.70	0.07	7.72	25.32	1947	5.28	6.45	6.32	27.33

Appendix Table 1, continued

Year	July	Aug.	Sept.	Yearly Total	Year	July	Aug.	Sept.	Yearly Total
1948	2.21	7.19	0.13	19.81	1962	12.12	6.60	8.31	39.47
1949	1.30	0.40	1.12	17.60	1963	1.47	4.21	3.54	13.77
1950	7.06	0.77	8.73	23.10	1964	6.99	5.51	4.37	20.20
1951	6.86	2.54	4.18	21.87	1965	3.00	0.64	3.51	17.75
1952	0.86	2.17	0.46	17.15	1966	1.73	5.20	3.18	16.56
1953	4.72	0.66	7.95	14.51	1967	1.22	4.06	4.64	21.79
1954	2.08	3.37	5.71	18.74	1968	5.33	5.61	2.47	24.74
1955	8.99	1.33	0.23	18.49	1969	6.76	3.76	2.95	24.89
1956	5.71	1.68	0.00	9.14	1970	8.20	1.42	0.56	15.82
1957	4.78	11.07	0.00	26.01	1971	3.05	4.24	3.10	21.26
1958	2.18	4.72	9.55	34.27	1972	5.28	9.17	2.11	34.47
1959	3.80	16.29	0.00	22.87	----	----	----	----	-----
1960	3.50	3.73	0.30	17.80					
1961	6.02	8.73	8.34	32.44	Avg.	4.43	4.42	4.33	22.85

Appendix Table 2. Monthly and annual total precipitation records for the Jornada site during the period of study, 1970 to 1972 (from U. S. Weather Bureau records).

Month	Precipitation (cm) 1970	1971	1972
January	0.0	0.28	0.20
February	0.71	0.0	0.0
March	1.52	0.0	0.0
April	0.0	1.02	0.0
May	0.0	0.0	0.66
June	0.08	0.71	5.13
July	8.20	3.05	3.65
August	1.42	4.24	7.75
September	0.56	3.10	3.45
October	1.88	4.45	6.73
November	0.0	1.75	0.0
December	1.45	2.67	0.0
Annual Total	15.82	21.25	27.57

APPENDIX II

FIELD DATA

Invertebrate Data

Aboveground invertebrate data collected at the Pawnee Site were recorded on Form NREL-30. These data are stored as Grassland Biome data set A2U30E8. A sample data form and an example of the data follow.

IBP

GRASSLAND BIOME

U.S. INTERNATIONAL BIOLOGICAL PROGRAM

FIELD DATA SHEET - INVERTEBRATE

DATA TYPE	SITE	INITIALS	DATE			TREATMENT	REPLICATE	PLOT SIZE	QUADRAT	TROPHIC	HOST	ORDER	FAMILY	GENUS	SPECIES	SUBSPECIES	LIFE STAGE	TOTAL NO.	DRY WT.	NO. WEIGH
			Day	Mo	Yr															

DATA TYPE

01	Aboveground Biomass
02	Litter
03	Belowground Biomass
10	Vertebrate - Live Trapping
11	Vertebrate - Snap Trapping
12	Vertebrate - Collection
20	Avian Flush Census
21	Avian Road Count
22	Avian Road Count Summary
23	Avian Collection - Internal
24	Avian Collection - External
25	Avian Collection - Plumage
30	Invertebrate
40	Microbiology - Decomposition
41	Microbiology - Nitrogen
42	Microbiology - Biomass
43	Microbiology - Root Decomposition
44	Microbiology - Respiration

SITE

01	Ale
02	Bison
03	Bridger
04	Cottonwood
05	Dickinson
06	Hays
07	Hopland
08	Jornada
09	Osage
10	Pantex
11	Pawnee

TROPHIC

0	Unknown
1	Plant feeding (tissue)
2	Plant feeding (sap)
3	Plant feeding (pollen and nectar)
4	Plant feeding (seed)
5	Predator
6	Parasitoid
7	Parasite
8	Scavenger
9	Non-feeding stage

TREATMENT

1	Ungrazed
2	Lightly grazed
3	Moderately grazed
4	Heavily grazed
5	Grazed 1969, ungrazed 1970
6	
7	
8	
9	

LIFE STAGE

00	Undetermined
10	Adult
20	Pupae
30	Egg
40	Nymph or Larva
41	Nymph or Larva, early
42	Nymph or Larva, middle
43	Nymph or Larva, late
50	Instar
51	Instar, 1st
52	Instar, 2nd
53	Instar, 3rd

IBP-30 NATURAL RESOURCE ECOLOGY LABORATORY - COLORADO STATE UNIVERSITY - PHONE (303) 491-5571 - FORT COLLINS, COLORADO 80521

*** EXAMPLE OF DATA ***

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        1         2         3         4         5         6
12345678901234567890123456789012345678901234567890123456789012
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3008MAE07077211	.512	COLECOCC	10	1
3008MAE07077211	.512	HYMEFORM	10	2
3008MAE07077211	.512	ARANSALT	10	1
3008MAE07077211	.512	ACAR	40	1
3008MAE07077211	.512	COLLSMIN	10	1
3008MAE07077211	.512	HYMEBRAC	10	1
3008MAE07077211	.512	HYMEICHN	10	1
3008MAE07077211	.512	DIPTMUSC	10	1
3008MAE07077211	.512	HOMOPSEU	40	2
3008MAE07077211	.512	HYMECHA2	10	1
3008MAE07077211	.512	HEMITING	10	1
3008MAE07077211	.512	DIPTCHLO	10	1
3008MAE07077211	.5114	COLLSMIN	10	1
3008MAE07077211	.5114	COLESCAR	40	1
3008MAE07077211	.5114	HYMEFORM	10	1
3008MAE07077211	.5114	DIPTMUSC	10	1
3008MAE07077211	.5150	COLLSMIN	10	56
3008MAE07077211	.5150	ACARCAEC	10	4
3008MAE07077211	.5150	HYMEBRAC	10	1
3008MAE07077211	.5150	HOMOCIC1	10	2
3008MAE07077211	.5150	HOMOCIC1	40	3
3008MAE07077211	.5150	THY2THRI	10	1
3008MAE07077211	.5150	HYMEICHN	10	1
3008MAE07077211	.5248	COLECLER	10	1
3008MAE07077211	.5248	COLLSMIN	10	4
3008MAE07077211	.5248	HYMEANTH	10	1
3008MAE07077211	.5248	COLLENTO	10	2
3008MAE07077211	.5248	ARANLYCO	40	1
3008MAE07077211	.5248	ARANSALT	10	1
3008MAE07077211	.5326	HEMITING	10	3
3008MAE07077211	.5326	COLLENTO	10	1
3008MAE07077211	.5326	HYMEBRAC	10	1
3008MAE07077211	.5326	HYMEFORM	10	1
3008MAE07077211	.5326	ACARCAEC	10	1
3008MAE07077211	.5326	HOMOCOCC	40	1
3008MAE07077212	.524	HEMILYGA	10	3
3008MAE07077212	.524	HEMILYGA	40	2
3008MAE07077212	.524	HYMEFORM	10	2
3008MAE07077212	.524	COLECOCC	10	3
3008MAE07077212	.584	ACARCAEC	10	1
3008MAE07077212	.584	HYMEICHN	10	1
3008MAE07077212	.584	COLLSMIN	10	1
3008MAE07077212	.584	ARANTHERLA MA	10	1
3008MAE07077212	.584	HEMITING	10	1

3008MAE07077212	.5212	HYMEICHN	10	1
3008MAE07077212	.5212	ACARCAEC	10	1
3008MAE07077212	.5212	HEMILYGA	40	1
3008MAE07077212	.5212	HOMOPSYL	10	1
3008MAE07077212	.5266	LEPINOCT	10	1
3008MAE07077212	.5266	HYMEFORM	10	2
3008MAE07077212	.5266	DIPT	40	1
3008MAE07077212	.5266	NEURCHRY	40	1
3008MAE07077212	.5266	HOMOCOCC	40	1
3008MAE07077212	.5266	HYMESPHE	10	1
3008MAE07077212	.5266	HYMECERA	10	1
3008MAE07077212	.5266	COLENITI	10	1
3008MAE07077212	.5362	ARANSALT	10	1
3008MAE07077212	.5362	THY2PHLOHA	10	1
3008MAE07077212	.5362	HYMEBRAC	10	2
3008MAE07077212	.5362	DIPTCHLO	10	1
3008MAE07077251	.590	HEMITING	10	5
3008MAE07077251	.590	COLLSMIN	10	15
3008MAE07077251	.590	THY2THRI	10	1
3008MAE07077251	.590	HYMEFORM	10	5
3008MAE07077251	.590	DIPTCHLO	10	1
3008MAE07077251	.590	HOMOCOCC	40	13
3008MAE07077251	.590	ACARCAEC	10	4
3008MAE07077251	.590	LEPITORT	10	1
3008MAE07077251	.590	HOMOMEMB	40	1
3008MAE07077251	.590	HOMOCIC1	40	1
3008MAE07077251	.590	THY2PHLOHA	40	2
3008MAE07077251	.590	COLETENE	40	1
3008MAE07077251	.590	HYMEBRAC	10	1
3008MAE07077251	.590	HEMILYGA	40	1
3008MAE07077251	.5606	ACARCAEC	10	1
3008MAE07077251	.5606	HOMOAPHI	10	1
3008MAE07077251	.5606	HOMOAPHI	40	5
3008MAE07077251	.5606	HOMOCIC1	10	1
3008MAE07077251	.5606	HEMITING	40	1
3008MAE07077251	.5606	HYMEPOMP	10	1
3008MAE07077251	.5606	COLLSMIN	10	19
3008MAE07077251	.5606	LEPIGEOM	40	1
3008MAE07077251	.5606	DIPTCHLO	10	1
3008MAE07077251	.5606	DIPT	10	1
3008MAE07077251	.5606	HEMILYGA	40	2
3008MAE07077251	.5672	HEMITING	10	2
3008MAE07077251	.5672	HEMITING	40	2
3008MAE07077251	.5672	ACARCAEC	10	1
3008MAE07077251	.5344	COLECOCC	10	1
3008MAE07077251	.5344	DIPTMUSC	10	1
3008MAE07077251	.5344	HEMITING	10	14
3008MAE07077251	.5344	HEMITING	40	8
3008MAE07077251	.5344	COLLSMIN	10	35
3008MAE07077251	.5344	THY2THRI	10	1
3008MAE07077251	.5344	HOMOAPHI	40	1
3008MAE07077251	.5344	HEMILYGA	10	1
3008MAE07077251	.5344	HYMECERA	10	1
3008MAE07077251	.5344	HOMOCOCC	10	1
3008MAE07077251	.5344	HYMEICHN	10	1

3008MAE07077251	.5178	COLECOCC	10	1
3008MAE07077251	.5178	COLLSMIN	10	8
3008MAE07077251	.5178	HYMEEULO	10	2
3008MAE07077251	.5178	HOMOCIC1	10	2
3008MAE07077251	.5178	HYMEVESP	10	1
3008MAE07077251	.5178	HYMEICHN	10	1
3008MAE07077252	.5448	HOMOCIC2	10	1
3008MAE07077252	.5448	HYMEEULO	10	1
3008MAE07077252	.5448	HYMEBRAC	10	1
3008MAE07077252	.5448	HEMITING	10	6
3008MAE07077252	.5448	COLE	40	1
3008MAE07077252	.5448	HOMOCOCC	40	1
3008MAE07077252	.5448	HYMEICHN	10	1
3008MAE07077252	.5448	COLLSMIN	10	2
3008MAE07077252	.5156	HOMOCIC1	40	1
3008MAE07077252	.5156	LEPITORT	40	1
3008MAE07077252	.5156	HYMEFORM	10	1
3008MAE07077252	.5156	ACARCAEC	10	2
3008MAE07077252	.5156	HOMOCOCC	40	1
3008MAE07077252	.5156	HYMEVESP	10	1
3008MAE07077252	.5156	HEMITING	10	1
3008MAE07077252	.5156	HYMEICHN	10	1
3008MAE07077252	.5206	HYMEPOMP	10	1
3008MAE07077252	.5206	HEMITING	10	31
3008MAE07077252	.5206	HEMITING	40	11
3008MAE07077252	.5206	ACARCAEC	10	2
3008MAE07077252	.5206	HOMOCOCC	40	3
3008MAE07077252	.5206	HOMOFULG	40	1
3008MAE07077252	.5714	HEMILYGA	40	1
3008MAE07077252	.5714	HOMOPSEU	40	1
3008MAE07077252	.5714	HOMOAPHI	40	4
3008MAE07077252	.5714	HYMEPOMP	10	1
3008MAE07077252	.5714	HYMEFORM	10	4
3008MAE07077252	.5714	HEMITING	40	1